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R & D PRODUCTIVITY

new CHALLENGES

for the U.S. Space Program

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A conference sponsored by the Lyndon B. Johnson Space Center and the University of Houston-Clear Lake in cooperation with the American Institute of Aeronautics and Astronautics and the American Productivity Center.

QUALITY PRODUCTIVITY EXCELLENCE

PROCEEDINGS

R&D PRODUCTIVITY:

NEW CHALLENGES FOR THE U.S. SPACE PROGRAM

Edited by
Otis W. Baskin
Center for Advanced Management Programs
University of Houston-Clear Lake
and
Leslie J. Sullivan
NASA/Johnson Space Center

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with AIAA and the American Productivity Center
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FORWARD

Central to this nation's leadership in aerospace and other advanced technologies is our long-term commitment to research and development. The historic accomplishments of the Apollo Program not only captured the attention of the world but also demonstrated the utility of achieving great technological breakthroughs through government/industry/university combined ventures. Now with Space Transportation a reality and the future of Space Station close at hand, attention is focused anew on productivity of the nation's R&D organizations as essential for the next round of major achievements in space as well as other industries and disciplines.

The Lyndon B. Johnson Space Center and its neighbor, the University of Houston-Clear Lake, are committed both to quality and productivity in their respective roles as research and development organizations. Certainly, the flow of new ideas, products, and technologies necessary to secure a bright future for our world demand constant attention to the strategies and techniques of managing R&D. Through sponsorship of this conference, we hope to build upon the solid base of past and present experience from the American space program to encourage future accomplishments in science and technology.

We believe that the contents of this volume and interactions at the conference itself will prove to be a positive catalyst for all organizations represented. We are proud that our organizations are cooperating in this joint venture.

Gerald D. Griffin
Director
NASA Lyndon B. Johnson
Space Center

Thomas M. Stauffer
Chancellor
University of Houston-
Clear Lake

PREFACE

This volume contains the manuscripts of papers presented as part of "R&D Productivity: New Challenges for the U.S. Space Program," September 10-11, 1985. This conference was planned and operated as a joint project between the University of Houston-Clear Lake and the Lyndon B. Johnson Space Center in cooperation with the American Institute for Aeronautics and Astronautics and the American Productivity Center.

The 51 papers published in this volume were selected for presentation through a rigorous review process from 112 papers submitted for consideration. However, all those who submitted papers made a distinct contribution to the success of this conference whether or not their work is contained in this publication. The response to the call for papers was overwhelming and many excellent contributions had to be turned down because of the limitations of time and space. Therefore, we express our thanks to all those who submitted abstracts because their ideas, work and creativity are the foundation of our efforts.

A conference of this size and scope requires the support of many individuals. Thanks are due the 22 reviewers from AIAA, JSC, and UH-CL whose tireless reading, rereading, evaluating and organizing produced a program high in both quality and interest. Special thanks to Bob Lewis of AIAA for his ability to enlist the help of so many colleagues in this task.

Special mention also must be made of the vast and various contributions of Alma Martin from JSC. Her ability to facilitate, coordinate and otherwise cut through red tape made our efforts more productive. In addition, the work of Betty McSheehy, Jeane Conway-James and Steve Dubuc from the Center for Advanced Management Programs was tireless and professionally performed. Their efforts in organizing and executing the details of this conference made us efficient and effective.

Our appreciation must also be expressed to Harry M. Porter and his staff at the JSC Printing Management Branch. Their ability to meet tight schedules with quality work has made this book a reality.

Finally, the contributions of Les Sullivan to the concept and content of this program and the guidance of Wayne Young in the process are gratefully acknowledged.

Otis W. Baskin

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IMPLEMENTING QUALITY/PRODUCTIVITY IMPROVEMENT INITIATIVES IN AN ENGINEERING ENVIRONMENT

Roger R. Ruda, McDonnell Douglas-Houston

ABSTRACT

Quality/Productivity Improvement (QPI) initiatives in the engineering environment at McDonnell Douglas-Houston include several different, distinct activities, each having its own application, yet all targeted toward one common goal - making continuous improvement a way of life. The chief executive and the next two levels of management demonstrate their commitment to QPI with hands-on involvement in several activities. Each is a member of a QPI Council which consists of six panels - Participative Management, Communications, Training, Performance/Productivity, Human Resources Management and Strategic Management. In addition, each manager conducts Workplace Visits and "Bosstalks", to enhance communications with employees and to provide a forum for the identification of problems - both real and perceived.

Quality Circles and "Project Teams" are well established within McDonnell Douglas as useful and desirable employee involvement teams. The continued growth of voluntary membership in the circles program is strong evidence of the employee interest and management support that have developed within the organization.

Every member of upper management and over one-third of the remainder of the workforce have been trained and are actively involved in some activity to enhance McDonnell Douglas' continuous improvement goal.

INTRODUCTION

In a McDonnell Douglas Corporate Policy Statement, S. N. McDonnell, Chairman and Chief Executive Officer, gave the following direction, "The responsibility for quality and productivity improvement rests with every MDC employee. Corporate, component and subsidiary chief executives have primary responsibility for establishing and maintaining an effective quality/productivity improvement process that involves all employees."

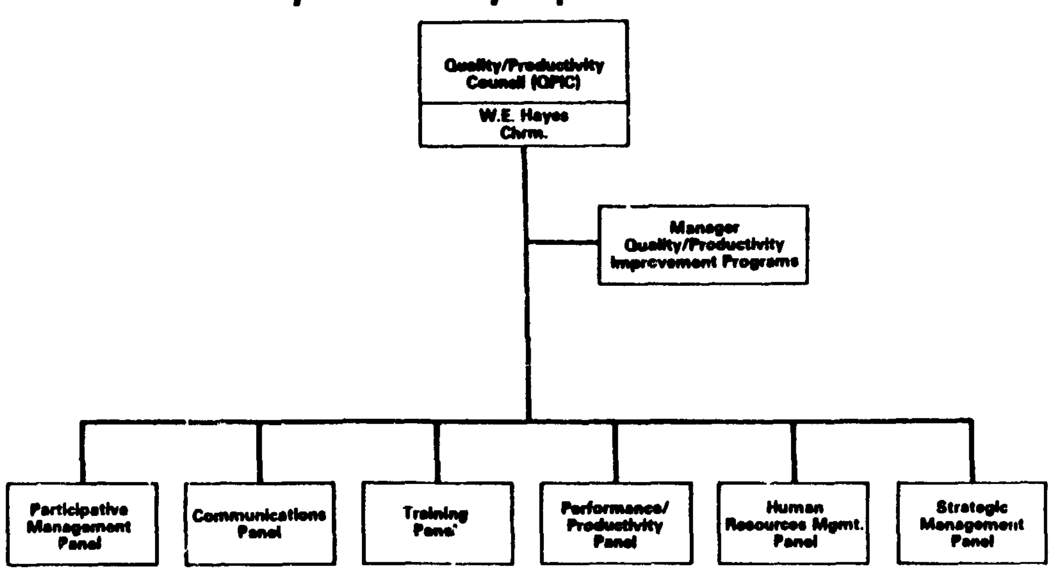
McDonnell Douglas-Houston's Quality/Productivity Improvement (QPI) process emphasizes six specific initiatives - Participative Management, Communications, Training, Performance/Productivity, Human Resources Management and Strategic Management. Continuous improvement in each of these areas is the common goal of the activities that have been implemented to date. There is still much to be done. but with the following mechanisms and activities in place, and with the total commitment of top management to keep them in place, it will get done.

DISCUSSION

In January, 1984, the Director and Chief Executive of McDonnell Douglas' Houston Operations established a Quality/Productivity Improvement Council (QPIC) chartered to identify and implement activities to further the Corporate QPI initiatives. Membership of the council is composed of the Director and the next two levels of management. Membership is mandatory and presently consists of 32 managers. Each manager is also assigned to one of the Council's six panels (Figure 1).

Figure 1

Quality/Productivity Improvement Council



Each panel meets weekly and reports progress and recommendations twice monthly at the QPIC meetings. The QPIC is chaired by the Chief Executive to emphasize top management commitment and involvement and a new management position was created to assist him. The new manager of Quality/Productivity Improvement is assigned full-time responsibility for coordinating all QPI activities within the Division, other components and Corporate, and for identifying methods and techniques to train and motivate every employee to become involved in the QPI activities.

Initial training in quality improvement techniques was provided QPIC members utilizing the "Juran on Quality Improvement" videotape series [1] and the Juran "Project Team" approach was applied by each panel. Follow-up training has included "Action Plans for Implementing Quality and Productivity" [2] and "Toward Excellence" [3]. Agenda items at each regularly scheduled panel and council meeting emphasize the commitment to continuous improvement and provide additional opportunities for discussing past, present and future activities.

This QPI approach has resulted in several improvements in each initiative area as illustrated by the following examples.

Participative Management

The Participative Management (PM) panel began its activities identifying what type of PM activities could be applied in the engineering organization and defining available training to help understand and implement PM techniques. Several consultants and much library research led the panel to conclude that PM was no single technique that could be, or was, packaged, available and applicable in the aerospace engineering support services environment. The panel then developed a workshop, "Introduction to Participative Management", and conducted it for all employees of the division. The workshop included examples of participative management styles, the organizational and environmental barriers to using PM techniques, and the advantages and effectiveness of employee involvement in management decisions. Projects the PM panel is working on now include defining PM training requirements for supervisors and defining techniques for evaluating managers and supervisors effective use of PM techniques in their work environment.

Communications

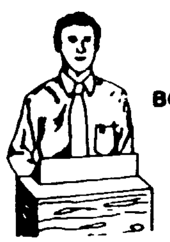
There have been noticeable improvements in communications within McDonnell Douglas as a result of the initiatives described. Shortly after its formation, the Communications panel recommended publishing a local newsletter to increase the workforce's knowledge of ongoing Divisional activities. "The Houstonian", a high quality, eight to twelve page newsletter is now published monthly. It has greatly improved top-to-bottom, and, with employee inputs and articles, bottom-to-top communications as well.

"Workplace Visits", or Management by Wandering Around (MBWA), is utilized extensively by all QPIC members. Visits are unscheduled, informal, and provide direct bottom-to-top communications and problem identification.

"Bosstalks" are held regularly, usually weekly, by the Division Director. Thirty to forty personnel from all organizational levels are invited to attend these meetings. The meetings have no fixed format, the Director solicits topics and problems for discussion from attendees. Problems identified at these meetings are later assigned to managers for resolution. Some typical problems and their resolutions are shown in Figure 2. Each Department Manager is encouraged to conduct similar meetings with his personnel. Lateral communications is greatly ennanced by having the top three organizational management levels in attendance at the regularly scheduled QPIC and panel meetings.

Figure 2

CONSTANT IMPROVEMENT THROUGH BOSS TALKS AND WORKPLACE VISITS



SAMPLER OF PROBLEMS IDENTIFIED	.... AND RESULTANT ACTIONS
● NEED MORE COMPUTER TERMINALS	● MANY ADDED, MORE PLANNED
● POOR COPIER SITUATION	● DAILY MAINTENANCE
● NEW BUILDING CONCERNS/ISSUES	● APPOINTED PARTICIPATIVE TIGER TEAM
● EXCESSIVE CONTROL OF SUPPLIES	● ELIMINATED SIGN OUT REQUIREMENT
● LATE DELIVERY OF HOUSTONIAN NEWSLETTER	● REVISED DELIVERY SYSTEM

Training

Training, in all areas - management, administrative and technical is needed to ensure a top quality, productive workforce and sustain a continuous improvement process.

Prior to the formulation of the Training panel, various types of training were arranged for and scheduled by individual managers. The Training panel's initial task was to determine what skills were being taught to whom, what other drills were needed and what would be needed in the future.

A consultant firm was used to help define what the management training needs were for supervisors, mid-level and executive level managers. Surveys of project and department managers identified technical requirements. After the needs were established, the search for effective training programs was begun. Some are being developed internally.

An evening study program existed to provide employees an opportunity to develop skills that would contribute to their personal growth. The program was greatly expanded and a full time training coordinator was hired to enhance the programs quality and content.

Training in statistics and quality control is presently being provided at all levels to aid personnel in recognizing what can and should be measured or monitored to improve processes, and to detect and resolve errors. This training is being conducted as part of a "Continuous Improvement" workshop, where the need for statistics is examined and examples of their use in monitoring processes are presented.

Performance/Productivity

The major objective of the Performance/Productivity panel has been to define a Performance Measurement System (PMS) applicable to an engineering organization where performance is considered to consist of both quality and productivity factors. Their initial efforts were to analyze non-productive engineering time so that measurements of this factor could be an indicator of improvements. The collection and tracking of information proved to be too unwieldly however, and this approach was dropped. The PMS presently in use is much more flexible and applicable to the whole organizational environment [4]. It is based on the American Productivity Center's "family of measures" system that was developed by the panel after attending APC's "Knowledge Worker Measurement" workshop.

The present task being worked by this panel is to assess the status and results of the Continuous Improvement process at McDonnell Douglas-Houston, and to identify areas where further improvements should be emphasized.

Human Resources Management

The Human Resources Management panel's initial projects were to analyze and improve the employee career counselling procedures, to devise a means for making employees more aware of job opportunities within the company and to increase the effectiveness and quality of the Recognition and Awards program. The new Job Posting System is in place, allowing employees to be aware of job openings and apply, confidentially, for a job that may be more in line with their career goals.

The Career Counselling Supervisor's Handbook was developed and is in use by each supervisor in the division. Existing Certificates of Achievement, New Technology Awards, and the Employee Suggestion Program were revised and revitalized. The "Directors Award" was created to reward the one most outstanding achievement each month. The project presently being worked by this panel is to ferret out restrictive company policies and procedures and revise them to be more in line with the new organizational culture.

Strategic Management

The Strategic Management panel was just recently added to the QPIC as an individual improvement initiative. The panel's charter is to establish strategic management as a "Way of Life", where the approach to business is the identification of a) the changes the company faces in the future and b) the alternatives that can be developed for dealing with those changes. The initial project then, for this panel, is to define the long range business plans and the current business strategies for implementing those plans.

Quality Circles

Quality Circles at McDonnell Douglas-Houston were a forerunner of the formal QPI organization. They were established in 1983 with the formation of three pilot engineering circles. There was some doubt initially as to the applicability of traditional quality circle techniques within a purely engineering environment. At present, there are twenty-five circles (23 in engineering) involving over 260 employees, and the original three circles are still operating effectively. Six circles are presently self-facilitating, i.e., they totally lead and manage their own activities.

The circles program at McDonnell Douglas is named SPACE - Solving Problems Among Creative Employees. Each circle leader receives 28 hours of training which includes traditional quality circle problem-solving techniques, as well as group leadership techniques. Circles are formed within existing work groups, each usually having six to fourteen members. Each circle, with the help of a facilitator, proceeds with problem-solving techniques training and immediately begins working on a work-related problem of their choice. Circles have voluntary membership and meet for one hour per week on company time. When a recommendation for a solution to a problem has been formulated, a presentation is made to management. Management has responsibility for making the decisions to implement or not implement suggestions. Almost every proposed solution has been implemented to date. Typical problems chosen include: improving the contract documentation review cycle, improving intragroup communications, standardizing crew training scripts, reducing memo routing-time and improving Ascent quality assurance procedures.

A key ingredient to a successful quality circle program is management commitment, and as that has been provided in support of QPI activities, the circles have done well in this engineering environment.

Project Teams

Project Teams are created at McDonnell Douglas whenever a specific management-related problem needs to be solved. Membership of each team is comprised of management and non-management personnel, at any level, across the organization, who have the knowledge necessary to solve the problem. Each team leader receives group problem-solving training, either through the Quality Circles program or "Juran on Quality Improvement". An individual team exists only as long as it takes to define, analyze and solve that particular problem. All QPIC members and eighty-five middle managers in Houston have taken the Juran series, and over 260 supervisors and engineers have received Circles training. More are being trained continuously to meet our goal of 100% employee involvement in QPI initiatives.

SUMMARY

The Quality/Productivity Improvement Council is the heart, and the brains, of the McDonnell Douglas-Houston QPI initiatives. The six QPI Council panels - Participative Management, Communications, Training, Performance/Productivity, Human Resources Management and Strategic Management are continually identifying, developing and implementing plans and activities to capitalize on every improvement opportunity. This top management team, led by Bill Hayes, Director and Chief Executive of Houston Operations, is committed to continuous improvement.

The remainder of the workforce is also becoming very involved in the continuous improvement process. There are twenty-five Quality Circles and the number is continuing to grow. Employee involvement and training in QPI techniques presently includes over one-third of the workforce, one hundred percent is our goal. Employee recognition for achievements provides additional motivation for everyone to get involved. Implementation of continuous quality/productivity improvement activities is well underway at McDonnell Douglas-Houston.

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BIOGRAPHY

Roger R. Ruda, Manager of Quality/Productivity Improvement at McDonnell Douglas Technical Services Company-Houston, Texas, received a Bachelor's degree in Electrical Engineering from the University of Wisconsin in 1965. Since that time, Mr. Ruda has been employed with McDonnell Douglas, where he has held various engineering and management positions. He was appointed to his present position in September 1983.

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THE USAF SYSTEMS COMMAND AND R&D PRODUCTIVITY

Vince Luchsinger, Maj.Gen. USAFR
Mob. Asst. to Commander, USAF Systems Command
& University of Baltimore

ABSTRACT

The United States Air Force Systems Command (AFSC) is charged with the development and acquisition of aerospace technology systems. Much of that activity is concerned with space systems development, acquisition, and operations. Heavy emphasis is being placed on productivity in organizational and process functions which will keep aerospace systems on the leading edge of technology, with plans extending capability into the future. The productivity emphasis ranges from people-oriented activities to resource and technological functions which support national aerospace objectives. The AFSC space-related missions will be discussed as a special area of productivity efforts.

INTRODUCTION TO THE COMMAND

The primary mission of the Air Force Systems Command (AFSC) is to advance aerospace technology, apply it to operational aerospace systems development and improvement, and acquire qualitatively superior, cost-effective, and logistically supportable aerospace systems. The Command has been involved in space missions from the earliest United States ventures, going back to the early 1950's in exploratory work by General Bernard Schriever a past Systems Command commander.

The Air Force Systems Command also supports the major space responsibilities of the Department of Defense, including basic and applied research, development, test and engineering of satellites, space launches and missions, boosters, space probes, and related space systems. The Command is presently heavily involved in the research activities of the Space Defense Initiatives program, under the command of a space vetern of AFSC experience, General Abrahamson. In addition, AFSC supports many NASA programs and projects that operate under agreements between the Department of Defense and NASA.

AFSC Resources

The Command is one of the larger Air Force Commands. In scope of financial activity, it would rank sixth among the Fortune 500 of United States corporations. The personnel ranks of AFSC list 27,500 military and 29,500 civilian personnel. The nature of its research, development, test, and acquisition means that AFSC is the primary Air Force employer of scientists, engineers, and technically oriented personnel.

In the current 1985 fiscal year, Systems Command is managing approximately $38 billion. Within that amount, $23.1 billion goes for procurement of aircraft ($16 billion), missiles ($5.3 billion), and other equipment ($1.8 billion). Beyond that, $10 billion is applied to research, development, test, and evaluation (RDT&E), $1.5 billion for operation and maintenance, and $540 million for military construction. The remaining $3 billion comprises foreign military sales ($1 billion), reimbursables ($1.2 billion), and military pay ($900 million).

The magnitude of the resources entrusted to AFSC dictates a heavy responsibility for productivity in discharging its missions to ensure the best output for the resources involved. As a vital segment of the Air Force structure, AFSC administers thirty-eight percent of the total Air Force budget, while utilizing only 6.5 percent of the personnel of the Air Force. As a final indicator of the key role of the Systems Command, AFSC currently administers 29,000 active contracts valued at approximately $108 billion.

Organization

The heart of AFSC contains four product divisions:

1. The Space Division (Los Angeles AFS) which develops, tests, and supervises launch and operation of space craft. Facilities include Vandenburg AFB (which will provide for future shuttle launches and recoveries), the eastern space facilities at Patrick AFB, and the Space Technology Center at Kirtland AFB.

2. The Electronics Systems Division, which develops, tests, and procures electronic systems for aerospace and ground missions.

3. The Armament Division which develops and tests conventional weapons.

4. The Aeronautical Systems Division which develops and tests aircraft systems.

The Balistic Missile Office at Norton AFB is involved in the development and testing of missiles and their component systems. The Foreign Technology Division monitors a wide variety of foreign technological activity, with special emphasis on space. The Contract Management Division oversees the contracts for acquisition of aerospace systems, including space systems. The Aerospace Medical Division studies the effects of manned flight, with space flight constituting a focal area of research and training. A variety of laboratory and test locations are very involved in space-related research and test activity to examine the conditions, hazards, and potentials for pursuing missions in the space environment.

The Space Technology Center at Kirtland AFB is a relatively new organization established to support the space mission of the Command. Subordinate to the Space Division, the Space Technology Center supervises the Geophysics, Rocket Propulsion, and Weapons Laboratories. Planning, development and test activities support a wide range of space ventures, with the Strategic Defense Initiative research project : prime client.

Transforming the resource and organizational capability of AFSC into satisfaction of aerospace missions and objectives means the blending of Command activities into orchestrated efforts to meet challenges. Actions to pursue Command challenges in a productive and cost-effective manner will be discussed in the context of people, resource, and program initiatives.

PEOPLE PRODUCTIVITY INITIATIVES

One vital segment of the productivity program of AFSC rests in people programs. In August, 1984, General Lawrence Skantze assumed command of AFSC and indicated a concern for productivity initiatives within the Command. While entrusted with thousands of talented people and a large fiscal and acquisition responsibility by the Air Force, General Skantze saw that executing the mission of the Command would soon involve "doing more with less." The vast array of program responsibilities with increasing costs would test the ability of the Command to respond.

Changing the Culture

Contemporary management research and writing attests to the need for assessing the culture of organizations to verify goals and values in pursuing goals of excellence, change, or renewal. The culture change process is at work in AFSC. As is often the case in a change of command, the new commander will establish his style and working expectations in carrying the organization to the accomplishment of missions. Since AFSC is a linking pin between the using operational commands of the Air Force and the community of research and development (R&D), acquisition, and civilian contracting firms, the Command finds itself a military organization with multiple ties to segments of the civilian world.

General Skantze (3) has placed emphasis on managing the Air Force acquisition role in a "business-like" manner. This means that AFSC military and civilian personnel not only must meet military standards, but must be able to perform creditably in dealings and negotiations with civilian contracting organizations and R&D enterprises. AFSC personnel performing well will best support their colleagues in the operational and combat commands. "Buying smartly" would become more than a catchy slogan.

Managing intelligently includes a deep concern for quality. Quality assurance is a major element of AFSC acquisition and contract management programs. Quality in staff work and business management programs of the command are endorsed as a corollary of the desired quality sought in procurement activities.

People Programs

An array of ventures to involve Command personnel in improving productivity and quality operations includes:

1. Suggestion Programs which have been emphasized to generate ideas submitted to propose improvements. The quantity and quality of suggestions has been gratifying in response to Command emphasis. While a common management tool, suggestion systems have reflected commitment of organization members.

2. Sensing sessions with senior officers from field commands have assessed problems and opportunities in those organizations, as well as examined inter-organization relationships. Input from those key personnel has been instrumental in working out kinks in operations, and in reducing we-they confrontations. This was one of many innovations with behavioral science flavor.

3. Off-site sessions by general officers and key staff reviewed objectives, values, weaknesses, strengths, threats, and opportunities which face the Command. These work meetings (in civilian clothes) promoted creative and cohesive options for future Command operations.

4. An organizational survey of the AFSC headquarters was conducted by the Air Force Leadership and Management Development Center to provide data to managers of organizational components. These data cover job satisfaction, attitudes toward work group and supervisors, organizational communications and other topics. These findings should provide opportunities for improving management and productivity in the headquarters.

5. A civilian personnel work force effectiveness study group has been convened with representation from all field units. This group is generating initiatives for optimizing the contributions of the civilian work force, an important segment of the AFSC family.

6. Enhanced career development programs are being put in place to provide career pathing for personnel. Career satisfaction and progress is important for the support of individual and work group productivity, as well as to provide work force stability.

7. Decentralization is encouraged, whenever possible, as a means of establishing the importance of the "work place" and the "work unit." Senior officers, such as General Larry Welch, vice chief of staff (5), have endorsed decentralization as a move to promote participation of personnel at all levels in pursuing quality and productivity objectives.

The foregoing are some examples of an emphasis on people programs in AFSC which are designed to promote an awareness of quality and productivity in the culture of the Command. The entire Command has been sensitized to the need for greater attention to the use of people and other resources to meet goals of each organization in AFSC. Working "smarter" and "better" is encouraged as a means of dealing with the continually increasing workload of the Command.

RESOURCE PRODUCTIVITY

Since AFSC is entrusted with a major segment of the Air Force buying role, the use of sophisticated and contemporary tools and techniques are required to manage the development, test, and acquisition activities of the Command. Some of the major productivity impacts follow.

Management Information Systems

To administer the functions inherent in the AFSC mission, the management of information is essential. Vast amounts of data must be selectively acquired, stored, analyzed, and presented to decision makers to manage the Command. Executive Information System (EIS) capability is available within and between elements of the command to maintain real-time communications. While electronic mail and filing (among other electronic capabilities) are common place in industry, the military necessities of security, readiness, and global coverage accentuate the EIS contribution.

A new staff directorate (KR) was formed in 1984 to deal with computer resources and management information systems. The system architecture is being developed, with growth and versatility of function a key element. This capability includes use and networks of micro-computers, as well as networking with main-frame and support computing facilities. It is worth noting that AFSC facilities include equipment ranging from mini-computers to super-computers. Needless to say, extensive design and training activity is involved to achieve and maintain the productivity that can be attained from electronic capabilities.

Industrial Modernization Incentives Program

Typical of many productivity ventures in AFSC is the Industrial Modernization Incentives Program (IMIP). IMIP, simply stated, is contracting for productivity. IMIP uses traditional and innovative contracting techniques to solicit, "incentivize" and sustain contractors in increasing productivity.

As used, IMIP is a partnership between a contractor and the Air Force directed at systematically bringing the latest manufacturing technologies, and the capital investments needed to produce them, onto the production floor of a contractor's facility. Resulting efficiencies in production yield savings to DOD weapon system contracts which are then shared with the contractor. This allows the contractor to realize a satisfactory return on the investment.

AFSC has 32 IMIP's on contract, which includes both prime and subtier contractors within the aerospace industrial base. The Air Force's commitment of over $400 million for factory analysis and manufacturing technology development has been matched by a $1.4 billion contractor commitment for development of new manufacturing technology and acquisition of capital equipment. The projected savings as a result of these commitments exceed $4.5 billion on DOD production programs through 1990.

The use of IMIP combines the best of technology and good manufacturing management to enhance production capability. In high cost, short production run, and long lead time situations as found with space system projects, the IMIP venture is showing great productivity potential.

Productivity is a challenging objective in advanced technology programs, with costing a particular nemesis. The "Should Cost" programs attempt to determine what costs reasonably ought to be rather than costs are or have been. There is evidence that the cost curve can be bent, rather than continuing to escalate [1]. IMIP is then seen as a tool to help combat the serious threat to productivity by program instability and cost overruns.

Planning

Better management for productivity involves improved planning with accompanying control systems. In the quest for more productivity in its mission areas, AFSC uses planning extensively. A prime example is the Space Technology Plan [4], a product of the Space Technology Center. This type planning has a strong impact on the Command and relationships with DOD, NASA, other government agencies and industry.

Space technology planning focuses all Air Force space technology investment and execution in support of future space mission requirements. Selected space technology development projects will pursue objectives in: on-board processing and hardened electronics, spacecraft autonomy, space power, and advanced military spacecraft capability.

Artificial intelligence, power cell research, and advanced space computer technology are hoped to provide increased spacecraft lifetime, memory, survivability and autonomy. The productivity of this research is tied to unique features of space needs. Some of those factors include:

1. Space systems have long lead times and long life times.

2. Technology development must start very early before systems are well defined.

3. There is a premium on accurate forecasting of technology needs.

The complexities of technologies of development, test, and production make the tasks of AFSC challenging. Partnerships are being forged with other agencies and industry to provide proactive approaches to managing for quality outcomes in a cost-effective manner.

CONCLUSION

A recent NASA report on improving Quality and Productivity in Government and Industry [2] captures the essence of the AFSC quest for productivity in its activities. Quality of work, quality of work life, and quality of management are cornerstones for increasing productivity. Technology and production bases help provide the setting for quality of work in meeting standards and requirements for products and outputs.

People programs generate commitment and work environment conditions which contribute to the success of the organization. Quality of management fosters leadership that has the technical and leadership skills to provide direction and feedback in guiding the organization to its objectives. The people of AFSC are working toward those quality conditions in the pursuit of productivity.

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Major General Vince Luchsinger is a member of the Air Force Reserve and serves as Mobilization Assistant to General Lawrence Skantze, commander of the Air Force Systems Command at Andrews AFB, MD. He also serves as Dean of the School of Business at the University of Baltimore, Baltimore, MD.

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SELF-RENEWAL: A STRATEGY FOR QUALITY AND PRODUCTIVITY IMPROVEMENT

D. H. Hutchinson
McDonnell Douglas Astronautics Company
Huntington Beach, California

ABSTRACT

Eighty-three management improvement projects initiated at the McDonnell Douglas Astronautics Company since April 1983 provide case studies of productivity improvement techniques and measurements of improvement. These projects were initiated as part of a program of self-renewal that Sanford N. McDonnell, McDonnell Douglas Corporation chairman and chief executive officer, outlined in his May 1984 message to the corporation. He described the following five initiatives designed "to foster self-renewal throughout the corporation and thereby prepare for the future":

1. Strategic Management. A continual dynamic open-ended planning process that focuses on overall goals, long-range needs, problems, and opportunities to ensure that the corporation grows and meets the requirements of an ever-evolving marketplace.

2. Human Resource Management. The company assures itself of a continuing cadre of top-flight people by helping employees plan and meet career goals and by identifying and grooming those with the greatest potential.

3. Participative Management. A two-way process that allows employees to share in the shaping of the future of the company by encouraging people to express their opinions and by training managers to listen to those opinions and consider them very carefully.

4. Productivity Improvement. Productivity: another word for efficiency--for achieving the maximum in product value while avoiding unnecessary costs both in house and at vendors to meet the challenge of aggressive competitors.

5. Ethical Decision-Making. Adherence to high ethical standards is a commitment to excellence and a central part of the Corporation's traditions and world-wide reputation.

This paper discusses productivity improvement: Sandy McDonnell s fourth key for corporate self-renewal. The concept of productivity or efficiency is supplemented with two additional concepts of productivity improvement: effectiveness and innovation. Dr. W. Edwards Deming,

early in the 1950s, applied statistical techniques to the improvement of quality [2], and Dr. Kaoru Ishikawa worked with the Quality Circle Headquarters of the Union of Japanese Scientists and Engineers in Tokyo [4]. These activities provide the basis for the well-documented process of improvement of efficiency and productivity in several American and Japanese industries, and for the process of continuous improvement in the McDonnell Douglas Corporation. Case studies of improvement of efficiency, effectiveness, and innovation at McDonnell Douglas are presented in this paper.

INTRODUCTION

Strategic objectives and business unit planning are the framework for quality and productivity improvement at McDonnell Douglas Astronautics Company in Huntington Beach, California (MDAC-HB). Business units, organized around products, are expected to manage continuous improvement during product life cycles. The mission, focus, and methods of improvement are adapted to the achievement of program goals during product life cycles. The methods must afford continuous improvement. Mission and focus are adaptive as the program life cycle moves from conception through design and development to operations and support.

THE READAPTIVE PROCESS

The dilemma facing American industry has been well documented. In industry after industry, US firms are losing their competitive advantage. This loss is the underlying cause for the country's present economic distress and many related social problems. In an effort to turn this loss around, industrial leaders have sought ways to renew the competitive edge. The readaptive processes of the automobile, steel, hospital, agricultural, residential construction, coal, and telecommunications industries have been well described [7]. The aerospace industry is not exempt from world-wide competition; it also must renew itself. The readaptive process in the aerospace industry has begun to receive the combined attention of government, industrial, and educational institutions. The approach used at McDonnell Douglas includes performance improvement project teams (Appendix) that focus upon and solve problems as part of a continuous process of improvement (Figure 1).

The forces that lie behind the form that readaptation takes in the seven basic industries studied by Lawrence and Dyer [7] and those giving form to the readaptive process at McDonnell Douglas are similar. The most remarkable are changes in core technologies, policies, competition, and the importance of choices in organizational strategy.

The readaptive process (Figure 2) involves seeing organizations as socio-technical-learning systems. The idea that organizations must

FIGURE 1. PERFORMANCE IMPROVEMENT LIFE CYCLE – THE READAPTIVE PROCESS

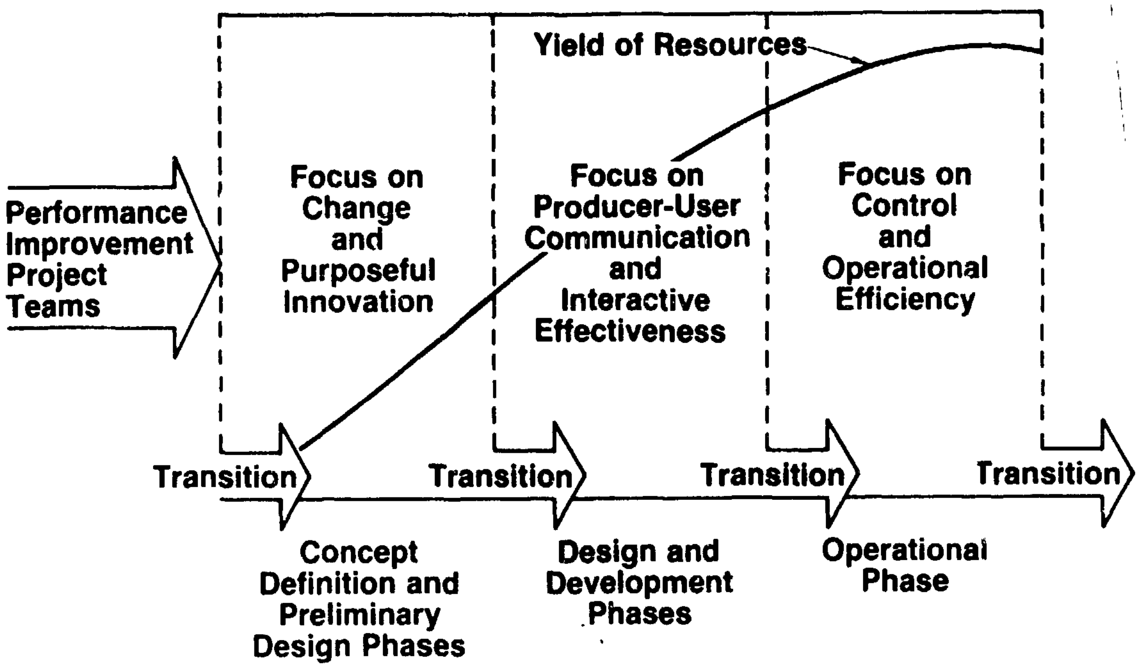
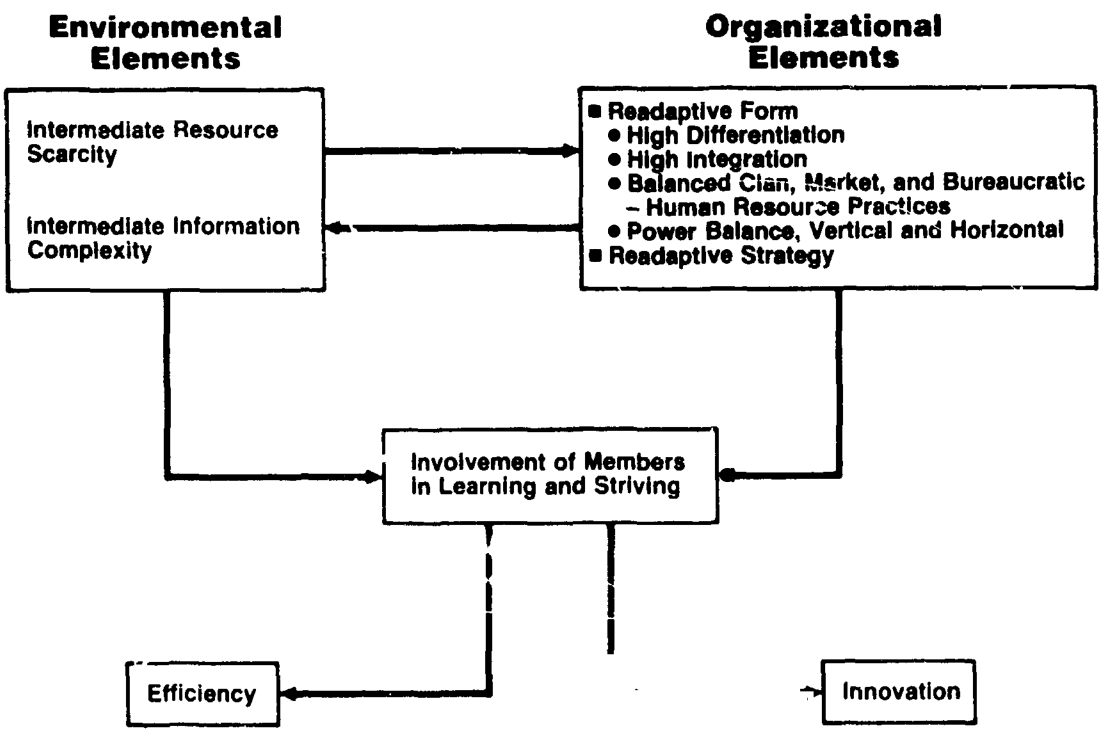


FIGURE 2. RELATIONSHIP AMONG THE FACTORS IN READAPTIVE PROCESS (AS DEFINED BY LAWRENCE AND DYER)



be learning systems is not new; it was the central theme of James March and Herbert Simon's classic 1958 work [8]. It is also the basis of rigorous studies of adaptive systems technology [9]. What is involved is a change in ways of looking at organizations. The old concepts of mechanical efficiency and bureaucracy are replaced. An integration of innovation and efficiency must take place through the involvement of all of the employees in active processes of learning and striving (effective interaction). At each stage in a program's life cycle, the process of performance improvement must develop an appropriate focus so as to improve quality and productivity. The focus of effort will change as the task evolves. Early phases of programs are characterized by the need for purposeful innovation.

<u>Purposeful Innovation (Doing Well What Has Never Been Done Before)</u>

The early stages of a program life cycle focus on purposeful innovation. Innovation is the heart of renewal. Case studies from <u>Renewing American Industry</u> [7] suggest that if organizations are to be efficient operational systems, they must also be innovative learning systems. Systematic innovation consists of the purposeful and organized search for change, and the systematic analysis of the opportunities such change might offer [3]. The term innovation as used here is an economic, social, and technical term. It is the improved yield of resources.

<u>Effective Interaction (Doing the Right Thing--The Integration of Innovation and Efficiency)</u>

Organizations are interacting sytems in the process of development. New programs demand renewal of these systems.

As programs reach the development stage, each department must learn to adapt and effectively interact with other departments. Effective interaction occurs when producers know what users need and produce what satisfies them. Successful programs depend upon effective interaction. Improvement projects must focus on producing <u>useful</u> information: budgets, schedules, contracts, tests, software, and so forth. The interactions of these services provide a source of organizational effectiveness improvement. Improvement in interactive effectiveness is prerequisite to improvement in operational efficiency. One must be doing the right thing, then improve the efficiency of the operation. Effectiveness improvement is a task of the developing organization.

<u>Operational Efficiency (Doing It Right the First Time)</u>

As programs move toward operational phases, the focus shifts again, this time toward process control. The central focus of the productivity movement embraced in Japan after World War II was operational efficiency. The work objective was to do it right the first time. Doing the right job correctly is the key to productivity. Through the development of quality circles in Japan, this resulted in the Japanese worker's having almost total authority within his discipline.

There is a convergence of interests that amounts to participative management.

Many companies in Japan and in the United States are currently involved in intensive efforts to incorporate quality concerns into problems of product-line transitions, applications to design, relations with customers, and research and development. Although operational efficiency is necessary in these functions, it is not sufficient. Effectiveness and innovation are also critical.

INNOVATION, EFFECTIVENESS, AND EFFICIENCY CASE STUDIES

Operational reliability, quality, and productivity depend upon having all of the parts working right in a process. When organizations like McDonnell Douglas and NASA take on new projects, they take on tasks of organizational transition. Transitional adaptation through the life cycle of a program, from concept development to operationally successful missions, includes an adaptation of performance improvement techniques to the changing nature of the problems encountered. J. M. Juran has called improvement projects "problems scheduled for solution" [5]. The problem-solving methods pioneered by Dr. W. Edwards Deming [2], Dr. Kaoru Ishikawa [4], and Dr. Juran in Japan have resulted in the continuing development of a <u>management improvement process</u>. This process is an ideal vehicle for continuing to improve quality and productivity as a program makes the transition from research and development to operational maturity.

The current Space Station program, committed to putting a permanent manned station in space by the early 1990s, is in its definition and preliminary design phase. Thus, Space Station program performance improvement projects must be devoted to purposeful innovations. The spirit of entrepreneurship, of newness, of finding opportunities to do economically, socially, and technically what has not been done before facilitates this stage. Perspective must be shifted from the operational worker as a follower of practices on some previous project to a knowledgeable worker guided by a renewed sense of purpose and a sense of the new whole of which he is a part.

<u>Purposefully Innovative Systems (Doing Well What Has Never Been Done Before)</u>

Case Study No. 1: E/E Development Versus Production	A focused factory or "plant within a plant" was developed at MDAC in 1979 to answer the need for high-technology electronics manufacturing within the company. The need for complex electrical and electronic (E/E) products required a highly technical manufacturing capability and recent contract demands for concurrency of design and development required a quick-response capability. The systems of the new "plant within a plant" were not fulfilling this quick-response requirement. A reevaluation of the plant's developmental and production roles and missions was in order.

A Juran project (see Appendix) was implemented to explore ways for the "focused factory" to meet quick-response requirements and expectations. A team from management and engineering was selected and the problem was stated: existing systems were not fulfilling the need for the highly technical, quick-response manufacturing capability required by complex products and concurrent development of electrical/electronic items. The improvement project team thus set as its objectives to (1) assess existing methods and procedures and structure new methods and procedures aligned more in keeping with a developmental approach, (2) establish task definitions for the implementation of a developmental shop, and (3) recommend organizational and support function changes. The team met periodically for nearly a year.

The problem with development projects had been evidenced in schedule slips, cost overruns, drawing release delays, and errors in work instructions. Systems being used stressed control rather than innovation, and fitted mature products rather than development projects. This pattern appeared in drawing preparation, production planning, manufacturing, inspection, and test. Also, the knowledge gained during development was often lost; job classifications were not appropriate, drawing systems needed changing, and organizational reporting relationships needed adaptation.

The statistical (variance reduction) techniques of the Juran process were not very useful for this kind of performance improvement project. This project required a form of performance improvement that Peter Drucker has recently described as "purposeful innovation" [3]. The key recommendation was to form a development team that has the flexibility to depart from the past and invent new ways of working so as to adapt to the variables of developmental projects. The improvement project team worked out remedies in the drawing system, provided development work instructions, and focused responsibility for development tasks. More involvement in goal setting and planning was needed at the interface of engineering and manufacturing to increase flexibility and efficiency, match people to tasks, and account for costs. The problems, causes, and remedies are shown in Figure 3.

FIGURE 3. CASE STUDY NO. 1—E/E DEVELOPMENT VERSUS PRODUCTION

Problems	Causes	Remedies
■ Unrealistic schedule	■ Requirements geared to mature projects	■ Implement development drawings
■ High cost	■ Work instructions difficult to change	■ Provide development work instructions
■ Delays in drawing and production release	■ Departments geared to stable operations	■ Focus responsibility for development tasks
■ Key contributions missing	■ Policy and practices emphasize control instead of flexibility	■ Encourage capture of good ideas
■ Incomplete development holding up production	■ Development knowledge not captured	■ Allow all involved to make inputs
		■ Involve others in goal-setting
		■ Tailor to needs of situation

Interactive Effectiveness (Doing the Right Thing)

Case Study No. 2	A pilot "white-collar" productivity improvement project (WCPI) was initiated in MDAC's Department 147, Financial Controls--Direct Budgets, in 1984. It has been a unique project. It addresses the renewal of a department. A project team of nine represented the 33 members of the department. This team was confronted with the demands of interactive effectiveness.

A pilot "white collar" productivity improvement project (WCPI) was initiated at MDAC to explore productivity in a department whose function is to provide useful services and information. The American Productivity Center's six-phase WCPI framework* provided a methodology. This particular WCPI project involved three groups of people:

- The Producers. Meetings were held in which all 33 members of Department 147 worked together to diagnose problems and opportunities for improvement. Complete feedback was given to each member of the department regarding the results of a 200-question survey of attitudes, leadership, communication, participation, goals, measurement, rewards, resources, and related concerns. They then set out to make improvements.
- The Users. One-hundred and fifty fiscal, program, and business managers as well as engineering and operations users in eight different program or business units were surveyed and interviewed. Feedback from this material provided a basis for (1) redesign of the services of the department to meet strategic plans, (2) team building for new teaming alignments, and (3) technology applications for improved service to users.
- The Managers. A management group included the Director of Financial Controls, the Controller, the Vice President-Fiscal, and the Director of Productivity. Department 147's manager became a member of the producer project team in an example of participative management in action.

The greatest block to interactive effectiveness in organizations is the attempt to protect interest groups and preserve old ways of doing things. These interests must be worked through person by person. This WCPI pilot project provided a framework to make transition processes a part of personal and organizational renewal, a concept to be instituted on a department-by-department basis in selected parts of the company.

The lessons learned, expressed by the improvement project's team members, included the following:

1. Commitment to Improvement: Producers, users, and managers must be committed to improvement.

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*The American Productivity Center's six phases of a white-collar productivity improvement project are, briefly, diagnosis, objective setting, measuring, service redesign, team development, and development of technology parameters.

2. People Involvement: Everyone's personal opinion, valid or not, influences interaction.

3. Producer Ownership: Each producer and each user is a stake holder who must own and share in the gains of improvement.

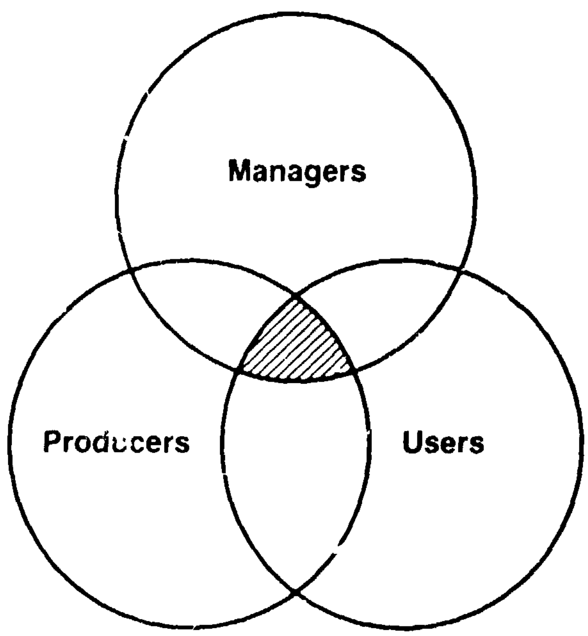
4. User Involvement: Effectiveness means doing the right things and requires interaction between producers and users.

5. Responsiveness: Services must be responsive to the needs of those who are served.

6. Efficiency/Effectiveness: The role of the WCPI is to develop organizational effectiveness.

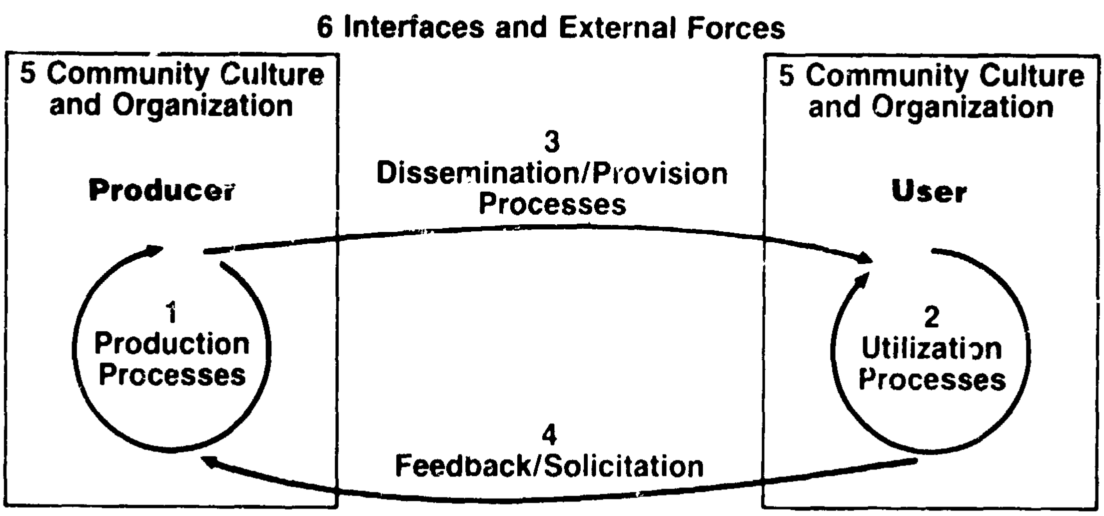
The WCPI process works. Its improvements accrue to producers, users, and managers (Figure 4) if they believe in it. But credibility must be won. In the Department 147 project, not one of the three groups was easy to convince. Even the pilot coordinator and managers had to go through the process. The key is complete honesty and feedback. The first meeting with the entire department did not result in belief because the will to change was not apparent. It took action to show that manager, user, and producer groups had the will to do something. Once members of the department received feedback and became involved in diagnosis and objective-stting, things turned around dramatically. Commitment came even in the midst of the heavy daily workload.

FIGURE 4. INTERACTIVE EFFECTIVENESS



The WCPI resulted in the improvement of attitudes, participation, communication, leadership, goal-setting, measurement, rewards, recognition, and use of resources within the department. It resulted in the involvement of management not only in getting to know the work of the department more thoroughly, but in providing a sense of mission and focus and in selecting the team and then allowing the team to actually make improvements. The WCPI also resulted in improvement of the relationship of the producers to managers and users (Figure 5). This began with identificaton of the users continued with attempts to see the department through their eyes, and resulted in further improvements that will continue to be made in the future.

FIGURE 5. OVERVIEW OF THE PRODUCTION/UTILIZATION SYSTEM



(Adapted from Killman [6])

1. Production Processes
2. Utilization Processes
3. Dissemination/Provision Processes
4. Feedback/Solicitation
5. Community Culture and Organization
6. Interfaces and External Forces

<u>Operational Efficiency (Doing Things Right the First Time)</u>

Case Study No. 3: Crush Grind Process Control	Hardware acceptance is determined after manufacture by part inspecton. However, inspection does not prevent nonconformance of parts. Since a significant percent of machine shop rejections is accounted for by machine operation, more hardware could be accepted if the manufacturing process could be controlled so as to prevent nonconformance of parts.

ORIGINAL PAGE IS
OF POOR QUALITY

MDAC had recently been discussing the merits of a quality control philosophy based upon prevention rather than detection of defects. To test this concept and solve this specific parts-rejection problem, management chartered a team representing manufacturing, planning, and quality departments.

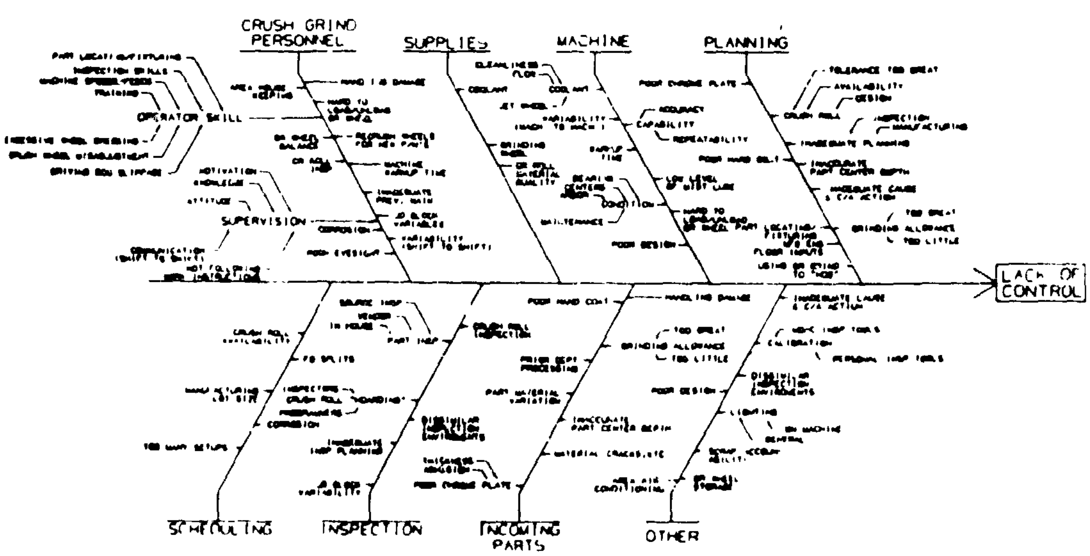
Through analysis of prior nonconformance costs, a particularly unsatisfactory machining process was identified. This process is required to hold very close dimensional tolerances, but it consistently produced defective parts. Many traditional approaches to corrective action had been tried but had met with little success. Thus, the team felt that a new approach was in order.

The team used the following investigative procedure: (1) identify likely causes, (2) test these possibilities to determine their actual effect, (3) evaluate test results and implement corrective solutions, (4) test these solutions for effectiveness, (5) train operating personnel in the new approach, (6) reduce or eliminate in-line inspection and accept the product on the basis of process control.

To identify potential causes of defective parts, the team held a brainstorming session. Over 75 opinions or possible causes were gathered through this process. These opinions were categorized and diagrammed on an Ishikawa "fishbone" chart [4] to show their interrelationships (Figure 6). Next, copies of the fishbone chart were distributed to persons familiar with the machine process under investigation. These people were asked to identify the ten most likely causes of process nonconformance. These results were then correlated to produce a list of the most likely causes.

The group then determined what data and experimental approaches were required to prove or disprove these most likely causes. In this case, a process capability analysis was considered crucial to evaluate the possible defect causes.

FIGURE 6. CRUSH GRIND PROCESS CONTROL



Once the experiment was performed, the data were analyzed with simple statistical techniques (Figure 7). These statistical tools included histograms (Figure 8) that showed how the data were distributed.

FIGURE 7. RUN CHART

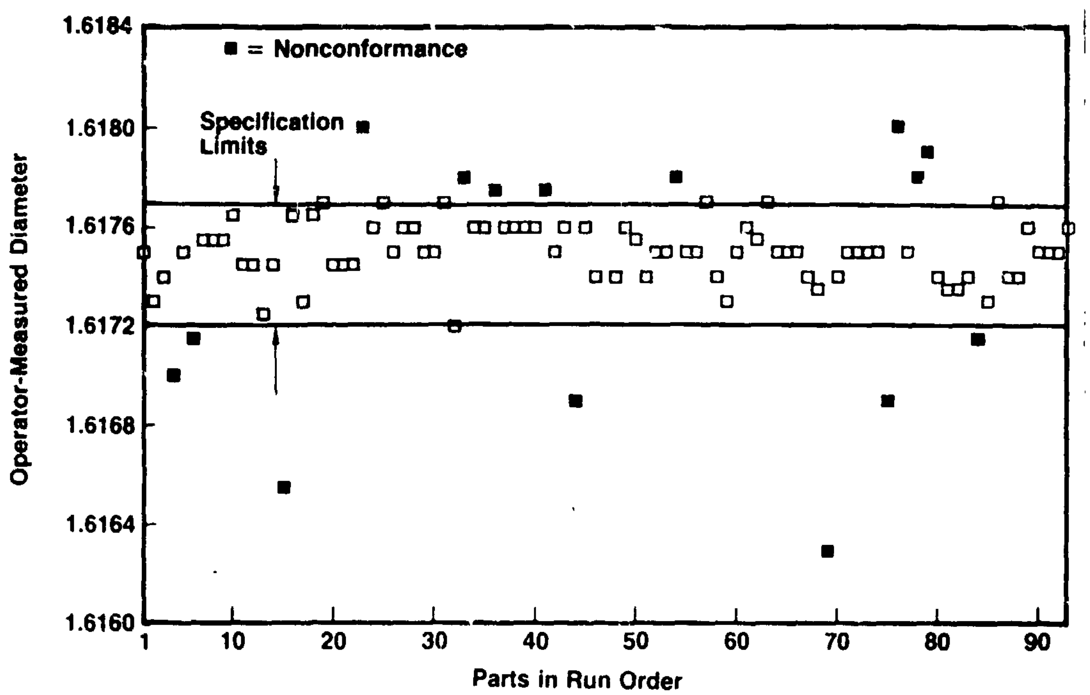
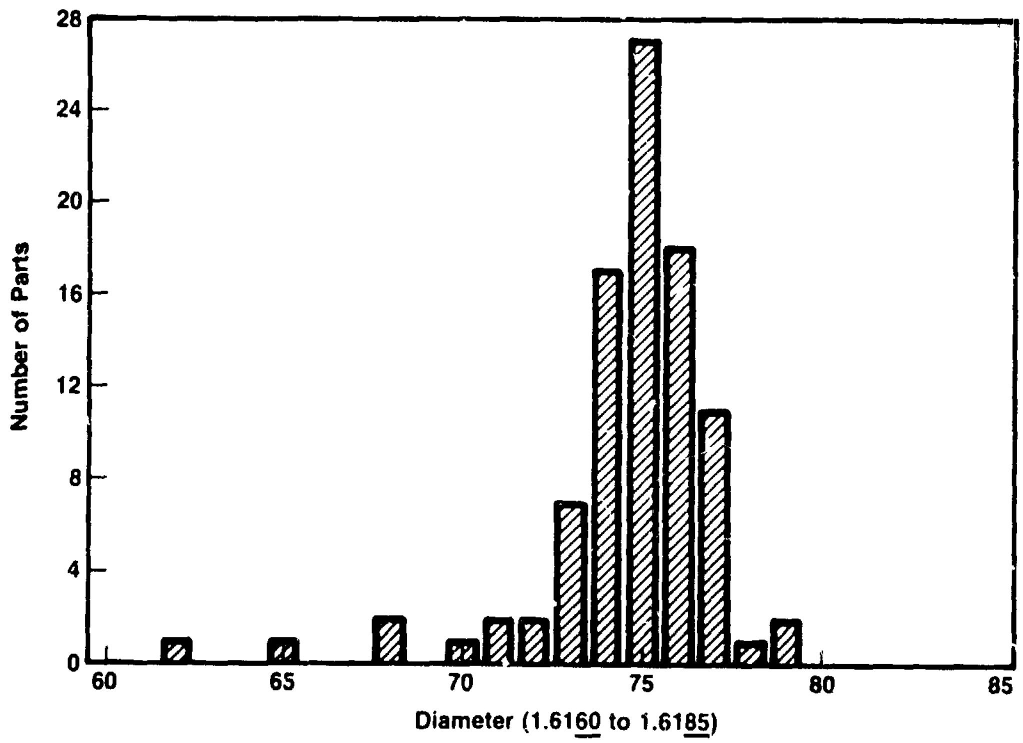


FIGURE 8. HISTOGRAM



The analysis revealed several significant conclusions. Of greatest importance, it revealed that the process was not capable of consistently producing parts within the design tolerances. In fact, the experimental results suggested that a 25% failure rate should be expected from this process. Differences in inspection techniques between operators and inspectors used as much as 20% of the design tolerance. Variations in part center depths (this process grinds parts on centers) were as high as ± 0.025 in., requiring a new setup for each part.

Clearly, this was new and interesting information. Here was a machine process <u>destined</u> to make defective parts regardless of the efforts of the operator. To correct this obviously unsatisfactory situation, equipment was ordered that could be attached to the machine to improve its capability and automatically compensate for variations in part center depth. This equipment cost less then $20,000 and will pay for itself in less than 1-1/2 years. In addition, manufacturing and inspection agreed to use the same inspection tools and techniques.

Once the new equipment is received and installed, the study team will perform a new process capability study to prove that the machine enhancements are effective. Once this is demonstrated, the machine operators will be trained in simple statistical techniques, especially control charts. The operator will then implement normalized process control charts and Quality Assurance will inspect by monitoring the control charts and auditing the manufacturing inspections.

This project has been very successful so far and has served to show the viability of the process control approach to quality control [10]. In addition, it strongly suggests that a process isn't thoroughly known until it is known statistically.

MDAC anticipates more projects of this kind in the future, leading to significant improvements in quality and reductions in costs through improvement in operational efficiency, in office technology as well as in manufacturing.

CONCLUSIONS

The mission, focus, and methods of quality and productivity improvement projects are part of a renewal or readaptation process that changes during the life cycle of aerospace programs. The industry is beginning to become aware of the need for managing life-cycle transitions and developing self-renewing organizations. William Bridges, a consultant to MDAC-HB, has summarized the challenge of organizational transition [1]: "'Change' is when something stops happening or when something starts happening. 'Transition,' on the other hand, is an inner reorientation process that an organization and all the individuals in it go through when a change requires everyone to work on a new team, fill a new role, and act in new way."

APPENDIX: PROJE\ "EAMS AT MDAC-HB

	Juran Project Teams	White Collar Productivity Improvement Projects	Quality Circles
1. Team composition/ leadership	4 to 10 members on an intradivisional or interdivisional basis with management leader	A representative team from the department works with project manager, coordinator, and APC liaison	5 to 15 members, not necessarily from the same work group, with a leader
2. Participation	Not voluntary; nature of projects selected determines participation	Participant management is developed in the process	Voluntary for circle members
3. Project selection	Projects selected by Management Improvement Project (MIP) Council	Project selected by MIP Council	Projects selected by team members
4. Problem complexity/ time required	Complex problems requiring substantial time for analysis	Focus on organizational effectiveness	Moderately complex problems requiring time for analysis
5. Training	Entire team trained in problem solving and statistics; leader training for team leader	Training provided by the American Productivity Center (APC) and project coordinator	Entire team trained in problem-solving; extensive leader training
6. Facilitator or internal consultant	Facilitators and statisticians available	Facilitator/coordinator required; liaison support and conferences at APC	Facilitators and statisticians available
7. Coordination	MIP Coordinating Committee ar ' Functional Steering Committee	Pilot project coordinator from the company assigned to work with manager and APC	Coordination by Performance Improvement Department
8. Decision-making authority	Higher authority required to decide on recommended actions	Relies on participative management and local decision	Limited authority to decide on action; make recommendations to management

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BIOGRAPHY

D. H. Hutchinson is currently a coordinator and internal consultant to leaders of management improvement projects at the McDonnell Douglas Astronautics Company. He has been a facilitator and trainer on the initiation of Juran projects and the white collar productivity improvement pilot project as well as providing support to training and communications in the "Five Keys to Renewal" since the inception of these initiatives at MDAC Huntington Beach. Hutchinson has gained extensive experience in Engineering, Program, Human Resources, and Operations departments during his 29 years at McDonnell Douglas. He received his BA and M.Ed degrees from UCLA and is currently in the doctoral program at Claremont Graduate School. His dissertation, entitled "Resymbolization of Work", deals with a theory of knowledge-work productivity and will be published in 1986.

THE SPACE TRANSPORTATION SYSTEM AS A PRODUCTION PROCESS

N86-15161

THE KEY TO SUCCESSFUL MANAGEMENT OF STS OPERATIONS: AN INTEGRATED PRODUCTION PLANNING SYSTEM

William A. Johnson, Rockwell International
Christian T. Thomasen, Rockwell International

ABSTRACT

STS operations managers are being confronted with a unique set of challenges as a result of increasing flight rates, the demand for flight manifest/production schedule flexibility and an emphasis on continued cost reduction. These challenges have created the need for an integrated production planning system that provides managers with the capability to plan, schedule, status and account for an orderly flow of products and services across a large, multi-discipline organization. With increased visibility into the end-to-end production flow for individual and parallel missions in process, managers can assess the integrated impact of changes, identify and measure the interrelationships of resource, schedule, and technical performance requirements and prioritize productivity enhancements.

BACKGROUND

The Operations Challenge

The Space Transportation System (STS) flight-to-flight reconfiguration process at Johnson Space Center (JSC) encompasses initial flight feasibility assessments, flight trajectory design, flight operations planning, flight production generation, facility reconfiguration, flight crew and controller training, real-time mission support and post-flight reconstruction. As the STS transitions to mature operations, this end-to-end process must be streamlined to minimize cost while maintaining acceptable quality and risk levels. Reconfiguration schedules must be reduced while maintaining late manifest and flight content change flexibility. Increased flight rates must be accommodated within production capacity and manpower limitations. These challenges have created the need for an integrated project/performance management system to provide managers with improved visibility and control of the reconfiguration process flow and the flight production line.

Production Line Environment

Each STS mission flown increases the experience database and the potential for a higher degree of commonality between a new set of mission requirements and those of a previous flight . Continued standardization of flight products and configurations promote maximum utilization of generic data and minimizes th effort required to generate flight specific updates. Incorporation of other process enhancements such as such automation, modularization, consolidation, simplification and elimination contributes to a changing operational environment that parallels a production line methodology. As management focuses on the challenge of maintaining an orderly flow of products and services across the large , multi-discipline organization responsible for the JSC flight-to-flight reconfiguration process, the supporting project/performance management system must be oriented to provide the capabilities of an integrated production planning system.

Reconfiguration Process

The flight-to-flight reconfiguration production process is composed of three major elements. First, the activities, products, schedules and associated resources within each technical discipline that are structured to meet flight specific requirements and milestones. Second, the interrelationship of the flight preparation, production, mission operations and support functions that establishes process constraints between technical disciplines for a specific flight. Third, the composite set of flights in serial and parallel processing that compete for utilization of the common manpower, facilities, hardware and software resources. The end-to-end process covers approximately a one year period from the Flight Definition and Requirements Directive (FDRD) baseline through launch of the mission. It is a relatively dynamic process with the possibility of changes in the flight manifest configuration, vehicle assignments, flight schedules or mission requirements occurring late in the flow. The impact of these changes may be to a single mission or domino into several flights.

Integrated Production Planning System

The integrated production planning system must provide managers with the capability to plan, schedule, status and account for all the work involved on a single and multimission basis within this dynamic environment. As a resource management tool, the system must support the integrated forecasting and performance assessment of the resource requirements and resource-leveling techniques where necessary to stay within production capacity limitations. As a work process analysis tool, the system must facilitate the identification of schedule conflicts and production process choke-points and support the evaluation of productivity improvement options and determination of relative priority for implementation. As a change assessment tool, the system must provide data which clearly defines the integrated impact of the management decisions to be made on a single mission basis and the potential domino effect to parallel in-process missions. As a model of the flight-to-flight reconfiguration process the integrated production planning system can provide an invaluable tool in the successful management of STS operations.

METHODOLOGY

Activity Categorization

The methodology used in developing a model of the flight-to-flight reconfiguration process is based on a building block approach from an individual activity level to an integrated flight-specific work plan, and ultimately, into a composite multimission work plan. Initial analysis of the NASA and contractor work requirements identified in three basic activity categories:

1) Manifest-dependent activities that are dedicated to or directly associated with specific flight schedules and requi.ements. These activities (e.g., the Orbiter on-board mass memory unit (MMU) load production) are generic for each mission.

2) Manifest-related activities that are institutional in nature, but with periods of dedicated support to a specific flight. These activities may be derived from the composite multimission resource-utilization profiles associated with the manifest-dependent activities

(e.g., Central Computing Facility (CCF) operations) or added to the generic manifest-dependent activities for a specific flight requirement (e.g., Shuttle Flight Operations Manual (SFOM) update).

3) Manifest-independent activities that are regularly scheduled, on-going or discrete project activities having little interaction with flight requirements. These activities (e.g., CCF preventative maintenance) would be integrated with the manifest-related or independently scheduled (e.g., Integrated Management Center (MIC) development).

Generic Process Flows

The manifest-dependent activities with their associated resource requirements (manpower/facility/hardware/software) are the basic standard building blocks for the model. Generic process flows can be constructed for each technical discipline linking the activities with their key input and output products, milestone events, and serial or parallel time-phasing for a typical high complexity mission. Integration of these generic process flows for each technical discipline into an end-to-end network logic flow establishes the interrelationships and process constraints between disciplines. The data can be structured into several levels of hierarchy for corresponding levels of management visibility. Hammock activities are established at higher levels to span the composite duration and summarize the status of a group of lower tier activities.

Key milestones can be fixed at a given launch-minus date to conform to top-level templates previously negotiated. The number of these fixed milestones should be kept to a minimum, however, this allows activities to float between the earliest possible start and the latest possible finish dates imposed by input/output dependencies with other portions of the network process flow. As discussed later, this factor becomes critical in the ability to level the utilization of resources.

Flight-Specific Tailoring

Flight-specific tailoring is required to transform the generic network logic flow into a series of flight-specific plans consistent with each set of mission requirements. An analysis of the relative mission-unique drivers and complexity factors war performed to determine how one mission differs from another. The first conclusion was that five levels of complexity are desirable to tailor activities, products, schedules, and resources to mission specific requirements: high, medium, low, DoD, and launch-on-need (LON). Second, different disciplines are affected by different mission-unique drivers and complexity factors: a single overall rating for the total network logic flow is not always applicable. Third, complexity can vary as a function of the mission phase. Fourth, an approach that considered relative complexity by mission phase and discipline provides an opportunity to reduce selected portions of the network logic flow where a uniform complexity reduction of the total flow is not possible. Development of a parametric matrix approach to the mission-unique drivers for each mission phase allows a judgement weighting factor of relative complexity to be applied to a set of specific flight requirements.

Flight-Specific Plans

Application of the mission-unique driver matrix to a projected flight rate model and generic network logic flow results in a series of flight-specific plans. Activity durations and the associated resource requirements for lower complexity tasks can be reduced accordingly. Adjustments can be made for utilization of dedicated DoD secure resources where applicable and manifest-related activities added where appropriate. While each flight-specific plan conforms to the same top-level template of key milestone launch-minus dates, flight-specific tailoring by technical discipline and mission phase results is essentially a unique critical path for each plan. Each flight-specific plan is also tailored to achieve the minimum production cost by consideration of the relative mission complexity factors in developing the activity duration and associated resource requirements. These schedule and cost targets can be planned a[illegible]asured on a flight-by-flight basis.

Multimission Work Plan

A composite multimission work plan is created from the individual flight-specific plans. Each activity and event is coded to identify the associated flight number, responsible technical discipline and organization, authorizing work breakdown structure (WBS) code and other selection/sort flags to facilitate a variety of composite output reports and graphics. Other manifest-related and independent activities can be overlayed, to complete the scheduled work profile for any given time span.

Analysis of the multimission work plan data can identify potential schedule conflicts, production flow choke-points and timeframes where the resource utilization requirements exceed the composite production capacity and manpower limitations. Automated resource-leveling can be performed by establishing a resource availability curve and allowing the computer to reschedule the effected activities to a more opportune timeframe within the network logic constraints for each mission. Groups or categories of activities can be given relative priorities to influence the automated rescheduling process. Successful resource-leveling may not be possible if the network logic does not provide sufficient schedule flexibility with activity float between the earliest and latest possible start dates.

The impact of a change in mission requirements can be assessed by revising the appropriate flight-specific activities, products, milestones, interrelationships and associated resource utilization requirements. The revised flight-specific plan(s) can be incorporated into a composite multimission work plan to evaluate the integrated impact of the change to the current baseline or combination of baseline and other pending changes. This same approach can be applied to evaluation of proposed productivity enhancements. Revision of the generic network logic date corresponding to the improved process flow or revised resource requirements can be projected to a multimission scale to determine overall gain in production efficiencies.

APPROACH

System Prototype

A prototype of an integrated production planning system was developed utilizing the PROJECT/2 project management software to validate the concept and methodology described above. PROJECT/2 software was selected for the prototype based upon the availability of a mainframe installation within our corporate resources, which met the system performance criteria. Other considerations included accessibility of experienced users, and a demonstrated user-friendliness. The key factors in the success of any project management system are the structuring of the database which must simulate as accurately as possible the real-world environment and the capability to present the data in formats which managers can readily assess plans, status, analyze alternatives and incorporate changes. The focus of the prototype development was to demonstrate these capabilities.

A generic network logic flow was created interrelating over 500 activities, products, and milestone events to model the JSC flight-to-flight reconfiguration production process. The structure of the network logic flow was built around the definition of 11 technical disciplines which provided a better validation of their functional interrelationships. The responsible organization, WBS coding, selection/sort flags, and associated resource utilization profiles were added to the database for each activity and event defined. Samples of flight-specific work plans at several levels of hierarchy were generated in both the graphic and tabular form.

A composite multimission work plan was created combining 36 flight-specific plans representing flights from 51-L (01/22/86 launch) through 81-G (02/15/88 launch). The multimission database contained over 19,000 activities, products, and milestone events, and over 30,000 logical interrelationships. Samples of composite production schedules and resource utilization profiles were generated. A preliminary evaluation of automated resource-leveling and priority scheduling options ware also concluded. A data transfer approach was developed and demonstrated to facilitate interchange of data between the prototype system and the other existing project management/scheduling systems.The results to date have proven the feasibility of the concept and validated many of the conclusions reached in developing this methodology.

Conclusions

A realistic amount of schedule flexibility (critical path float) must be provided within the network logic for each mission to accommodate unplanned changes and resource-leveling when required. The net impact to a single mission and potential domino impact to parallel missions in process must minimized to maintain overall production efficiency. While reduction of the end-to-end production template for a mission does provide a minimum schedule, it does not necessarily provide a corresponding reduction in the composite production costs for all missions if flexibility is lost.

As the STS flight rate continues to increase, the relative time between missions decreases resulting in a higher degree of overlap for the same activities in parallel processing for different missions. This creates an increase in the number of equivalent missions competing for utilization of the same common manpower, facility, hardware and software resources. A shorter production template maybe needed to reduce the overlap and reduce the number of equivalent missions in parallel processing. The challenge is achieving a balance between a shorter template and retaining the necessary schedule flexibility.

One solution is a continued emphasis on productivity enhancements. Standardization of flight products and configurations through utilization of generic data reduces their sensitivity to unplanned changes in requirements and the need for schedule flexibility to incorporate the changes. Automation, modularization, and consolidation of activities generally reduce the end-to-end processing time and increases flexibility. Task simplification reduces the required skill level and associated production cost. Specific enhancements must be evaluated in terms of the integrated production process on both a single and multimission basis to determine the net benefit and relative priority for implementation.

An integrated production planning system is one of the keys to maintaining a productive workforce and identifying where improvements are needed. The availability of a management system tool that provides the capability to develop accurate work planning schedules, project resource requirements, assess program status/evaluate impacts and alternatives to changes is essential to the management decision process. Continued refinement of the prototype model of the JSC flight-to-flight reconfiguration process will provide a more in-depth analytical capability to support management in meeting the challenges of the dynamic STS operations environment. Long term improvements include the development of an expert system application where the management decision process based on manual analysis of scheduling alternatives is automated to produce an optimum schedule.

Authors' Biography

William A. Johnson is a Project Manager with the Rockwell STS Integration Project Office. He received his B.S. degree in Mechanical Engineering from Carnegie-Mellon University. His 16 years of Apollo/Shuttle experience includes flight and ground systems design integration, test and mission operations support requirements and management systems integration.

Christian T. Thomasen is a Plans/Schedules Management Adminstrator with the Rockwell STS Management Information Systems Office. He received his A.A. degree in Business Data Processing/Computer Science from San Jacinto Junior College. His 16 years of experience encompasses a wide-variety of applications spanning both the commercial and aerospace industry including computer operations, data base management, hardware/software evaluation and project/performance management systems.

N86-15162

THE STAR SYSTEM: A PRODUCTION ENGINEERING APPROACH TO STS

Robert C. Angier, IBM Corp.
Leon D. Swartz, IBM Corp.
Joe H. Wilson, IBM Corp.

ABSTRACT

This paper documents a fundamental change to the way Space Transportation System flight preparation is done. It involves (1) systematic restructuring the STS flight preparation task, to minimize its R&D content, (2) development of the STAR System to structure and support the remaining work flow. STAR is an integrated software system providing automation and quality control mechanisms necessary to create a production-like process. This approach has been implemented using tools and methodology developed by IBM under NASA contract, to produce payload flight data requirements. It offers increased product quality, reduced cost per flight, and greater responsiveness to change.

INTRODUCTION

The Space shuttle was designed for operational flexibility necessary to take on a variety of missions. Its flexibility is achieved by adapting orbiter and ground systems to the specialized requirements of each flight. However, the scale of modification is immense. The systems which have evolved require extensive software tailoring in order to perform orbiter and ground operations and training. For a typical flight, several million individual requirements must be defined, integrated, and validated. The flight preparation process to create these requirements takes many months and extensive resources. Our ability to produce flight-specific requirements in an era of increasing flight rate is a major challenge for future STS growth.

The NASA Spacecraft Software Division was early to recognize and respond to this challenge. In 1979, they chartered an IBM task to define an approach to flight preparation of Orbiter Avionics Software in the Shuttle Operations era. The goal of this task was to define a way to reliably produce mission-reconfigured Flight Software products for a high flight rate (over 20 flights per year), at a greatly reduced cost per flight [2]. This set of objectives focused attention on potential application of production-line methods to STS flight preparation.

The task scope covered preparation and verification of the flight-tailored Primary Avionics Software System (PASS) load, and integration of the orbiter's Mass Memory Unit (MMU) contents. The former includes flight-critical Guidance, Navigation, and Control (GN&C) systems, as well as Systems Management and Payload Management systems essertial to mission success. These applications necessitate rigorous control of product quality.

The Space Transportation Automated Reconfiguration (STAR) System was developed by IBM to address this need. It is both a tool and an approach, which results in restructuring the R&D tasks of Shuttle preparation to form a production process.

PRODUCTION ENGINEERING APPROACH

The approach utilizes production methods to re-engineer the tasks of flight preparation [1]. Existing methods made extensive use of R&D processes and tools, treating every flight as a special case. Flight requirements were defined in terms of differences from a previous flight baseline, causing simple manifest changes to result in wide-spread changes. These techniques could not support the demands of an increasing flight rate

A production engineering discipline was applied to the preparation of flight-tailored software, in a manner analogous to early automobile manufacture. Starting with a hand-crafted prototype (eg. STS-5),

- re-design it for manufacturing
- design and build an assembly line to produce it on
- establish a supply system for basic parts
- establish a quality control system for production

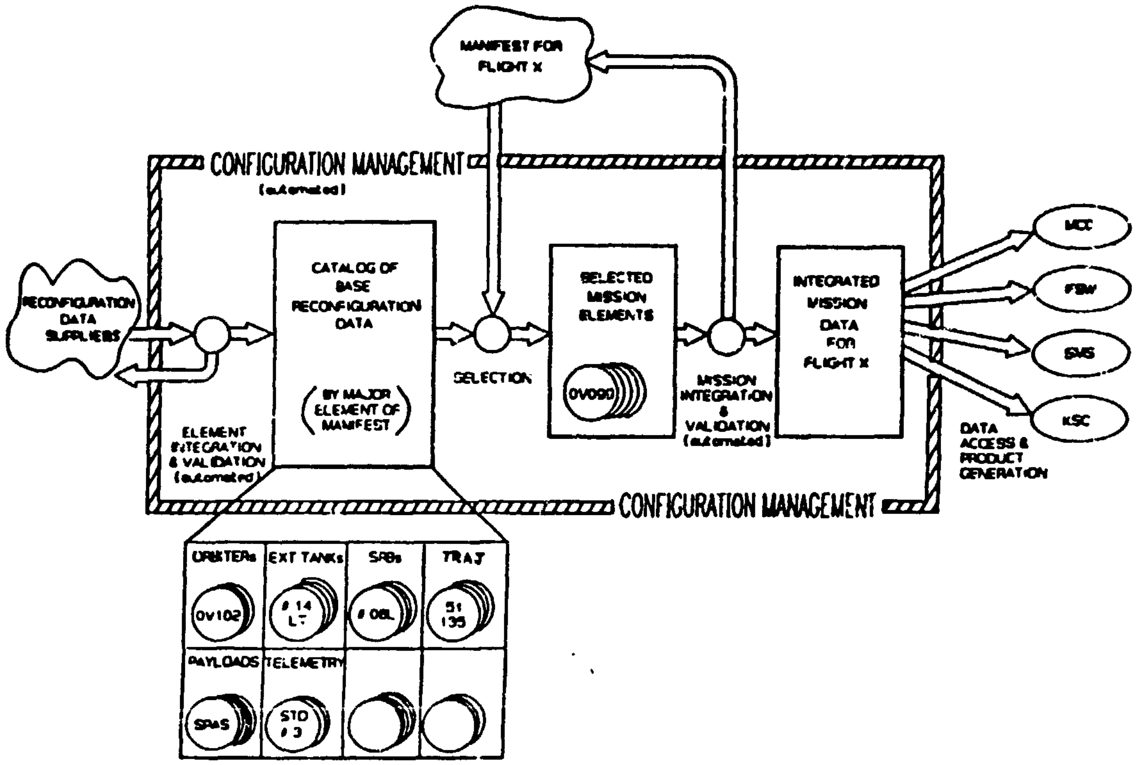
The principal difference is that these tasks were applied to logic and data, rather than glass, rubber, and steel.

The production-line approach depends on ability to isolate independent components, which presented several technical challenges. It was first necessary to separate the effects of flight preparation from those resulting from development of new capabilities. Once functional changes were separated out, monolithic collections of data requirements remained, containing tens of thousands of parameters. A flight preparation process had evolved which managed changes to an integrated set of requirements, obscuring the origins of its content.

Secondly, it was necessary to identify component parts. Major drivers were identified, which include the launch site, launch date, orbiter vehicle, flight trajectory, and cargo characteristics. Identification of drivers causing changes in subsets of parameters made it possible to divide the data into smaller parts. Each component contains a group of functionally related parameters, which change at the same time, for the same reason. These exist independently of flight assignment, and remain relatively stable in content.

Third, the rules governing selection and integration of parts had to be defined. Grouping of data into components provides leverage for flight selection: identification of a higher level name is equivalent to many detailed parameter substitutions. Integration and validation functions can also be automated to simplify flight-related tasks. When all components have been selected and integrated, a flight-specific require-

FIGURE 1 - CATALOG-BASED RECONFIGURATION APPROACH



ments baseline can be produced. The full approach is illustrated by Figure 1.

This approach constitutes a basic change to the way the flight preparation task is viewed. Rather than development of a unique fligh* requirements baseline, the task becomes collection of flight-independent components, which are later selected and integrated on a flight basis. This concept allows research and development efforts to focus on provision of new components based on projected future needs, while streamlining and automating production tasks. Once this capability is in place, available components build up until it becomes effective to reuse existing elements. A measure of standardization also encourages the reuse of previously collected elements. As a result, R&D effort is minimized.

Production engineering converts recurring R&D activities to one-time tasks, in a structure which encourages their reuse. The task objective is changed from development of an integrated product to development of components with broader applicability, which can then be reliably integrated together. This approach considers R&D efforts to be capital investments, to be utilized by the STS Program long after the flights for which they were performed.

The Space Transportation Automated Reconfiguration (STAR) System is the first major implementation of the production engineering approach. It is a pathfinder providing major new capabilities to the STS program. It divides flight configuration requirements into separately manageable components (called "units"), which exist independently of flight. It combines quality-enhancing functions of validation, inspection, and configuration control into the requirements collection process. It allows controlled integration of units into larger assemblies; at each step, consistency constraints are validated. Flight-specific requirements are produced by integrating only the highest level units needed to define its content. This provides the flexibility necessary to respond to the changes in flight definition which are inherent to a transportation system.

THE STAR SYSTEM

The Space Transportation Automated Reconfiguration (STAR) system is a software configuration and data management system developed by the IBM Corp. under contract to NASA. The initial delivery in June, 1985, provided the basic capabilities needed to collect, validate, and integrate Space Shuttle Systems Management and payload data into the overall reconfiguration production process. This data includes the definition of payload related telemetry streams, uplink commands, onboard displays, and the onboard processing required to command and control the payloads themselves. The first flight using products from the STAR system is STS-61E which is scheduled to fly in early 1986. Subsequent planned upgrades to STAR will add additional payload processing capabilities plus incorporate data management support of the vehicle parameters monitored by the on-board General Purpose Computers (GPC's).

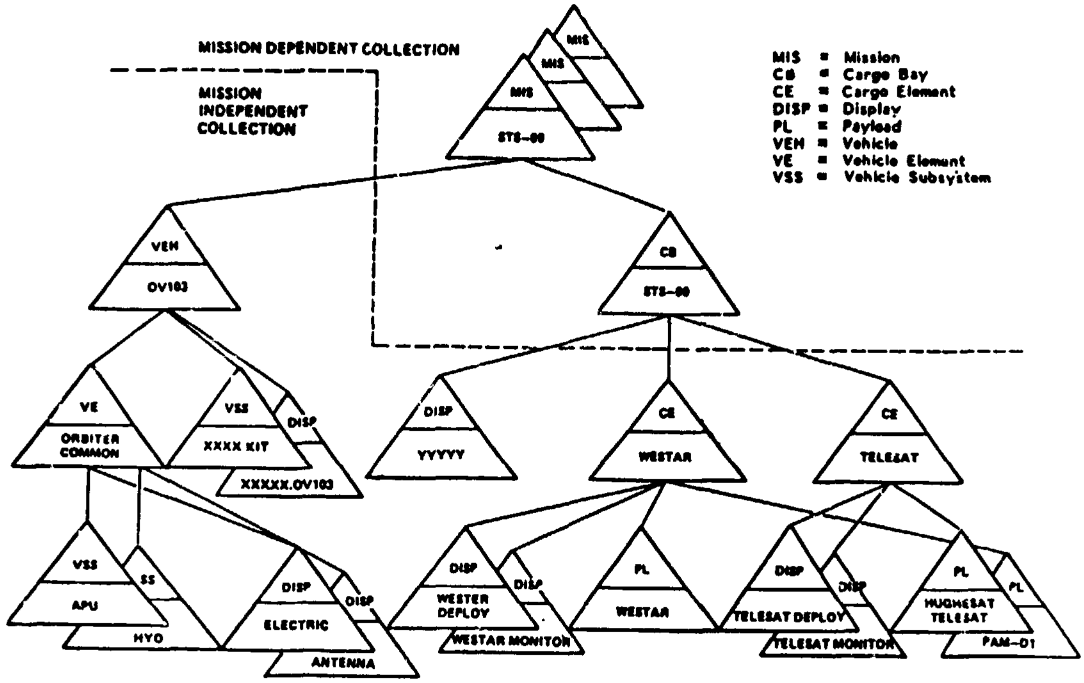
The development of STAR began in late 1982. IBM was responsible for all aspects of the software engineering task: requirements analysis and specification, implementation and integration, and coordination of the customer's user acceptance testing and release to operational production. Over 149,000 source lines of PL1 and ADF code were delivered. At the time of release, NASA engineers had already input over 22,000 payload parameters and 55,000 description definitions defining 54 payloads. The transition to production was smooth and the system readily accepted because the user community was very involved right from the beginning. Therefore useability received as much consideration as functionality.

Purpose of STAR

Several years ago NASA realized that the reconfiguration data management tools and techniques they were using would not support their future Shuttle flight frequency goals. The process was labor intensive and error prone because of of the amount of data involved and lead time required. Additionally, there was no convenient means of reusing previously defined data, so each mission required a "custom" system put together by a team of "experts". The impact of errors was frequently significant because they typically weren't caught until late in the critical path processing for a flight. STAR is one of several new tools intended to eliminate those problems and deficiencies.

The purpose of the STAR system is to automate, centralize, and control the collection of Shuttle reconfigurable data that is processed by the ground and on-board flight computers. The remainder of this paper describes the concepts and approach chosen by IBM, and the features and capabilities of the STAR system itself.

FIGURE 2 - A MISSION UNIT HIERARCHY IN THE STAR SYSTEM



Basic Concepts

The basic STAR concepts are:

- Software enforced configuration control
- Software enforced data quality/error detection rules
- Automated selection for reuse
- Streamline and control mission manifest tasks

SYSTEM FEATURES

The STAR system enforces these basic concepts via: Data Structure, Data Integration, Data Control, User Access Control and Data Partitioning. These terms are introduced below. Additional detail on each topic is provided in subsequent sections.

Data Structure is controlled by use of a predefined hierarchy, shown in figure 2. This hierarchy segregates each group of reconfiguration elements into controlled structures called "units". The units used in STAR include: Mission, Cargo Bay, Cargo Element, Payload, and Display. Data is controlled by only allowing data in a "working" state to be changed. Data may only be used for a reconfiguration after all audits have been passed and the data has been "baselined" for use. Access to the STAR data bases are limited to a set of predefined users. The tasks that a user can perform are further restricted by user function (e.g. data entry clerk, data suppliers, data coordinators, mission managers, approval board chairperson). Data integration is enforced at data entry for audits that detectable on a single screen of data (called a list or data category). Audits that cross screens of data are verified by manually initiated batch processes called integrators. Each unit type has an integration processor. All screen audits and integration checks must be successfully passed before data can be submitted for baselining. Data collection is performed mission independently to allow data reuse on multiple flights (e.g. parameters required by the Payload Assist Module (PAM) upper stage are stored once and reused on each flight). Mission dependent data values (mission manifest, payload bay address, etc.) are collected in a mission independent data base which contains all known missions. A mission dependent data base is created for each mission to allow the mission independent units to be configured with the mission dependent values.

Data Structure

The data structure of the STAR system is hierarchical and is controlled via a template called a prototype. Collection within the prototype is further controlled by data categories, list categories and units. These categories define the content, constraints and structure.

DATA CATEGORIES contain actual data values which define or share some common purpose or function. For example, the calibration coefficients for a parameter would be collected in a single data category. Each data category has a corresponding specifically designed input data screen. Each data category also has a set of intra-data category audits which are enforced at data entry. These audits must be passed before the data can be baselined.Examples of audits include value, format, range and inter-value constraints.

LIST CATEGORIES contain REFERENCES to other list and data categories. List categories are used to group multiple parameters with a common source or function together. Examples of a list category include the references to the set of payload measurements and payload commands for a payload. The list categories are used to construct a template called a PROTOTYPE . The prototype defines the lists and data categories that may be referenced within the specified prototype. In addition, the prototype defines the number of list categories that may be referenced in the specific prototype. For example, the Cargo Bay prototype defines the maximum number of Cargo Elements that may be defined in the Cargo Bay. Any number of specified data categories may be referenced within the prototype. For example, many parameters may require calibration in a payload. The filled in structure of a prototype is called a UNIT. The Space Shuttle payload units are: Display (an onboard display description), Payload (an upper stage, pallet or spacecraft on an upper stage or a subset of a large payload like Spacelab), Cargo Element (a collection of Payload and Display units which are manifested as a group), Cargo Bay (the Cargo Elements and Displays (which contain multiple Cargo Element data) which make up a Shuttle Cargo Bay), and Mission (the Cargo Bay and Space Shuttle Vehicle which will fly on the specified mission).

References are made via a standard name structure consisting of the category name, occurrence name and a qualifier. The category name selects the specific category definition. The occurrence name defines a specific instance of the category. The occurrence name may have specific audits. The qualifier is used to distinguish between concurrent versions of the occurrence name. Qualifiers allow different models of a parameter or unit to be maintained concurrently in the data base. For example, an upper stage may have a new model which has unique parameters from the old model. The new model may reference all of the unqualified common parameters and the new unique qualified parameters. The old unit would continue to reference the unqualified parameters.

Data Integration

Some audits cannot be performed online because they exceed allowable online computer resources, validate inter-category audits, or prevent units that contain invalid inter-category data from being submitted for review. These audits are grouped into batch processes called integrators. Each unit has a dedicated integrator. Special data categories exist to allow batch job submittal, the review of resulting error/warning messages, and to view other relevant data collected by the integrators.

Data Control

All changes to data are inventoried under an authorizing control instrument called a Data Change Request (DCR). An authorized user must create (OPEN) a DCR before any data can be changed. The unit or units to be changed must be selected or a new unit may be defined using the prototype. Within each unit the author must authorize the set of categories to be changed. Other authorized suppliers of a category may change or define occurrences of the authorized categories. All changes are contained in change records called WORKING COPIES. All working copies must pass all defined audits before the occurrence can be submitted for review (FROZEN). Before a DCR can be submitted for review all occurrences must be frozen and the authorized and supplied categories must match. The control board must then approve the DCR and the batch process which baselines the data must be executed to change the working copies from the frozen to baseline state.

Access Control

Access control is enforced by user identification, user function and other restrictions. Only authorized users may log on. Each user has a unique ID which is used to tag each change made by that user. Users are organized into functional groups. These groups are: configuration control (maintains access control data), data suppliers (change data values), DCR coordinators (control DCR submission), board chairperson (dispositions DCRs), reviewers (browse data), product generators (perform production product generation), and mission managers (only authorized supplier in mission dependent data bases). A separate access control data base further restricts users within the above general groupings. This data base defines users, alternate users for each user, categories, data suppliers for each category, DCR coordinators, qualifiers and mission managers.

Data Partitioning

Data collected in STAR is partitioned into mission dependent values and mission independent values. Mission dependent values are collected at a high level. This allows mission independent data to be reused on multiple missions. In STAR, the Display, Payload and Cargo Element

Units are collected in a mission independent manner. This allows standard upper stages to be used on multiple missions without reentering the data values. Data is separated into units with this goal as a major consideration. For example, the PAM upper stage is broken down into several Payload units differentiated by whether or not the parameter is for standard upper stage, optional upper stage services, upper stage spacecraft services or upper stage Orbiter software generated parameters.

This separation of data allows NASA to easily update mission manifests when changes are required. Only the Cargo Bay unit needs to be changed to define the new mission dependent data value set. On the Shuttle the mission dependent data values include the data buss addresses, data buss device type, display numbers, flight software load, IDs which differentiate between multiple payloads of the same type (e.g. multiple PAMs) and other similar values.

Since this data is maintained in a mission independent data base users viewing the mission independent data do not "see" the mission dependent values on the same screen as the mission independent values. A mission dependent data base is created for each mission to capture a complete set of data for a specific mission. The mission dependent values are "buried" in the low level occurrences so that users viewing the data can see mission dependent and independent values simultaneously. Changes are restricted to mission managers in the mission data base. Only make work mission unique changes are intended to be entered directly into the mission data bases.

The payload data is provided to the various facilities that use payload data via a standard transfer data set called a Payload Data Transfer Format. These facilities include the flight software, mission simulators and the launch facility. In some cases the additional channelization data is added to the data produced by STAR by another element of the reconfiguration system prior to delivery to the user.

SUMMARY

The STAR system implements a production engineering approach which minimizes the effort and errors encountered in building mission manifests for the Space Shuttle payloads. STAR accomplishes this by providing:

- A flight-independent catalog of data components
- Enforced configuration control of all data changes
- Enforced audits which validate data on entry
- Data reuse by selection and integration of catalogued components
- Tools to aid the manifest/remanifest process

STAR also controls reconfigurable Space Shuttle vehicle parameters that are required to be monitored by the onboard general purpose computers. STAR is currently being upgraded to also process all reconfigurable data values for the Orbiter Guidance, Navigation and Control computers. When this is accomplished in the spring of 1986 STAR will contain generic functions which will allow control of any data. The approach taken by STAR is general, and can be applied to all areas of STS flight preparation.

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Robert Angier is an Advisory Systems Engineer in Space Systems Software Technology, IBM Federal Systems Division, Houston, Texas. He lead concept formulation and initial definition of the STAR System.

Leon Swartz is Manager, IMS Data Base Applications Development, IBM Federal Systems Division, Houston, Texas. He managed the development effort which produced the STAR System.

Joe Wilson is an Advisory Systems Engineer in the Reconfiguration Systems Development organization, IBM Federal Systems Division, Houston, Texas. He was technical manager of the initial release of the STAR application.

R&D MANAGER DEVELOPMENT

N86-15163

MANAGEMENT BEHAVIOR, GROUP CLIMATE AND PERFORMANCE APPRAISAL AT NASA

George Manderlink
Lawrence P. Clark
William M. Bernstein
W. Warner Burke

Teachers College, Columbia University

ABSTRACT

This study examined the relationships among manager behavior, group climate and managerial effectiveness. Survey data were collected from 435 GM14-15 managers and their subordinates at NASA concerning management practices and perceptions of the group environment. Performance ratings of managers were obtained from their superiors. The results strongly supported a causal model in which subordinates' climate perceptions mediate the effects of manager behavior on performance. That is, the development of group climate provides the process through which the effects of manager practices may be understood. Analyses also revealed that the function performed by a manager and his group (e.g., research) influenced the specific nature of the causal dynamics. Some implications of the results for management training and development are discussed.

INTRODUCTION

Social science research has shown that the behavior of leaders and managers is a potent determinant of group motivation and behavior [4;5]. Moreover, recent research has shown that both a manager's own sense of his behavior, and the extent to which his subordinates share his perceptions of his behavior must be considered in order to explain a manager's effect on his group [1].

A manager's view of himself, and the congruence between his view and his subordinates' view of him, operate to effect group behavior by influencing various perceptions and expectations held by subordinates about the group environment. Quite sensibly the variables that have been found to be useful for predicicting the achievement and social behavior of groups include:

(1.) the extent to which subordinates perceive their goals, tasks, and roles clearly

(2.) the extent to which subordinates believe that nigh, challenging standards are being used to evaluate their performance

(3.) the extent to which subordinates expect to receive evaluative feedback about their performance and to have input into group decision making (i.e., the extent to which subordinates expect to participate in group evaluation and decision making)

(4.) the extent to which subordinates expect to be rewarded monetarily and with praise for achieving performance standards

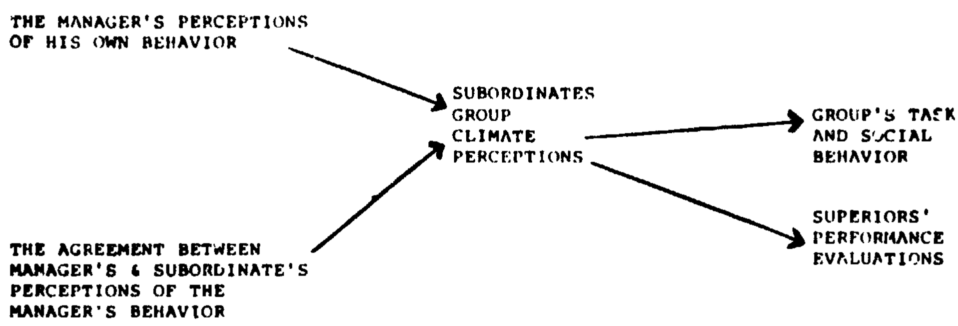
(5.) the extent to which subordinates expect that affiliating with other group members will result in their being rewarded with positive social feelings of friendliness, support, and trust

(6.) the extent to which subordinates believe their group has open, cooperative relations with other organizational units

Taken together, these perceptions of the group environment which are important predictors of task and social behavior have been called group climate.

In sum, social science research and theory indicate that a group's performance may be explained and predicted through the use of a general causal model (see Figure 1). This model assigns group climate perceptions a central, mediating role. Self- and subordinate perceptions of manager behavior influence climate which then determines the quality of the group's task and social outcomes. The formation of group climate perceptions thus provides the process through which the motivational and performance effects of management practices can be understood.

Figure 1
Schematic Model of the Climate Mediation Process



The present study represents an application of the practice---- climate idea to the realm of manager development at NASA. In particular, the findings to be discussed indicate the way in which manager behavior and subordinate climate perceptions effect the perceptions a manager's superior has about the manager's competence. In some sense, of course, a superior's perceptions of a group's manager may be related to group performance. But the models tested here do not include group performance measures. The prime usefulness of these models resides in their ability to map the dynamics controlling the communication of performance relevant expectations and perceptions between managers, their subordinates, and their supervisors.

A further aim of the present study was to determine whether group climates most advantageous for manager performance ratings differ by function within NASA. That is, different aspects of the group environment may facilitate better performance outcomes and social relations depending upon the nature of the group members' functional responsibilities. In terms of the proposed model, this dependency would be manifested in different climate perceptions mediating the effects of manager behavior on performance appraisals in different functions.

METHOD

Overview

The first step in assessing the causal dynamics prevailing within functions among management practices, group climate perceptions, and superiors' performance evaluations was to measure each of these variables. This task was begun by collecting data about perceptions of manager behavior and group climate from 435 middle-level (GM14-15) managers and their subordinates at NASA. More specifically, managers and subordinates were asked to rate the extent to which 80 different management practices and 42 different climate expectations prevailed in their groups.

Factor Analysis of Practices and Climate Perceptions

Given the large number of management practices and climate perceptions assessed, factor analyses were performed to reduce the complexity of data within these domains. Accordingly, two factor analyses were conducted, one for manager perceptions of their own behavior, and another for group perceptions of climate. The goal of these analyses was to represent the rather large variable sets in terms of smaller groups of hypothetical variables [3]. These underlying factors can be interpreted as organizationally shared schemes for organizing thoughts and perceptions about the NASA environment.

A principal components factor analysis with oblique rotation was applied to managers' ratings of the extent to which they performed each of 80 different behaviors. A set of 10 factors was found to reflect the dimensions along which NASA managers perceive their own behavior. These were: Promoting Achievement, Monitoring Projects, Identifying with the Organization, Taking Others Perspective, Dealing with Performance, Creating Trust, Involving Others, Recognizing Others, Managing Resources, and Dealing with Problems. A self-rating scale was then derived from each of the factors. High scores on these scales (range: 1-5) mean that a manager sees himself as performing more of the definitional behaviors.

In order to assess agreement between a manager and his subordinates concerning the manager's behaviors, subordinates' ratings were averaged over each of the items comprising a factor, and then subtracted from the manager's self-rating. Positive difference scores then indicate that the manager has rated his behavior more favorably than his subordinates have rated it. Negative difference scores indicate that the subordinates have a more favorable view of the manager's behavior than the manager has of his own behavior.

A principal components factor analysis with oblique rotation was also applied to subordinates' perceptions of their group climate. The results revealed that group climate perceptions were found to vary along six basic dimensions: Clarity (of goals and tasks), Getting the job done, Participation (in decision-making and performance evaluation processes), Standards (level of), Social Rewards, Interunit Relations. Six group climate scales were created based on this solution.

Performance Evaluations

Performance ratings of managers were then obtained from their superiors. The system used to derive these performance ratings is outlined in the NASA Supervisory and Managerial Performance Rating System (1980). This system uses a behaviorally anchored rating technique; detailed guidelines specify how performance objectives should be developed, evaluated, and reviewed. In order to use performance appraisal ratings as an outcome variable in the planned analyses, managers were assigned points based on their ratings each year over a three year period (FY 1980-1982). The following method of scoring was used: Managers were given 10 points for each outstanding rating received during the FY 1980-1982. They received five points for every highly successful rating received, and one point for every successful rating. Managers were not given any points for satisfactory ratings. No managers in this sample received unsatisfactory ratings.

Both the set of 10 manager self-perception variables and 10 manager-subordinate perceptual difference variables were included as predictors of climate and performance appraisal outcomes in the subsequent evaluation of the basic causal model. Scores on the group climate scales were tested as mediating variables. These analyses we e conducted seperately for work groups having different functional responsibilities. Each group was classified according to the manager's reported function. This resulted in a four-way classification of groups: engineering, research, project management and administrative/resource.

Path Analysis

In order to demonstrate that group climate perceptions mediate between perceptions of manager behavior and evaluations of his performance three requirements must be satisfied [2]:

(1.) a manager's perceptions of his own behavior and the extent to which his subordinates agree with those perceptions affect his performance rating. If these effects do not exist, there is nothing for group climate perceptions to mediate.

(2.) manager and subordinate perceptions of manager practices influence group climate. Climate perceptions can only mediate the effects of manager behavior variables if they are themselves affected. Individual climate variables which pass this test can be considered "potential" mediators of manager practice effects.

(3.) group climate perceptions must influence superior's ratings of manager performance when the effects of manager and subordinate perceptions of manager behavior are controlled. Satisfaction of this requirement represents the actual mediating effect of group climate.

If these three requirements are met, mediation can be claimed. That is, the effects of manager behavior variables on performance evaluations can be understood in terms of their influence on subordinates' perceptions of group climate.

To test these requirements for mediation, path analytic techniques were used. Path analysis is a type of multivariate statistical method for testing causal inferences with correlational (or survey type) data [6]. First, superiors' ratings of manager performance were regressed on the 10 manager self-perception variables, and the corresponding 10 manager-subordinate perceptual difference variables. Next, each of the six climate variables was regressed on these 20 manager behavior variables. Finally, superiors' ratings of manager performance were regressed on the six limate variables and the 20 manager behavior variables (i.e., the full path model). Entering all six climate variables into this equation makes it possible to evaluate their relative mediating effects. These three equations were estimated for each of the four functions in order to examine whether the causal dynamics among practices, climate, and performance-related outcomes differ in relation to the primary task performed by the manager's group.

A step-wise regression procedure was used to test the effects of the multiple predictors on each of the climate variables and superiors' performance ratings. Variables were entered into the regression equation if the p-value associated with the variable's path coefficient (beta weight) was less than .10. It is these analyses which establish the causal chain in which perceptions of managerial practices affect group climate perceptions, which in turn affect superiors' ratings of a manager's performance.

RESULTS

An examination of the path models for each of the four functions indicated that group perceptions of climate did mediate the effects of manager behavior perceptions on superiors' ratings of manager performance. In addition, a manager's perception of his own behavior and the extent to which his subordinates agreed with those perceptions affected performance evaluations directly. That is, the effects of some manager behavior variables were not mediated by group climate perceptions. The results also suggested that not all group climate perceptions are relevant in determining a superior's evaluation of the group manager's performance. Precisely which group climate perceptions play a mediaiting role depends on the function performed by the manager's group.

The path models for the research and engineering groups are presented in Appendix A to illustrate some of the major aspects of the present analysis. Only statistically significant relations between predictors and the mediating and outcome variables are represented in the path diagrams. Both the research and engineering path models predicted meaningful variation in performance ratings that cannot be attributed to chance (Research, 18%; Engineering, 11%), indicating that the models have predictive validity.

Research Groups

The full path model for research groups is displayed in Appendix A, Figure 1. These results demonstrate that superiors' evaluations of manager performance are directly af[illegible]ed by two factors, the perceived climate for participation a[illegible] subordinates and a manager's self-perception of the extent to whi[illegible] he involves his subordinates in group planning and decision-making (Involving Others). Specifically, a manager's performance rating is higher:

(1.) the more his subordinates expect to participate in the areas of decision-making and performance evaluation (path coefficient=.32).

(2.) the more he perceives himself as creating opportunities for his subordinates to become involved in the planning of work, and to have influence during the decision-making process (path coefficient=.27).

Taken together, these results suggest that recognition of effective management of research groups at NASA is based on a manager's ability to communicate a participative approach to his subordinates and supervisors. Manager's who are able to develop a climate high in participation are recognized by their superiors as more outstanding performers. At least two hypotheses can be suggested to explain this relation: 1.) research groups characterized by higher levels of participation actually achieve more and have better social relations, and 2.) those who evaluate the performance of managers of such groups hold the "implicit theory" that participation by subordinates is important in attaining these positive outcomes. Of course, these hypotheses are not mutually exclusive; as discussed previously, superior's notions of what leads to good performance are likely to be correlated with the actual determinants.

The direct effect of Involving Others on performance evaluations provides further evidence that participative behavior on the part of the manager is particularly valued by his superiors. Moreover, by allowing group members to contribute to planning and decision-making processes, a manager may actually be communicating to those outside his group that his subordinates are extremely competent.

As noted, the path model indicates that the evaluation a manager receives from his superiors can be increased by raising his subordinates' expectations about participation. In fact, 53% of the variation in subordinate participation expectations can be attributed to manager behavior perceptions. Hence the four paths to the climate variable suggest how a manager may proceed to raise these expectations. Participation is expected to be higher the more a manager sees himself as creating trust (i.e., building supportive relationships with subordinates, emphasizing cooperation; .30), and the more willing he is to involve subordinates in planning/decision-making (.33). With respect to the Involving Others variable, the perceptual agreement between a manager and his subordinate is a stronger determinant (-.66) of Participation than the manager's self-perception. It appears that subordinates' participation expectations are higher the less the manager's estimate of his willingness to involve others in planning exceeds his subordinates' ratings of his behavior in this regard. In other words, a climate of participation is undermined when group members perceive their manager making inauthentic claims about his attempts to solicit their opinions and include them in the unit's planning process.

Manager-subordinate perception differences on the Recognizing Others dimension also determine group perceptions of participation. Specifically, participation expectations will be higher the less a manager's claims for his recognition behaviors (i.e., providing informal feedback to subordinates, taking a personal interest in subordinates) exceed those of his subordinates (-.26).

Engineering Groups

The analysis for engineering groups indicates that subordinates' climate perceptions concerning both participation and inter-unit relations mediated management practice effects on the outcome variable (see Appendix A, Figure 2). Self- and subordinate perceptions on two management practice variables also directly affected superiors' evaluations. Specifically, Figure 2 shows that a manager's performance rating is higher:

(1.) the more his subordinates expect to participate in the areas of decision-making and performance evaluation. (.23)

(2.) the less his subordinates perceive their relations with other organizational units as open and cooperative. (-.23)

(3.) the less he perceives himself as involving others in planning/decision-making processes. (-.18)

(4.) the larger the difference between the manager's evaluation of his participative approach and his subordinates' evaluation of him. (.32)

(5.) the more he perceives himself as identifying with organizational goals and objectives. (.28)

(6.) the less his perception of the extent to which he identifies with the organization exceeds his subordinates' perceptions of him on this dimension. (-.35)

As was true of those supervising research groups, engineering managers who are able to effect a climate high in participation are evaluated more favorably by their superiors. These evaluations may be based on relatively objective performance criteria with groups characterized by an atmosphere of participation actually performing better.

The extent to which subordinates expect to have input in decision-making depends heavily upon several aspects of their manager's behavior. Managers who see themselves as understanding of others' point of view (Taking Others Perspective) will increase subordinates' expectations for participation (.18). However, the manager's effectiveness in this regard is constrained by the extent to which his subordinates share his perceptions about the meaning of his behavior. If the manager-subordinate difference is large, particpation is lowered, as evidenced by the negative path coefficient (-.31). Several other aspects of the manager's behavior also influenced performance expectations. These variables were also found to affect the climate for participation in research groups and do not require further discussion here.

Although group climate perceptions of high participation are likely to enhance a manager's performance rating, the manager's own participation behaviors seem unappreciated by his superiors. That is, the more a manager perceives himself as involving others in decision-making, lower is his performance evaluation (-.18). Apparently, the superiors of engineering group managers feel that a directive approach is more appropriate than a more participative style. These results suggest that a manager's performance evaluation is likely to be better to the extent that he is seen by his superiors as using a nonparticipative approach with his unit. Just the opposite impression, however, should be managed with ones' subordinates in order to enhance performance ratings.

Interunit functioning, the second mediator of management practice effects, has a negative impact on superiors' evaluations of manager performance (-.23). Interestingly, this is the only instance in which the "more is better" rule does not apply with respect to a climate mediator, i.e., more positive perceptions of a unit's relations with other groups are related to lower performance ratings. It appears that "good interunit" relations or "cooperative relations" are not valued by the superiors of engineering group managers. The prevailing notion may be that competition among groups and accompanying feelings of territoriality and distrust are more potent motivating forces than cooperative tendencies. Managers who are perceived to be able to maintain a basic level of insecurity are benefited given this value orientation (i.e., competition over cooperation).

The model indicates that a manager's ability to create trust and respect among his subordinates, and his recognition behaviors are important determinants of interunit functioning. To illustrate, if a manager perceives himself as interested in his subordinates and as providing recognition, and if this interest is seen as genuine by the subordinates themselves, better inter-group relations result. These results suggest that good "inter-group" relations are facilitated by good "intra-group" relations.

The final set of effects to be discussed concern an engineering manager's perceived identification with the organization. The meaning of these results seem apparent. To the extent that managers identify with the organization, emphasize accomplishing the work of the organization and have good relations with upper level executives, they will be awarded high performance ratings. In short, "team players" are valued among those in engineering.

MANAGEMENT DEVELOPMENT

The causal models produced by the present study (and other similar models) have been used as part of the NASA Management Education Program (MEP) conducted at the Wallops Island Training Center. An important part of the two week MEP training program involves feedback to participant managers about their subordinates' perceptions of the managers' behavior, group climate, and the differences between manager and subordinate perceptions.

In March 1985, feedback to managers was accompanied by presentations of the models generated by the present study. Since the usual feedback process provides managers with information about a large set of different behavior ratings and climate perceptions, the models can work to focus participants'attention on the practice and climate dimensions that may be most critical for explaining the managers' effects on others.

The 30 March MEP participants were divided into four groups according to functional area. One MEP trainer was assigned to each group (research, engineering, project, and administrative). The trainers first described the nature of the results to the group. Then, the managers were asked to comment upon the face validity of the results, i.e., "Did the model seem to be a sensible representation of influence processes within their own group?". By and large, managers reported that the models were not inconsistent with the way they perceived practice to climate effects. And, the models tended to make some effects of their behavior more salient or explicit.

Managers were then asked to try to relate their own personal feedback results (given in terms of NASA GM14-15 norms) to the models. For example, the administrator model suggests that subordinates' expectations of receiving social rewards are increased to the extent that managers are seen as performing three types of behaviors (perspective taking, recognizing others, and involving others). Administrators interested in increasing subordinates' social reward expectancies were advised to check their ratings on these practice dimensions to locate weak areas, or areas that might be improved. By focusing the attention of certain managers on specific practice areas that likely affect the perceptions of others, training becomes more focused and, hence, practical.

The notion that "one's behavior effects others" can be transformed through this type of work. The change is from a general, rather banal, "law of social behavior", to many more precise, instrumental percepts to guide and energize change.

Work with both model generation and training application techniques is now proceeding. We feel we have only begun the process of increasing the impact of rigorous empirical social research on management and organization development.

George Manderlink (PhD, Columbia) is an adjunct professor and postdoctoral fellow in organizational psychology at Teachers College, Columbia University.

Larry Clark (PhD, Syracuse) and William Bernstein (PhD, University of Texas, Austin) are both organization consultants.

W. Warner Burke (PhD, University of Texas, Austin) is Professor of Psychology and Education at Teachers College, Columbia University. He has consulted with a variety of organizations, including NASA, and is the author of the book <u>Organization Development: Principles and Practices</u>.

APPENDIX A

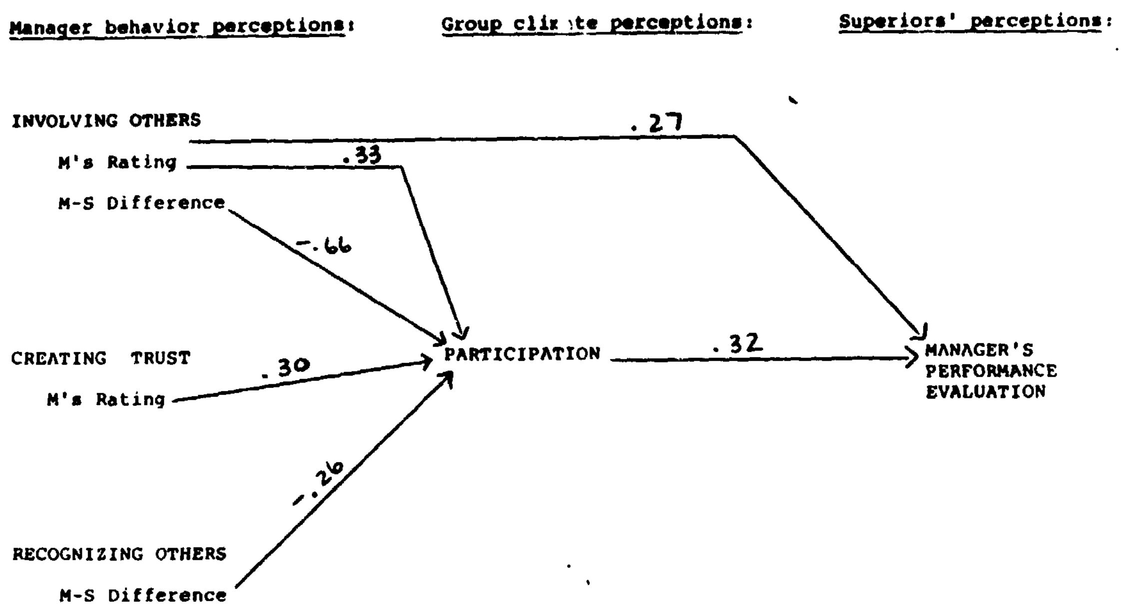


FIGURE 1: RESEARCH

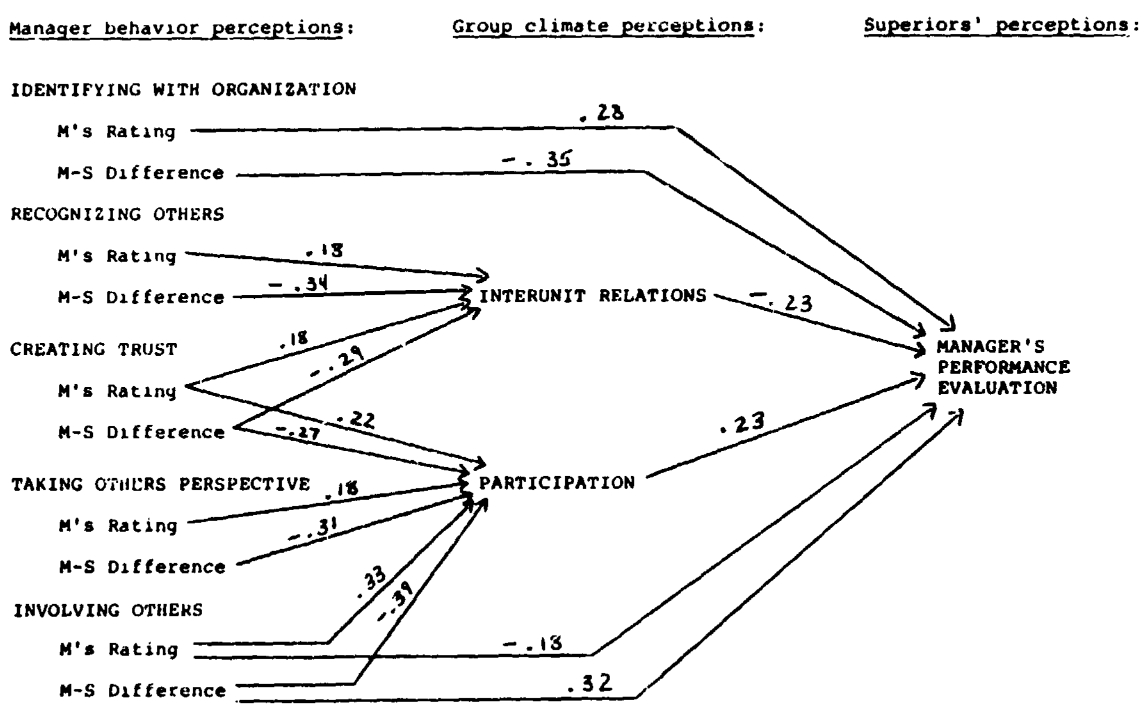


FIGURE 2: ENGINEERING

M's Rating - Manager's perception of himself
M-S Difference - Manager-Subordinate perceptual difference

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MENTORING AS A COMMUNICATION CHANNEL IMPLICATIONS FOR INNOVATION AND PRODUCTIVITY

Lee Avant, Federal Express Corporation
Robert W. Boozer, Memphis State University

ABSTRACT

This paper investigates the impact of a formalized mentoring program as a communication channel for enhancing information distribution, innovation, and productivity. Formal and informal approaches to mentoring are discussed. Interviews with 11 members of formal mentor-protege teams indicate communications in the mentoring relationship can affect individual and organizational innovation and productivity.

INTRODUCTION

A major premise of this paper is that the U.S. aerospace program interacts with an environment that has been described as post-industrial society - an environment characterized by increasing knowledge, complexity, and turbulence. Such an environment places special demands on organizations: more rapid, frequent, and complex decision making, more rapid and frequent innovation, and more continuous, wide-ranging, and directed information acquisition and distribution. To be effective in such an environment requires that organization structure and process be designed to reflect these demands. [3]

The purpose of this paper is to investigate the utility of one alternative for meeting some of these demands. In particular, this paper investigates the utility of a formalized mentoring program as a communication channel for enhancing information distribution, innovation, and productivity within an organization.

Mentoring - The Informal Approach

As traditionally conceptualized, mentoring is an informal relationship between two people - one a senior and more experienced individual (mentor) and the other a more junior and less experienced individual (protege). The term for the relationship - mentoring - derives from Greek mythology. As the story goes, Odysseus entrusted the education of his son Telemachus to a trusted friend. This friend Mentor, became responsible for tutoring , sponsoring, and coaching his protege, Telemachus, while Odysseus was away from home. Similar relationships have continued through history as seen in doctor - intern, master - apprentice, and teacher - student relationships.

Recent research indicates some consensus about the characteristics of mentoring relationships. First, they involve a number of roles similar to those performed by Mentor. Kram [6], for example, identifies five career roles and four psychosocial roles. The five career roles are those that enhance career development. These include: (1) nominating and supporting the protege for promotion and advancement (sponsorship); (2) assigning responsibilities which bring the protege into contact with key organization figures (exposure and visibility); (3) assigning work that helps develop the protege's technical and managerial skills (challenging assignments); (4) providing guidelines and feedback about work behavior (coaching); and, (5) shielding the protege from criticism, adverse publicity, etc. (protection). The four psychosocial roles are those that enhance the individual's sense of self-esteem, identify, etc. These roles include: (1) providing a set of values, beliefs, and behaviors for the protege to follow (role-model); (2) providing mutual liking, mutual respect, and positive feedback about performance (acceptance and confirmation); (3) creating a supportive climate where the protege can discuss anxieties, fears, and conflicts that interfere with productive work behavior (counseling); and (4) establishing a mutual relationship of liking, understanding, and informal social exchange (friendship).

A second characteristic is the dynamic nature of mentoring relationships; they evolve through a number of phases similar to other human relationships. For example, Kram [6] identifies four phases: initiation, cultivation, separation, and redefinition.

A third characteristic is the informal nature of mentoring relationships. That is, the relationships develop without specification and guidance from the formal organization. Rather, the relationships are influenced by factors found to influence other types of informal group and social network formation [13]. For example, the initial phase is influenced by proximics and attraction factors. Individuals in close proximity (face-to-face job interview, task force meeting, etc.) are afforded the opportunity to interact and discover similar interests and activities. These similarities form the basis for attraction and future interaction (cultivation) in the development of a mentoring relationship.

A fourth characteristic seems to be the pervasive importance of the informal mentoring relationship in fostering career development and success for the protege. For example, in Roche's [12] study of 1,250 executives, 63% indicated they had a mentor. Furthermore, those executives with a mentor reported higher salaries, bonuses, total compensation and career satisfaction than non-mentored executives. Other research indicates most corporate presidents have had mentors at some stage of their career [4]. As the title of one article puts it - "Everyone who makes it has a Mentor" [2].

Beyond its impact of personal and career development, mentoring can also impact broader organizational functions and activities. Roberts [10], for example, includes sponsoring (mentoring) as one of the five key roles personnel must perform which are necessary for effective performance of the R&D function. Roberts notes that, beyond providing protection, coaching, and encouragement, the mentor can help establish the appropriate organizational culture for effective R&D. Zey [14] discusses at least seven benefits to the organization including enhancement of the processes of management development, management succession, and socialization to power. Another benefit, of particular interest here, is that of improved organizational communication.

Zey views the mentoring relationship, in part, as a means of promoting communication between various levels of the organization in that the mentor and protege act as "linking pins" in the sense that Likert used the term [7]. These linking pins thus act as a communication channel by which information can flow between two management groups at different levels in the hierarchy. While Likert conceived the linking pin relationship to be a formalized one (between members of the chain of command), Zey, in his research, found that proteges he interviewed tended to perform many of the linking pin functions in their informal mentoring relationships.

The informal mentoring relationship also has its risks. In a study of 3000 mentor-protege pairs, Blotnick [1] found only 34 pairs were able to maintain the relationship for three or more years. Moreover, 1200 of the 3000 proteges were eventually fired by the mentors! While not all studies indicate such drastic outcomes, research on the phases of informal mentoring relationships does indicate that change, organizational and/or individual, can place strain on the relationship which leads to conflict and separation, often with negative consequences. For example, as the protege gains confidence and experience, he or she may desire more autonomy, thus pressuring the mentor to "loosen the reins". Should the mentor perceive the need for autonomy as premature, or if the mentor has become too dependent upon the protege, conflict develops due to individual change. Organizational changes such as promotions and transfers also can leave the participants in a mentoring relationship feeling as if they were left "holding the bag".

A question that arises at this point is: "can some program be created and managed which maintains the advantages of the mentoring relationship while reducing or eliminating the disadvantages?" The general response seems to be "It may or may not be worth a try" with some organizations implementing formal mentoring programs and other individuals pointing to the risks of such formal programs [6,9].

Mentoring - The Formal Approach

One company that has launched a formalized mentoring program is Federal Express Corporation. Because of rapid growth and a promotion from within policy, the corporation has a very specialized management workforce without the broad base of experience needed to be the future leaders of the company. A formalized mentoring program was identified as a means of "cross-fertilizing" these managers.

Four years ago, one division implemented such a program, and it has proven successful. In 1984, a Leadership Institute was founded in which outstanding managers were selected as instructors, or "preceptors", for a twelve to fifteen month tenure. These people were targeted for participation in a revised and revamped mentoring program.

In the program designed for the preceptors, there are four roles or functions: (1) the preceptor/protege, (2) the mentor, (3) the natural boss, and (4) the HRD coordinator, who is responsible for working with the people involved to facilitate and track the relationships. Some of the critical elements of the program design are:

1. the program is a voluntary developmental opportunity;
2. the preceptors must select a mentor who is from a different division and is two levels above the preceptor;
3. both parties must agree to a no-fault conclusion.

The inclusion of these elements has been found to best facilitate the needs of both the organization and the people involved.

Through a series of self-analysis activities, the preceptor identifies three executives for consideration as mentor. After a mentor candidate is interviewed by the HRD coordinator, the preceptor is told who is interested, makes a selection, and participates in an introductory meeting, which is facilitated by the HRD coordinator.

The true success of these relationships is then a reflection of the time, energy and interest dedicated to them by the mentors and proteges. The HRD coordinator periodically checks on the status of the pairs, and the natural boss is encouraged to review and reinforce the activities and discussions in which they are involved.

At present, the Leadership Institute has seven preceptors: six men and one woman. There are two other women, outside of the Institute, who sought developmental support from HRD and are also involved in the program. Only one member of this group, a woman, is black; none of the mentors are black. All of the proteges are between 30 and 40 years old; the mentors range from 40 to 55.

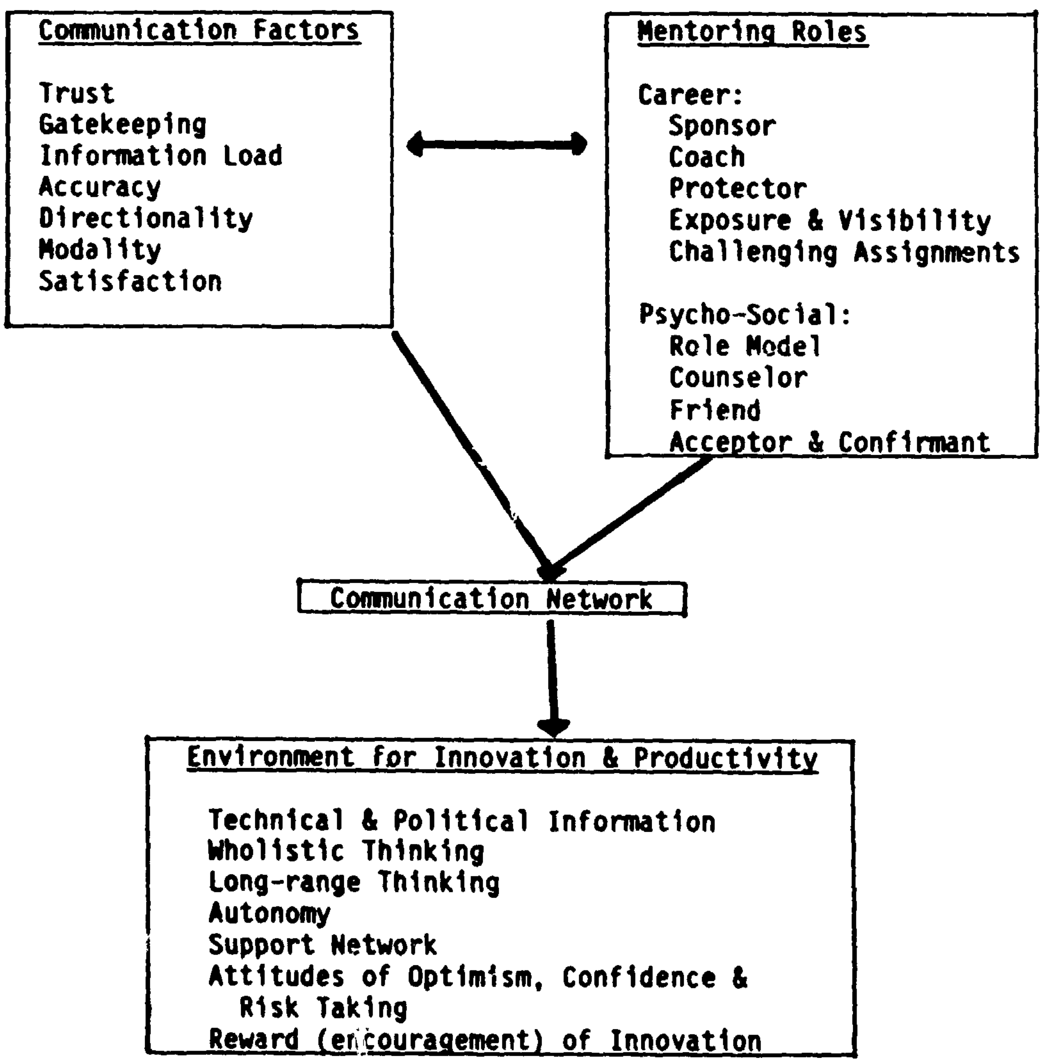
Mentoring and Communication

As mentioned earlier, the mentoring relationship can have an impact on the organization beyond enhancing personal and career development. In particular, if the formal mentoring relationship discussed above is viewed as an organizational communication channel, there intuitively would seem to be implications for information dissemination, innovation, and productivity - factors which have been proposed as essential in post-industrial society.

A conceptual framework for exploring the relationships between mentoring, organizational communication and innovation and productivity is indicated in Figure 1. First, mentoring involves performing certain roles described earlier (sponsor, protector, etc.). [6] Second, performing these roles entails and evokes, at the same time, specific communication dimensions characterizing organizational communication. [11] Third, the combination of roles and communication dimensions implies the existence of an organizational network which can help create organizational conditions which have been found to facilitate innovation and productivity [5,8].

FIGURE 1

Relationship of Mentoring as a Communication Channel to Innovation and Productivity



An example might help. One factor commonly associated with innovation is the existence of a long-range perspective. Conceptually, this perspective could be conveyed to a protege by the mentor performing a number of roles. By providing assignments which require long-range thinking, the protege is challenged to incorporate this perspective. Furthermore, the assignment might be one with exposure and visibility where the protege could come into contact with key organizational personnel who are known by the mentor to value and encourage this perspective. Whether this mentoring strategy is effective, however, also depends upon the nature of communications within the network. For example, if the mentor does not trust the protege, she/he is not likely to provide challenging assignments which have exposure and visibility. If the protege receives too much information (overload) from the mentor and/or key personnel, learning effectiveness is likely to be decreased. In summary, these examples indicate a delicate balance between mentoring roles and communication dynamics in creating and maintaining an organizational network for enhancing information dissemination, innovation, and productivity.

While the foregoing model proposes logical relationships between mentoring, communication, and innovation and productivity, the concepts in the model are based largely on research results involving informal networks. Very little information is available concerning formal mentoring relationships and even less information is available concerning the impact of formal mentoring programs on innovation and productivity. Thus, the applicability of the model to a formal setting was investigated.

THE STUDY

Interviews were conducted with 11 members of mentor-protege teams involved in the Federal Express program. No specific hypotheses were established prior to the interviews. Rather, an interview format was constructed so as to elicit personal insights into three areas of information: (1) the mentoring roles (sponsor, coach, etc.) that were prevalent in the relationship, (2) the communication dimensions (trust, gatekeeping, etc.) that characterized these roles, and (3) the impact the relationship has had on personal and organizational innovation and productivity.

An open-ended format was used to allow mentors and proteges to relate their insights into these three aspects of the relationship. Given the exploratory nature of the research, it was felt that sample members should have as much freedom as possible to provide insights which may not be represented in the model. At the same time, however, the interview format was structured so as to require sample members to comment, at some time in the interview, on the specific dimensions of the model.

All interviews were conducted by one of the researchers who previously had established a rapport with sample members. This individual had participated in the development and implementation of the formal mentoring program and had interviewed the sample members at various times during the life of the program. The contents of the interviews were recorded and transcribed for analysis.

The interviews produced 121 single-spaced pages after transcription. Both researchers worked separately on the analysis which involved an inductive approach to generating propositions about the model. Each researcher generated propositions which could be illustrated by quotes from the transcripts. The researchers then met and combined propositions.

FINDINGS

In general, the findings support the model. Numerous examples were found which indicated the mentoring relationships did act as a communication channel and that information dissemination, innovation and productivity were impacted by the mentoring relationships The results also indicated, however, that the relationships were not equally effective. Rather, certain factors seem to be needed for the formal relationship to achieve its potential.

A first proposition is that the formal mentoring team must go through developmental phases similar to those found in informal relationships. This proposition evolved out of a comparison of the responses from newly formed teams and those from teams which had previously some informal relationship. The following quote from one mentor, who is involved in both kinds of relationships, illustrates this proposition:

> It takes a while for each of those two personalities to know the other one and feel comfortable...In the case of people I worked with for a longer period of time, we had been through that cycle...you have to go through a whole series of subjects and discussions until you find out that you respect each other's competence. Then you go through another phase where the, I guess, the respect level continues, and then it finally gets to something that is, I guess, trustful.

A second proposition is that the potential for the formal relationships to immediately impact innovation and productivity is limited by the extent to which the parties in the relationship see this potential. When questioned about the benefits of the relationships and whether it had any effects on personal or corporate innovation and productivity, most of the individuals viewed the major impact in terms of long-term management development. When asked questions such as, "Can you describe a situation or conversation you've had with your mentor/protege in which they helped you solve a problem or your mental 'light bulb' came on?", most individuals could not give an example.

A third proposition is one related to the second proposition. The potential for the relationship to impact innovation and productivity also seems limited, initially, by the cross divisional structure of the formal relationship. While one of the human resources objectives of the formal relationship is to provide the protege with a mentor from another division, and thereby broaden the protege's corporate perspective, the difference in perspective is, initially, a barrier to be overcome. The barrier seems manifest in at least two ways. First, both mentors and proteges expressed a concern about the accountability of what the protege learned. For example, one mentor was concerned the protege would only be able to apply the experience in the mentor's division. Second, in those relationships where the mentor and protege had some prior relationship or were within a common division, the common background was found to facilitate innovation and productivity more so than in the cross-divisional relationships. This factor was particularly clear in the interview when the protege indicated her mentor (from the same division) was able to brainstorm ideas with her.

CONCLUSIONS AND RECOMMENDATIONS

As exemplified by the Federal Express case, the formalization of the mentoring process is possible, and has the potential for both immediate and long-term benefit to the individuals involved and to the corporation. However, it seems that the chemistry that occurs in informal relationships must still be established in order for the formalized relationship to be fully productive. While informal relationships typically are founded on friendship and a mutual trust, formalized pairings must take some time to determine where they "stand" on critical issues.

Additionally, since they are founded on the premise of personal development, most formalized pairs seem to have some difficulty in seeing the utility of the learning that occurs beyond the relationship itself. This narrow focus is further emphasized by the barrier created by the matching of cross-disciplines in the pairs. In order for these relationships to enhance the innovation and productivity of the corporation, and not just the individuals involved, it would seem appropriate for these issues to be addressed at the initiation of the relationship.

When viewed from the perspective of the organization with a large research and development population, it would seem that a formalized mentoring program would serve as a valuable development tool for the individuals and an investment in the future for the organization. With the proper preparation and facilitation of the individuals and their pairings, a mentoring program could not only broaden the people involved beyond their individual projects and responsibilities, but could also increase the probability of a smooth and progressive integration between their current activities and their organization's mission for the future.

BIOGRAPHICAL STATEMENT

Lee Avant is a Sr. Human Resource Development Specialist at Federal Express Corporation, working with the Leadership Institute. In addition to her interest in mentoring relationships, she is studying thinking and learning styles. Robert W. Boozer is an Assistant Professor in Memphis State University's Fogelman's College of Business and Economics, Department of Management. His research interests include stress, neuroticism, mentoring, communication and innovation.

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MULTI-ORGANIZATIONAL COOPERATION

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N86-15165

MANAGING COOPERATIVE RESEARCH AND DEVELOPMENT VENTURES

William J. Murphy, Harvard Business School

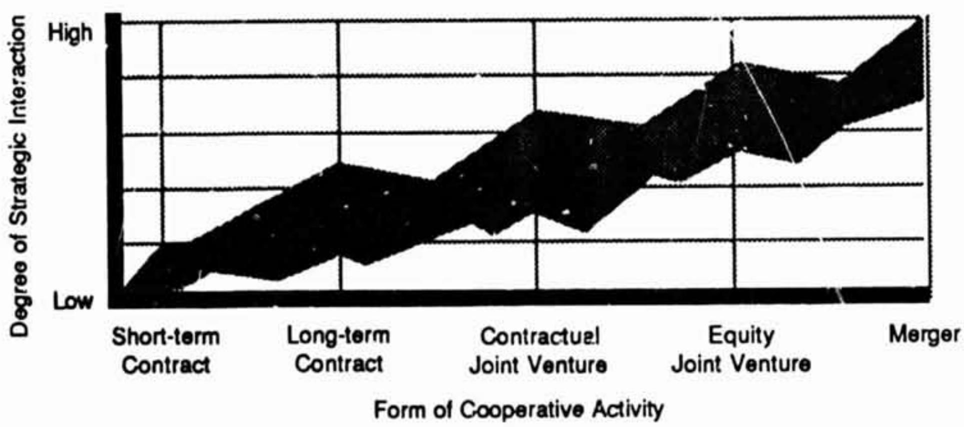
ABSTRACT

As cooperative ventures to conduct research and development become increasingly attractive, management of these collective undertakings poses new challenges to executives. In selecting the most appropriate organizational structure and strategy the author suggests that the collective enterprise executive must strike the best balance among three distinct but related elements. Eight types of cooperative R&D ventures are proposed with discussion of the unique management tasks associated with each type.

Introduction

Companies are not independent entities but exist in a complex web of external relationships with other companies and governmental institutions that range from minimal interaction, as exemplified by short-term contracts with buyers and sellers, to the full integration of mergers and acquisitions. In between these two extremes lie joint or cooperative ventures.

Continuum of Interaction



Cooperative ventures also exist along a continuum of interaction. On one hand are the contractual cooperative ventures which, in their simpliest form, are merely agreements between two or more companies regarding a specified exchange of performances. At the

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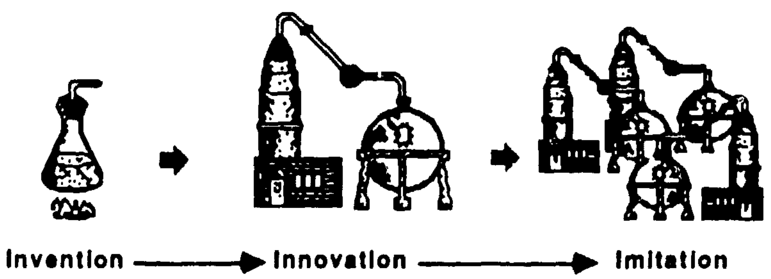
other extreme are equity cooperative ventures which provide for joint decision making within the context of a jointly-owned enterprise. Neither contractual nor equity cooperative ventures are new.[3] Although the creation, existence and death of cooperative ventures have been going on for decades they have received increased attention lately as more corporations look to collective activity to achieve strategic objectives. In particular, there is growing interest in cooperative ventures to undertake research and development.

The Importance of R&D and the Need for Cooperation

Although "technology" and "R&D" are commonly used words, it is doubtful that a common meaning of the terms can be implied from this frequent usage. For the purpose of clarity the following definitions will apply. The term technology describes the knowledge required for the production and delivery of goods and services. Likewise, technological innovation is the process by which this knowledge is developed and ultimately transformed into specific goods, products, and services. One should note that these definitions encompass not only technology that is directly traceable to "scientific" knowledge but also includes knowledge in areas that have not been or can not be classified as scientific. But, this only takes care of the "R" part of R&D and all too often this is a common ommission on the part of those discussing R&D policy and management. Development is an important and easily overlooked part of the process that takes the new information or knowledge that results from research and transforms it into a form that is useable, either as a base on which additional knowledge can be built or as an actual product or service improvement.[13, p.6] This transformation process is particularly important with regard to cooperative research and development ventures.

The first crucial steps in the complex process of technological innovation are research and development activities through which increased understanding and control of various "technologies" are gained. Economist Joseph Schumpeter's concept of the process had three distinct segments. The first segment is invention, that initial insight that identifies and defines a new capability. Following invention is innovation, the transformation of the capability into a form useable by society. The last phase Schumpeter referred to as imitation, which describes the diffusion of technology as others copy and make improvements on the orignal innovation.[11; 6, p.21] Some authors contend that too often the invention phase is over emphasized as the critical part, whereas innovation and imitation (or diffusion) maybe be of equal or perhaps greater importance to society.[10, p.67]

Schumpeterian Notion of the R&D Process



In that a society's or institution's limited and valuable management time and energy must be allocated among various competing activities, an examination of the relative importance of R&D activities, collective or otherwise, is required. There is little question that technological innovation plays a critical role in modern society. This observation is particularly pertinent to the last fifty years during which industrial, social, medical, legal, and organizational innovations have lead to incredible economic (and ultimately social progress) that has been experienced by nearly all countries and peoples. Despite its recognized importance to prosperity and the promise of a "better life" the innovation process is only a vaguely understood phenomenon. This perceived importance of innovation is evidenced by an increasing chorus of concern regarding the state of R&D in this country and others.

Research and development activities are generally cited as having four significant positive effects on the "commonweal". First of all, R&D, as part of the overall innovation process, is credited as the primary driving force behind economic growth.[9, p.14] The second major contribution claimed for research and development activities to economic health is in improving international competitiveness. In fact, some analysts of the apparent decline of competitiveness on the part of United States firms point to a lack of innovation as a possible cause.[4] R&D activities as an important aspect of national defense efforts is generally recognized as the third area of contribution. Since the United States bases much of its defense strategy on the concept of quality instead on quantity, any threat to the technological lead the U.S. enjoys in advanced weapons systems is cause for serious concern. As a consequence a major portion of federally-supported R&D goes into defense-related projects.[2, p.11] The final area of societal contribution cited for R&D activities is employment. It is argued that as certain industries mature and decline new products and services as well as new methods of production are the only hope to replace lost jobs and generate new ones.[1, p.98] This employment debate is complicated since some argue that a portion of R&D actually results in the reduction of employment opportunities.*

Three forces are at play in the modern economy that make cooperative R&D ventures increasingly attractive. First, marketplace pressures exerted by foreign companies, most notably the Japanese which have a history of cooperative R&D activity orchestrated by MITI and other governmental institutions, have caused domestic corporations to reexamine the prevailing "go it alone" attitude. Second, the amount of resources (both finanical and human) necessary to carry out many modern-day high

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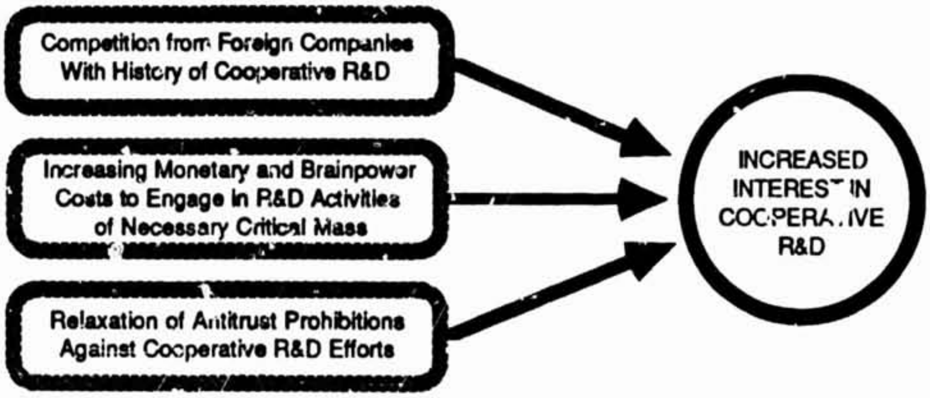
* This employment debate is complicated by the fact that some argue that a portion of R&D actually results in the reduction of employment opportunities. Economists, in recognition of the fact that technological innovation can either create or destroy jobs, refer to efficiency increasing innovation as either "factor biased" or "factor neutral". An innovation is said to be factor neutral if adoption of the innovation does not result in a change in the relative quantities of inputs consumed per unit of output (assuming constant relative prices). Conversely, an innovation is factor biased if adoption results in a change in the relative quantities of inputs consumed per unit of output. To give an example, let us say that a machine has been developed that can weld automobiles at a fraction of the cost of human welders. Industry adopts the new machine (but does not change output because of the adoption). That innovation is said to be factor biased in favor of capital. Such factor bias, at least in the short-term, will cause unemployment. It is this type of innovation (and the supporting policies such as certain tax treatments) that appears to generate a substantial amount of controversy.[5, p.19]

technology projects has become so vast that fewer individual companies can tackle these projects as independent entities.[12] And finally, changes in the antitrust prohibitions against cooperative research and development efforts have lessened the legal uncertainties surrounding joint activities among competing companies.[5; 7]

Forces Encouraging Cooperative R&D



One example of this new breed of cooperative R&D effort is the Microelectronics and Computer Technology Corportion or MCC, a collection of 21 United States computer and component manufacturers headquartered in Austin, Texas. It is the stated objective of MCC to help bring into being the fifth generation of computers. The importance of the technology being developed by this cooperative venture is well-recognized, not only by the companies directly involved and associated industries that stand to benefit but also by governmental agencies. But common recognition of the significance of the technology does not necessarily lead to a common approach regarding its development.

Just as the MCC researchers will be required to develop new technology, MCC managers will be required to develop new management systems and techniques to deal with the unprecedented problems facing a collaborative effort of this nature. One of the management tasks facing retired Admiral Bobby Ray Inman, President, CEO and Chairman of MCC, will be to forge a consensus among the participants regarding solutions to shared problems.

Management of Cooperative R&D

Managing a cooperative R&D venture differs in important ways from managing a single participant R&D organization. The data suggest that the tasks facing the general manager of a collective undertaking are significantly different from those facing the general manager of a single participant organization. In particular, there is evidence that in a cooperative venture the essential executive functions of (1) establishing and maintaining a workable communication system among the participants, (2) securing the necessary efforts and resources from them, and most importantly, (3) formulating and defining an acceptable purpose are complicated by the presence of multiple sponsors.

As the number of participants rises there is a corresponding increase in the need for negotiation among them. The multiplicity of participants in a cooperative venture places the general manager under increased pressure, when compared to the general manager of a single participant enterprise, to discover and put into operation methods of accommodation. This process of accommodation and negotiation undertaken by executives of cooperative ventures expresses itself in (1) the strategy-making process, (2) the organizational structure, (3) the compensation and control systems, and (4) the resource allocation process. As more and more companies find cooperative research and development attractive, the need to understand the managerial tasks associated with such collaborative organizations increases.

For analytical purposes cooperative R&D activity can be divided into three distinct but nonetheless interrelated elements: (1) contribution of the participants, (2) creation of benefits, and (3) transfer of benefits to contributors. The success of a cooperative R&D venture depends on how well these three elements are balanced with one another. For example, in setting up a cooperative R&D venture the participants often focus heavily on the first element, determining what each party will contribute to the effort. This can lead to the adoption of structures and procedures that hinder the creation of the sought after R&D knowledge and its transfer to the contributors, the second and third elements. The transfer of technology within the context of a multi-firm cooperative venture is a particularly important and difficult management task. Again using the three-element model, various methods to ease the difficulties of technology transfer (element three of the model) can be obtained by the adoption of specific management practices.

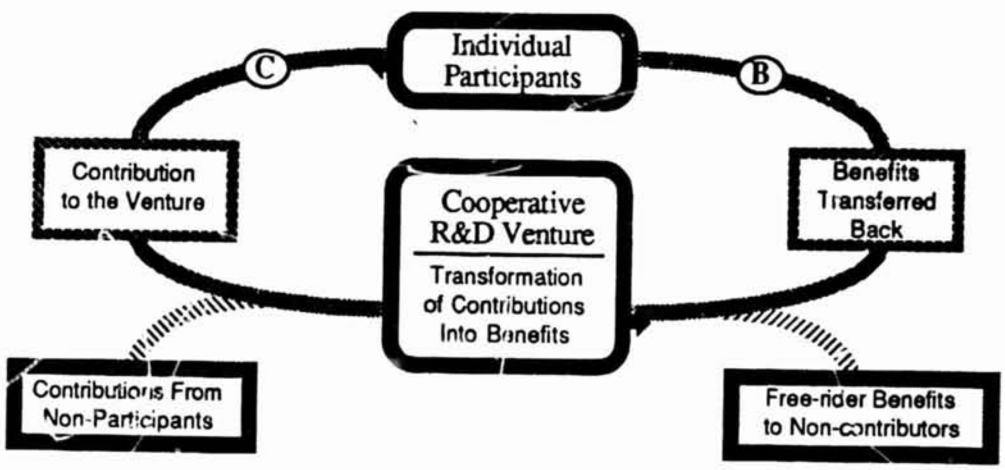
Elements of Cooperative R&D Ventures

The reasons that propel individual companies to cooperate in a collective R&D effort differ according to the ability or necessity to share costs and benefits. Different situations involve different potential costs and benefits to the participants. Maintaining an acceptable distribution of costs and benefits among the participants is one of the fundamental tasks facing the general manager of a collective enterprise. In assessing the attractiveness of a cooperative R&D venture the individual participant is basically concerned about two linkages with the collective venture. One is the individual participant's required contribution to the collective venture and the other is the flow of benefits from the collective venture to the individual participant. The decision to join and continue in a cooperative R&D venture will be determined by the prospective participant's assessment of the relative value of these two linkages.

In the flow chart that follows, the required contribution from the participant in both tangible and intangible resources and assets is labeled C. The benefit expected to be derived from the cooperative activity is labeled B. As long as the perceived value of B is greater than the perceived value of C, the participant has an incentive to maintain cooperation. It is the function of the joint venture executive to establish and manage a cooperative structure that yields benefits in excess of contributions.

Referring to the three-element model of a cooperative R&D venture, the general manager of the collective activity can adjust the relative perceived values of B and C, and thereby the value of the cooperative venture to the participants, by managerial actions that affect any one or combination of the three elements. In other words, the collective venture executive can increase the value of the collective activity by: (1) decreasing the contribution required, (2) improving the efficiency and effectiveness of the collective venture's ability to transform contributions into benefits, or (3) improving the efficiency and effectiveness of mechanisms that transfer benefits back to the contributing participants. Often the nature of the cooperative R&D effort itself or the contractual agreement among the participants sets limits on how much of a change in a participant's contribution can be affected by managerial action, so the general manager of a cooperative effort generally must concentrate on actions that focus on the latter two options.

Cooperative R&D Venture Flow Chart



The literature abounds with advice and counsel to the R&D manager, of a collective venture or otherwise, regarding how to improve the efficiency or effectiveness of the the process that transforms financial and brainpower inputs into new technology and inventions. But, there is an important difference between inventing a new technology and getting the technology employed in useful products and services. To emphasize this point concerning the importance of the development phase of R&D consider the example of penicillin. Every schoolchild is dutifully taught that Alexander Fleming discovered penicillin and, by implication, that his "discovery" was the single most important event in introducing penicillin to society. The facts tell another story. In 1928 Fleming discovered that the mold *Penicillium notatum* produced a substance that inhibited bacterial growth. It wasn't until ten years later that the substance was isolated and identified by a large number of scientists and researchers who had spent many dozens of man-years on the effort. Millions of dollars and hundreds of additional man-years were subsequently invested before a clinically useful drug was obtained.

As one can readily appreciate the expensive and time consuming portion of penicillin's development was not Fleming's basic discovery (or invention in Schumpeter's

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conceptual framework) but the unnoticed, unheralded, and often mundane work that took the discovery from a scientific capability to a useful and cost effective product. As the National Academy of Sciences reported in its summary of the August 1976 Woods Hole Workshop: "Much of the cost and time are associated with the stages beyond the generation of the basic technology itself, specifically, with the production and marketing of new products made possible by new technology."[5, pp.12-13] The importance of both aspects of R&D is recognized by the Organization for Economic Co-operation and Development (OECD) in its "Frascati Manual" which proposed standard practices for surveys of research and development. In the Frascati Manual, research and experimental development are defined to: "comprise creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, *and* the use of this stock of knowledge to devise new applications".[8, p.19]

Types of Cooperative Research and Development

The motivation to seek out partners for a collective R&D undertaking differs according to individual circumstances, but despite the wide range of possible reasons for engaging in cooperative R&D venture company, motivation can be broadly grouped into the following eight categories. It is important that the collective venture participants as well as the collective venture manager be aware of which motivation categories apply to the situation at hand and what is the relative importance of each motivation category to the participants. The reason for this awareness is that different organizational structures and strategies are appropriate for the various motivation categories. Although eight separate motivation categories are suggested it is often the case that any individual participant faces a combination of motivations, some more important that others. Likewise, it is expected that no two participants in a cooperative R&D effort experience the exact same set of motivations in the exact same ranking of importance. These differences in motivation further complicate the collective venture manager's task.

1. Cooperation as a way to attain scale economies.

Achievement of scale economies is often an important element of an individual company's motivation to participate in a cooperative venture, but there is an important limitation to scale economies as a motivating force for corporations. If the projected benefits from the cooperative effort are seen as yielding significant improvements in competitiveness it is unclear that a corporation would want to share these benefits with potential competitors unless the scope of the investment was so great as to exceed the resources of the individual participant. But because individual corporate resources vary from company to company the "power" of this motivating element will differ. For example, the VLSI project in Japan, a collective research and development effort in advanced semiconductor technology, changed the relative market positions of the participants. As a direct consequence of the cooperative venture, some companies improved their competitive position vis-a-vis other participating companies and for some their relative competitive strength was weakened. For the companies with more limited resources the allure of cooperation to attain scale effects was greater than companies more favorably situated.

A cooperative effort is attractive if the collective benefit obtained (and presumably distributed to the participants) can be obtained at less cost to the individual than "going it alone". The greater the disparity between the individual cost and the collective cost relative to the benefit, the greater is the incentive to participate. Similarly, if the perceived benefits of the cooperative effort are remote or uncertain, a pooling of effort can change the "scale" of the project facing any single corporation and thereby change the decision on whether or not to join.

To the extent that the collective enterprise is designed to exploit scale economies the benefits to be derived by the individual participants from cooperation should vary according to the degree scale economies are attained. An individual participant should prefer collective effort to individual effort regarding the achievement of scale economies if the expected value of the perceived benefits, less required contribution, associated with collective action, is greater than the value of the perceived benefits, less contribution, from individual action. Likewise, the individual participant should welcome additional contributor/participants so long as the value of perceived benefits, less contribution, without the additional member is less the the value of benefits, less cost, with the additional member. Generally, this means that addition partners will be sought until the desired economic size of effort is reached.

2. Cooperation as a method to permit a more efficient use of some limited resource.

This second motivation category is also related to the attainment of scale economies but differs from the first in important ways. First of all, it encompasses more than just financial resources. Secondly, the limited resource may or may not be scale sensitive. To cite an example that illustrates both points, in certain "frontier" R&D projects the resource constraint is not money, but people, in the form of trained scientists and researchers. This was the situation facing both the Japanese VLSI project regarding expertise in working with crystals of exotic materials and the chemical industry when it formed the Chemical Industry Institute of Toxicology (CIIT) regarding trained toxicologists. This is currently the situation facing MCC regarding experts in artificial intelligence and other highly specialized fields.

One would expect that cooperative R&D ventures established to permit the more efficient use of some limited resource to exhibit somewhat different characteristics than collective R&D efforts to exploit scale economies. The primary benefit flowing to the participants from this type of cooperation is increased access to a limited resource. To accomplish this objective the collective enterprise can either increase the supply of the limited resource available or ration the available supply. If the supply of the limited resource cannot be increased to meet or exceed the demands for that resource on the part of the participants then the general manager of the cooperative enterprise will have to devise and operate a rationing system. This makes the participants potential adversaries for access to the resource in short supply and the structure and processes of the collective venture should reflect this situation.

3. **Cooperation to facilitate individual investment in the development of a product that is not readily owned by those investing in its creation.**

Companies are naturally reluctant to make investments if the results are difficult to "capture" or "own". For example, investment that yields improvements in personnel skills rather than an actual material product are less likely to be funded since the investing corporation has less ownership or control over the investment output, in this case people. Because of this dilemma it makes sense for the total class of potential beneficiaries to cooperate in conducting the effort. As an example witness the formation of cooperative ventures like the Semiconductor Research Corporation and the Council for Chemical Research which seek to develop qualified specialists in much needed disciplines without having an individual corporation run the risk of funding its competitors' training.

Another set of examples in this category would be those investments in basic or fundamental research. Since this type of research often results in ideas and concepts that quickly spread (and whose spread is difficult if not impossible to legally contain) cooperative efforts in this area are also attractive. One of the missions of MCC will be to develop talent and technology that will be difficult for the investors to capture.

A third group of examples in this category are those investments in which the ownership or control of the investment output has been curtailed. As an example, the Toxic Substances Control Act [15 U.S.C. §2601 (1976)] requires that certain discoveries regarding toxicological effects of workplace chemicals be publicly disclosed so that rapid dissemination can take place. A cooperative venture would be useful to counteract the disincentive to invest Such situations have helped spawn cooperative ventures such as the Chemical Industry Institute of Toxicology and the Health Effects Institute.

With regard to this third type of cooperation the managerial task involves control of the flow of benefits to non-contributing outsiders, commonly referred to as the free-rider problem. A flow of benefits to outsiders who do not help pay for producing those benefits can jeopardize the viability of a collective venture. If the realization of benefits by the non-contributing outsider is the result of decreases in the benefit streams to the participant, the general manager of the collective will be compelled to either seek methods to stop the "leakage" of benefits or force the outsiders to become contributing participants. The possibility of outsiders enjoying the benefits without sharing the costs will also put pressure on the participants to switch status to non-contributing outsiders. As a consequence, one would expect the general manager of such a cooperative undertaking to try to structure and operate the collective venture so that participant exit is hindered. One would also expect that the participant contribution arrangement to resemble a private taxation system.

4. **Cooperation as a vehicle to achieve uniformity or standardization.**

There are two methods to assure uniformity if it is clear that there is a competitive advantage in having complementary technology. One is to achieve a monopoly or dominant status and thereby dictate the standard to the marketplace. The other is to engage in a cooperative venture to assure compatibility or uniformity. To cite one example, in the telecommuncations industry various devices must be able to communicate with each other.

For many years Bell Labs and Western Electric through the power of the AT&T monopoly provided the necessary system uniformity and standardization. The uncertainty (and opportunity) regarding the role these entities can perform following the antitrust suit settlement has prompted other corporations to form cooperative ventures aimed at achieving some degree of compatibility and standardization. In the PBX field, Sperry-Northern Telecom, IBM-Rohm, and Ericsson-Honeywell are all illustrative examples. Evidence of this motivational element can be found in cooperative ventures between computer manufacturers and component suppliers. One alternative would be vertical integration, but the resources required and the scarcity of certain critical talent would be restrictive.

With regard to cooperation that seeks uniformity or standardization, the collective enterprise executive should not be as concerned with the benefit transfer mechanisms in that the benefits are not normally divided up and distributed to the contributing participants. Instead the general management task will focus on the contribution arrangement and the nature of the uniformity or standards to be produced by the collective effort.

5. Cooperation to conduct research or develop a product that is mandated or required but does not yield a competitive advantage.

If investment is required by legal, moral, or ethical standards, and the outcome of the investment will not produce competitive benefits in excess of costs, then there is a strong impetus to seek out other corporations under the same compulsion in an attempt to pool resources and share results. Possible examples in this category are cooperative activities relating to pollution control or employee health and safety. This category can be contrasted with the third motivational category in which the investment output has value but that value cannot be readily captured. In this category are investments in which the output can be owned or controlled but does not have competitive value. Companies already in a marketplace would be likely candidates for a cooperative venture that spreads the costs of some competitively valueless investment they had to make. However, there would be reluctance to permit potential entrants to share in the fruits of such a cooperative venture since even a competitively valueless investment can still serve as a barrier to entry. Only those who have already paid the price of entry will be seen as attractive partners.

One illustrative example is the Health Effects Institute which was established to explore the impact of internal combustion engine by-products on biological organisms. One of the major difficulties facing General Motors' management in helping to set up HEI was determining what each participant would contribute. There was no problem regarding distribution of results since the research results were to be equally distributed among the participants. GM management feared that GM's contribution to the cooperative venture would be so large relative to the other participants that in essence GM would be merely funding research necessary to its competitors. At the outset the primary concern of the general manager of this type of collective activity will be establishing an acceptable contribution arrangement. After an approved cost-sharing mechanism is devised and cooperation is established, the general management task should shift to one of maintaining participant interest and support. This latter task could be a difficult one in that participating company interest and support of a cooperative venture with no competitive impact is likely to wane.

6. Cooperation as a method to maintain independence or credibility.

In certain conflict situations investments that seek to examine and resolve the subject matter of the controversy will often be more valuable if both sides to the controversy make a joint investment in the examination project. For example, R&D conducted by the automobile makers regarding the health effects of auto emissions is not likely to have a high level of credibility with certain environmental groups no matter how well the actual research is done. In such circumstances a cooperative venture, such as the Health Effects Institute, that includes other interested parties can be particularly attractive. This category would also encompass projects that are subject to participatory demands by groups potentially affected.

Independence of the collective effort can facilitate cooperative R&D even though the participants remain fierce competitors regarding the products using the technology developed through cooperation. Independence and credibility can also be useful in attracting research talent and insulating research projects from the short-term budgetary focus of the sponsoring companies. In this type of collective venture the benefit from cooperation is derived not so much from the actual output of the collective effort as from the nature of its production. In other words, the significant general management tasks regarding cooperative enterprises in this category are more likely to be associated with the method of output production rather than the benefit transfer mechanism. Cooperative R&D ventures of this nature often arise from adversarial situations in which two or more opposing "sides" are trying to produce the same or similar output, usually for the consumption or use of a third party. Such a collective venture requires the general manager to design an organizational structure that keeps the participants' antagonistic demands from interfering with the operation of the cooperative effort. Consequently, one would expect cooperation so motivated to be characterized by extensive negotiation among the sponsors during formation and then by extensive autonomy during subsequent operation and management.

7. Cooperation as a means to reduce the costs or risks associated with an entry or strategic movement.

A firm contemplating a business entry into a new endeavor or a strategic movement in an older one can often reduce the associated cost or risk by cooperating with others. The risk or cost reduction from cooperation occurs because of the differing circumstances of the participants. Reducing the risk or cost of entry or strategic movement can be accomplished by cooperation with firms that are already favorably positioned. The Kodak/Matsushita and the General Motors/Toyota cooperative ventures are two significant examples of this type of cooperation. For example, in the GM/Toyota joint venture GM wants to develop small car manufacturing expertise, a skill of Toyota, and Toyota wants to learn about automobile manufacture in the United States, an area of GM expertise. By cooperating, each partner can "purchase" skill or knowledge possessed by the other partner. Since the "selling" partner has already fully paid for acquiring the skill or knowledge in the first place, the "buying" partner should be able to purchase at a lower cost when compared to de novo or independent action. The difficulties appear when one of the partners acquires the strategically-sought skill or knowledge before the other and the incentive to continue cooperating disappears.

With cooperative R&D ventures that seek to reduce the costs associated with breach of entry or mobility barriers, the benefits to one set of participants are the contributions of others. Companies should find this type of cooperation attractive if entry or mobility costs can be reduced by cooperating with firms that have already paid the price of overcoming the entry or mobility barrier. Since the objective of such collective effort is, in essence, to assist in the establishment of a closer competitor in exchange for something of value, the cooperation should be relatively unstable. The general management task surrounding such cooperation will need to focus on the difficult issues of what to do after entry or strategic movement has been facilitated. There is also the very real possibility that one of the partners will acquire the srategically sought skills or knowledge before the others. At that point the satisfied partner has the incentive to cease cooperation.

8. Cooperation to permit risk diversification or risk sharing.

Often a firm wishes to diversify its risk by making a larger number of smaller investments. By placing more although smaller bets, the riskiness of investments can be averaged out, thereby eliminating some of the downside risk in exchange for some of the upside opportunity. Mining and drilling companies often engage in cooperative exploration to diversify the risks involved. In some situations, such cooperation may be seen as insurance in which a class of "at risk" entities are protected against cataclysmic change in circumstance. For example, R&D among competitors may insure, with minimal individual investment, that no one competitor makes an independent breakthrough that would put the others at competitive disadvantage.

The benefit to the participants in cooperative R&D ventures that serve a risk sharing or portfolio facilitating function is that cooperation permits the firms to place smaller bets on a larger number of investments. In that the participant's motivation to cooperate is to diversify investment risk, the relationship among the participants should not, in general, be antagonistic. As a consequence, the management task concerning such cooperation need not focus as much on establishing elaborate mechanisms to maintain participant cooperation as with other types of cooperative ventures. Instead, developing valuable technology and establishing technology transfer mechanisms should pose more of a difficulty to the collective venture general manager.

Conclusion

Cooperative research and development ventures are becoming increasingly attractive as a part of the technological innovation process. Yet, despite the advantages collective action can offer the participants, the difficulties in managing such consortiums can turn opportunity into chaos. Confusion and disappointment can be alleviated by managerial action aimed at balancing the three elements of a cooperative venture, participant contribution, benefit creation, and benefit transfer, and by matching organizational structure and strategy to the type of cooperative venture involved.

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AUTHOR BIOGRAPHY: William J. Murphy is currently working on his doctoral dissertation at the Harvard Business School. After having served five years as an antitrust trial attorney for the Federal Trade Commission in Washington, D.C., from 1974 to 1979, Mr. Murphy earned his MBA with distinction from the Harvard Business School in 1981 and subsequently received a fellowship from the Harvard Business School to study cooperative ventures. As a doctoral candidate the author has continued his research into cooperative ventures, with specific emphasis on the Microelectronics and Computer Technology Corporation in Austin, Texas. The data collected by Mr. Murphy over the past three years cover MCC from idea to organizational reality and form the core of his doctoral thesis. Mr. Murphy teaches at the University of Massachusetts/Boston Harbor Campus and the Radcliffe Seminars Advanced Management Program.

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GOVERNMENT-TO-GOVERNMENT COOPERATION IN SPACE STATION DEVELOPMENT

Samuel H. Nassiff
International & External Affairs Office
Space Station Program Office
NASA Johnson Space Center

ABSTRACT

Memoranda of understanding have recently been signed between the United States (NASA) and three international Space Station partners - Canada, European Space Agency (ESA), and Japan. The international partners are performing parallel Phase B preliminary design studies, concurrent with the U.S., on their proposed elements/systems for possible integration and operation with the U.S. Space Station System complex. During the 21-month Space Station Phase B study, a large amount of technical interface data will have to be transferred between the U.S. and the international partners. Scheduled bilateral technical coordination meetings will also be held. The coordination and large number of interfaces required to integrate the international requirements into the Space Station require a "clean" interface management organizational structure and operation procedures to accomplish the integration task. The international coordination management organizational structure, management tools, and communications network are discussed including the proposed international elements/systems being studied by the international partners.

INTRODUCTION

The President, in his State of the Union Message in January 1984, directed NASA to develop a permanently manned Space Station within a decade. At the same time, he also invited friends and allies of the United States to join in the program in order to share its benefits. In April 1985, NASA initiated a 21-month Space Station Phase B preliminary design study. Shortly thereafter, government-to-government cooperative agreements, in the form of memoranda of understanding (MOU's), were signed between the U.S. and three international partners. The MOU with Canada was signed on April 16, 1985, with Japan on May 9, 1985, and with the European Space Agency on June 3, 1985. Since the international partners are conducting parallel Phase B studies with the U.S., an organizational structure has been set up within the Space Station Program Office to coordinate technical and operational activities with our international partners to ensure proposed international requirements/elements are integrated into the U.S. Space Station program. This is accomplished through the International & External Affairs Office in the Space Station Program Office.

For the first time in NASA's history, a radical departure in program management has taken place from that of past spaceflight programs in that four NASA "Work Package" Level C Centers (MSFC, JSC, GSFC, and LeRC) are responsible for developing specific Space Station Program Elements/Systems. The Level B Space Station Program Office, located at JSC, will perform overall program management and the Systems Engineering and Integration (SE&I) function for the Space Station Program. Because of the physical locations and distances involved with the international partners and that of the NASA Centers it is evident that innovative management techniques and a telecommunications capability is needed for voice conferences and data transfer. During the parallel Phase B studies, large amounts of technical interface data will be transferred between the U.S. and the international partners. Multilateral and bilateral technical meetings will also be held. International liaison representatives for each partner are located at JSC for the Phase B studies. During Phase C/D, it is anticipated that U.S. liaison representatives will be located in Canada, Europe, and Japan. The Space Station Program will be international in nature, i.e, contain international elements/modules with an International Crew.

SPACE STATION PROGRAM INTERNATIONAL COOPERATION

NASA has conducted a number of successful spaceflight programs such as Mercury, Gemini, Apollo, Apollo/SOYUZ, Skylab, and Space Shuttle. Each of these programs have contributed significantly to the ability of man to work productively and live in space. The next logical step was to develop a permanently manned Space Station which would operate in low earth orbit. Recognizing that the U.S. Space Station is the next large development program, substantial international interest has been exhibited due to past and present cooperative activities with NASA such as foreign contributions to the Space Shuttle Program.

Following President Reagan's invitation to U.S. allies and friends to participate in the Space Station Program, the NASA Administrator visited Europe, Canada, and Japan for high-level discussions on international participation. Subsequently, the European Space Agency (ESA), Canada, and Japan have signed memoranda of understanding (MOU's) with NASA that provides the framework of cooperation on Space Station during Phase B preliminary design. The main features of the MOU's are delineated as follows:

- It recognizes participation in prior cooperative programs,
- Defines cooperation during Phase B and a basis for longer term cooperation through development and operation phases,

- o Identifies principles that must be defined for station access, cost sharing, barter, and crew participation during subsequent negotiations for Phase C/D/E,
- o Provides a basic description of U.S. and International Space Station Program,
- o Program phasing and schedule,
- o Respective responsibilities,
- o Management reviews/liaison relationships,
- o Advanced Development Program,
- o Data exchange and rights, and
- o Financial and legal matters.

Three aspects of potential cooperation exists. The first is as a "user" of the Space Station who essentially defines missions and utilizes the Station capabilities. Secondly, as a "builder" who participates over a long term in definition and development programs and supplies funding and hardware, thereby enhancing the Station capabilities. And thirdly, as an "operator" who would participate in a specific system operation on-board the Station. The three international partners are viewed as "builder/operator" in the Space Station Program.

Space Station partners must be sensitive to U.S. concerns abo technology transfer, exporting jobs, and efficient overall management resources. The MOU's do not authorize cooperation in the Advanced De opment Program area. Cooperation in the Advanced Development Program will be considered on a case-by-case basis and entered into only when it is mutually beneficial to both sides. Matters for future discussion and agreement between the partners are foreseen as follows:

- o Respective responsibilities in design, development, operation, and utilization,
- o Principles regarding access to all Space Station elements,
- o Pricing policy,
- o Barter of hardware and services to offset costs,
- o Length and type of commitment to the program,
- o Protection of proprietary information and intellectual property rights,
- o Crew participation in the Space Station,

- Definition of appropriate technology interchanges,
- Operational costs, and
- Appropriate legal arrangements.

SPACE STATION PROGRAM MANAGEMENT

The Space Station Program management structure is divided into three levels; Level A - located at NASA Headquarters provides policy and overall program direction; Level B - located at the Johnson Space Center provides program management, budget, and technical control; and Level C - located at JSC, MSFC, GSFC, and LeRC field centers provides project management for element definition and development. Figure 1 shows the Level B Program Office organization. Four line offices report to the Program Manager. The Systems Engineering and Integration Office establishes and manages the technical content of the Space Station Program in response to the system requirements established by Level A. The Data Management Systems and Operations Office establishes and manages the data management architecture and overall flight and ground operations. The Customer Integration Office establishes customer requirements, coordinates mission data base, and integration of users and their requirements. The Program Management Office manages the program resources to the budget and schedule guidelines provided by Level A. The Technical Management Information System Staff Office is responsible for developing technical program and data management needs and implementing an automated computerized network of distributed engineering and management data systems. The International and External Affairs Staff Office serves as the focal point for interfacing with the international community and is responsible for technical and management integration of international partner's requirements and proposed hardware elements into the Space Station Program. This office also serves as the focus for policy analysis, strategic planning, and interfacing with congressional activities, White House visitors, academic community, and other federal agencies and departments.

International Coordination and Management Process

An integrated technical coordination and management process has been established to interface with the international partners (Canada, ESA, and Japan) to process and manage change requests, conduct formal and informal meetings, and provide the framework for carrying out the objectives of the cooperative project as established in the MOU's. The Space Station management functions for international participation for each level is as follows:

Level A: Provides overall policy and program direction

- Decisions on international elements
- Planning for evolutionary growth
- Negotiate MOU's

Figure 1 - Space station program level B organization

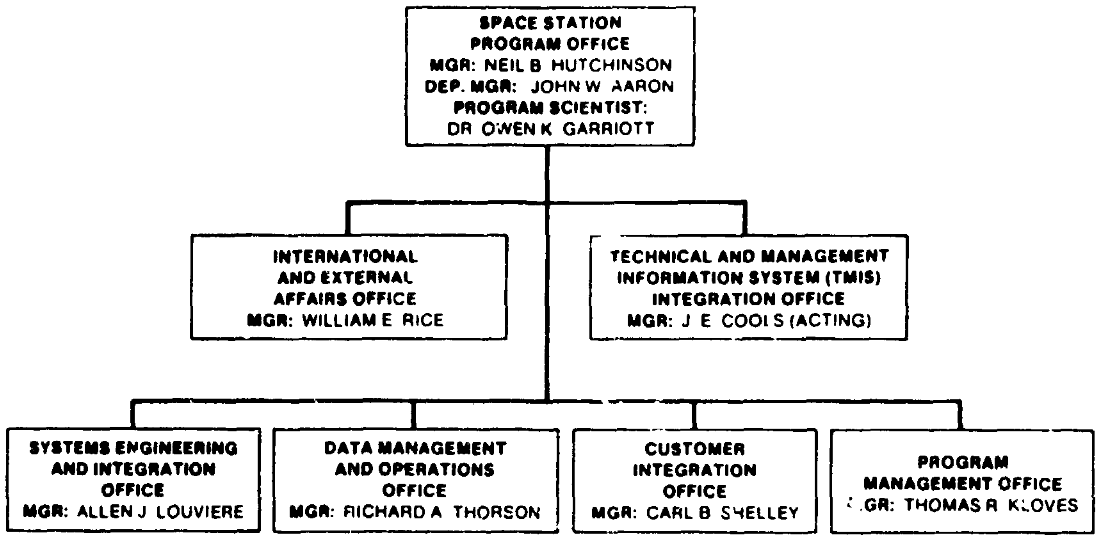
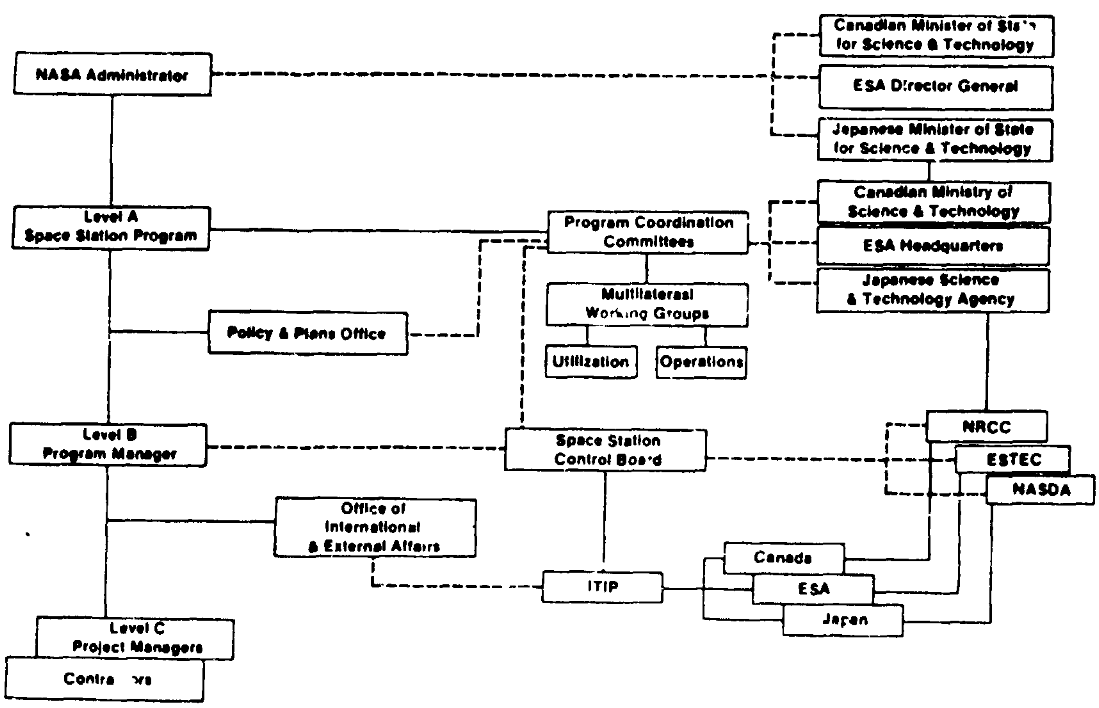


Figure 2.- International cooperation management framework for phase B



Level B: Program Implementation

- Technical coordination of system requirements
- Baseline and control technical data base
- Integration of international elements into baseline configuration
- Establish and control ICD's

Level C: Project Implementation

- SE&I support to Level B on impact of international elements
- Impact of international elements on Work Package Centers
- Develop system and end items

Figure 2 illustrates international cooperation management framework for Phase B. The interfaces and coordination can be seen between the U.S. management levels and counterpart international levels. The International Technical and Integration Panel (ITIP), located at Level B and chaired by the Manager of the International and External Affairs Office is the forum used for technical coordination of activities between NASA and the international partners. Membership on the ITIP and formal change control flow is shown in figures 3 and 4, respectively. The Program Coordination Committee--co-chaired by the NASA Associate Administrator and international counterpart--is responsible for overall program direction and coordination, the main focus is decision on functional and technical aspects of international participation. The membership on this committee is shown in figure 5. The Space Station Level B Control Board--chaired by the Space Station Program Manager --integrates the Phase B study activities into baseline Space Station configuration and lay the basis for initiation of preliminary design activities on all Space Station elements. Membership on this board is shown in figure 6. The structure of the Space Station Control Board is shown in figure 7. It consists of four main panels (Operations, Customer Intergration, and International Technical and Integration) and the Systems Integration Board. These four entities are, in turn, supported by fourteen technical integration panels.

Management Tools

The management tools used for Phase B international coordination at each management Level consists of program review, coordination committees, technical working groups, and project liaison coordination. The management tools are:

Level A

- Bilateral Program Coordination Committee
- Multilateral Program Review
- International Working Groups
- Working Group on International Cooperation
- Liaison Oversight

FIGURE 3

INTERNATIONAL TECHNICAL AND INTEGRATION PANEL MEMBERSHIP

OBJECTIVE: FOCUS FOR INTERNATIONAL TECHNICAL, OPERATIONS AND UTILIZATION INTERFACES AT LEVEL B

MEMBERSHIP:

CO-CHAIRMAN: NASA MANAGER, LEVEL B INTERNATIONAL AND EXTERNAL AFFAIRS OFFICE, AND INTERNATIONAL COUNTERPART

EXECUTIVE SECRETARY: MANAGER, PMO DOCUMENTATION AND CONFIGURATION MANAGEMENT OFFICE, JSC

NASA MEMBERS:
MANAGER, SYSTEMS ENGINEERING AND INTEGRATION OFFICE, JSC
MANAGER, DATA MANAGEMENT SYSTEMS AND OPERATIONS OFFICE, JSC
MANAGER, CUSTOMER INTEGRATION OFFICE, JSC
REPRESENTATIVE, SAFETY, RELIABILITY, AND QUALITY ASSURANCE, JSC
SPACE STATION PROGRAM SCIENTIST
REPRESENTATIVE, JSC
REPRESENTATIVE, MSFC
REPRESENTATIVE, GSFC
REPRESENTATIVE, LeRC
REPRESENTATIVE, KSC
REPRESENTATIVE, LaRC
HQ's DELEGATES (CODE SPC, LID, AND SE)
REPRESENTATIVE, NATIONAL STS PROGRAM OFFICE, JSC

Figure 4.- International technical and integration panel exchange flow.

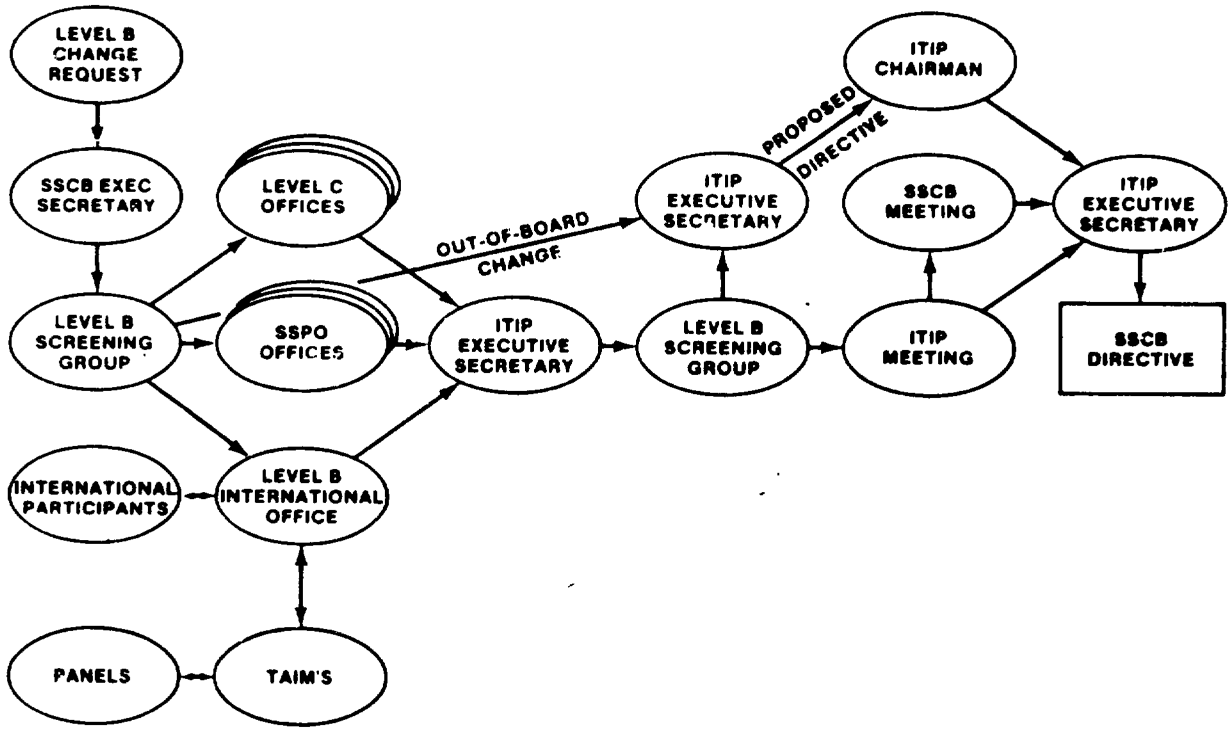


FIGURE 5

PROGRAM COORDINATION COMMITTEE

OBJECTIVE:	RESPONSIBLE FOR OVERALL PROGRAM DIRECTION AND COORDINATION - MAIN FOCUS IS DECISION ON FUNCTIONAL AND TECHNICAL ASPECTS OF INTERNATIONAL PARTICIPATION
MEMBERSHIP:	
CO-CHAIRMEN:	NASA ASSOCIATE ADMINISTRATOR AND INTERNATIONAL COUNTERPART
NASA MEMBERS:	DIRECTOR, POLICY AND PLANS DIRECTOR, UTILIZATION AND PERFORMANCE REQUIREMENTS DIRECTOR, ENGINEERING DIRECTOR, OPERATIONS DIRECTOR, BUSINESS MANAGEMENT DIRECTOR, INTERNTIONAL AFFAIRS LEVEL B PROGRAM MANAGER
EXECUTIVE SECRETARY:	COOPERATIVE PROGRAMS BRANCH CHIEF

FIGURE 6

SPACE STATION CONTROL BOARD MEMBERSHIP

OBJECTIVE: INTEGRATE PHASE B STUDY ACTIVITIES INTO BASELINE SPACE STATION CONFIGURATION AND LAY THE BASIS FOR INITIATION OF PRELIMINARY DESIGN ACTIVITIES ON ALL IOC ELEMENTS

MEMBERSHIP:

CHAIRMAN:	MANAGER, SPACE STATION PROGRAM OFFICE (SSPO)
ALTERNATE CHAIRMAN:	DEPUTY MANAGER, SSPO
EXECUTIVE SECRETARY:	MANAGER, PROGRAM MANAGEMENT OFFICE, JSC
NASA MEMBERS:	MANAGER, SYSTEMS ENGINEERING AND INTEGRATION OFFICE, SSPO MANAGER, DATA MANAGEMENT AN OPERATIONS OFFICE, SSPO MANAGER, CUSTOMER INTEGRATION OFFICE, SSPO MANAGER, INTERNATIONAL & EXTERNAL AFFAIRS OFFICE, SSPO SPACE STATION PROGRAM SCIENTIST, SSPO DIRECTOR OF RESEARCH AND ENGINEERING, JSC DIRECTOR OF SPACE OPERATIONS, JSC MANAGER, SPACE STATION PROJECT OFFICE, MSFC MANAGER, SPACE STATION PROJECT OFFICE, JSC MANAGER, SPACE STATION PROJECT OFFICE, GSFC MANAGER, SPACE STATION PROJECT OFFICE, LeRC MANAGER, SPACE STATION PROJECTS, KSC CHIEF, SPACE STATION/COMMERCIALIZATION OFFICE, ARC MANAGER, SPACE STATION OFFICE, JPL MANAGER, SPACE STATION OFFICE, LaRC REPRESENTATIVE, NATIONAL STS PROGRAM OFFICE, JSC

Figure 7 - Space station board and panel structure

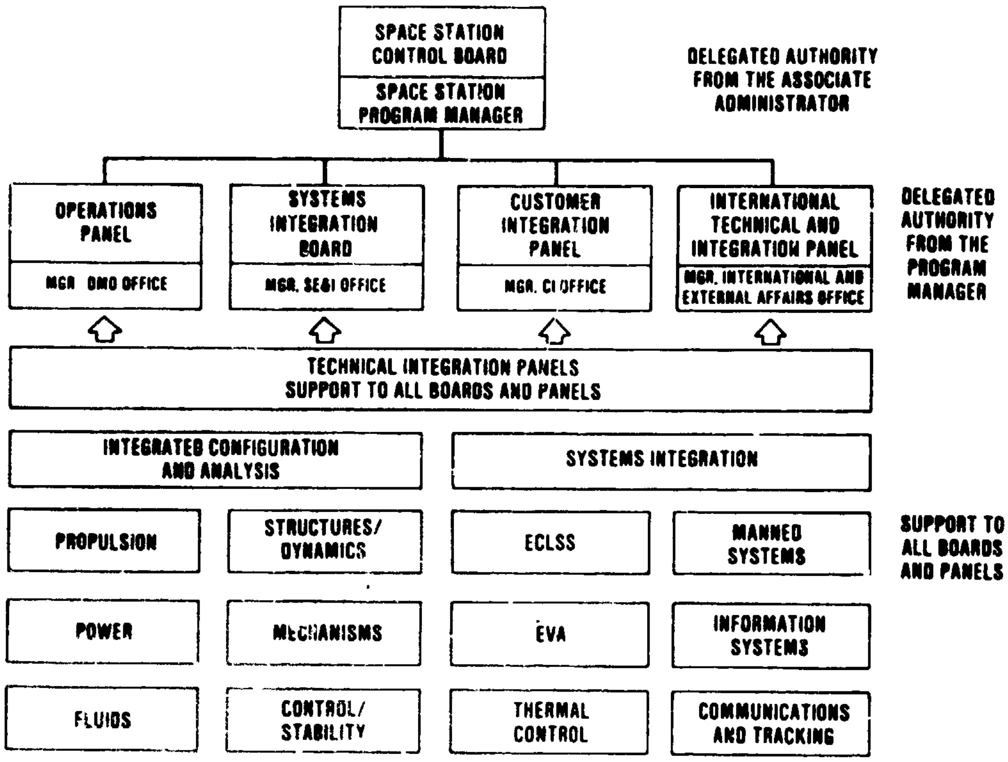
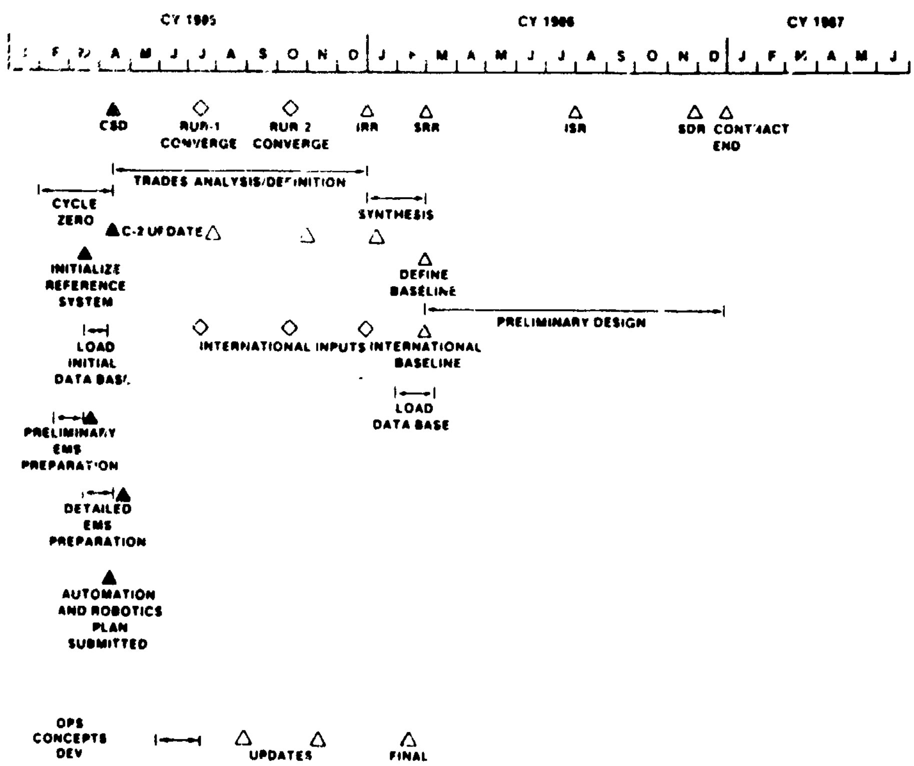


Figure 8 - Phase B milestone schedule.



Level B

- o Program Managers Board, as required
- o International Technical and Integration Panel
- o Membership on International Working Group
- o Membership on Working Group on International Cooperation
- o Resident International Project Liaison

Level C

- o Membership on International Technical and Integration Panel
- o Membership on International Working Groups
- o Membership on Working Group on International Cooperation
- o Liaison, as appropriate following SRR

Figure 8 shows the Space Station Program schedule with the program milestones. The main tool used by the Program Office for integrating the activities of Level B and Level C work package centers, contractors, and international partners is a systems referred to as "Engineering Master Schedule" (EMS).

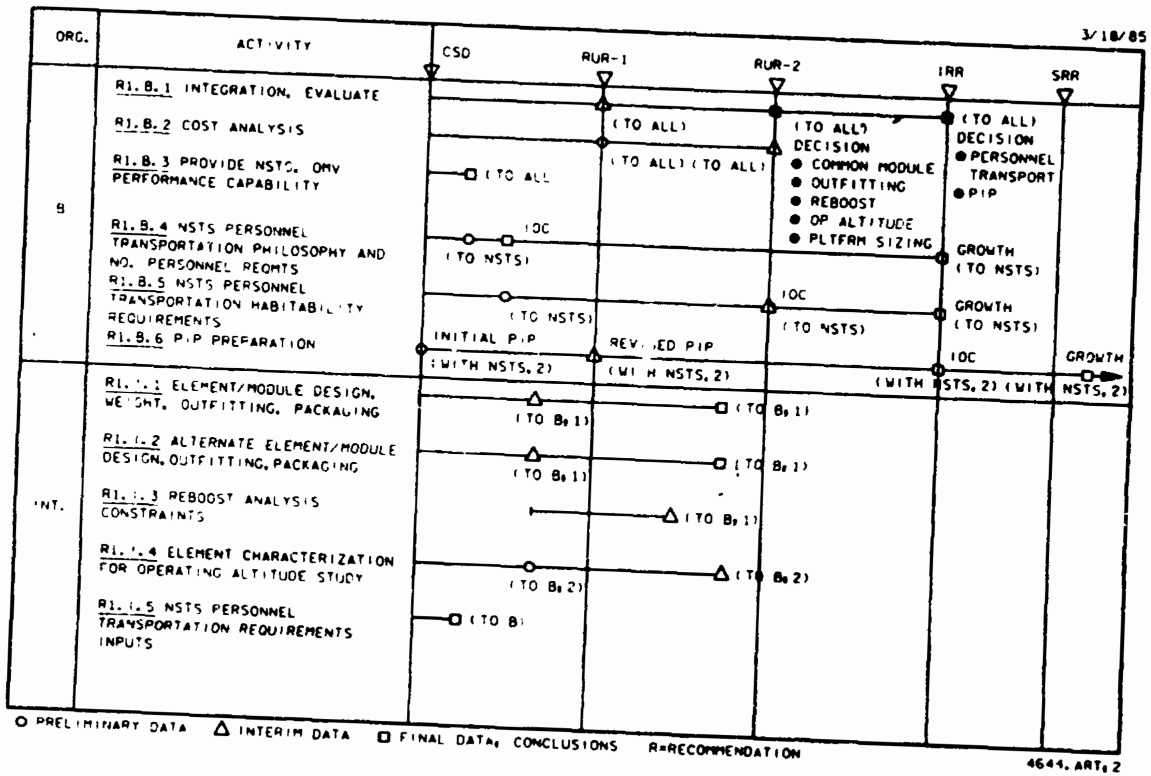
In addition, an options list and options matrix is used. The options list specifies the proposed international elements to be examined across the program and the options matrix specifies which elements are to be examined in combination with other options. Basically, the EMS is a system that specifies twenty major program themes which have been grouped into three categories: requirements, configuration, and strategy. The themes are broken down into specific engineering study activities which are scheduled to support the major program milestones. An example is shown in figure 9.

Technical Management Information System

An Engineering Data Base, which is used for integrating international systems and elements into the U.S. Station, is under development. This data base includes baselined configuration drawings, systems/subsystems schematics, system requirements, schedules and plans, and engineering data books. The EMS, discussed previously, will control the content of the Engineering Data Base. Engineering, operations, customer integration, program management, and international interface documentation is also under development which requires transmittal and review by our international partners. Additionally, scheduled NASA/International Partners Technical Coordination Meetings require presentation material transfer, action item generation, tracking, and followup.

In view of the above, and coupled with the vast distances between our international partners and location of the various NASA field centers, it is imperative that a telecommunications system and technical and management information transfer system are implemented. The current capabilities for international communications are:

Figure 9 .- EMS requirements.



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- o Electronic Mail
  - Telemail

- o Text/Image Interchange
  - Facsimile

The Technical and Management Information System (TMIS) for the Space Station Program is being developed in two phases. The International System, for Phase I (present to March 1987) is in an implementation process and availability is targeted for early 1986. The Phase II acquisition process has been initiated and initial implementation is scheduled for March 1987.

The TMIS is an integrated system of hardware, software, procedures and people resulting in the information and products required to support the Space Station Program. It is a network of distributed engineering and management data systems for information exchange linking NASA field centers, contractors, and international partners.

Figure 10 illustrates how the TMIS will be connected to the various centers through the NASA Program Support Communication Network. Typical TMIS architecture at a NASA center is shown in figure 11. The functional capabilities of the TMIS are: data base management, CAD/CAE/CAM, models/analysis tools, documents management, scheduling, planning, resources, electronic mail, and office automation.

INTERNATIONAL DEVELOPMENTS UNDER STUDY

A brief overview and description is given of the proposed international elements/modules being studied by the international partners during Phase B.

Canadian Integrated Servicing and Test Facility

Figure 12 shows the ISTF attached to the Space Station. The ISTF truss structure with its accommodations occupies a volume of approximately 75 ft. x 60 ft. x 20 ft. This volume contains the following static accommodations:

- o Positioning systems for payload servicing
- o OMV Hangers
- o ORU Pallets
- o Mobile Base
- o RSS Parking Fixture
- o Robotic Test Bed Accommodations.

The dynamic elements like the RSS, the SSMRMS, the payloads and large space construction facilities will protrude beyond this volume during operations on the ISTF. The ISTF centralizes some servicing functions on the Station such as payload/spacecraft serving, integration, and checkout; OMV servicing and accommodations; proximity operations with tools and EVA work station; robotics test bed, etc.

Figure 10.- Technical management and information system.

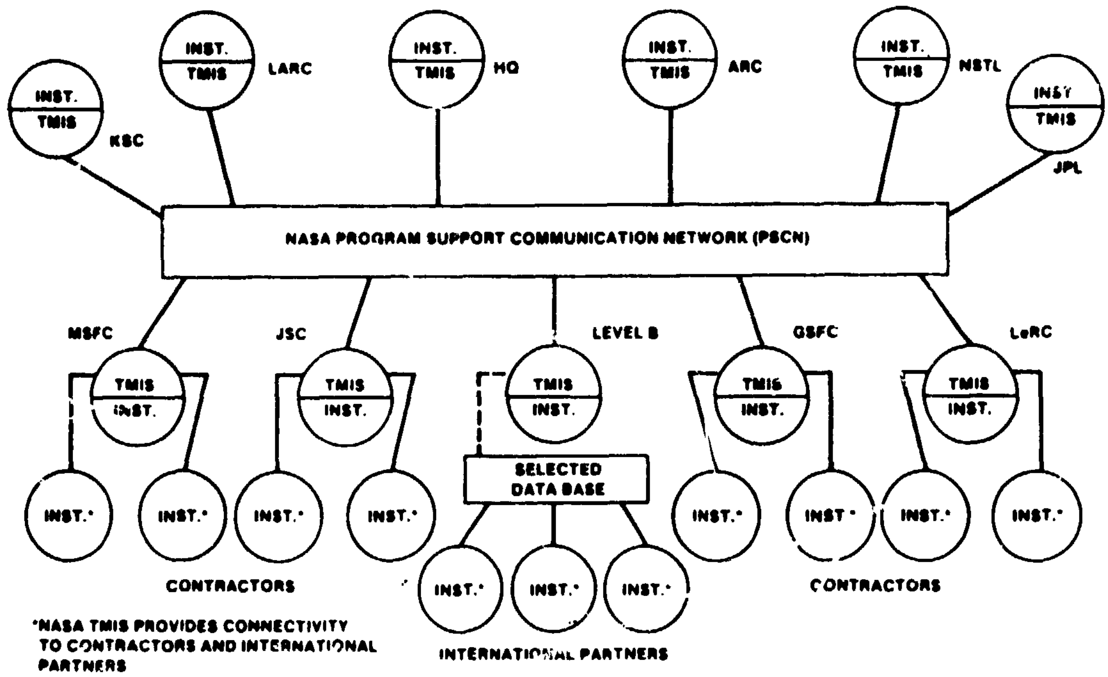

Figure 11 - Typical TMIS architecture at a NASA Center

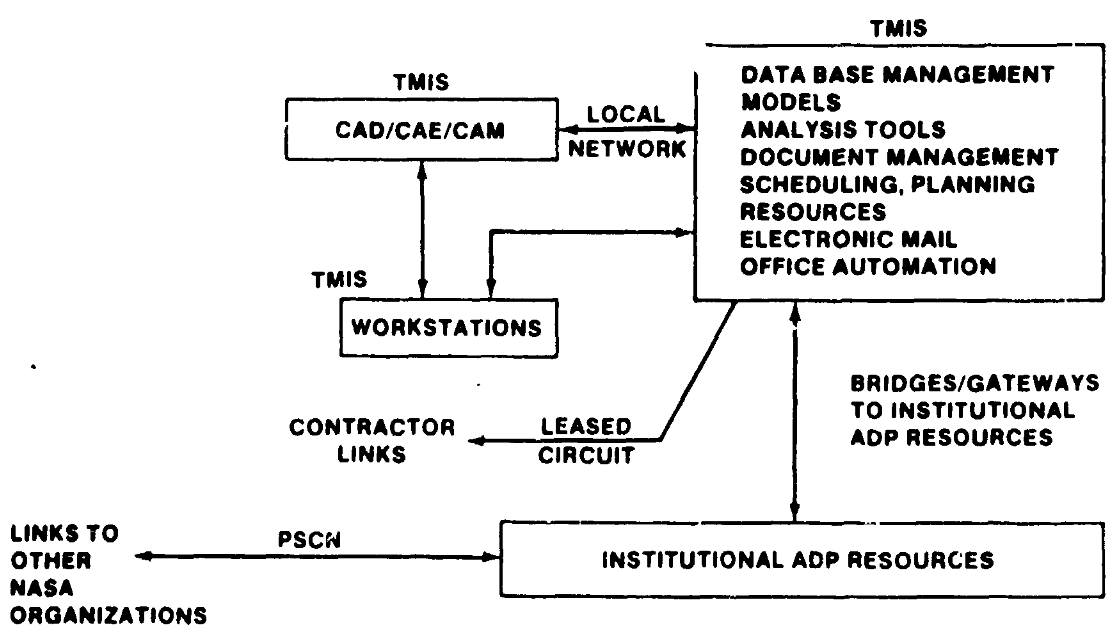

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Figure 12.- Canadian Integrated Servicing and Test Facility (ISTF) concept

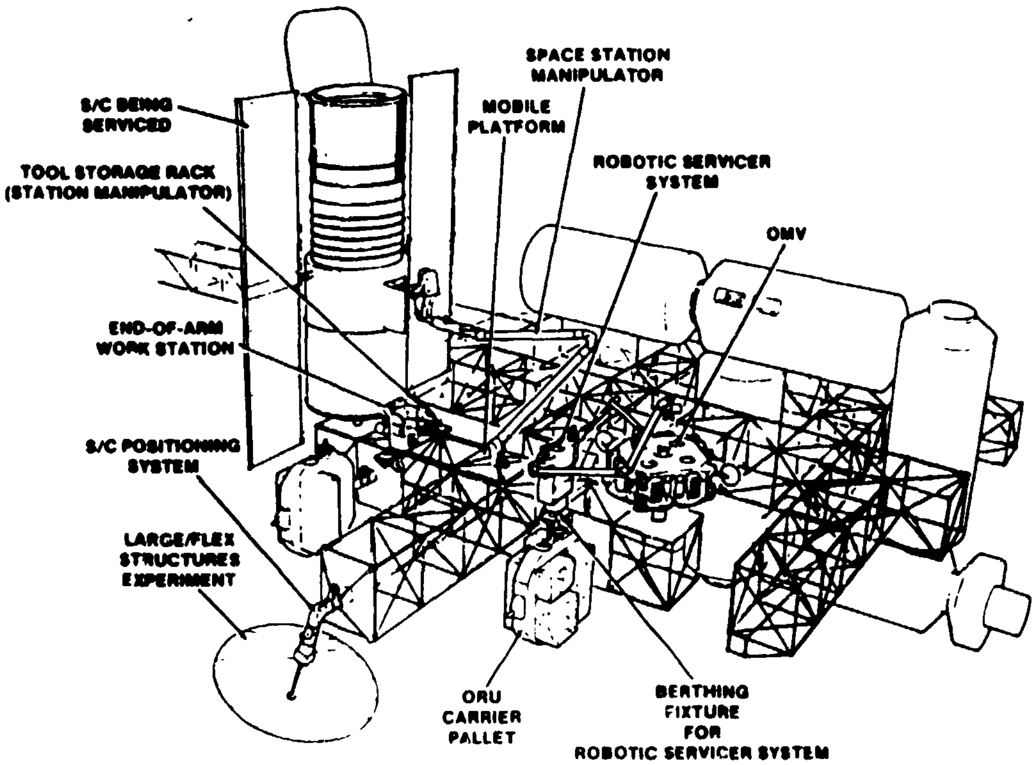
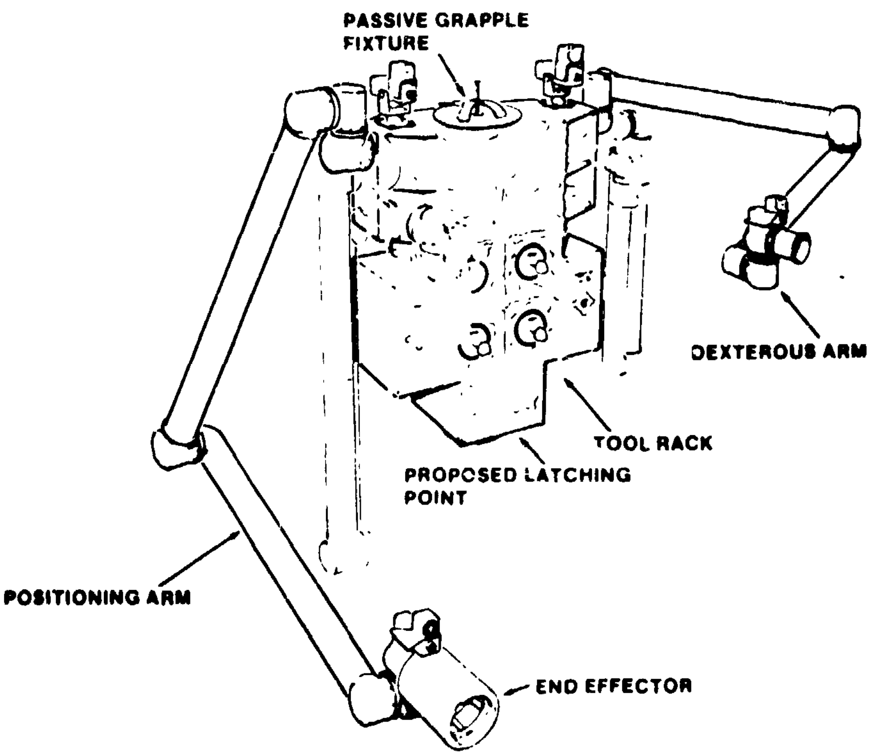


Figure 13.- Robotic servicer system concept.



The growth philosophy for the ISTF allows accommodation of evolving technologies and evolving requirements. Some major areas of growth are forseen in replacement of modified SRMS by advanced SSRMS, incorporation of artificial intelligence technologies and sensors into ISTF robotic systems for supervisory mode of control, and two MRMS operation simultaneously from two different control stations.

A concept for the Robotic Servicer System is show in figure 13. It is comprised of a positioning arm with end effector, dexterous arm, toolrack, latching location, and passive grapple fixture. This system may be used on the ISTF for automated servicing operations.

Canadian Remote Sensing (RADARSAT)

RADARSAT is a free-flying platform which operates in a sun-synchronous orbit at 1000KM, and 99° inclination. The Earth Observation Satellite includes a synthetic aperture radar, a micro-wave scatterometer, and advanced high resolution radiometer and an optical sensor. RADARSAT stowed dimensions are 23 ft. long and 14.3 ft. in diameter. Tip-to-tip deployed solar array is 137 ft. Figure 14 shows the fully deployed configuration.

ESA - Columbus Preparatory Program

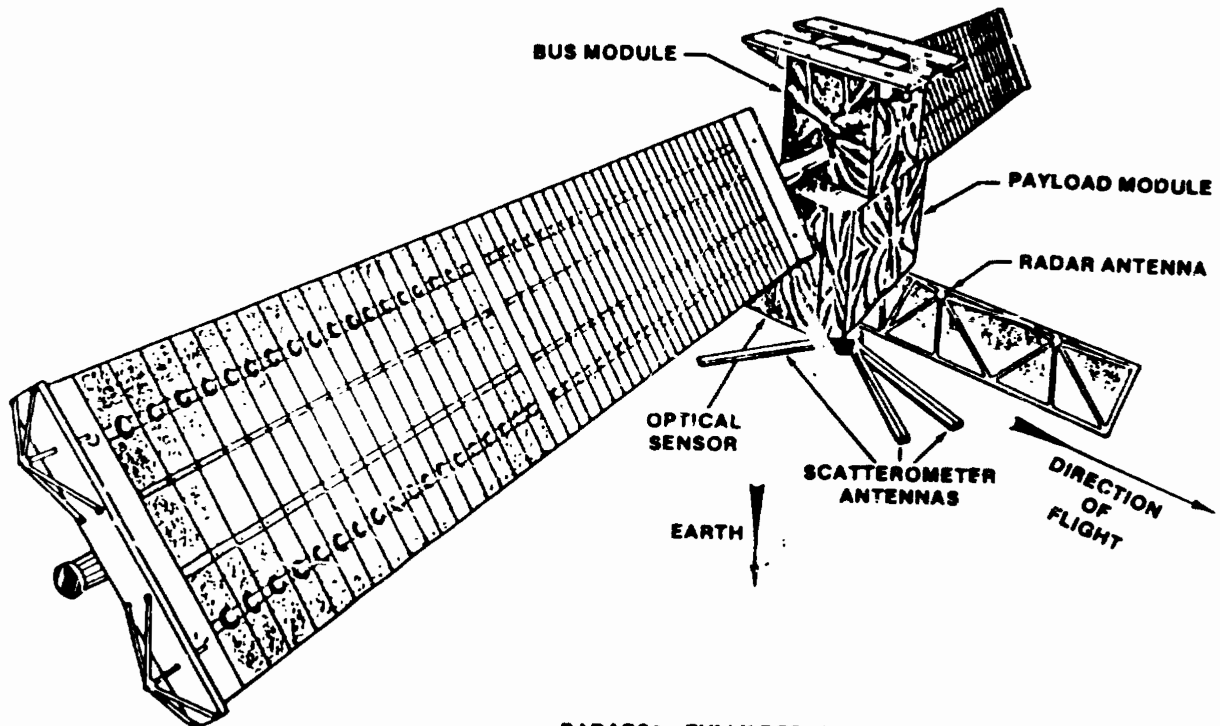
The objective of the Space Station Columbus Program, as adopted by the eleven members of the European Space Agency (ESA) long-term space plan on January 31, 1985, is to develop the set of elements shown in figures 15 and 16. The Columbus Program is based on previous experience acquired in Europe with Space Lab. The elements include:

- A pressurized manned laboratory module which will be used as a life science and/or materials laboratory while attached to the Space Station.
- Unmanned platforms for co-orbit and polar orbit applications.
- Unmanned service vehicle to support platform operations.
- Resource module to support the pressurized module free-flying man-tended option.

The pressurized laboratory will require interfaces with the Space Station for power, thermal, and communication services. It can be configured to optimize user requirements and desired mission and payload operations.

Platform missions will serve different objectives and needs such as material and fluid physics, life and space sciences payloads requiring micro-gravity and payloads for Earth observations, Stellar, and Sun pointing. Servicing vehicle missions (unmanned) will be utilized to perform at different orbits (1000 KM/28.5° or 700 KM/98°), operations such

Figure 14.- Canada RADARSAT



RADARSA FULLY DEPLOYED ONFIGURATION

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as refueling or exchange of standard ORU's, visual inspections by camera, etc.

Japanese Experiment Module (JEM)

The JEM is a pressurized multi-purpose experiment module approximately 33 ft. long and 14.5 ft. in diameter. Figure 15 shows the IOC Configuration which consists of the pressurized module, experiment logistics module, fixed manipulator, air lock, and exposed work deck. Growth projections shown in figure 16 include addition of another exposed work deck, structural mast, OMV hanger, movable manipulator, man-tended free-flyer, teleoperator, and associated service facilities. Some of the functions to be supplied by the Space Station to the JEM are: (1) primary power supply and heat rejection, (2) data relay to and from ground, (3) primary air supply, and (4) accommodations for crew assigned to the JEM system.

The crew in the pressurized module can operate a wide range of missions such as material processing, life sciences, space medicine, etc. The exposed work deck is used for accommodating high energy cosmic ray experiment, space robotic, liquid propellant handling, material science, commercial space processing, etc. The experiment logistics module which is 18 ft. long and 14 ft. in diameter consists of pressurized and unpressurized sections. The pressurized section can accommodate up to two crewmen and can serve as a safe haven. The module stores and transports experiment specimens, experiment gases, spare parts, special experiment equipments, etc. The fixed manipulator is used for servicing equipment on the exposed deck and manipulates or changes out components, experiment samples, etc. The airlock located between the pressurized module and exposed deck is used to transport equipment and samples with the aid of the fixed manipulator.

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Figure 15 - Space station international reference configurations (Initial)

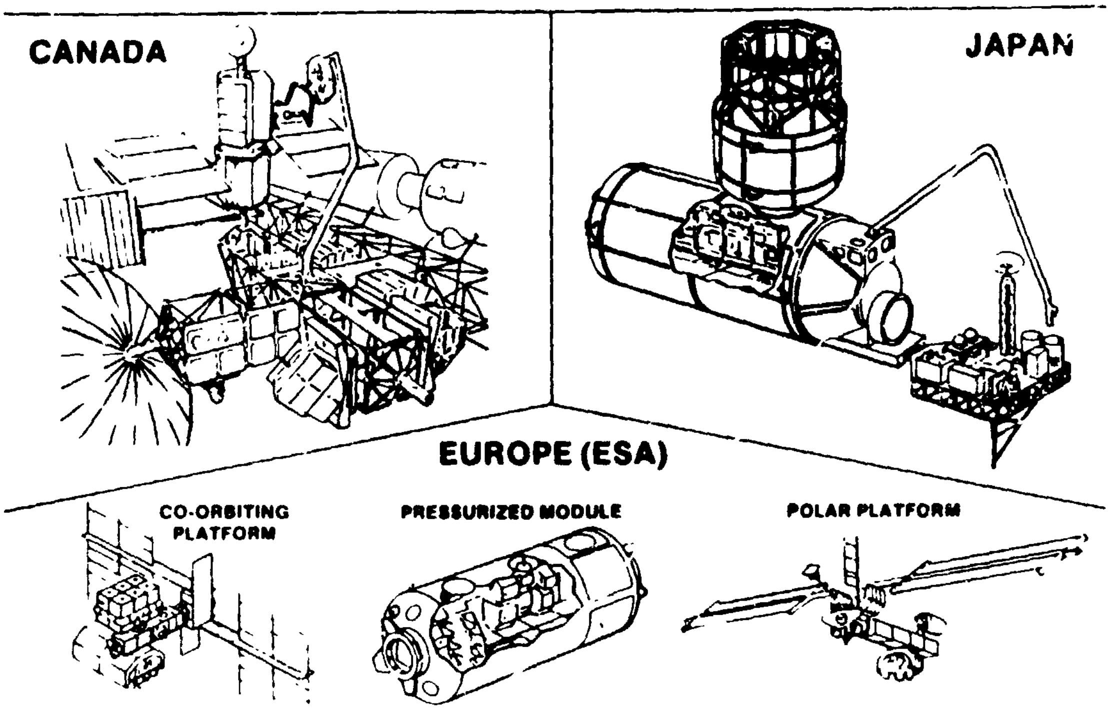
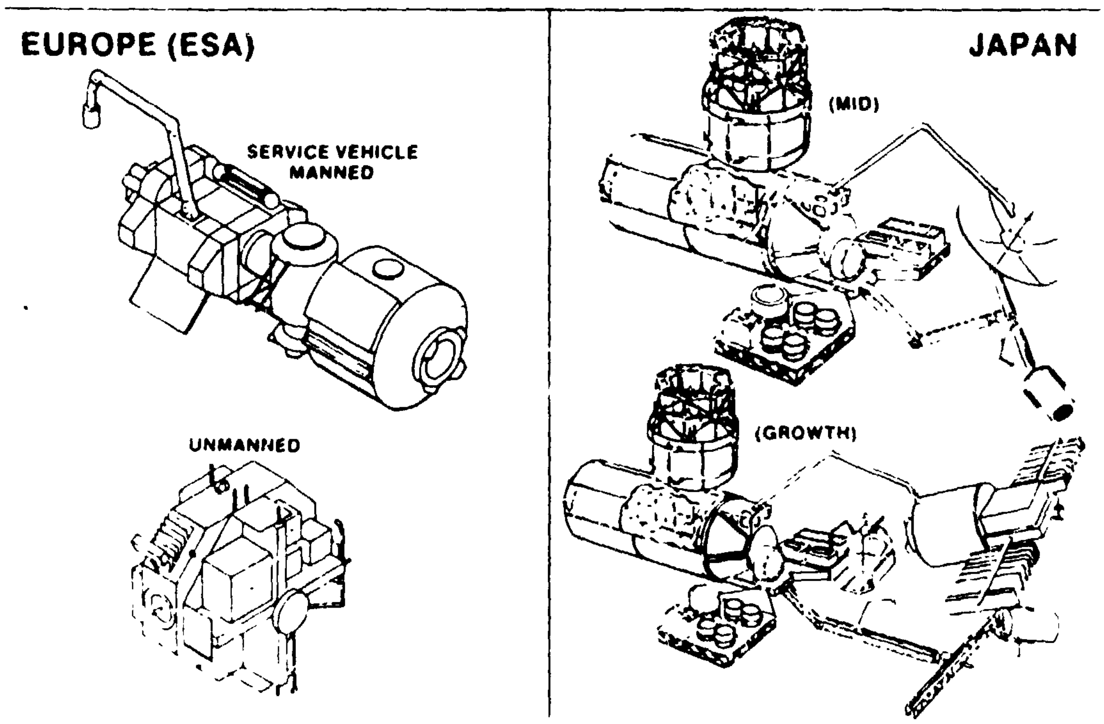


Figure 16.- Space station international reference configurations (Growth).



BIOGRAPHY

Mr. Nassiff received a B.S. in Aeronautical Engineering from the University of Florida and was employed at General Dynamics (Convair), Fort Worth for 6 1/2 years in the Airplane Stability and Control Group. He joined NASA JSC in 1963 and has been involved in the Gemini, Apollo, Apollo/Soyuz, Spacelab, and Space Shuttle Programs in the areas of simulation design/training, spacecraft design, advanced missions studies, and engineering project management as related to spacecraft design and mission requirements. He is currently Manager of International Projects in the International and External Affairs Office, Space Station Program Office and is responsible for technical interface, management integration and coordination of international requirements and hardware elements into the Space Station Program. Mr. Nassiff is an associate fellow in the AIAA, and registered Professional Engineer in Texas.

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PRODUCTIVITY ISSUES AT ORGANIZATIONAL INTERFACES

Albert W. Holland
Universities Space Research Association

ABSTRACT

The need for close interdependence between large numbers of diverse and specialized work groups makes the Space Program extremely vulnerable to loss of productivity at organizational interfaces. Trends within the program also suggest that the number and diversity of interfaces will grow in the near term. Continued maintenance of R&D excellence will require that interface performance issues be included in any future productivity improvement effort.

The types and characteristics of organizational interfaces are briefly presented, followed by a review of factors which impact their productivity. Approaches to assessing and improving interface effectiveness are also discussed.

INTRODUCTION

In order to accomplish its objectives, the United States Space Program relies upon the contributions of a wide variety of engineering, scientific, technical and support personnel representing a large number of diverse organizations. This is necessary, of course, to create a program structure of sufficient technical power and flexibility to fulfill its mandate. Yet achieving the effective integration and coordination of so many specialized work groups is an enormously challenging task, and there are indications that this task will become increasingly complex in the near future.

Several trends within the space program suggest that the number and diversity of work interfaces will be growing rapidly. First, the sheer number of concurrently operating space transportation systems and facilities is increasing. An example of this is the development and operation of the space station, which will be maintained and serviced by the space shuttle. Although shuttle operations are now being consolidated under a single contractor, NASA nevertheless continues overall supervisory activities in that program <u>in addition</u> to space station management. Second, the number and diversity of participants is expanding. The development and use of the space station will be a multinational, multidisciplinary initiative surpassing any previous endeavor in terms of interface management. The station will also encourage private sector users in pursuit of their own proprietary R&D ventures. Third, the indentification of opportunities for commercial profit will be accompanied by concerted pressure from industrial consumers to expand and diversify space facilities, transportation and services. To accomodate the broad demand, existing arrangements of critical interfaces will be pressured to multiply in number and to reconfigure more frequently. Finally, NASA is actively encouraging small businesses to enter the contractor ranks. This not only increases the number of contractor participants but the range of specialization, internal resources and experience as well.

Effective integration will become an increasingly complex task for management at all levels. Indeed, the emergent skill of leadership might be the ability to manage work unit boundaries and regulate cross-unit transactions [10]. In order to do this effectively, something must be known about the characteristics of interfaces, factors affecting their performance, and approaches to assessment and improvement.

CHARACTERISTICS OF INTERFACES

Interactions and transactions between work groups flow from the requirements of task accomplishment which necessitate some form of linkage or interface between groups. For our purposes, three basic types of interfaces are of particular interest: (1) the horizontal interface between work groups within an organization, (2) the vertical interface between authority levels, and, (3) the lateral interface between organizations. The three types can be considered similar in structure, with representatives from their respective groups interacting within the interface. Activity occurring within the interface is also influenced by the larger organization or environment in which it is embedded. It is important to remember that the interface can be viewed as a work subsystem in its own right, with its own boundary, internal dynamics and degree of structure [5].

Representatives that populate the interface serve to import and export information and technology that is required to solve problems and reduce ambiguities [15]. Sometimes referred to as a boundary spanner, a considerable amount of research has been conducted on the power [18, 19, 23], role stress [1, 13], job satisfaction [14, 15], and organizational impact [8, 19] of the representative occupying the interorganizational interface. Somewhat less attention has been given to the activities of boundary spanners within vertical and lateral intraorganizational interfaces, although many of the activities are the same.

Based upon the work of Miles, Brown and Schwab [7, 20], boundary-spanning activities may be classified into eight general categories as follows:

- Linking: Establishing and maintaining relationships with representatives of other key groups;
- Importing: Acquiring task-related information, technology and resources;
- Exporting: Distributing task-related information, technology and resources;
- Gatekeeping: Selectively communicating information gathered at the interface back to home decision makers;
- Representing: Selectively communicating information about the home group to other representatives for the purpose of shaping opinions, behaviors, and outcomes;

Protecting: Thwarting external pressures and influence attempts which might otherwise disrupt home group operations;
Scanning: Searching for and identifying emerging trends or events which might represent threats or opportunities for the home group;
Monitoring: Tracking environmental trends or events which have been identified as probable threats or opportunities for the home group.

Brown and Schwab's study [7] of twenty-four electronics firms showed that the frequency of the various boundary-spanning activities varies according to the representatives' functional areas. For example, engineering representatives tended to engage in more monitoring than manufacturing representatives. Furthermore, activity frequencies varied by subgroups within functional areas; section engineers engaged in significantly more linking activities and fewer scanning activities than did project engineers. These findings are congruent with those of other writers [5, 17] who contend that the division of labor inevitably fosters a variety of fundamental differences between work groups, including differences in goals, priorities, time horizons, formality of structure, and interpersonal orientations. These basic differences in behavior and perspectives are most readily recognized when they are juxtaposed as they are at the organizational interfaces.

FACTORS AFFECTING INTERFACE PRODUCTIVITY

Factors which influence productivity at interfaces are those which facilitate or impair the occurrence of necessary transactions. Often these factors are not readily detectable. Drawing on the concepts and research of previous authors [3, 4, 5, 6, 7, 9, 11, 12 ,22, 25], nine general factors can be identified which affect interface productivity. These are outlined in Table 1 and discussed below.

Essentiality: Within any given work system, subunits contribute in various degrees to the accomplishment of overall system objectives. Some work groups are more critical to the task at hand than others. This is a by-product of the subunits' relative centrality or position in the work flow. Furthermore, subunits within a given work system vary in degree of interdependence with one another. The extent to which a work group views another as essential to its task accomplishment influences activity at the interface [17]. For example, a representative of one unit may put considerably more time and energy into interface maintenance and activities than his counterpart within the same interface. Essentiality inevitably creates formal and informal subunit power differences which by themselves can provide a basis for potentially disabling interface dynamics.

Structure: The extent to which an interface is organized affects the degree of conflict within that interface and the representatives' ability to effectively conduct transactions [5]. The degree to which representatives allow information, resources and people to enter and leave the interface is one element of interface organization. A highly permeable interface, or one that is readily open to disruptive inputs or losses of critical resources, is said to be underorganized [5]. An impermeable or overorganized interface boundary is one that is relatively closed to important inputs or outputs of information/resources and one which rigidly maintains a fixed composition of people and data sources.

Other elements of interface structure are clarity of representatives' roles, clarity of authority, and effective procedures governing formal interactions. On the whole, a balanced, clearly defined, yet flexible structure offers the best support for interface activities [5].

Representatives: A person's effectiveness in the boundary-spanning role is related to the choice and frequency of activities which he pursues. Brown and Schwab [7] suggest that representatives should be coached in which activities to engage. Their work indicates that overall congruence between a representative's boundary-spanning activities, his job position, and interface essentially might be related to effectiveness. Certainly, neglect of critical boundary-spanning activities, such as scanning or importing, could adversely impact his home work group.

Context: Events within the interface are influenced by events in the immediate and larger environment. Management within the representative's work unit control formal and informal incentives which affect his interface activity. Representatives also frequently recruit allies from their home work groups and from powerful third parties in the larger environment [5].

History: Interactions within the interface are shaped by interface events which have occurred in the past. The relationship between two work groups may be relatively young or old, however expectations based upon past events are still carried forward by representatives. Interface behavior may be shaped by broad stereotypes and folklore circulated within the home groups or by specific events experienced by the representatives. Souder [22] describes situations of distrust which began as individual personality conflicts and later became institutionalized at the departmental level.

TABLE 1
Factors Affecting Interface Productivity

1. Essentiality
   - Work group centrality differences
   - Perceptions of mutual criticality
   - Formal and informal power differences
2. Structure
   - Boundary permeability
   - Definition of roles
   - Definition of authority
   - Effective rules and procedures
3. Representatives
   - Congruence between activities and job position
   - Congruence between activities and interface criticality
4. Context
   - Control of incentives
   - Activities of third parties
5. History
   - Specific events
   - Stereotypes and folklore

6. Communication
   . Task-related data
   . Interface maintenance data
   . Quality and flow of information
7. Norms
   . Behavior within the interface
   . Ability to self-examine
8. Resources
   . Delegation of authority to representatives
   . Strategic ideas
9. Goals
   . Definition of goals
   . Differences in priorities
   . Commitment to goals and priorities

Communication: The exchange of important information is a key function of the interface. Representatives must import and export information of two types: (1) data related to tasks at hand (e.g., task requirements, coordination, milestones, problems) and (2) data required for maintenance of an effective working relationship (e.g., information about the interface itself or the nature of the transactions within it). Information exchanged within interfaces can either contribute to or distort the mutual understanding of functioning, abilities and resources across parties [9]. The usefulness of such exchanges further depends upon the extent to which the representatives are connected to internal decision makers, representatives' selection of what information to transmit, and information timeliness.

Norms: Norms which regulate behavior between work groups act to support or inhibit interface productivity to varying degrees. For example, representatives who are able to openly discuss interface maintenance issues will more likely be able to adapt the interface to unexpected work contingencies. However, the ability to engage in self-examination is extremely difficult in an interface which is constrained by norms suppressing such discussion. Argyris [3,4] emphasizes the importance of being able to question the fundamental norms and assumptions which govern our work behavior, and he convincingly describes the negative outcomes that result from not developing that ability.

Resources: The extent to which work groups delegate appropriate authority to their representatives is important to representatives' actions. If a boundary spanner has insufficient power to make decisions of a tactical nature at the interface, then his ability to buffer internal decision makers will be compromised, and top management will be swamped with minor details [26]. Excessive representative authority takes management out of the decision loop and results in decisions being made without benefit of the larger picture. In addition, the home group is an excellent source of ideas concerning negotiating and influence strategies, as well as a sounding board for planned initiatives.

Goals: In order for work to proceed, specific and attainable subgoals are negotiated within the interface. The extent to which these subgoals are clearly defined and are congruent with one another is associated with the degree of conflict between representatives [5]. Since most interfaces manage multiple goals concurrently, significant differences in priorities assigned to mutual goals would likewise impact transactions. Finally, the extent to which goals and priorities are accepted by all parties influences the extent of commitment to those goals.

Many of the factors underlying interface productivity affect interfaces in overt, readily identifiable ways. However others, such as context and structure, act in a subtle manner upon elements and interactions. Although the actions and interaction of the factors themselves may not be readily apparent, their effects generally are more discernable. Determining the configuration and extent of these effects permits us to identify opportunities for improving interface productivity.

EVALUATION AND IMPROVEMENT TECHNIQUES

Although some underlying factors are more readily observable than others, one approach to evaluating interface productivity relies on estimating the underlying factors by assessing discernable effects. Some of these effects, symptomatic of productivity loss, are shown in Table 2.

TABLE 2
SYMPTOMS OF PRODUCTIVITY LOSS*

. Hostility
. Extreme stereotyping
. Severe information distortion
. Distrust
. Mutual avoidance
. Excessive competition or collaboration
. Bilateral self-serving manipulations
. Disruptive turnover of representatives
. Concurrent use of redundant interfaces
. Little cross-party involvement
. Poor mutual understanding of party functioning, abilities and resources
. Inflexible roles, rules and procedures
. Inability to discuss issues pertaining to the interface itself
. Task expectations not voiced
. Unclear roles or points-of-contact
. Reluctance to utilize other party expertise in project planning
. Overt and covert task sabotage
. Excessive agreemeent
. Avoidance of sensitive but relevant issues
. Appeasement
. Suppression of disagreement
. Decision by default or "rubber stamping"
. Chronic recurrence of problems once thought solved

* Based in part upon [2, 5, 6, 7, 8, 9, 22].

Techniques used to evaluate R&D productivity within work groups can be applied to interface assessment. This author agrees with others [21] who favor semi-quantitative measurement techniques (e.g., rating scales) over highly quantitative (e.g., ratio) or highly qualitative (e.g., antecdotal/ intuitive) approaches. Pappas and Remer [21] suggest using peer ratings in which R&D project personnel rate each other in terms of productivity.

Rather than enter the arena of individual performance appraisal however, ratings of the interface might incorporate the advantages of semi- quantitative data without the problems of peer ratings. Interface incumbents could complete a survey containing Likert-type scales, rating characteristics of the interface along relevant factors. This approach offers several advantages:

(1) It focusses incumbents' attention on a single subject of mutual interest: the interface;
(2) Ratings are of salient interface characteristics, rather than of each other, providing a superordinate goal instead of a source of tension;
(3) As a self-evaluation, the technique is mobilizing and motivating. All interface incumbents participate, and the data are "owned by the participants;
(4) Results provide an issue-oriented focus, around which constructive dialogue can occur;
(5) Estimates of interface functioning can be made periodically, providing participants with an opportunity to make comparisons;
(6) The method is easily embedded into a wide variety of improvement programs and approaches.

The basis for individual items might be the underlying factors influencing productivity, the ability to effectively conduct boundary-spanning activities, and/or the presence of positive and negative effects. Such an approach would indicate not only the overall health of the interface, but would also direct improvement efforts along specific lines. The Management Analysis Office at Johnson Space Center is currently considering utilizing a workshop format in which key interface managers would complete ratings of this sort as a method of promoting awareness and discussion of interface issues.

A sample of the types of changes that might be made to improve interface productivity are shown in Table 3. The particular interventions selected for use in any given situation depend, of course, upon the configuration of reported effects.

TABLE 3
SAMPLE OF POTENTIAL INTERVENTIONS*

1. Fractionate issues to reduce their size.
2. Increase believable communications between representatives.
3. Redefine mix of personnel and resources at the interface.
4. Clarify incentives for collaboration.

5. Generate credible information and discussion regarding the interface itself.
6. Recruit third parties to regulate amount of conflict.
7. Resolve non-controversial issues first.
8. Increase or decrease buffering.
9. Train personnel in interface factors and boundary-spanning activities.
10. Increase ambassadorship, cross-party visibility and involvement.
11. Systematize cross-party job rotation, transients or visitation.
12. Establish a decision authority charter.
13. Legitimize the interface to work group incumbents and third parties.
14. Improve communication channels between representatives and decision makers.
15. Conduct a mutual check of goal priorities.

* Based in part upon Brown [5,6] and Souder [22].

Since organizations and their interfaces are dynamic in nature, specific interventions must accomodate shifting factors and effects. What was appropriate last year may be inappropriate today. This emphasizes the importance of making specific changes within the structure of a flexible and on-going assessment/improvement process. Constructive changes made without the supporting framework of such a process are likely to be short-lived.

CONCLUSION

As the space program enters a new era of commercialization, competition, and global involvement, management will be required to commit increased levels of effort to interface productivity. It is time to incorporate interface issues into existing and planned productivity improvement programs and research. Although boundary-spanning activities have been central to much research [12, 14, 16, 18, 19], little attention has been given to factors impacting their effectiveness or to the relationship between interface functioning and productivity of the larger work group.

There are numerous approaches to productivity measurement and improvement, however managers are in need of tools and processes which meet significant constraints on their time, manpower and funds. Specifically, needed are tools and processes which: (1) minimize disruption of work group operations, (2) maximize "user-friendly" techniques (e.g., checklists), (3) maximize participant ownership, (4) maximize organizational self-evaluation and self-improvement, (5) focus only upon issues relevant to and under the control of the participating organization, and (6) are capable of self-perpetuation.

Interface performance is only one element to consider when examining the productivity of a work system. However, in an effort as heterogenous and interdependent as space work, its inclusion is essential.

Albert W. Holland, Ph.D. is a Visiting Scientist at the NASA Johnson Space Center under the auspices of Universities Space Research Association. A licensed industrial/organizational psychologist, Dr. Holland is presently working on a variety of projects and applied research in support of ground-based and space station productivity.

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PROGRAM MANAGEMENT TOOLS AND TECHNIQUES

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EFFICIENCY AND INNOVATION: STEPS TOWARD COLLABORATIVE INTERACTIONS

Cynthia A. Lengnick-Hall, Purdue University
Donald C. King, Purdue University

ABSTRACT

Research and development units are faced with the challenging objective of being cost effective while developing high quality, innovative products. Advanced technology is only part of the solution. It is increasingly clear that organization structures and managerial processes must also be designed and structured to meet the dual objectives of quality and efficiency. This paper presents the results of an empirical case analysis of a large R & D division which is attempting to meet this challenge.

INTRODUCTION

Many firms in both the public and the private sectors of the economy view the process of generating and implementing creative designs and product advances as critical to their success. Competitive challenges for the internal resources of the firm and in the larger external marketplace have put pressure on research and development units to be simultaneously creative and cost effective. Since the innovation process has traditionally been viewed as costly and inefficient, the dual demands of creativity and efficiency have not been easily met.

In other functional areas such as manufacturing and distribution, automation has been a significant tool for reducing the costs of operation. However, until recently automation implied reduced flexibility, loss of creative capacity, and high overhead making it incompatible with the R&D environment. The assumptions which were inherent in the early developments in automation, are quite similar to the assumptions which guide <u>mass</u> production. Assembly lines, numerically controlled machines, and machines in which the hardware is programmed are based on the same concepts of standardization, specialization, routinization and simplification which form the basis of efficient and effective mass production operations. Research, development, and batch production, in contrast, require a substantially more sophisticated technology. Machines which are, at minimum, programmable, and more often contain sensing and self-programming features are needed to effectively automate development and small batch operations.

The use of computer-assistend design and manufacturing systems for research and development activities and for small batch production, has been offered as a potential solution to the difficult problem of generating creative designs while maintaining a bottom line. Computer-assisted design and manufacturing techniques and computer-assited communication systems help to reconcile the need for flexibility with a concern for efficient operations. However the design of state-of-the-art technical systems is not sufficient, by itself, to lower costs and simultaneously enhance innovation. Problems in the effective use of advanced technology more often stem from poor implementation or from managerial uncertainty regarding how to capitalize on the flexibility provided than from technical design deficiencies. In fact, a number of research studies (e.g., 5, 3, 8) indicate that non-technical organizational factors were the crucial barriers to effective and efficient innovation. Thus, the design of a state-of-the-art research and development effort must include the design of appropriate organization structures and processes.

While the notion that organization structures and processes are important factors in achieving organization effectiveness is not new, this concept has often been overhsadowed by technological features in the research and development environment. This paper assumes that advanced technology is available and focuses instead on the work environment and organizational processes which facilitate or inhibit the attainment of research and development objectives.

TWO IMPORTANT CONTINGENCIES

After many decades of research, it is generally conceded that there is no one best way to organize. It is also agreed that not all ways of organizing are equally effective. If an organization is to marshall its resources effectively and efficiently to achieve some desired objective, the way in which the firm is designed should be compatible with the goals which are to be achieved and with the situational factors which provide the context for organizational activity (1, 4, 6). Thus, organizational goals and contextual factors are two important contingencies which influence what types of organization structures and processes are likely to be most effective in a given situation.

Organizational Goals

Organizational goals serve a number of different purposes. Goals establish a direction for activities or describe a future state which the firm is attempting to realize. Goals help to legitimize the existence of a firm or unit, and goals provide a standard for evaluation. Research and development units, like most other parts of an organization have many types of goals. However, because of the nature of the research and development unit's contribution to the activities of the organization as a whole, two types of objectives are of particular importance: (1) providing for high quality research applications, and (2) product design efficiency and effectiveness.

In this research study high quality application was measured by items such as improved engineering standards, improved service standards, improved manufacturing standards and decreased cost of design changes. These items appear crucial to developing a product which is distinguished in the marketplace by exceptional quality and by responsiveness to customer needs. Such factors permit a firm to adopt a competitive strategy of product differentiation based on quality. These factors also affect how well the research and development unit is integrated with other functional units in the organization. Application quality is one indicator of the innovative capacity of the R&D unit.

The second type of goal, design efficiency and effectiveness, was measured in this study by items relating to increased efficiency in document production (this was one of the primary outputs of the R&D department), increased efficiency in design, increased effectiveness in design, and increased efficiency in developing product definition documents. These items are linked with costs. The more efficiently a research and development unit is able to design and document various products the fewer resources it will require to achieve a given magnitude of performance, or the greater its performance will be with a given level of resources. These factors permit a firm to adopt a cost leadership strategy.

These two goals, (application quality and efficient, effective design) comprise one type of contingency considered in this study of designing structures and processes for a research and development operation.

Contextual Factors

In a research and development environment, one of the most important contextual factors is the extent to which the task to be done is understood, familiar, routine, and otherwise analyzable (2, 7, 8). Issues which indicate a high degree of analyzability or familiarity include: job monotony, lack of basic interest in the work, the belief that the longer an employee holds a job the more boring it becomes, a job situation where change is minimal, and the employee has more than adequate training and skills. Issues which suggest a low degree of analyzability/familiarity include the feeling of challenge a job provides to what the employee thinks he or she can do, belief that the job may be frustrating but it is never dull, and indications that something new happens on the job every day.

On an absolute scale, a research and development environment is considered largely nonroutine, having many exceptions, surpirses, and situations which are difficult to analyze. Studies suggest that over ninety percent of the work in an R&D environment involves nonroutine technology and activities. Yet, on a relative scale, some of the tasks are clearly more easily understood and performed than others. Therefore, this contingency remains important despite the overall "uncertain" nature of research and development activities.

A measure of the extent to which the work environment and subsequent tasks are seen to be familiar and analyzable is the second contingency considered in this study.

METHODOLOGY

The study is based on an empirical and case-based research effort undertaken at a large-scale research and development division of a major midwestern company. Managers, support technicians, engineers, and administrative employees in the research and development division were given a version of the Michigan Organization Assessment Questionnaire (MOAQ) which had been modified to fit the conditions of the organization. The sample size of 274 represents slightly over 50 percent of the relevant employees. Organization culture dictated that participation in the study be voluntary. As a result, the sample has disproportionately high representation from nonunion employees such as managers, technicians and engineers. However, data analysis shows no significant difference in responses between union and nonunion employees.

In addition to the questionnaire a content analysis of formal organizational documents provided diagnostic information regarding goals, structure, organization performance and organization culture. Fifteen interviews with key decision-makers and multiple observations of the unit in operation over a period of a year and one half provide the context for the empirical analysis.

The research and development division being studies has changed from a top-down, functional structure to a workgroup centered structure. Twentythree workgroups are identified within the division. Each workgroup has a unique set of goals, tasks, evaluation criteria, time-frames for deliverables, and relationships with other parts of the division and other parts of the company. Each workgroup contains a mixture of skills and hierarchical levels. This structure permits comparison among units having different work environments and workflow processes and facing different task contingencies.

Based on composite responses to items related to familiarity and analyzability, the workgroups were split into two categories: those which faced conditions of comparatively high familiarity and analyzability and those which faced conditions of comparatively low familiarity and analyzability. Eleven workgroups were classified as operating under conditions of lower familiarity/analyzability. Twelve workgroups were classified as operating under conditions of higher familiarity/analyzability. As mentioned previously, the scores reflect relative rather than absolute scales of these items.

Every workgroup was to some extent responsible for achieving goals related to both quality applications and efficient, effective designs. Employee's aggregate perceptions of the extent to which goals are being achieved were the performance measures used in the study. A two-by-two correlational analysis enabled investigation of those structural and organizational process characteristics which facilitated or inhibited goal achievement under each of the two contextual conditions.

Five categories of organization structure and process variables were investigated: (1) supervisor characteristics, (2) workgroup characteristics, (3) employee attitudes and feelings, (4) job/task characteristics, and (5) information processing emphasis. Each of these factors

FIGURE 4 Correlates of Employee Attitudes With Quality and Efficiency Goals Under Conditions of High and Low Familiarity/Analyzability

TYPE OF GOAL	FAMILIARITY/ANALYZABILITY: LOW	FAMILIARITY/ANALYZABILITY: HIGH
QUALITY APPLICATIONS	**INSPIRE** POSITIVE FACTOR Challenge (56*) NEGATIVE FACTOR Desire to Change Jobs (-67*)	**SUPPORT** POSITIVE FACTORS Job satisfaction (81***) Org involvement (59*) Responsibility (56*) Control (76*) NEGATIVE FACTOR Turnover intent (-75***)
EFFICIENT EFFECTIVE DESIGN	**MANAGE** POSITIVE FACTOR Committment (.70***)	**LASSEZ FAIRE** POSITIVE FACTORS Desire to change jobs (58*) Turnover intent (.60*) NEGATIVE FACTORS Org involvement (-61*) Responsibility (-59) Control (-67**)

* p=05, ** p=01, *** p=005 N = 23

Conditions of high familiarity and/or analyzability suggest a different attitude pattern. It may be that the greatest design efficiency is achieved by moderately discontented employees. Design industries are frequently characterized by employee mobility. Further, it is recognized that movement is dependent on recent performance; an employee is only considered as good as his or her last design in many cases. Perhaps this interest in change and knowledge of the performance prerequisites foster desirable engineering and design activities or perhaps such employees are more willing to take more unconventional approaches to design. High performance with regard to quality applications appears to be fostered by a more contented attitude. Job satisfaction, feelings of responsibility and involvement, a more centralized, directive structure, and an interest in remaining in the current position contribute to high quality applications under familiar/analyzable conditions.

Three of the four contingent conditions show a positive response to task characteristics generally associated with "enriched" jobs (see Figure 5). Only an effort to achieve efficient designs under high analyzability seems to be positively influenced by a more focused and more loosely coupled job-task characterization. Variety and feedback seem to be the most important factors overall. Quality applications appear to be aided by an interconnectedness with other units in the organization. This seems to complement the feelings of organization involvement which make a similar contribution. The positive effects of interdependent may also indicate greater knowledge of the interests and fundtions or diverse operations within the firms. This knowledge increases the implementation feasibility of many research and development efforts.

analyzable (see Figure 3). Again the direction of influence is reversed for the two types of goals. Fragmentation and heterogeneity

FIGURE 3 Correlates of Group Characteristics With Quality and Efficiency Goals Under Conditions of High and Low Familiarity/Analyzability

FAMILIARITY/ANALYZABILITY

TYPE OF GOAL	LOW	HIGH
QUALITY APPLICATIONS	**INSPIRE** None Evident	**SUPPORT** POSITIVE FACTORS Fragmentation (76***) Heterogeneity (76***) NEGATIVE FACTOR Open processes (-72***)
EFFICIENT EFFECTIVE DESIGN	**MANAGE** NEGATIVE FACTOR Fragmentation (-58*)	**LASSEZ FAIRE** POSITIVE FACTOR Open processes (83***) NEGATIVE FACTORS Fragmentation (-64*) Heterogeneity (-72***)

* p=.05, ** p=.01, *** p=.005 N = 23

have strong positive effects on quality goals and strong negative effects for design efficiency. Open communication among group members has a negative effect on quality applications yet a positive effect on design efficiency. This pattern suggests that work segmentation and some degree of specialization may be appropriate for achieving quality applications, but that shared values and group cohesiveness are important conditions for achieving efficient designs.

An interesting pattern is evident when employee attitudes are correlated with strong performance under the four contingent situations considered in this study (see Figure 4). If employees feel challenged by their jobs and if they have no desire to change jobs, quality applications are achieved under conditions of low familiarity/analyzability. An overall feeling of commitment (to the organization and to the job) has the strongest influence on design achievements under conditions of low certainty. This suggests that in both cases internal motivation has a strong effect on performance. Further, it appears that application goals require more of a job focus, while design goals respond to a more general organization orientation.

A supervisor's behavior and managerial style appear to have the strongest positive effect when promoting quality applications under conditions of high familiarity and analyzability (see Figure 2). Under this set of contingencies, supervisor's who actively encourage employee participation in decision-making, who facilitate subordinate interactions, goal setting and problem solving, who are aware of work progress and activities and who treat subordinates as respected individuals positively contribute to achieving quality applications. In contrast, these same behaviors have a strong negative effect if analyzability remains high but the goal is to develop efficient designs. It appears that under this latter contingency set, active, facilitative supervisors tend to inhibit performance. If familiarity/analyzability is low, however, some of the active supervisor characteristics (such as facilitating decentralized control) appear to have a positive effect of efficient design performance. Supervisor behavior did not appear to have any influence on the development of quality applications when familiarity/analyzability is low.

FIGURE 2 Correlates of Various Supervisor Characteristics With Quality and Efficiency Goals Under Conditions of High and Low Familiarity/Analyzability

TYPE OF GOAL	FAMILIARITY/ANALYZABILITY: LOW	FAMILIARITY/ANALYZABILITY: HIGH
QUALITY APPLICATIONS	**INSPIRE** None Evident	**SUPPORT** POSITIVE FACTORS Participation (.58*) Control of work (.80***) Facilitative relations (.52*) Goal setting (.81***) Problem solving (.69**) Consideration (.50*)
EFFICIENT EFFECTIVE DESIGN	**MANAGE** POSITIVE FACTORS Facilitative relations (.53*) Goal setting (.76***) Consideration (.61*)	**LASSEZ FAIRE** NEGATIVE FACTORS Participation (-.66**) Control of work (-.75***) Facilitative relations (-.60*) Goal setting (-.58*) Problem solving (-.80***) Consideration (-.56*)

* p = .05; ** p = .01, *** p = .005   N = 23

These findings support the argument that the most effective supervisors may be those who are both versatile and somewhat inconsistent, effectively matching their behavior and direct involvement in the workflow to each situation. These findings suggest that training supervisors to expand their repertoire of skills might be particularly useful when the task environment is fairly familiar and analyzable, but that this type of investment would not have a strong effect on performance when the job is performed under conditions of extremely low analyzability.

Similarly, the characteristics of the immediate work group have the strongest effect when the situation is relatively familiar and was considered for quality application and for efficient, effective design goals under conditions or high or low familiarity/analyzability.

RESULTS AND DISCUSSION

Results of this study suggest an interesting pattern of relationships. Under conditions of high familiarity/analyzability, quality application goals appear to be fostered by an actively supportive and nuturing work environment. In contrast, efficient design under conditions of high familiarity/analyzability, appears to thrive under a more lassez faire work environment. Such a lassez faire approach may aid performance by removing bureaucratic impediments to performance.

Looking at conditions of low familiarity and analyzability, efficient, effective design appears to be facilitated by an actively-managed work environment, while quality applications appear to rely on inspiration and motivation. Figure 1 depicts the general work environment characteristics and organization processes which facilitate and inhibit quality applications and efficient designs.

FIGURE 1 Patterns of Organization Structure and Processes Which Aid Goal Attainment Under Conditions of High and Low Familiarity/Analyzability

TYPE OF GOAL	FA[illegible]RITY/ANALYZABILITY: LOW	FA[illegible]RITY/ANALYZABILITY: HIGH
QUALITY APPLICATIONS	**INSPIRE** ENCOURAGE challenge learning DISCOURAGE desire to leave	**SUPPORT** ENCOURAGE creative discontent involvement supervisor interaction DISCOURAGE desire to leave complex decision structure
EFFICIENT EFFECTIVE DESIGN	**MANAGE** ENCOURAGE subordinate interaction commitment job enrichment DISCOURAGE conflict over-analysis	**LASSEZ FAIRE** ENCOURAGE open discussion desire for mobility DISCOURAGE control/structure variety

FIGURE 5. Correlates of Job-Task Characteristics With Quality and Efficiency Goals Under Conditions of High and Low Familiarity/Analyzability

FAMILIARITY/ANALYZABILITY

TYPE OF GOAL	LOW	HIGH
QUALITY APPLICATIONS	**INSPIRE** POSITIVE FACTOR Variety (.69**)	**SUPPORT** POSITIVE FACTORS Variety (52*) Feedback (51*) Training (68**) External interdep (59*) Internal interdep (64*)
EFFICIENT EFFECTIVE DESIGN	**MANAGE** POSITIVE FACTORS Variety (62*) Feedback (.58*) NEGATIVE FACTOR Know results (- 57*)	**LASSEZ FAIRE** NEGATIVE FACTORS Variety (- 71***) Task importance (- 79***) External interdep (- 59*)

* p= 05, ** p= 01, *** p=.005 N = 23

With respect to information processing, achieving efficient designs appears linked with insuring that two undesirable conditions do not occur. First, the manner in which information processing takes place should not be dictated. This suggests that under conditions of high analyzability, information processing activities should flow from the specific tasks at hand rather than from some predetermined approach to information analysis. Under conditions of low familiarity, the greatest danger seems to come from premature analysis. Correspondingly, a second condition to be avoided is having routine information and information processing use such a large proportion of time or resources that none is left for non-routine, explorative, inventive approaches. Quality applications appear facilitated by insuring that adequate information is shared and available and that prior decisions and solutions are recorded. These results are presented in Figure 6. The composite pattern suggests that efficient designs are most likely to be inhibited by information overload, while quality applications are most vulnerable to omissions in information.

CONCLUSION

The correlational patterns which emerged from this study suggest two important considerations for the structure and design of research and development units. First, it is clear that a decision needs to be made whether to separate or to integrate the two primary types of goals most often present in these units. If the choice is made to separate these activities, then diverse organization structures must co-exist in the same unit, and must frequently interact to achieve organizational goals. Separation will likely increase the need for information sharing and for conflict management, since developing quality applications and

FIGURE 6 Correlates of Information Processing Emphasis With Quality and Efficiency Goals Under Conditions of High and Low Familiarity/Analyzability

FAMILIARITY/ANALYZABILITY

TYPE OF GOAL	LOW	HIGH
QUALITY APPLICATIONS	**INSPIRE** POSITIVE FACTOR Instruction (53*)	**SUPPORT** POSITIVE FACTORS Instruction (57*) Routine info exch (54*) Nonroutine info exc (86***) Compiling info (.59*) Documentation (63*)
EFFICIENT EFFECTIVE DESIGN	**MANAGE** POSITIVE FACTORS Negotiation (53*) Interviewing (54*) NEGATIVE FACTOR Analysis (-56*)	**LASSEZ FAIRE** NEGATIVE FACTORS Advising (-62*) Instruction (-61*) Routine info exc (-71***) Nonroutine info exc (-64*) Combining info (-65*) Compiling info (-81***)

* p= 05, ** p= 01, *** p= 005   N = 23

efficient designs cannot and should not be self-contained activities. If the choice is made to integrate two types of goals within a set of job or workgroup activities the stress of reconciling diverse objectives becomes an individual rather than an organizational problem. Thus if integration is the choice, supervisors, workgroups and individuals require training and experience in stress management. Further, they need to develop many different sets of skills and operating styles as well as the ability to choose an approach to fit a given situation.

A second issue also emerged. Researchers and practitioners appear to know much more about how to structure and manage circumstances which have some degree of familiarity and analyzability. Despite the range restriction inherent in looking solely at an R&D environment, strong differences were found between lower and higher degrees of familiarity and analyzability. An important issue to be resolved, therefore, is whether performance under highly uncertain and unfamiliar circumstances is almost exclusively a result of individual talents and capabilities or whether traditional measures and indices of organizational structure and process are just not the appropriate factors to consider. If the former explanation is true, selection rather than training or organization design must be the dominant human resources issue for many research and development operations. If, however, the latter explanation is true, there is a need for designing creative and unconventional organization structures and measures to accomodate the unique environment of the research and development unit.

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GAMMA RAY OBSERVATORY PRODUCTIVITY SHOWCASE

Richard L. Davis, TRW
Donald A. Molgaard, TRW

ABSTRACT

The Gamma Ray Observatory (GRO) Program has been proclaimed to be the showcase productivity program for NASA and TRW. Among the multiple disciplines of a large-scale program, there is opportunity and need for improved efficiency, effectiveness, and reduction in the cost of doing business. This paper describes the efforts and tools that will or have been implemented to achieve this end.

Since the GRO Program is mainly an engineering program with the build of one satellite, the primary emphasis is placed on improving the efficiency and quality of management and engineering.

Top management of TRW, NASA/Headquarters and GSFC are totally committed and firmly endorse productivity for the GRO Program as shown by their willingness to implement potential cost saving tools and replacing older operating procedures with new ones that take advantage of today's technologies for more efficient performance.

During the initial part of the Gamma Ray Observatory (GRO) Phase D contract, the project designed and developed a high-fidelity full-scale model (FSM) of the GRO. In addition to its use as a design, fit check, and personnel handling and training aide, the principle design objective for the FSM was to evaluate (prior to the Critical Design Review) the current design in terms of its suitability for performing both planned and contingency extravehicular activity (EVA) operations in the deployment, repair/refueling, and retrieval missions of the GRO. Typically, spacecraft development programs have not performed this type of EVA design evaluation tests at such an early stage of program development. Normally the EVA evaluation exercises are performed as part of the astronaut crew training operations 3 to 9 months prior to launch. A program could incur significant cost/schedule impact from design deficiencies identified this late in the program. By addressing the EVA design compatibility early in the program, the GRO project was able to accommodate proposed changes with minimal cost and no schedule impact.

TRW is building the GRO platform to carry four large instruments to conduct a full sky survey and study selected objects of interest in the gamma ray region of the electromagnetic spectra. The Observatory is 25 feet long, 15 feet wide and 12 feet high weighing over 34,000 pounds. The solar arrays span 70 feet. Figure 1 shows the GRO configuration.

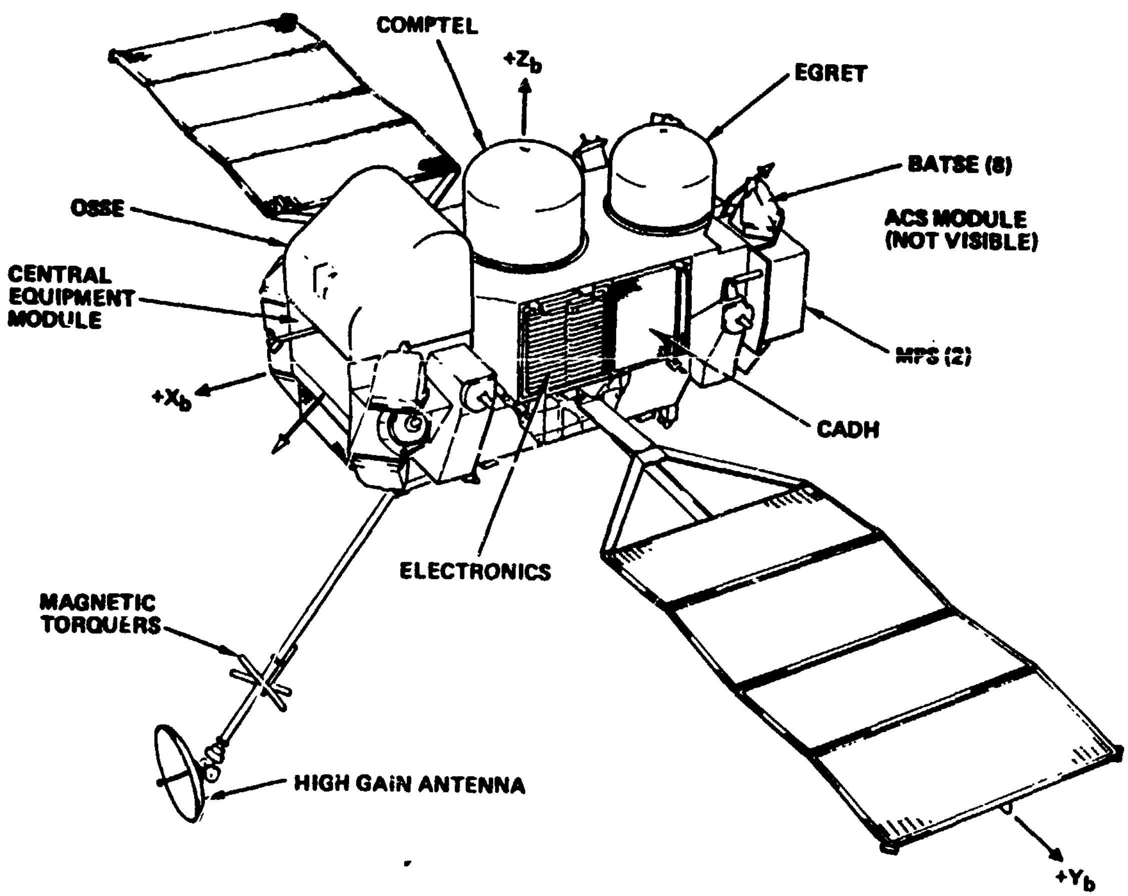

Figure 1. Gamma Ray Observatory

The GRO will be launched by the Space Shuttle and placed in a low Earth's orbit for a minimum of 2 years when it will either be retrieved or refueled by the Shuttle.

PRODUCTIVITY IMPLEMENTATION

Within TRW, productivity is an integral part of the organization and operation. The GRO Program has a Productivity Manager who reports directly to the Program Manager. He is also a member of the Federal Systems Division Productivity Council which reports to the Division Vice President. This Council reports to the Space and Technology Group Productivity Council. Through this network the productivity actions of all the groups are coordinated to ensure that the maximum benefit is passed on to all organizations.

Initial Actions

At the beginning of the program, a one day brainstorm session was held with program management to develop productivity ideas. From this session macro goals were established. These were presented to the NASA Productivity Steering Committee on 13 July 1983 along with a commitment for implementation within one year.

Simplified Performance Measurement System

In order to determine the status of a Work Breakdown Structure (WBS) element, work package and/or task, the manager must wade through a large computer printout which is not only time consuming but often does not get done properly due to the magnitude of the task. A simplified automated method was required to ensure quick and accurate assessment of the program status.

The Air Force developed such a method for the MX program which was called Red Flag. The PMS data is inputted into PCs and the output displays are then available for any level of the WBS. These outputs are color coded as a function of variance levels for easy identification of problem areas. The trend from the corrective action can be taken immediately. Displays are available for cost and schedule variances, variance at completion, manpower plots, performance factors, etc.

Automated Critical Path Schedule Network

Several years ago Pert was the preferred method of tracking a program schedule status. However due to the many hours required to manually draw the network(s) and status the critical path, Pert was dropped in favor of Gantt charts which could be easily drawn and even automated. But Gantt charts did not provide all the necessary information. Today several automated Pert programs are available. TRW is utilizing the Project 2 Scheduling System. This is a totally automated network schedule system coded to provide traceability to the lowest level planning milestone in the PMS. It is to be updated monthly. It features critical path networks, logical related bar charts, subnets with multiple work calendars, interactive graphics and has a "what if" analysis capability.

Improved Communications

TRW must interface with GSFC, NASA Headquarters, four major instrument teams, McDonnell Douglas (MTS), Fairchild (CADH) and four major subcontractors all of which are located away from TRW. TRW and GSFC are located 2500 miles from each other. An improved method of communication was required to increase efficiency, effectiveness and motivation while decreasing the cost of doing business.

Two method have been incorporated to achieve this goal, a computerized network system and video teleconferencing.

Computerized Network System

TRW and GSFC jointly analyzed and selected the most cos effective personal computer system for improving not only communications but also to improve office efficiency. The DEC Rainbow 100 was selected as offering the most capability, highest speed and best operation at the lowest cost. 21 work stations have been installed at TRW and 11 at GSFC. These stations have either letter-quality or matrix printers and high speed modems for inter-computer communications.

The initial software packages procured were word processing (Wordstar), electronic spread sheets (Multiplan and Lotus 1-2-3), data base management (Dbase II) and communications (Mite). One cost effective use was the development of computer generated graphic presentations which is used for all design and management reviews.

Training classes have been held on the use of the computer and each of the software packages. These classes will continue to train new personnel and teach the operation of new software packages as they are acquired.

Video Teleconferencing

A normal meeting time span is approximately 2 hours involving 5 to 10 people. When travel is required to attend a meeting 2 to 3 days are spent away from the office. Full-frame video teleconferencing for technical and program meetings can reduce the travel expenses and time away from the office thus improving program efficiency.

Several test meetings have been conducted using rented facilities in Los Angeles and Washington D.C. The success of these meetings convinced both TRW and NASA to install video teleconferencing facilities at both locations.

Maximize Technology Transfer and Lessons Learned

GRO is maximizing the technology transfer and lessons learned not only among TRW programs but also amoung other NASA programs. TRW is a matrix organization where except for some of the project management the majority of people are supplied by functional groups. These functional groups support not only NASA programs but also defense and commercial programs. As a result the technical achievements on these programs can and will be used during the GRO development, manufacturing, assembly and test phases.

The NASA personnel will supply technical guidance learned from other programs as well as supplying safety, reliability and design alerts. The NASA design review team is composed of members who have experience on many programs to ensure that past mistakes are not repeated.

Improved Procurement Cycle

A reduction in paperwork and rapid responses turnaround time will greatly enhance productivity between GSFC and TRW and between TRW and our subcontractors. Three procedures have been or will be implemented to achieve the NASA goal.

The NASA 533 have been automated reports using the company PMS and converting to the NASA format. A productivity incentive clause has been implemented which will allow TRW to obtaina higher fee based on ideas for measurable cost savings. For every major cost saving generated and approved by NASA, TRW will retain 20 percent. If the program is overrun at launch, 50 percent must be returned. If there is an on-orbit failure that was caused by TRW, 50 percent must be returned. A portion of this will be distributed to the GRO employees.

The TRW GRO Program has prepared a subcontractor communications plan which flows down the program requirements, including lessons learned, and utilizes TRW's computerized network. Each subcontract contains the product assurance requirements which include previous TRW spacecraft programs lessons learned. GRO subcontracts is providing these lessons to subcontractors in request for proposals to facilitate their learning and reduce costs. The GRO Program Office will perform design reviews and materials and process audits to assist subcontractors in applying lessons learned. TRW will implement utilization of personal computers and freeze-frame video conferencing for selected subcontractors. When fully implemented, these productivity improvements will reduce the time and cost of manually prepared cost and schedule reports, personnel travel expense, and cost of message transmission.

TRW did hold a subcontractor productivity seminar on 12 and 13 January 1984. 13 potential subcontractors were invited and 10 accepted and participated in the meeting. 43 productivity ideas were generated and are being evaluated for implementation.

Individual Award System

Improving productivity and enhancing personal motivation requires an individual recognition/reward program which has been implemented. Recognition is achieved through two ways. The first is the GRO Briefs, the monthly program newsletter, which recognizes achievements of individuals who have contributed in a productive manner. The second is letters of recognition which are issued by GSFC, GRO Program Office, and/or Federal Systems Division Manager for individuals who have performed outstanding accomplishments.

Individual rewards are achieved through three ways. The first is that any individuals contributing to a program cost savings of more than $500,000 will receive a GRO model at an all-hands meeting. The second is each award fee period (every 4 months), individuals, SFM or below, who the Program/GSFC feel contributed the most to the program will receive a GRO model at an all-hands meeting. The third is during the year, TRW will continue its policy of rewarding a monitary bonus to individuals whose accomplishments warrent special attention.

Quality Circle

A Quality Circle has been formed within the GRO Project. It is headed up by the SPM for Thermal Design and meets once a week. Typically they look at the day-to-day operations to see if and where improvements can be made. Several positive ideas have been developed to date. Additional circles are envisioned as the labor mix changes in later program phases.

FULL SCALE MOCK-UP

In close coordination with NASA/Johnson Space Center (JSC) personnel, a series of GRO EVA design evaluation tests were scheduled and performed in the NASA/JSC Weightless Environment Training Facility (WETF) using the GRO FSM during the period from 13 February to 5 April 1985. Secondary objectives of these GRO FSM WETF test operations were to:

- Identify the need, if any, for special hardware bumper/shock protection on critical GRO components within the planned EVA work or translation routes.

- Validate the compatibility of the integral GRO berthing adapter with the GSFC FSS-developed A prime cradle scheduled for use on any GRO repair or refueling mission.

- Verify that all identified planned and contingency EVA operations can be performed using existing standard EVA tools and equipment.

- Familiarize the JSC flight crew personnel with GRO EVA operations to allow conceptual formulation of EVA scenarios. These scenarios could be reviewed and fine-tuned prior to the formal GRO EVA crew training operations scheduled in 1987, approximately 7 months before launch.

FSM Design and Fabrication

The GRO FSM was designed to be compatible with the water immersion environment of the JSC WETF. All materials and coatings used have proven tolerance to prolonged exposure to the chemically treated water in the WETF. No wood or wood products were used in the FSM. Primary structural elements were made of aluminum, with the secondary structures, experiments, and components made of Lexan. The FSM was fabricated by a vendor outside TRW from engineering drawings and pre-release flight drawings available at the time of PDR. The FSM was returned to the vendor for upgrade to the CDR configuration prior to the JSC WETF tests. The FSM was shipped partially disassembled from TRW in Los Angeles to the JSC WETF by commercial air-ride double-drop trailer operating with a wide load permit.

Crew-Supported Testing

The GRO FSM was reassembled at JSC and transported to the WETF on 25 February 1985. An initial series of pretest EVA evaluation exercises were performed by support personnel in scuba gear. The GRO FSM was subjected to five separate astronaut crew runs. These tests and the participants are identified in Table-1. The configuration of the GRO in the WETF for these tests is shown in Figure 2.

GRO/FSM EVA WETF Operations

As shown in Table 1, the individual tests were performed to support specific objectives for the deployment/retrieval and the repair/refueling missions. Because of the large size of the GRO and the relatively shallow depth of the WETF, a portion of the GRO protruded above the surface of the water. In most instances, however, this did not compromise or invalidate the test.

Deployment/Retrieval Mission EVA Simulation

The solar array and high-gain antenna appendage deployment mechanisms (Figure 2) on the GRO are designed for automatic motor-driven deployment initiated by ground command from the GRO/POCC after the GRO is out of the cargo bay but prior to release by the RMS. Should any of the latch actuators or drive mechanisms fail to operate normally, each appendage mechanism is equipped with a back-up, EVA-operated mechanical override capability that allows the suited astronaut in EVA to deploy the appendate using the standard EVA ratchet wrench in the orbiter tool inventory. In the unlikely event that the astronaut is unable to complete the EVA override appendage deployment operation, the design will allow the astronaut to restow and relatch the appendage prior to GRO return to the cargo bay for troubleshooting or return to earth. If the appendage mechanism has failed in a partially deployed condition and cannot be deployed or restowed, the appendage can be jettisoned by EVA action.

These EVA appendage operations were evaluated in two series of tests with different astronaut subjects. Based on comments received during the test and at the post-test critique, a recommendation was made to incorporate additional handrails and foot-restraint sockets to improve EVA accessibility at the various work stations. In addition, a recommendation was received to reclock the three solar-array jettison bolts for improved EVA tool accessibility. These

Table 1. GRO EVA Design Evaluation Astronaut Suited Runs

Date	Crew Participants	Activity	Mission Application
March 05, 1985	Dr. K.D. Sullivan Cptn. M.C. Lee	Solar array deploy, restow, jettison ORU module HGA deploy, restow, and jettison	Deploy/Retrieval
March 06, 1985	Dr. G.D. Nelson Lt. Cdr. D.C. Leestma	Repeat of March 5 test	Deploy/Retrieval
March 18, 1985	Dr. K.D. Sullivan Cptn. M.C. Lee	CADH and MPS ORU changeout FSS/GRO translation route Evaluation of added handrails	Repair
March 19, 1985	Dr. G.D. Nelson Lt. Cdr. D.C. Leestma	Repeat of March 18 test	Repair
April 03, 1985	Dr. G.D. Nelson	CADH and MPS ORU translation routes with deployed solar array On-orbit refueling coupling accessibility	Repair/Refueling

GRO FSM in WETF

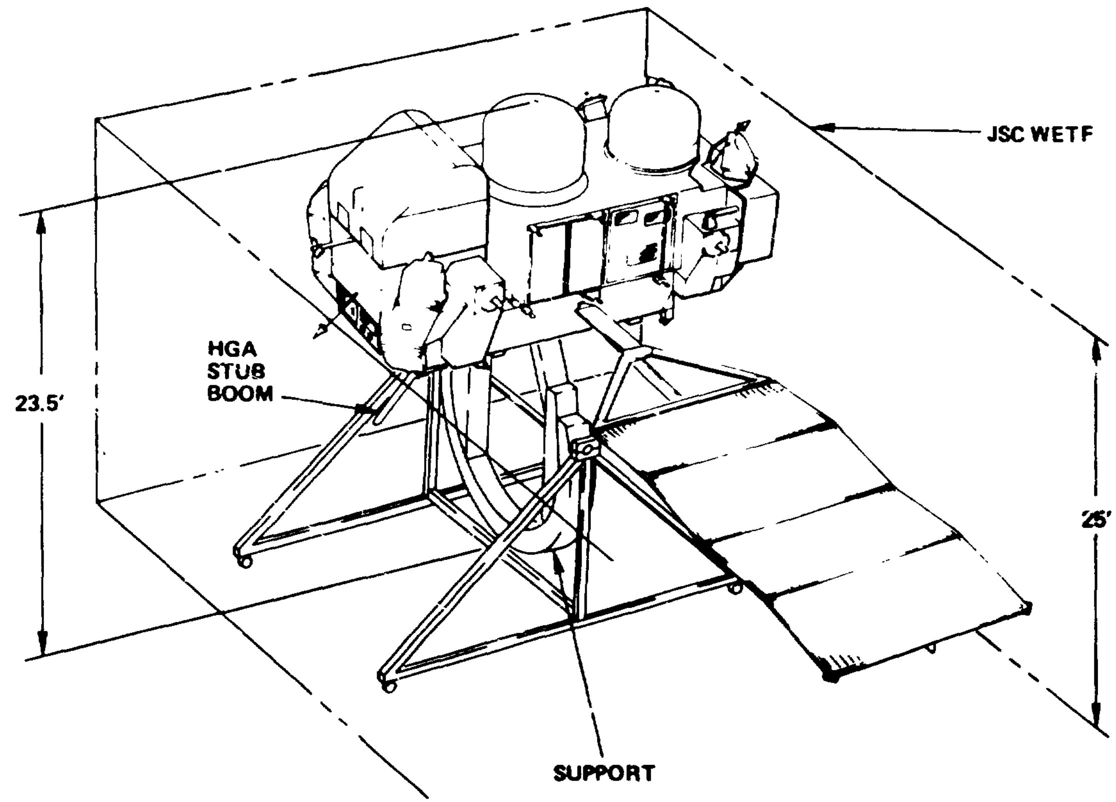

Figure 2. GRO FSM in WETF

recommendations were incorporated into the GRO FSM and were evaluated as part of the subsequent tests on March 18 and 19, 1985. The additions and modifications were approved by the test crew personnel. These modifications have been incorporated into the flight design.

Repair/Refueling Mission EVA Simulations

The GRO design incorporates three electronic subsystem modules that are capable of being removed and replaced on orbit by EVA. These Multi-mission Spacecraft (MMS) standard modules developed by NASA/GSFC are flight qualified and currently in use on the Solar Max and Landsat missions. The two GRO MMS power modules and the MMS communication and data handling module is identical in physical form and fit to the MMS module that was successfully replaced on the recent Solar Max Repair Mission.

The EVA simulations established EVA translation routes for handling of the large modules with a minimum of transfer and hand-off operations. Recommendations were received and incorporated for adding additional handrails on GRO.

The GRO is the first U.S. spacecraft to incorporate an on-orbit refueling capability. The on-orbit refueling coupler is being developed for JSC by Fairchild Controls. A mock-up of this coupling was provided for EVA evaluation with the GRO FSM. Several recommendations on handle placement and the ramping of the latch mechanism were made during the EVA simulation tests.

SUMMARY

The EVA design evaluation tests performed by the GRO project using the FSM significantly reduced the possibility for costly, time-consuming modifications that otherwise might not have been identified until the astronaut EVA crew training operation at 3 to 9 months before launch. Required design modifications observed during these GRO FSM WETF activities have been incorporated into the flight design with minimal cost impact and no schedule impact. The JSC astronaut crew personnel and their support planning organizations have become familiar with GRO at least 2 years before the final EVA astronaut training operations are scheduled. With the knowledge and hands-on experience gained by all participants in this initial operation, the final EVA training operations should be much easier and minimize significantly the possibility of costly real-time rework and retest.

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A CASE STUDY IN R&D PRODUCTIVITY: HELPING THE PROGRAM MANAGER COPE WITH JOB STRESS AND IMPROVE COMMUNICATION EFFECTIVENESS

Wayne D. Bodensteiner
Assistant Professor
University of Texas at Arlington
Former Deputy Chief Naval Material for Acquisition

Edwin A. Gerloff
Associate Professor
University of Texas at Arlington

ABSTRACT

This paper describes certain structural changes in the Naval Material Command which resulted from a comparison of its operations to those of selected large-scale private sector companies. Central to the change was a reduction in the number of formal reports from systems commands to headquarters, and the provision of Program Management Assistance Teams (at the request of the program manager) to help resolve project problems. It is believed that these changes improved communication and information-processing, reduced program manager stress, and resulted in improved productivity.

BACKGROUND AND PROBLEM STATEMENT

The Naval Material Establishment is responsible for the development, acquisition, and support of all the complex weapons systems needed by the Navy to meet its world-wide commitments. The procurement of Naval weapons systems often involves substantial advances in technology because the equipment is required to operate in extremely diverse and hostile environments. Advances in technology, in turn, mean that a given program manager (PM) must contend with high levels of uncertainty in managing the assigned project. Ideally, the PM seeks a technically sound weapon, delivered on time, and within budget. Practically speaking, however, the PM finds these objectives to be somewhat in conflict with one another. When coupled with the inherent uncertainty of R&D, the simultaneous accomplishment of technical performance, schedule, and cost objectives are powerful sources of stress for the PM. Further, the substantial uncertainties of R&D create an extraordinary demand for intra- and inter-organizational communication if the project is to be effective.

Critical issues for the Naval Material Command (NMC) and the PM in managing such high technology are concerned with how effectively their organizations are able to communicate the information needed to deal with uncertainty, and also how well individual PM's are able to cope with the stresses of their jobs. This paper reports the results of a case study at NMC. Specific attention is given to certain organizational changes made by executives at NMC to help PM's improve communication and cope with the stress of their projects. It is believed that these changes improved overall program productivity. The case presented here was part of a broader investigation which involved a comparative analysis between NMC and selected major private sector corporations. The specific purpose of the investigation was to improve the efficiency of NMC and its headquarters staff (Gerloff, 1985).

COMPARATIVE ANALYSIS

The NMC was originally organized in 1966 to centralize Naval procurement and R&D. At its inception, NMC was organized in a divisional or systems command format which included Naval air, sea, electronics, and supply divisions (commands). The new structure was comparable to many large commercial organizations and resulted in an improvement in the Navy's diverse acquisition efforts. However, by 1980 there were some indications that NMC's structure was no longer quite as efficient as it had been initially.

The headquarters staff was now very large (in excess of 1000 people). Executives believed NMC was becoming too centralized, too concerned with its own issues, and too slow to respond. To some extent, top management was finding itself bogged down in problems that could better be handled at the system command level. Further, there were some indications that this was interfering with the efficiency of the systems commands. System command personnel were unable to give their full attention to developing and acquiring the technology needed by the Navy. Some of their time was consumed in preparing reports for NMC headquarters. Though no major difficulties had yet occurred, executives at NMC wanted to tighten their system and head off any problems that might be developing. To accomplish this purpose, a comparative analysis was undertaken to see how the NMC headquarters staff operation compared to that used by large private sector firms. Over a 6-month period, NMC headquarters officials interviewed executives and observed the headquarters operations of several major U.S. corporations.

Findings

On their return to Washington, executives at NMC used the information gathered in the field study to analyze the headquarters operation at NMC. They concluded that the managerial approaches of the several private sector companies were very similar to each other and very different from that used at NMC in four ways (Gerloff, 1985, p. 273):

1. All were decentralized and had small headquarters staffs.

2. All used both long- and short-range corporate planning (strategies).

3. All paid very close attention to the management of their technology base, in particular, the early development stages of new products.

4. All managed their operating divisions via the careful allocation of resources and maintained oversight and control with a minimum of upward information flows. Needless reports and excessive interference were avoided.

Corrective Measures

In view of these findings, several important changes were made in the NMC headquarters structure and operations (Gerloff, 1985, p. 274). The size of the headquarters staff was reduced (from over 1000 to about 500 people) and the role and scope of its operations were reduced. However, special emphasis was given to managing the technological base. The volume of upward reports from the systems commands (to NMC headquarters) was cut by 90 percent. Each system command was made fully accountable for its individual mission. An NMC Board of Directors was established which included the heads of the systems commands in its membership. An NMC corporate plan was developed to guide operations over the long term.

PROGRAM MANAGEMENT ASSISTANCE TEAMS (PMAT)

Against this background of general change in the structure and operations of NMC headquarters, certain additional changes were introduced which were specifically beneficial to the individual program managers as they carried out their missions. The job of a PM is made difficult by the high uncertainty of R&D and the consequent need for problem-solving information and communication. Simultaneous pressures to meet changing operational requirements, project schedule dealines, and cost limits while solving complex technical problems often mean the PM must also endure severe levels of stress.

Special Program Management Assistance Teams (PMATs) were established at NMC which were instrumental in helping the PM access needed problem-relevant information while also coping with the inherent stresses of program management. Each PMAT consists of a group of experienced, former program managers who are available at the request of a given PM. The PMAT can provide consultation, added expertise, assistance with special problems, or program assessment depending on the desires of the individual PM. The PMAT reports only to the individual PM, and no written reports are used unless requested by the PM.

Benefit to the Program Manager

Executives at NMC believe the PMATs have been extremely effective and have improved the efficiency of the various programs. They have also been well received and used by the PMs themselves. Further, the PMAT concept seems to be soundly based on communication and behavioral science research. For example, the communication literature has long argued the benefits of using the richer face-to-face communication channels when dealing with complex problems (Bodensteiner, 1970; Wofford, Gerloff, Cummins, 1977; Gerloff, 1985). Further, the behavioral science literature suggests that an affiliation with others can help individuals to cope with high anxiety or stressful situations (Schacter, 1959). Thus, the PMAT presented a troubled PM an opportunity to discuss problems with people who (1) understood because they have experienced similar problems before, and (2) are technically knowledgeable and able to introduce additional problem relevant information. It should be emphasized that such face-to-face discussions are superior to more formal and less rich communication channels, especially where complex problems are involved (Bodensteiner, 1970: Daft and Wigenton, 1979; Wofford, et al, 1977). A side benefit is that the technical experts, who had over the years moved from the systems commands to the headquarters staff, gained a new sense of accomplishment. By serving on PMATs, they were able to use their technical know-how in a way that ordinary staff work often did not permit.

Benefit to Top Management

Beyond such valuable assistance at the program level, NMC found that PMATs were also beneficial to higher management in its effort to manage the technological base. The management literature indicates that an important part of managing high technology involves the need for top managers to be active in the early phases of a project (concept formulation, design, and development). Decisions made in the early phases will have long term and high dollar impacts (Gluck and Foster, 1975).

Executives at NMC found that they could use the expertise of PMATs in the early assessment of a new program, about 6 months after start-up. This would be before any requests for assistance by a PM, and was not associated in any fashion with the primary function of the PMAT as described previously. At this early juncture in a program, it is critical for higher management to assess whether adequate dollars, personnel, and other resources have been made available to the PM for successful program completion. The PMAT has proven invaluable to this early assessment.

At the same early critical juncture, the PMAT can be used to assess whether operations at the program level are organized to efficiently use the resources allocated by higher management. The point of the assessment being to determine the likelihood that the program can produce the desired technology on time and within budget. Though this phase of the analysis can be a threat to the PM, NMC executives do not feel that it has interfered with their (the PMs) use of the PMAT in later phases of the project life cycle. The overall benefit of such an early assessment of resource allocation by top management and efficiency in resource utilization in a given program enhances the likelihood that a poorly conceived program can be scrubbed where circumstances warrant. Such a use of the PMAT concept opens the possibility that top managers and PMs alike will find it easier to cope with the stresses of scrubbing a troubled program before the sunk costs (in terms of both dollars and psychological costs) are too high.

Wayne D. Bodensteiner is an Assistant Professor at the University of Texas at Arlington and received his Ph.D. in management and operations research from the University of Texas at Austin (1970). Prior to his retirement as a two-star admiral, he was a ranking military expert in the Navy's research, development and acquisition process, administering more than $40 billion in development and acquisition programs.

Edwin A. Gerloff is an Associate Professor at the University of Texas at Arlington and received his Ph.D. in management and statistics from the University of Texas at Austin (1971). Prior to joining the University he was employed by the American Telephone and Telegraph Company. He has published articles in IEEE Transactions on Engineering Management, Engineering Management International, and Journal of Applied Communication Research.

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INFORMATION MANAGEMENT
AND THE SPACE STATION PROGRAM

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TECHNICAL AND MANAGEMENT INFORMATION SYSTEM THE TOOL FOR PROFESSIONAL PRODUCTIVITY ON THE SPACE STATION PROGRAM

G. Montoya
P. Boldon

McDonnell Douglas Technical Services Company

ABSTRACT

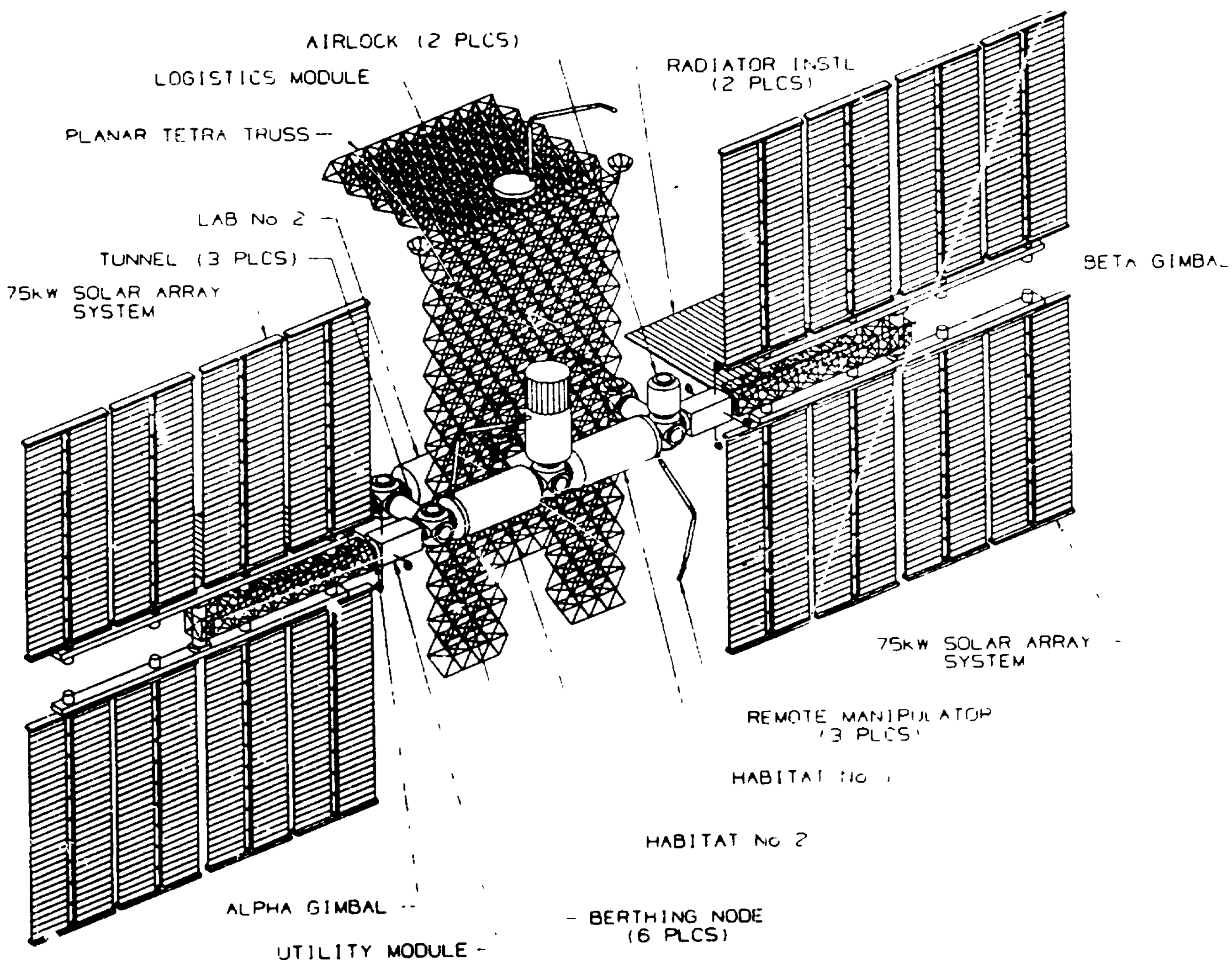
The Space Station Program is highly complex not only in its technological goals and requirements but also in its organizational structure. Eight Contractor teams supporting four NASA centers plus Headquarters must depend on effective exchange of information-- the lifeblood of the program. The Technical and Management Information System (TMIS) is the means by which this exchange can take place. Value of the TMIS in increasing productivity comes primarily from its ability to make the right information available to whomever needs it when it is needed. This paper addresses productivity of the Aerospace professional and how it can be enhanced by the use of specifically recommended techniques and procedures for information management using the TMIS.

1. INTRODUCTION

Mercury, Gemini, Apollo, Skylab...The Space Shuttle. Next in that series of technology expanding endeavors is the Space Station. Where previous spacecraft were intended for relatively short visits to space, the Space Station is intended to provide the base for a permanent presence of humans in space. The key characteristic that makes the Station different from previous spacecraft is that, rather than a means for transportation, it is a laboratory and a factory in the sky not intended for a single, short duration mission but expected to remain in service for an indefinite length of time that spans well into the next century.

The Station includes a variety of systems and depends on knowledge from a multiplicity of disciplines. It is composed of a structure that supports experiments and space production equipment, pressurized habitation and laboratory facilities, utility equipment such as power generation and communications equipment, and Station operations support facilities such as satellite servicing provisions and remote manipulator arms. Figure 1 shows one of the conceptual configuration now being studied.

FIGURE 1



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The Space Station Program

The Space Station Program (SSP) is currently in the early stages of Phase B, Definition and Preliminary Design. The overall program schedule leads to an initial operational capability (IOC) in 1992. The program management structure is shown on Figure 2. The program is divided into 4 work packages, each covering a set of end items and functional responsibilities under the management of a separate Center. Each center has under contract 2 separate contractors (or contractor teams) performing parallel Phase B studies.

The technical responsibility and geographical distribution of prime contractors (and their subcontractors), the Level C NASA centers, the Level B program management, and the Level A Agency Office create a complex network of information users and generators. This network feeds and thrives on the data that flows through it and the information distilled from this data. It is the proper acquisition, distribution, and processing of information that lead to the analysis, design, implementation, and successful operation of the Space Station.

The Problem: Making Information Readily Available

A key programmatic goal is the use of innovative concepts to increase productivity in the design, implementation, and operation of the Station. The complexity of the Station system requires large amounts of data to be processed and information to be analyzed. The diversity and geographic distribution of program participants demand that this information be made available in many places, at all times, and in several formats at various levels of detail. Streamlining of information exchange in this complex environment can significantly contribute to achieve the desired goal of high productivity in the Space Station Program.

The Solution: The Technical and Management Information System

NASA recognized the need for expedient distribution of and access to accurate, current information and specified in the Phase B Statement of Work that all contractors should use the Technical and Management Information System (TMIS). All NASA centers, contractors, and major subcontractors are required to exchange certain types of information and documents by electronic means via the TMIS, always striving to do business in a reduced-paper manner.

The TMIS is a distributed network of data processing nodes located througout all the facilities, government and private, of the organizations involved in the Space Station Program. The system includes the communications equipment and all the support software. NASA is in the process of developing the core and backbone of TMIS while each contractor is expected to develop its own segment of the overall network. Figure 3 shows a conceptual diagram of TMIS.

FIGURE 2
SSP PROGRAM MANAGEMENT STRUCTURE

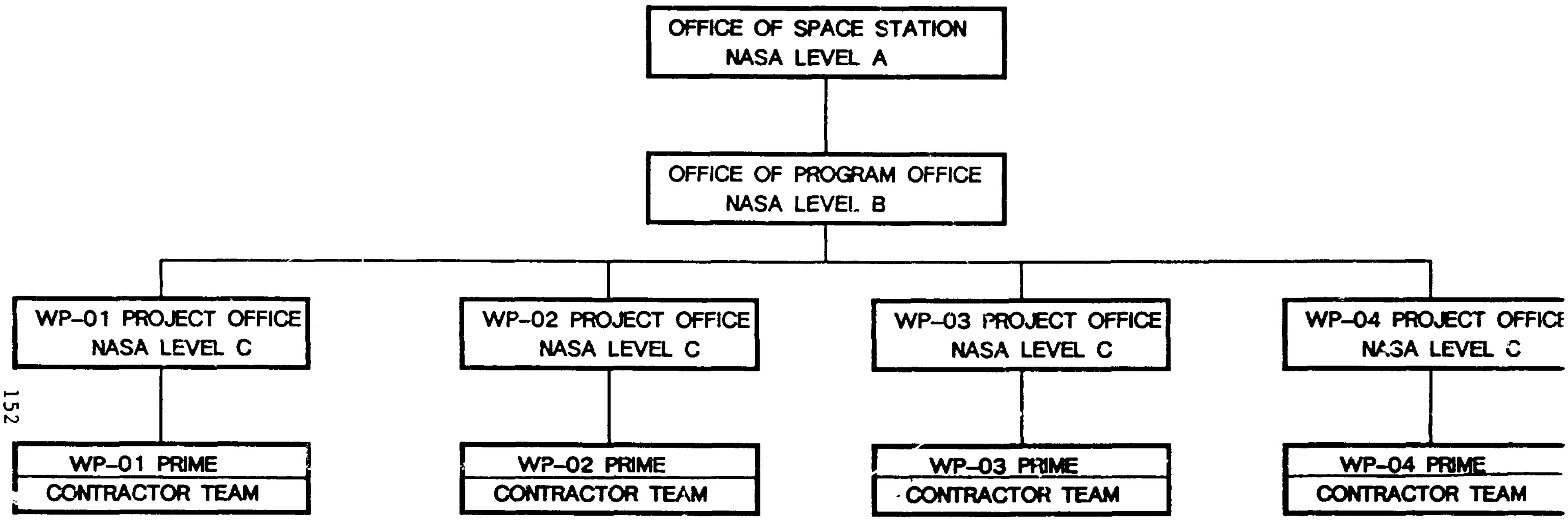
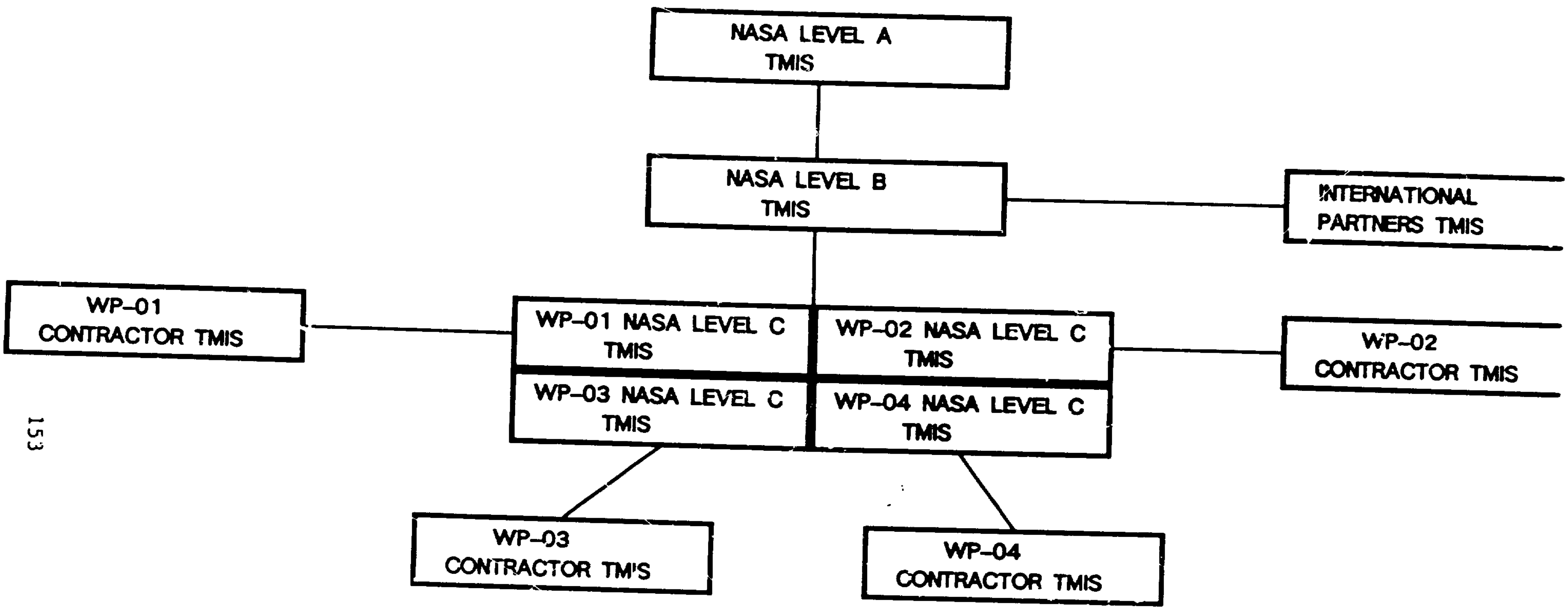


FIGURE 3
CONCEPTUAL DIAGRAM OF TMIS



2. INFORMATION EXCHANGE AND R&D PRODUCTIVITY

There has been a significant increase in awareness of the need for productivity improvements in all aspects of American industry during the last decade or so. This may be a response to what some economic and social commentators have referred to as the "Japanese Challenge". This awareness has led to several studies on productivity in different work environments. Manufacturing productivity has been of major concern to industries such as automotive and electronic production. The following studies deal with white collar or office productivity and they are reported here because of their relevance to Aerospace worker productivity, specially in an R&D environment.

The Hughes Aircraft Study

An extensive and continuing study of R&D productivity was undertaken by Hughes Aircraft Company from 1973 to 1977. Findings of the entire five year study effort were documented in a report entitled R&D Productivity [Reference 1]. The study concentrated on identifying factors most likely to impact productivity in an R&D environment and then determine what techniques help to counteract the effect of each factor. Table 1 lists the 25 most significant factors from this study.

These factors were then analyzed through surveys, interviews, study groups, and expert consultations to determine how each factor detracts from productivity. Results of this analysis were used to formulate a series of techniques, procedures, and organizational characteristics that can bring about significant increases in productivity when incorporated in the work environment. For 19 of the 25 counterproductivity factors, effectiveness of the techniques applied depend primarily on improving information dissemination and facilitating information exchange. This should not be surprising when considering that the productivity of an aerospace professional depends on that individual's ability to obtain, assimilate, and issue information. Figure 4 illustrates the pivotal role of the scientist, engineer, or manager in the flow of information. The obvious conclusion is that the single most effective element in increasing productivity is the provision of a system for expedient information flow. The TMIS is such a system for the Space Station Program.

The NASA-JSC MIDAS Study

A more recent study on the effect of information flow on productivity of the aerospace professional was conducted at the Johnson Space Center Mission Operations Directorate. The purpose of this study was to determine the need and formulate requirements for an information network to be used by the Directorate as it moved from the R&D phase to the high flight rate, operational period of the Space Shuttle program. The resulting system was the now operational Management Information Database Automation System (MIDAS).

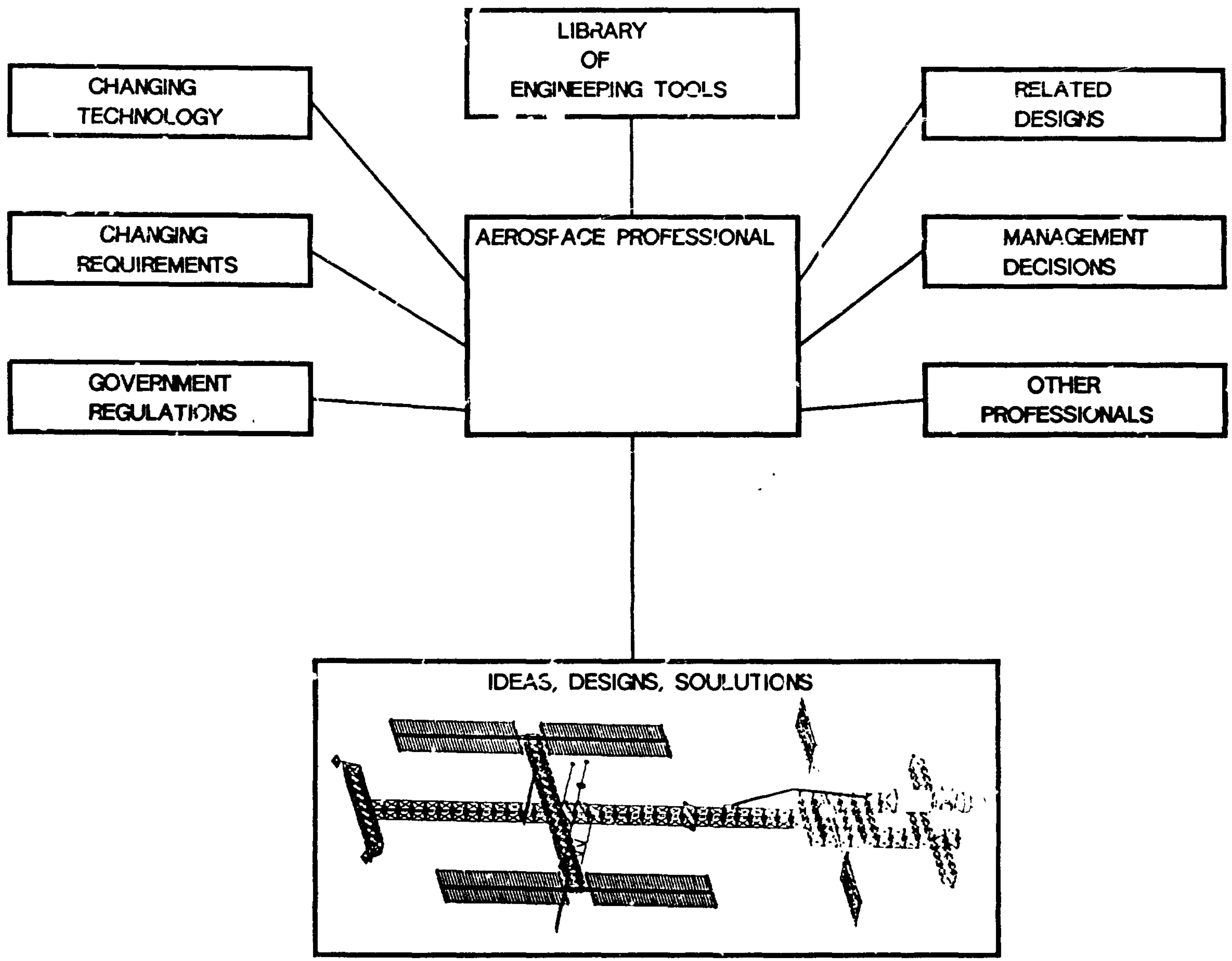
The study, conducted in 1983 by McDonnell Douglas under the engineering and operations support contract for NASA, was based on the

Table 1
25 Factors Most Likely To Cause Serious Counterproductivity Within R&D Organizations

- * 1. Ineffective planning, direction, and control
- * 2. Overinflated organiztion structures
- * 3. Overstaffing
- * 4. Insufficient management attention to productivity, and to the identification and elimination of counterproductive factors within the organization
- * 5. Poor internal communication
- * 6. Inadequate technology
- * 7. insufficient or ineffective investment in independent research and development (IR&D) efforts
- * 8. Poor psychological work environment
- * 9. Lack of people-orientation in management – insufficient attention to employee motivation
- 10. Misemployment
- * 11. Ineffective structuring of assignments
- 12. Lack of effective performance appraisal and feedback
- * 13. Insufficient attention to low producers
- 14. Technological obsolescence
- 15. Ineffective reward systems which inadequately correlate individual productivity and compensation
- 16. Lack of equitable parallel managerial and technical promotion ladders
- 17. Lack of equity in operations
- * 18. Ineffective customer interface
- * 19. Ineffective engineeringf/production interface
- * 20. Ineffective subcontractor/supplier interface and control
- * 21. Operational overcomplexity – constrictive procedures and red tape
- * 22. Excessive organizational politics and gamesmanship
- * 23. Excessive provincialism
- * 24. Ineffective management development
- * 25. Inadequate investment in, and lack of proper maintenance of, capital facilities

* Indicates where improving information exchange will alleviate the impact of these factors.

FIGURE 4
PIVOTAL ROLE OF AEROSPACE PROFESSIONAL



techniques of the IBM Business System Planning approach. This approach emphasizes two key factors in the successful development of an information sytem: 1) Commitment and support by top management, and 2) User orientation and involvement in the definition of system requirements and architecture. To satisfy the second factor, individual interviews were held with 35 managers and individuals whose job was data intensive, that is, people who spend the major part of their work day dealing with facts and figures, often stored in computers or stacks of record keeping books, such as personnel staff and training activity schedulers. Table 2 lists the questions that were asked of each individual interviewed.

Table 2
Survey Questions For MIDAS Study

1. What is your area of responsibility?
2. What are the main objectives of your job?
3. What are the three greatest problems you have met in achieving these objectives within the last year?
4. What has prevented your solving them?
5. What is needed to solve them?
6. What value (in man-hours saved, dollars saved, or programs enhanced) would better information have in these areas?
7. In what other areas of your responsibility could greatest improvements be realized, given the needed information support?
8. What would be the value of these improvements in man-hours saved, dollars saved, or programs enhanced?
9. How would you rate your information support with respect to adequacy, validity, timeliness, consistency, cost, and volume?
10. What is the most useful information you receive?
11. How are you measured?
12. How do you measure your subordinates?
13. What other kinds of measurement are you expected to make?
14. What kind of decisions are you expected to make?
15. What major changes are anticipated in your area in the next year? Three years?
16. What do you expect to result from this study?
17. Do you have any additional thoughts or comments?

The most significant finding relating to productivity and information flow from this study was that aerospace professionals spend from 50 to 90 percent of their work day searching for information. This condition leaves less than half and in some cases as little as one tenth of available time to operate on that information and be "productive".

Summary Finding

In attacking a management problem, it is important to identify the vital few factors that cause the greatest effect on the problem and then focus on those in reaching a solution. When the problem is the need to improve productivity, the above studies point to a single factor which can produce the greatest success: facilitating information flow throughout the organization. Therefore, any system which can make information available to whomever needs it, when needed, and in the form needed will have a significant effect in increasing productivity. The

Space Station Program took a significant step towards meeting its productivity goals when it committed to the development of the TMIS.

3. THE TMIS ROLE IN SPACE STATION PRODUCTIVITY

NASA Direction on Use of TMIS

NASA has made an agency-wide commitment to use TMIS on all possible aspects of Space Station design and program management and, in fact, has gone as far as placing a contractual requirement on all contractors to use the system in specific applications. General applications specified include: electronic mail, transmittal of engineering drawings, and transfer of all contractually deliverable data requirement list items, such as: monthly progress reports, design and trade study results, data packages, and cost and performance data. Specific applications will be developed by individual organizations, and as their utility become apparent, will be made available to all others. Under NASA direction, some applications will be mandatory for specific functions in support of the program. For example, NASA may dictate that all Review Item Dispositions (RIDs) be processed through a specific RID Tracking Application activated to support a specific programm design review.

Generic Applications Potential for TMIS

Generally, any need for information exchange across organizational lines can benefit from the facilities of the TMIS network. During the Definition and Preliminary Design activities, there is a continuing need for dissemination and access to information from ongoing trade studies that affect more than one function or end item. The TMIS can fulfill this need by serving as the storage for evolving requirements and interim analysis results. In addition to providing the data and storing results, the TMIS also provides the analytical tools to process that data and generate information. Technical data may be in the form of text, graphics, or tables.

Management functions supported by TMIS include the already mentioned contractual reporting; task planning, scheduling and status tracking; cost and schedule performance monitoring; and dissemination of personnel locator and assignment information.

Specific Applications Now On Line

At this time, NASA is using the Telemail system for electronic mail among centers and contractors. Level B program management is using a Cyber 830 computer for budget planning and tracking functions. Contractors, on the other hand, are implementing their own network for information exchange with all members of their respective teams. Table 3 is a partial list of the applications in use by the McDonnell Douglas Team. A large majority of these applications are built using the facilities of a relational database management system (RDBMS).

In determining which applications to implement, emphasis has been placed on the potential productivity gains achievable by the use of each application. Concern for productivity is carried through in the actual development of the applications and it is this concern that led to the selection of an RDBMS for that purpose. Significant productivity gains can be achieved by using an RDBMS for developing applications when compared to using a language such as PASCAL or COBOL. Gains of five to tenfold have been reported in programming productivity along with claims that certain applications would just never have been developed at all without availability of the RDBMS [Reference 2].

Other Potential Specific Applications

As with any other powerful tool, the value of TMIS to the program will grow with the number of applications the system supports. The creativity of users and system developers will determine how many applications and to what extent TMIS will support them. For example, Engineering and scientific reference data can be made available on the system to ensure consistency and accuracy of the data used by all players in the design effort. Using TMIS for storage of this type of reference data requires large storage capability and fast searching software tools. Technology is evolving to the point that today we have special purpose database processors, like the Briton-Lee Intelligent Database Machine (IDM), and very powerful database management software that bring the desired capability within reach.

One of the potentially most useful applications that TMIS may support in the future is document management. This application would support preparation, review, approval, maintenance, and configuration control of multi-disciplinary documents such as interface control documents (ICDs) and end item specifications. These documents require active involvement by many organizations, responsible for the contents of different sections or types of information. It is possible for all the cognizant organizations to maintain control of their specific areas through proper allocation of security authorities dealing with changes and approval for changes. Changes can be coordinated using Change Request files that can be electronically mailed to those potentially affected by the change. Reviews and coordination of changes can be conducted using scratch files and electronic mail. Approval of changes can be executed by configuration control managers by the use of specially assigned "signature" passwords. The key advantages of such a process is that all reviewers are assured of working on the same generation of the subject document and their comments are available for general review by the electronically redlined version of the document.

TMIS allows the aerospace professional to use computers and information networks in a manner not unlike science fiction works like "Star Trek" and "2001: A Space Odyssey" indicate. The technology available to the Space Station Program will provide the hardware and software needed to derive great productivity gains from TMIS. Only imagination and the willingness to store and format information will limit the extent and the ways in which the system can benefit the Program.

Table 3
TMIS Application Already In Use at McDonnell Douglas

APPLICATIONS	INFORMATION CONTENT
A. ADMINISTRATION:	
1. Personnel Roster	1. Locator data of personel on SS Project
2. Correspondence Control Log	2. Control log for correspondence between NASA, MDAC, and subcontractors
3. Contract Work Breakdown Structure	3. WBS information for phase B and C/D
4. Boards, Panels, and Working Groups	4. Listing of members and locator data
5. Subcontractors	5. Address, responsibility, personnel information
B. MANAGEMENT:	
1. Action Item Database	1. Description of action, to whom assigned, due dates, status
2. NASA Reviews	2. Function, date, location, contact for NASA reviews
3. Internal Executive Meetings	3. Log of all MDAC Executive Meetings
4. Major Subcontrators Meetings	4. Log of all meetings with MDAC Subcontractors
5. Technical Study Implementation Plan	5. Task level schedules and subtask data
6. Engineering Master Schedule	6. Schedule of Engineering Milestones for all WPs
C. TECHNICAL:	
1. System Requirements	1. SSP element system requirements
2. Configuration Characteristics	2. Descriptive items for a given station configuration
3. Functional Requirements	3. NASA Functional Requirements for SSP
4. Trade Studies	4. Listing of Engineering Trade studies to be performed
5. Analytical Tools Catalog	5. Listing of available Analytical Tools for Engineering studios

Characteristics Of TMIS That Enhance Productivity

No tool can increase productivity by itself. Results come only from the use of the tool. Information industry literature and experience in implementing information management systems indicate that the three key factors that stimulate the use of a tool such as TMIS are, in order of importance:

1) Commitment and support from top management,
2) Ease of use and availability of training, and
3) Benefit to the user.

The Space Station Program has done a commendable job of taking care of the most important factor by making a clear commitment to TMIS early in the program. It will be up to those implementing the system to make sure that factors 2 and 3 above are of paramount importance in defining system components and applications to be developed.

Item 2 is a measure of what has become known as "user friendliness". A dilemma arises here in deciding whether to give the user many powerful tools such as application generation languages, or to provide menu-driven, preprogrammed applications. The first approach requires a significant "capital" investment in developing the skills of many users who then can derive great benefits from the system. The latter approach reaches more users, thereby making the system unquestionably more user friendly, but at the cost of a more visible "capital" investment in a cadre of application developers. These developers, however, become quite adept at taking advantage of the suble capabilities of the system and are invariably more efficient in the development and maintenace of applications than the user who only programs as a sideline to his or her job responsibilities.

The degree to which TMIS is used will depend ultimately on the degree to which people accept the work stations and the role that electronic information exchange can play in their day to day work. This acceptance is growing and can already be measured by indicators such as: use of word processing equipment; presence of terminals and personal computers, not only in specially designated terminal rooms but on the work desk of the engineer, scientist, or manager; use of database management systems for data entry, query, and report generation; proliferation of data communication facilities; and the installation of local area networks to support individual facilities or agencies.

Electronic information exchange should not be the means to do the same work with less people. It should be a tool to help utilize the cognitive capabilities of humans to a greater extent so that we can do more work, and work of greater value, with the same number of people. Greater productivity can be achieved in quality as well as in quantity by working smarter rather than by simply doing more work.

4. CONCLUSIONS

As technology evolves and the size and complexity of systems grow in the aerospace industry, the need for accurate, timely dissemination of voluminous amounts of data has expanded to an almost unmanageable magnitude. The Space Station Program, commited to the use of innovative concepts for the attainment of high productivity, has recognized the importance of information availability in improving productivity by specifying the role of TMIS in the Program. TMIS, however, is a tool that must be used if it is to help bring about the desired productivity benefits and, to quote one of the managers interviewed during the MIDAS study, "it should be used to do better work, not to come up with better excuses as to why the work cannot be done".

REFERENCES

[1] Hughes Aircraft Company, "R & D Productivity", 2nd Edition, Hughes Aircraft Company, 1978

[2] Sobell, Mark G., "Database Management Systems Cut Application Development Time", Computer Technology Review, Spring 1985, pp.23-28

AUTHORS

Gonzalo Montoya is an Electrical Engineer with 23+ years experience in the Aerospace industry primarily in the area of Computer System Software Engineering. He was instrumental in the definition and development of the Management Information Database Automation System (MIDAS) for Mission Operations Directorate at JSC in his position as manager of the project. He is currently assigned to the Space Station Phase B Study Team and has been working on the TMIS and other issues for the Space Station.

Paul Boldon is a Software Engineer with 5 years experience in the Data Processing industry. He was an integral part of a team, which developed a database system for the University of Texas Medical Branch at Galveston, Texas. He is currently assigned to the Space Station Phase B Study team as Deputy Task Leader for TMIS for work package 2.

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NEW TECHNOLOGY IMPLEMENTATION: TECHNICAL, ECONOMIC, AND POLITICAL FACTORS

James W. Dean, Jr., Gerald I. Susman, and Pamela S. Porter

Center for the Management of Technological and Organizational Change
College of Business Administration
The Pennsylvania State University

ABSTRACT

This paper presents an analysis of the process of implementing advanced manufacturing technology, based on study in numerous organizations. This process is seen as consisting of a series of decisions with technical, economic, and political objectives. Frequent decisions involve specifications, equipment, resources/organization, and location. Problems in implementation are viewed as resulting from tradeoffs among the objectives, the tendency of decision makers to emphasize some objectives at the expense of others, and the propensity of problems to spread from one area to another. Three sets of recommendations, based on this analysis, are presented.

INTRODUCTION

In the past few years, a variety of new technologies have become available for use by manufacturing firms. These technologies include CADCAM, robotics, MRP, CNC, and CIM. Responding to the potential gains in productivity, quality, and flexibility offered by these technologies, many firms have included them in their plans for modernizing and automating their facilities.

While some of the gains promised by advanced manufacturing technology (AMT) have indeed been realized, firms have often experienced substantial problems in their implementation attempts. These problems are often not technical per se, but stem from difficulties in managing the relationship between the technical aspects of automation and other organizational considerations. The objective of this paper is to analyze the problems that firms typically encounter in implementing AMT, and offer some suggestions for resolving them, in hopes of increasing the success rate of such attempts.

The paper is divided into three sections:

1. What does the process of technology implementation consist of?
2. What kinds of problems do companies encounter in attempting to implement AMT?
3. How can these problems be avoided or overcome?

THE PROCESS OF TECHNOLOGY IMPLEMENTATION

The process of implementing new technology fundamentally consists of a series of decisions, which take place over a period of months or years. These decisions typically include the selection of the technology to be used, the identification of the vendor, the product or process where the new technology will be piloted, how quickly the technology will be spread to other units, and so on. Each decision is constrained to some extent by the decisions that precede it, and constrains in turn the decisions that come after it. In this way, the universe of technological possibilities is gradually narrowed to one system, with a specific set of capabilities, and a particular implementation approach. Thus, the resulting technology is the expression and sum total of all of the choices made along the way.

In order to be successful, decision-makers need to simultaneously consider three objectives: technical, economic, and political. The technical objective consists of developing a system that will perform the required task according to specifications. The technology must move material, cut metal, or process information, in an effective manner. Much of the effort is devoted to design and implementation demonstrating that the new technology can indeed perform as advertised.

Technical success is, however, not the sole criterion of effectiveness for new technology implementation. Since technical systems are imbedded in business organizations, the new technology must also achieve economic objectives. This involves demonstrating that the new technology puts the organization in a better financial position than it before. Depending on the organization, this may be expressed in terms of payback period, or internal rate of return. While some firms that are pushing automation have relaxed the economic criteria, they are almost always present to some extent.

The third objective to be met in implementing new technology is political. This consists of generating support from all the people in the organization, often spread over several departments, whose commitment is necessary to make the new technology work. The political problem exists because the technology is being inserted into an ongoing social system, and it will have an impact on that system. Few technologies will function effectively when people are indifferent or hostile. Thus, in order for implementation to be a success, the relevant individuals need to be committed, "on board," and excited.

It appears that part of the difficulty in technology implementation stems from the fact that there are almost always tradeoffs involved among these three objectives. For example, making a decision so as to maximize economic return may incur technical costs, and choosing so as to increase the political acceptability of the technology may limit its technical success. The presence of these tradeoffs alone, however, should not cause major problems for implementation. Making tradeoffs such as these are the stock in trade of managers. However, the technologies currently being implemented are very new, and most managers do not yet have a base of experience on which to rely. Thus, it often appears that, in making implementation decisions, there is an imbalance in the attention devoted to the three objectives identified above. Many decisions suffer from overattention to one or two of these criteria in decision making, and insufficient attention to the other(s).

By basing the decisions on only one or two of the criteria, managers often create problems on the one(s) ignored. Because of the connections among the technical, economic, and social systems, problems in one area often create problems in the others. In this way, the objective that was emphasized in making the decision may not even be achieved. A familiar example of this process would be if a manager were to attend solely to technical and economic concerns in making a decision. By ignoring the political objectives, the manager might create problems of user acceptance. Eventually, the problems could become so severe that the users would not want to make the technology work, and it would fail. Technical success would thus not be achieved, even though it was emphasized in the decision.

Research that has been conducted in a number of firms leads to the conclusion that this is a common scenario in the implementation of AMT. There are recurrent patterns involving systematic over- and under attention to specific criteria in specific types of decisions. Thus, attempts to implement AMT often run into trouble. The problems are not technical per se, but stem from the interdependence among technical, economic, and political factors. In the next section, we will describe how these dynamics have led to problems in the firms studied.

WHAT PROBLEMS DO FIRMS ENCOUNTER IN IMPLEMENTATION?

There are at least four different types of decisions common to new technology implementation: Specifications, Equipment, Resources/Organization, and Location. Our research has identified some patterns in how these decisions are made that create problems for the implementing firms. Each of these decision types will now be examined, along with examples from research of how excessive or insufficient attention to the three criteria has created problems in the firms studied.

Specification Decisions

The first type of decision commonly made in new technology implementation involves specifications. Simply put, these decisions determine what the new system will do, and what it will not do. In this way, what usually begins as a vague idea in someone's head is crystallized, put down on paper, and becomes the initial vehicle for generating support and commitment for the project. The prototypical situation for specification decisions is when political criteria are underemphasized, and constituencies that should be consulted are neglected. Failure to consider the political ramifications of specification decisions often leads to disillusionment among users and support personnel, and ultimately limits the technical effectiveness of the system.

Regretting this sort of decision process, one automation project manager mused, "I'd like to tell you that we didn't just design it and throw it at them, but there was some of that." The case in point was an information system, designed for use by manufacturing managers. While expressions of outright resentment of the system by this group were constrained by its support in upper management, there was quite a bit less than total enthusiasm, especially among first-line supervisors. In addition, a major component of the information provided by the system was considered unnecessary by the intended users.

Ironically, sometimes problems in specification decisions stem from overattention to the political dimension. It has often been noted that the initial list of system functions grows throughout the project, sometimes to the point where the original goal is but one of many. This is usually a result of new people becoming involved in a project, and saying, "Couldn't we also make it do...?". While agreeing to these requests is often an investment in the support of the individuals involved, it may lead to an overwhelming list of system functions, none of which are accomplished effectively. This is a result of political objectives being overemphasized, to the detriment of technical objectives. To complete the cycle, the lack of technical success in the project often disenchants the user community, so the political advantages of agreeing to the numerous requests are not realized.

Equipment Decisions

The second type of technology implementation decisions concerns equipment. One decision concerns whether technology will be purchased or developed in-house. If it is to be purchased, there is the question of which vendor or vendors to select. Often connected with these decisions is the exact type of technology to be used. Equipment decisions can usually be broken down into hardware- and software-related. A repeated finding is that some firms automate using the absolute lowest-cost equipment they can obtain. Often, this equipment does not perform as expected, and ends up costing more in the long run. For example, a building supply company decided to put their shop floor control system on a minicomputer, so as to avoid the high costs of using the corporate mainframe. Unfortunately, the minicomputer could only handle half of the company's product lines, and it would have cost a fortune to rewrite the software for the mainframe. To date the company has only half of their business on the system.

At first blush, this sounds as if it represents an overemphasis on economic criteria, and a resulting sacrifice of technical criteria. But often these scenarios arise because managers are reluctant to try to convince their superiors of the real cost of what they are trying to do. Thus, managers try to avoid a political battle by keeping expenditures at a point where they do not need approval from higher levels, or at least will not raise eyebrows at those levels. Sometimes this is achieved by dividing a major purchase into several smaller purchases. Given this background, which has been observed in a number of different firms, it appears that the technological objectives of equipment decisions are often undermined by a combination of economic and political factors.

Resource/Organization Decisions

The third type of decisions necessary for the implementation of new technology concerns resources and organization. The issue here is the amount of manpower to be devoted to the implementation attempt, and how the individuals who join forces in this effort will be organized. It is our observation that the level of manpower devoted to new technology implementation is often inadequate. Firms try to conserve funds by doing a project with half of one person's time, a quarter of another person's, and so on. Since people generally feel more loyalty to the tasks they have been doing and are familiar with, they often do not even devote the amount of time allotted to the implementation project. This problem is compounded by the fact that performance appraisal and reward system seldom adequately recognizes work of this sort.

In one instance, an accountant was slotted to spend over 50 percent of his time on a new MRP system. Unfortunately, the company had made no provision for the fact that the fiscal year was ending, and no one had been assigned to cover for him. Needless to say, not much of the accountant's time was devoted to the MRP. In another instance, an electronics firm was simultaneously implementing an automated material-handling system, a shop-floor control system, and moving into a new factory. This was attempted with only one full-time person devoted to the projects. Numerous technical problems were not able to be solved, simply because no one had the time to do it. The whole situation was demoralizing to both the implementers and the users of the new technology. As one of the foremen said, "In the long run, they'll wish they had spent a few more salary dollars." Characteristically, the attempt to save money by undermanning the project backfired. Because there was no funding for technicians, highly paid systems analysts ended up doing menial work such as running cables. Thus, the economic objectives sought by undermanning the project were not really achieved.

Related to decisions involving the level of human resources applied to an implementation project are decisions regarding how these individuals will be organized. It has been our observation that, in order to successfully implement AMT, individuals from several different parts of the organization need to coordinate their efforts. Depending on the specific technology, individuals from any of the engineering disciplines, production, information systems, accounting, and marketing may be involved. When, political problems between two or more departments serve to hinder coordination, the technical integrity of the project may be compromised.

One example of this is a project which was to develop an automated quality data collection system. The project was being championed by a plant-level quality group. While it appeared that their efforts could have been enhanced by help from the corporate quality and systems organizations, political problems among these groups led to the original group "going it alone." In another case, the installation of a CAD system was delayed for over two years by coordination difficulties between the product design and manufacturing departments.

The irony of this situation is that often the political problems can't be solved until the new technology exhibits some level of success. In order to protect their careers, people in organizations try not to be associated with anything that fails. So it often appears that potential participants and supporters are "waiting in the wings," to see if this uncertain technology will deliver as promised. If the technology falters, people will lose faith in both the system and its proponents, any initial enthusiam will be lost, and the chances of political success with the undecided will become more remote. As those who might potentially be able to help withdraw from the project, the likelihood of technical success decreases in turn.

Decisions about organization that are technically motivated may have outcomes that are quite unpredictable. In one firm, a woman who wrote procedures for assembly line workers got involved with the installation of a shop-floor control system. Her duties expanded to include trouble-shooting with the bar-code scanners used to collect data, and training for the system users. While neither her job grade nor her pay were increased, her elevated status was resented by the other procedure writers, many of whom had greater seniority. This presented difficulties for the project, as they would not make time to meet with her when the system was being introduced in their areas, making it difficult to expand the system beyond the initial test bed.

A final example of organizational decisions comes from a multi-division firm in a metals industry that was attempting to implement CIM. When the computer professionals within the firm first suggested that CIM was an important strategic direction for the firm, they were virtually sent packing, because the senior managers felt that the idea of computer integration ran counter to the prevailing corporate spirit of decentralization. The only way that CIM was eventually approved at the senior executive level was that the CIM advocates packaged it as something that could be under complete control of the business units. When it came time to develop the system, however, this organizational arrangement made it extremely difficult to devise a system that could be used throughout the corporation. Satisfying political objectives thus undermined the technical goals of the project.

Location Decisions

The final of the four types of decisions involves location. This includes the selection of an area (plant, product line) in which to pilot the new technology, as well as other areas in which it will be implemented. Politics often dictate which areas are selected, and which are avoided. In one case, the new technology was piloted on Product X.

As we observed the implementation process, we gradually realized that many of the start-up problems were being caused by the complexity of the product. When we asked the project manager about this choice, it turned out that he and others at his level would have preferred to pilot it "anyplace other than [Product X]." This decision had been made at a higher level, and was based on the politics of selling the new technology to the management of the various products. In a variation on this same theme, a company was selecting the product line for a robotics application. The line which was selected was primarily for economic reasons, because it was experiencing a large order backlog. It turned out, however, that the assembly process chosen was extremely complicated, and led to technical problems in developing the system. In addition, the pressure to ship products in this area kept the operators from spending time on training, which created further delays.

Our goal in describing problems that firms have in implementing AMT is not to discourage firms from attempting it. On the contrary, we hope that awareness of these problems helps firms to avoid them in future attempts. In the concluding section of the paper, we offer some suggestions for avoiding the kinds of problems that have been discussed.

HOW CAN THESE PROBLEMS BE AVOIDED OR OVERCOME?

Our overall recommendation is clearly that, in making the decisions of which technology implementation consists, one must be aware of the impact on all three of the areas. Many problems are caused by one area taking undue precedence over the others, or potential negative effects of a decision being overlooked. While awareness of the importance of each factor does nothing to ameliorate the problem of tradeoffs, it at least alerts managers to the potential problems caused by overattention to one or two of the objectives. In order to materially improve the implementation process, however, managers need to find ways to go beyond the tradeoffs, and attempt to jointly achieve technical, economic, and political objectives. This is, of course, more easily said than done. In many cases, the presence of tradeoffs among the three factors is simply a dilemma which must be faced. This should give one pause in evaluating the potential of "easy," off-the-shelf methods of new technology implementation. Recommendations for better practice should be grounded in an awareness of the complexity and dilemmas involved.

An overview of the problems discussed above would reveal the following process. In trying to limit expenditures on technology, managers buy or develop systems that are not as good as they need to be. The effectiveness of the technology is further limited by organizational considerations, such as barriers between departments. Over time, the technical shortcomings of the system give rise to political difficulties, as users and others whose support is needed become progressively more disenchanted. This eventually becomes a "vicious circle" of declining technical performance and political support. The ultimate outcome of this scenario is economic, as the benefits originally promised by the new technology are not realized. Usually, however, before the situation reaches this point, management intervenes. These interventions usually take two forms: more money and people are thrown at the problems, and the project manager is impressed with the implications for his or her career if the system is not soon operating as advertised. This threat then cascades down through the project organization. Simultaneously, the project manager and others are working both up and down the hierarchy to lower expectations for system performance.

As indicated above, there are limits to the extent to which these problems can be avoided, given the tradeoffs among objectives, and the fact that problems tend to spread from one area to another. Discussed below, however, are three sets of recommendations for managers, which are derived from the cases studied, and the conceptual framework abstracted from them. These recommendations emphasize the anticipation of problems before they occur, and the breaking up of the feedback loops, in which problems lead to more problems.

Technology and Resources

The first recommendation, and the one which will probably take the most courage to implement, is that managers should make every effort to convince their superiors to spend the money necessary to purchase or develop an effective system. This includes both the technical system and the personnel to properly implement it. The importance of making this attempt is underlined by the fact that, in a great number of cases studied, problems were initially created by managers trying to save money on technology, and these problems escalated into major threats to the technology's effectiveness. It is extremely rare for managers to feel that they should have spent less money on a system. This suggestion is made particularly difficult to practice by the fact that, in many firms, the ultimate decision makers on capital investment do not have technical backgrounds. Thus, the temptation is to make recommendations based on cost and return, with less consideration given to the long-run technical and political effects of this approach.

On the other hand, deciding not to even ask for what is really needed, on the assumption that one will be turned down, is a self-fulfilling prophesy. Sometimes, managers who take the time and the risk to sell their superiors on the need to spend money on technology are rewarded. One manager who "decided to make the guy earn his money, and tell us why we couldn't have what we wanted," actually got what he wanted. It is important to reemphasize that often this approach will save money in the long run. Even if the request is not approved, there are advantages to making the attempt. If the "champion" has to settle for less in terms of technology, if it doesn't work, this individual is at least on record as saying that more was needed. Also, making these arguments repeatedly may eventually sensitize upper management to the general problem, and lead to a more receptive climate for future requests.

Technical Effectiveness through Organization

The first recommendation reduces to achieving technical effectiveness by spending money. Technical success can also, however, be enhanced by organizational arrangements which do not have an economic or political cost. For example: in picking an area or product in which to introduce advanced technology, it is important to take advantage of existing organizational strengths, and avoid organizationally weak areas. Implementing new technology will tend to amplify both strengths and weaknesses. The ideal area for introducing new technology would have, for example, good leadership and cohesiveness.

Since several different subunits will probably be involved, both in the project organization and on the user side, individuals from these groups work together well should be selected for the project team. Recent work by the authors [1] has suggested that individuals who have complementary reward structures, broad backgrounds and knowledge, and are adept at sharing information and taking another's perspective can have a positive impact on the success of implementation. It is also helpful to have people involved who are willing to experiment, and who are not overly tied to the old ways of doing things. Some flexibility in terms of going beyond job descriptions will probably be necessary, so individuals who are willing to go in this direction (and those who aren't) should be identified. If such individuals are not available, some team-building activities may be helpful.

By carefully arranging the organization of a project, managers can improve the technical success of the new technology without absorbing economic or political costs. Thus, organization provides a way to avoid the vicious circle of technical and political failure.

Tolerance for Failure

Developing tolerance for failure is another way to disconnect technical problems from political problems. The goal of this effort is for users and support personnel to redouble their efforts when confronted with technical problems, rather than getting disgusted and distancing themslves from the project. To achieve this goal, it is important for firms to be somewhat conservative in their initial automation attempts. It is better to pick an application that has a high probability of success than one that has a high expected return. Developing momentum for automation within a firm is easier to do so with a few small successes than with a big failure. In one firm, the failure of an ambitious robotics project led to negative feelings about robots that lasted several years. It is crucial that the first attempts a firm makes at AMT do not leave people with a bad taste in their mouths. Otherwise, the first sign of technical problems in subsequent efforts will generate an instant political reaction.

The most time-honored solution to political problems is to involve users in the decisions that create the system. User involvement should also help to break the cycle of technical and political problems. While most managers are probably aware of the need to do this, time constraints and reluctance to negotiate with factory floor personnel over technical matters keep them from actually doing it. It is important to keep in mind that there is an inverse relationship between the amount of time it takes to make a decision and the amount of time it takes to implement it: the time that is not put into user involvement on the front end will be spent on the back end.

As the new system develops, the establishment of regular communication links to keep people up to speed is essential. Early in the project, it should be impressed on all participants that few technologies work right immediately, and that some problems should be expected. Eventually, this may include reminding people of start-up problems in systems that were ultimately a success. As the project progresses, communication needs to be maintained.

While progress reports via memos are the absolute minimum, periodic meetings among involved participants are better. Meetings have several advantages: First, they limit the extent to which technical difficulties become political problems, by supplanting the organizational rumor mill in providing information about the technology's level of success. The absence of hard information seems to leave the door open for "doomsday" rumors to proliferate. Periodic meetings devoted to sharing information should diminish the likelihood of this occurring.

Additional advantages of frequent project meetings include the fact that they allow the "accidental" solution of numerous little problems that arise in the course of implementation. We have often observed the time immediately before and after meetings being used by pairs of individuals to solve problems of this type. Also, working together in meetings helps to mold the individuals involved into a team, so that their future potential to work together is enhanced.

To minimize the time devoted to these meetings, we would suggest that all those involved in or affected by the project be identified. These people should be kept informed by memos of progress on the implementation. Periodic meetings should include only those individuals who are involved in the issues to be discussed. The project manager should have the power to ensure that the right people will be present at the right time. (Of course, if he or she has to work very hard to do this, there are probably fundamental political problems that need to be dealt with.)

Our final recommendation, and perhaps the most important, is to attempt to inspire the people who need to make the system work. This more than anything else, should prevent the political problems that usually follow technical difficulty. This can be accomplished by giving people a vision to work toward: a picture in their mind of where the project is going, and a burning desire to get there. Often, the "champions" of a new technology have such a vision, but they fail to communicate it to the troops. Many possibilities exist for communicating the vision, including site visits to other firms where it works, and videotapes demonstrating the concept. A key component is confidence in the face of adversity. As an engineering manager who had successfully implemented a CADCAM system said, "It's not sold in the meetings...you get a lot of this stuff accomplished by being one hundred percent positive in the informal contacts." If the vision of the champions can be shared with all of those whose dedication is necessary, the chances are much improved of creating systems that will be successful technically, economically, and politically.

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BIOGRAPHY

James W. Dean, Jr. is Assistant Professor of Organizational Behavior in the College of Business Administration, The Pennsylvania State University. His interests include the implementation of advanced technology, decision making, and organizational innovation and change.

Gerald I. Susman is Professor of Organizational Behavior in the College of Business Administation, The Pennsylvania State University. His research involves sociotechnical systems, new technology implementation, and organizational change and development.

Pamela S. Porter is a Doctoral Candidate in the College of Business Administration, The Pennsylvania State University. Her interests center around the design and implementation of advanced technology, and how this is affected by organizational structure and culture.

AUTOMATION AND INFORMATION MANAGEMENT

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COMPUTER SYSTEMS MEASURES

F. T. Crucian, The MITRE Corporation, Houston, Texas

ABSTRACT

In determining the productivity of a computing capacity, two of the costs to be considered are: the cost of lost productivity (user lost time) due to inadequate computer resources; and the cost of increasing the capacity of the computer system to reduce user's lost time. This document presents the results of a study conducted at NASA/JSC. The purpose of the study was to relate the cost of users' lost time to the cost of increased computer resources. The goal of the study was to identify the overall least cost to the computing facility. The document describes a survey designed to identify the user's lost time and the computer resource requirement to reduce lost time. The results of the survey are presented showing the trade off between user's lost time and cost of increasing system capacity.

1.0 INTRODUCTION

For the past several years the MITRE Corporation has provided support to the Central Computing Facility (CCF) of the Data Processing Systems Division (DPSD) at NASA's Johnson Space Center (JSC). This support has been in several areas including the gathering of requirements and the long range planning and procurement of additional computer systems. In providing this support, MITRE developed a method for comparing computer systems costs to costs incurred by the users due to insufficient computer resources. This paper describes the method used to accomplish that comparison.

2.0 Background and Approach

2.1 General Discussion

The government procurement process requires justification for new or replacement computer systems. The justification is prepared by the originating organization and submitted to higher level management for approval. It includes a description of the system configuration, a statement of requirements, the cost to the government to procure the computer system, and the benefits that would accrue if the system were acquired. In the approval process, the request is frequently returned with a request for more definitive statements of requirements and costs-benefits analysis. Frequently the user's requirements are prepared from data collected on a yearly basis from first and second level management. Data from this source can lack "granularity" because the resource requirements are usually raw requirements - i.e., requests for computer hours, mass storage, etc. The end user is not asked to describe how the task will be accomplished. Consequently, a method is required to:

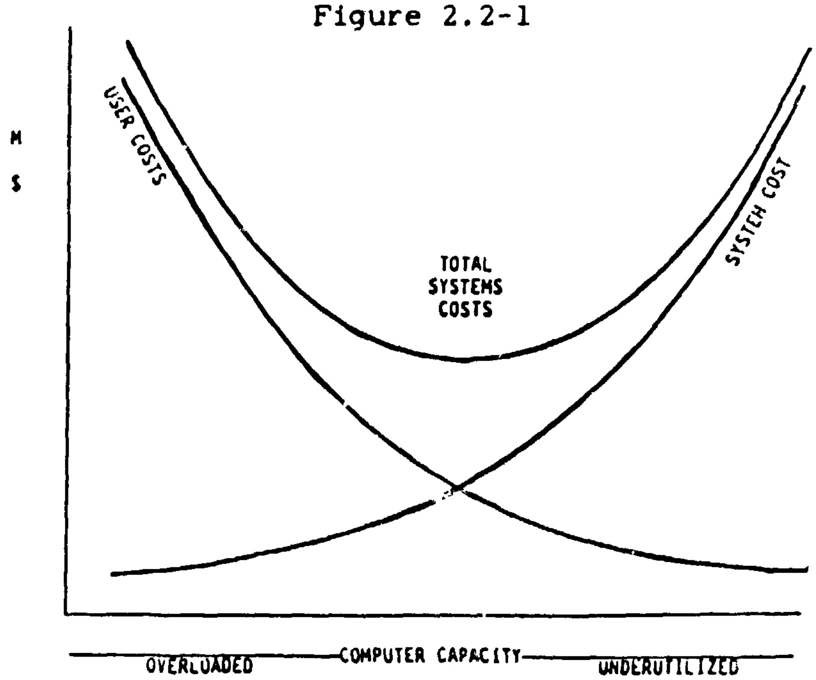
1) determine the adequacy of the current computer resources;
2) define the requirements needed to satisfy the user; and
3) compare the costs of the required computer resources to the user's costs. The goal is to identify the realistic costs of the requirements and compare these to the savings and/or benefits accrued to the facility.

2.2 User Cost vs. System Cost

MITRE has proposed a method for determining the total cost of computer services to an organization. This method is based on the relationship of user response time to the amount of system resources. In this relationship the total cost includes both the cost of system capacity and the users. (See Figure 2.2-1). The plot of Figure 2.2-1 shows three separate curves: a user cost; a systems cost; and a total cost. The user cost curve reflects the opinion that the cost of user lost time due to insufficient computer capacity will be reduced as additional capacity is provided and computer services improve. However, as systems capacity increases, the systems costs also increase. This relationship is reflected in the systems cost curve of the figure. These two "curves" are summed to produce the total cost curve. This curve includes the total costs to the facility for both user and the computer resources and also reflects the total cost/job to the facility. The left side of the "total cost" curve reflects an overloaded system and a cost/job high in user lost time. The right side of the curve reflects an under-utilized system and a cost/job high in systems cost.

The equation of the user cost curve is not known but is assumed to be a curve and not a straight line. This can be assumed because, as additional capacity is provided, service to the users improves and lost time is reduced. However, the first increments of increased capacity are more effective in reducing lost time than the last increments of increased capacity. For example, consider users with almost zero computer capacity being required to do their computational jobs manually. User cost would be quite high. Adding modest amounts of computer capacity decreases these costs significantly, and after a certain point is reached, only minimal gains are realized.

Figure 2.2-1



The system cost curve shows how system costs change as system capacities increases. The system costs could be a straight line depending on pricing policy of the vendors and the size of the capacity increments. For example, a systems configuration consisting only of microprocessors would produce almost a straight line. It should be pointed out that an almost straight line cost has more of an effect on the total cost curve than a cost curve similar to the cost curve in Fig. 2.2-1. The resultant cost curve reflects the sum of the changes in both user and system costs. The left part of the curve shows that the cost to the facility is high in user costs if the computer resources are overloaded. The right part of the curve shows that the costs to the facility are high in systems costs if the computer resources are underutilized. This curve will reach a low point which represents the minimum cost to the facility of both the users and systems costs.

2.3 Approach

The system cost curve in Figure 2.2-1 can be easily derived by costing the ranges of capacity. However, the user cost curve can only be determined and evaluated from information provided by the user. The user must provide the amount of lost time experienced for the current computer resources and project the amount of computer resources needed to essentially eliminate the lost time. From this data it is then possible to attempt to draw the two curves in the figure. The User Cost Curve can have three points:

1)a point on the Y axis corresponding to "zero" computer capacity and the total cost of the users

2)a point when the X value is the size of the current configuration and the Y value is the cost of the lost time using the current configuration; and

3)a point where the X value is the size of the projected configuration and the Y value is the cost of the projected system to reduce lost time costs to zero (or close to zero).

The total cost curve was then plotted by summing the Y coordinate values for each X coordinate to form the X and Y coordinates for the points on the total cost curve.

The methodology used was based on data acquired via questionnaires provided to the users of the computer facility. The objective was to identify the time lost because of insufficient computer resources and to state the computer resources needed to eliminate lost time. Statistical processing of the data allowed the results of the questionnaires to be viewed in a variety of ways. For the purpose of the survey, lost time was defined to be all idle time caused by insufficient computer resources and includes time spent inefficiently as well. This is discussed in more detail later.

2.3.1 Description of Questionnaire

A two part questionnaire was designed to identify the information. The first part of the questionnaire pertained to the user and the organization. The questionnaire included questions that identified organizational information, the individual identification data, resource usage, and lost time data. Information about the organization included location data, task assignment, engineering packages required, etc. The individual identification data included specific run data, account numbers, physical location of the user, experience level, etc. Actual resource usage included estimates for total resource (SUP) [1] usage, Batch and Demand (interactive) use, and terminal usage. The lost time data included time lost waiting for output, using demand terminals (slow response, facility waits, etc.), because of hardware failures, etc.

The second part of the questionnaire allowed the user to record the estimates of resources required to eliminate lost time and how the resources would be used. In this survey, the user was asked to specify computer resource requirements, expected turn-around time, and the time of day the batch runs were submitted or for the demand terminal session. Data provided in this form were used to form a profile of computer usage by time of day. The profile was then used to identify peak requirements, prime time averages, overnight requirements, etc. thus describing the computer resource requirement in finer detail than a total requirement. Once the profile was determined then it was possible to select the "requirement" to be met -- e.g., two hour peak load, prime time average, etc. Once the requirement was selected, it was possible to identify the computer configuration needed to satisfy that requirement.

In preparing the questionnaire, the specific wording of the questions was considered to be very important. A draft was prepared and reviewed by a small group whose primary function was capacity and configuration planning. The review process required many iterations before the questionnaire was considered satisfactory. Questions had to be self explanatory and words had to be selected that were not ambiguous. It was also necessary to prefix a short memo to the questionnaire defining the meaning of "lost time". It was critical that lost time be defined uniformly -- not as a large number of different users groups might define it. (To illustrate, ask

1 SUP - Standard Unit of Processing. The SPERRY 1100 measure of computer resource (CPU, IO, etc) utilization

several different people to define lost time. The definition will be forthcoming only after a few minutes of discussion with each person.) The questionnaire defined lost time as that time spent waiting for: return of output; retrieval of files and tapes; slow response on terminals; inefficient practices caused by resource limitations (e.g. insufficient core and SUP allocations, etc.); hardware failures; lost output; extra travel to retrieve output from other areas; travel to other areas to use graphics terminals not available at the place of work; and a special "other" category to be defined by the user. Time was not considered to be lost if the user had other duties that did not require computer resources -- e.g. attending meetings, reading documents, etc.

3.0 CASE STUDY

3.1 General Discussion

The survey was performed for an entire division of the engineering users of the Central Computing Facility. This division consisted of five separate organizations: a civil service group involved in the monitoring of contractor activities and development of engineering programs (Group A), and four contractor organizations. The four contractor groups each had separate but supporting functions. Group B is the largest of the four contractors and is involved in engineering tasks using computer system and software packages, with the primary responsibility of mission planning. Group C is responsible for providing software maintenance and enhancements for all the engineering processes developed for Groups A and B. Group D consists of software specialists involved in the maintenance and enhancement of general software packages used by all other groups. Finally, group D is responsible for providing general support to Group A.

At the time of the survey, the five groups used two Sperry systems - an 1100/81 and an 1110. These systems supported 100 concurrently active demand terminals which included 30 graphics terminals. The user could direct the computer output to a variety of devices - Sperry 770 line printers, Datagraphix Mini-Auto COM Fiche printer, III FR80 an CALCOMP plotters, and remote printers. Group D was the only group that did not have a remote printer or graphics terminals at their work area. During the prime shift (0730 - 1700), demand runs were given a high priority. Runs with large memory requirements were carefully monitored. A few batch runs were allowed to be submitted during the day but most batch runs were processed after prime shift. A backlog of unopened batch runs would build steadily during the week and would be worked off over weekends.

3.2 Survey Results

Approximately 700 questionnaires were distributed to the five groups. Of the 600 surveys returned, 320 of the responders declared themselves to be users of the CCF computer systems. Figure 3.2-1 presents a sample of the results of the analysis of the first questionnaire. This figure shows the results according to each group and the hours of time lost each week because of insufficient computer capacity. The time lost was attributed to the following reasons - wait for output, wait for terminal facilities (including poor response), wait for file access, insufficient allocations, and Hardware Failures and Reruns. The category "other" was folded into the last category. The time lost is also repeated as a sum for each group for the survey week and as a total hours lost.

FIGURE 3.2-1

ORG.	NBR SMPL.	WAIT FOR OUTPUT	WAIT FOR TERM.	WAIT FOR FILES	INSUFF. ALLOC.	H/W DOWN RERUNS	WEEKLY AVG. HRS.	TOTAL HOURS
ALL	320	0.9	1.4	0.6	1.5	0.3	4.7	1504
GROUP A	42	0.7	1.3	0.3	1.1	0.3	3.7	156
GROUP B	195	0.9	1.4	0.5	1.9	0.4	5.0	990
GROUP C	49	0.7	1.1	0.8	1.0	0.7	4.3	211
GROUP D	19	1.4	2.3	0.5	0.9	0.4	5.5	[illegible]4
GROUP E	15	0.8	1.5	0.2	0.9	0.1	3.5	53

- ESTIMATED LOST TIME COST SUMMARY
  TOTAL LOST TIME -- 1504 HOURS
  RATE -- $30./HR.
- WEEKLY COSTS OF LOST TIME - $ 45,120
- YEARLY COSTS OF LOST TIME - $2,346,240

As can be seen, all users lost a total of 1504 hours during the week for an average of 4.7 hours/user/week. Group D had the highest average of lost time mainly because of the time lost waiting for output and terminal facilities. This is to be expected because this group did not have access to a remote printer and traveled to different locations to use graphics terminals. Group B had the next highest average and the largest total of hours lost. Since this was the largest group - 61% of the total sample, the overall average was affected strongly by this group. Group B reported nearly twice as much time lost because of insufficient resources as any other group. All other categories of lost time for Group B were fairly close to the other groups. Group C reported more lost time due to hardware failures/re-runs than other groups, and waiting for files. (Further analysis would be necessary to identify the reasons for this.) The cost for these 1504 total hours of lost time was calculated at a rate of $30/hour/user and amounted to $45,120/week or $2,346,240/year. (The $30/hour rate is a figure that reflects the total costs to the government and includes such things as vacation, sick time, benefits, contractor overhead, profit, etc.)

The second questionnaire asked the user to identify the batch run and demand terminal session resources required to eliminate all lost time. Each of the 320 users was asked to collect the required runs into groups and specify five separate variables for each groups of runs - the number of runs, time of day the group of runs would be submitted, memory size of the group of runs, average SUP minutes required for the group, and the turn-around time needed for the runs. In the case of demand runs, the turn-around time was changed to demand terminal connect time. Figures 3.2-2 and 3.2-3 show the Computer Resources and Demand Terminal Resource profiles derived from the questionnaire.

Figure 3.2-2 shows the profile of the SUP requirements as described by the users. This figure was drawn by combining the weekly SUP requirements for 12-two hour periods (X axis). Thus, the requirement for the period of 0800-1000 hours is the sum of all the requirement for the period of 0800-1000 hours for the total week. The Y axis gives the SUP hours/hour needed to satisfy the requirement. According to the second questionnaire, the total requirement for the week was 1798 SUP hours. Assuming 15 shifts of operations (120 hours), this would require a configuration delivering an average of 15 SUP hours/hour. However, a peak requirement of 23.5 SUP hours/hour was identified occurring between 1000 and 1200 hours. Two other averages are: the 8 hour prime time average (0800 - 1600 hours) of 20.7 SUP hours/hour; and the 10 hour prime time average (0800-1800 hours) of 18.5 SUP hours/hour. Obviously, the user feels that most of the computer usage must be provided during the daytime hours if lost time is to be eliminated. It is also interesting to note that about 50% of the daytime requirement is for batch runs.

FIGURE 3.2-2

ESTIMATED COMPUTER RESOURCE REQUIREMENT

WEEKLY RESOURCE PROJECTIONS - 320 MPAD USERS

PROJ. BASE	SUP HRS./HR	TOT SUPS[1]	CAA	# TERMS	# 1181'S [2]
PEAK	23.5	2820	204	320	8.8
8 HR.	20.7	2484	204	320	7.8
10 HR.	18.5	2220	204	320	6.9
AVG.	15.0	1800	167	320	5.6

1 - 15 SHIFTS OF OPERATIONS

2 - CALCULATED @2.7 SUP HRS./HR REQUIRED FOR PEAK PROJECTION

Figure 3.2-3 shows the demand terminal requirement profile. This figure was drawn from data provided as described in the previous paragraph. This figure shows the number of Concurrently Active (CA) terminals over 12 two hour periods of the typical day as described by the users. The figure shows a peak requirement of 204 concurrently active terminals for the time period from 0800-1000 hours. The average of concurrently active (CAA) terminals for the prime time period of 0800-1600 hours is 167 terminals.

Figure 3.2-4 is a summary of the Computer Resource and Demand Terminal Requirements. The projection base provides four periods for the week used to determine the following requirements: the peak two hour period; the 8 hour prime time average; the 10 hours prime time average; and the average for 15 shifts of operation. The figure provides the delivery rate in SUP hours/hour, the total capacity in 120 hours of operation resulting from the rate, the Concurrently Active Average (CAA) of terminals, the number of terminals required, and an estimate of the number of 1100/81's required to provide the total capacity. (It has been determined that an 1100/81 will deliver 2.7 SUP hours/hour when processing the case workload described earlier.) As can be seen, the total SUP's available from each requirement ranges downward from 2820 to 1800 SUP hours for the four projection bases. This was determined by assuming the stated rate for 120 hours of operations. The number of terminals required to support the estimated number of CAA terminals is set at one terminal for each user. The estimates of the number of 1100/81's required ranges downward from 8.8 to 5.6 1100/81's. However, the profile (Fig. 3.2-2) indicated that a configuration of 8.8 equivalent 1100/81's was required to satisfy the user's prime time projection of resources needed to eliminate all lost time.

FIGURE 3.2-3

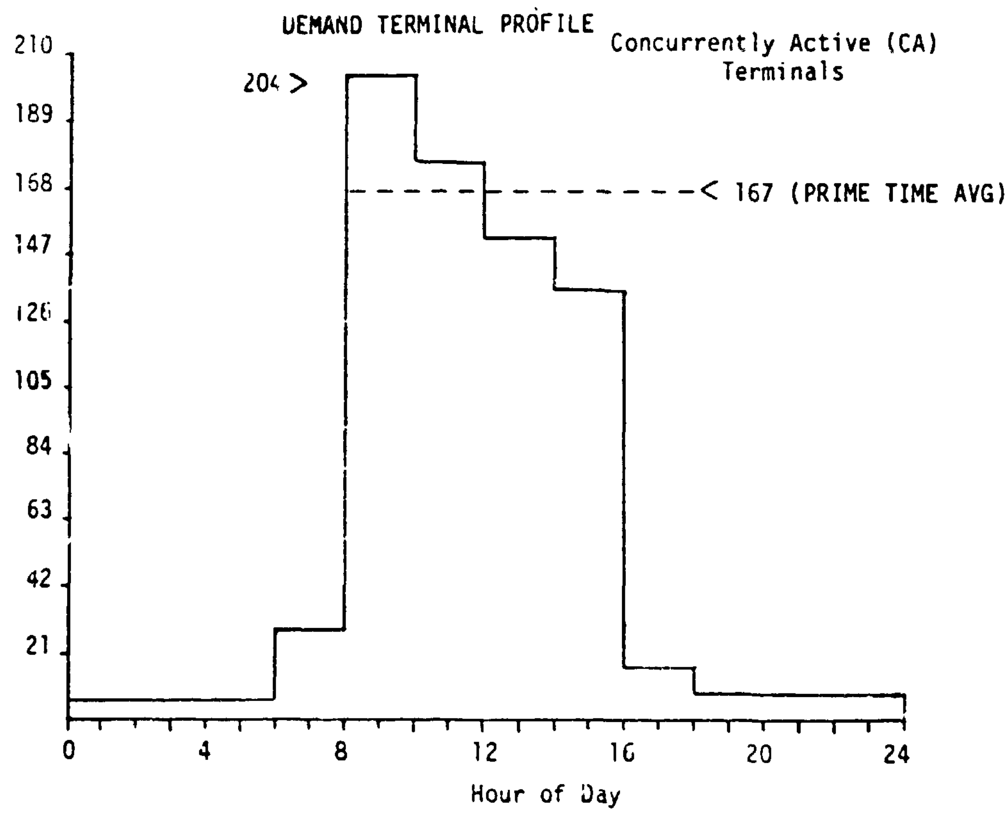
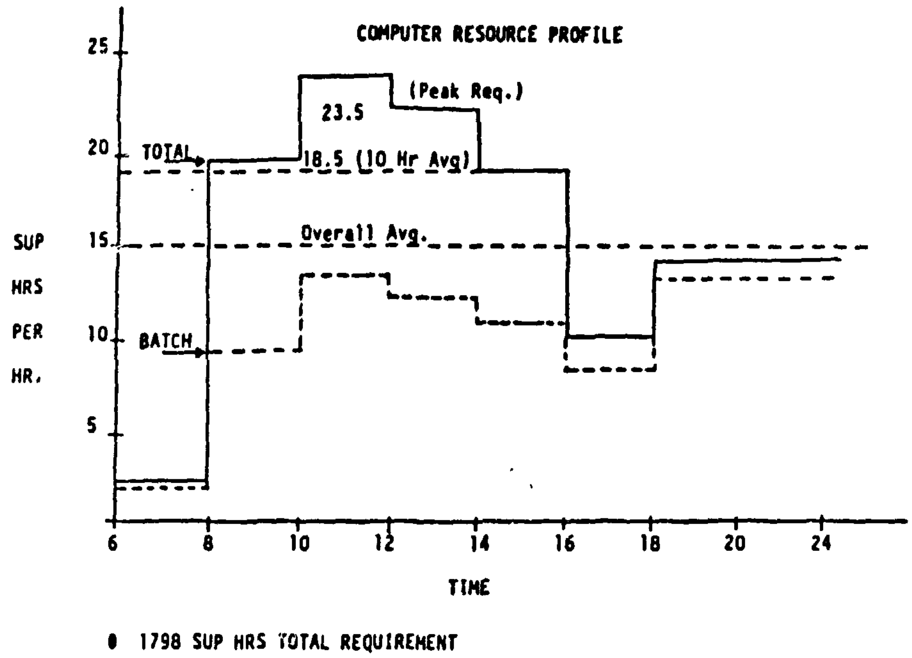


FIGURE 3.2-4



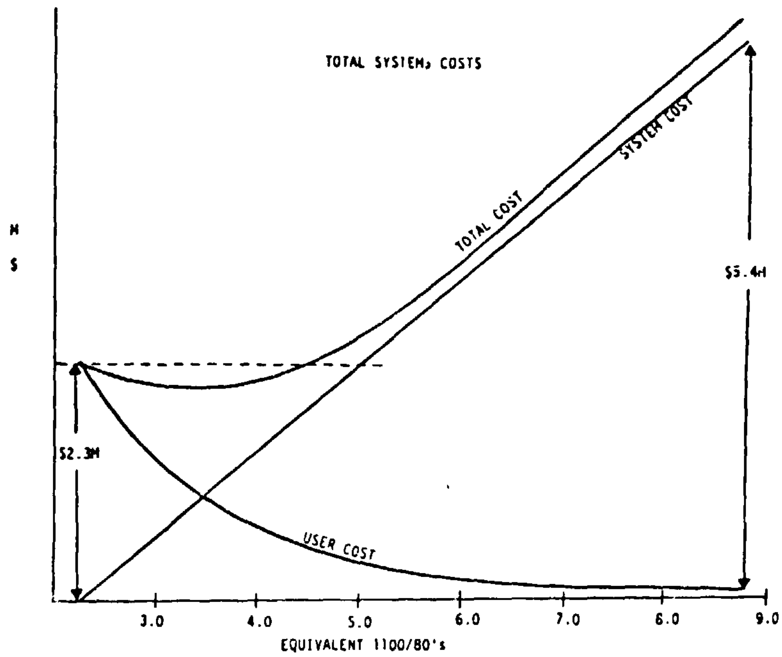
3.3 User Costs

As a result of the analysis described in the previous paragraphs, the points on the user cost curve discussed in Section 2.0 can now be determined. The analysis has provided the lost time costs of $2.3M using the configuration of an UNIVAC 1110 2X2 and 1100/81. At the time of the survey, these systems provided approximately 720 SUP hours/week. Using a 2.7 SUP hours/hour rate for an 1100/81 and 120 hours of operations, this translates to a capacity of 2.2 1100/81's. Thus, the user cost curve includes the points where the X coordinate is 2.2 equivalent 1100/81's and the Y coordinate reflects a cost of $2.3M/year in lost time.

Since, it is necessary to provide 8.8 1100/81's to eliminate lost time, the user cost curve must include the point where the X coordinate is 8.8 and the Y coordinate reflects a reduction of $2.3M/year in user lost time. Figure 3.3-1 depicts the user cost curve using these points and assuming the general shape of the user lost time curve discussed in Section 2.0. Using the same approach a systems cost curve is drawn showing the increase in systems costs to the facility to provide the required configuration to reduce user lost time costs to zero. This curve (or line) must include the following two points. The first point has an X coordinate of 2.2 equivalent 1100/81's and the Y coordinate of zero increased systems costs for the current system. The second point has an X coordinate of 8.8 equivalent 1100/81's and a Y coordinate $5.4M/year for the increased costs to support the systems capacity to eliminate user lost time. (The "system cost curve" is drawn as a straight line. This reflects the cost of the 1100/90 family and is affected by the vendor's pricing policy. This policy tends to have more of a straight line then a curved line relationship.) Using these two curves, a total cost curve was then drawn showing the sum of the "delta" costs for both the user and system. In preparing this figure the total cost to the facility for both users and system capacity was assumed to be the basis for the X axis.

The total cost curve in Fig. 3.3-1 has two X coordinates at the Y coordinate where the cost to the facility is $2.3M/year. On the left side of the curve, the system is overloaded and the cost to the facility is $2.3M/year for user lost time. This occurs at an X coordinate of 2.2 equivalent 1100/81's. On the right side of the curve, the system is not as overloaded and the cost to the facility is the sum of approximately $1M in user lost time costs and $1.3M in increased systems costs. This occurs at a X coordinate of about 4.5 equivalent 1100/81's. The minimum cost to the facility occurs at the X coordinate of about 3.5 equivalent 1100/81's. At this point, the total cost to the facility would total about $2M in both user lost time costs and increased systems capacity. Based on the total cost curve, the requirements and costs to the facility can now be quantified. It can be shown that the facility can: either retain the current configuration at a cost of $2.3M/year and continue to lose 1504 hours/week of user lost time; or can choose to provide a capacity of 8.8 equivalent 1100/81's at a cost $5.4M/year. There are also several choices in between. At the same cost of $2.3M/year the facility can choose to provide 4.5 equivalent 1100/81's at an increased cost of $1.3M/year and lost time costs of $1M/year. The minimum cost to the facility appears to occur at about 3.5 equivalent 1100/81's. At this point on the curves, the delta systems cost is about $0.8M/year and the user's lost time cost is about $1.2M/year and the total cost is about $2.0M/year.

FIGURE 3.3-1



Based on the systems costs curve, the facility can easily justify a configuration of 4.5 equivalent 1100/81's for the same cost as the current 2.2 equivalent 1100/81's. However, further justification not noted here would be necessary to justify the 8.8 equivalent 1100/81's to eliminate user lost time.

4.0 SURVEY CONCLUSIONS

MITRE made a presentation demonstrating that the cost/job: (1) is high in users lost time costs in an overloaded facility; and (2) is high in systems costs in an underutilized facility. A simple method was offered that showed that as computer resources increase, computer user's lost time decrease. In this relationship, it is possible to identify the total cost to a facility in the combination of increased systems cost and decreased users' lost time costs. To form this relationship it was necessary to identify: the cost of the user's lost time with the current computer configuration; the computer resources needed to eliminate lost time; and the cost of these computer resources.

A survey was performed on a selected division of NASA/JSC. Two questionnaires were sent to all members of this division. Three hundred twenty individuals indicated that they were users of the DPSD Central Computing Facility of 4 SPERRY 1100 computer systems. These users estimated an average loss of 4.7 hours/week. The total cost for this lost time was estimated at $2.3M/year. The same users estimated a requirement of 1798 SUP hours/week to eliminate lost time and an average of 167 concurrently active terminals. However, a profile was drawn showing that the users needed these resources primarily during the prime time. The profile indicated a peak use from 1000-1200 hours requiring a capacity of 2820 SUP hours (8.8 1100/81's). This capacity ranged downward to 1800 SUP hours of capacity (5.6 1100/81's). The profile also demonstrated a peak requirement of 204 concurrently active terminals. Using the survey information, a total cost curve was formed.

The total cost curve showed that at a cost of $2.3M/year, the facility could: continue the current system configuration of 2.2 1100/81's and lose the 4.7 hours/week/user; or increase the systems capacity to 4.5 1100/81's (an increased cost of $1.3M in system cost and decrease in user's lost time cost to $1.M/year). The total cost curve also showed that it is not cost effective to eliminate all users lost time (a savings of about $2.3M/yr.) since the cost to provide 8.8 equivalent 1100/81's is prohibitive (about $5.4M/yr.).

BIOGRAPHY

Mr. Francis T. Crucian is a Member of the Technical Staff of the MITRE Corporation with 25 years of computer system experience. He has provided support to the Johnson Space Center for over 13 years as a computer systems analyst. He has performed a variety of tasks to identify the resources needed to increase the productivity of the engineering user at JSC. Mr. Crucian is the author and co-author of numerous technical reports.

N86-15174

OFFICE AUTOMATION

THE ADMINISTRATIVE WINDOW INTO THE INTEGRATED DBMS

Georgia H. Brock
Computer Services Division
Center Support Operations Directorate
National Aeronautics and Space Administration
John F. Kennedy Space Center, FL 32899

ABSTRACT

In parallel to the evolution of Management Information Systems from simple data files to complex data bases, the stand-alone computer systems have been migrating toward fully integrated systems serving the work force. The next major productivity gain may very well be to make these highly sophisticated working level Data Base Management Systems (DBMS) serve all levels of management with reports of varying levels of detail. Most attempts by the DBMS development organization to provide useful information to management seem to bog down in the quagmire of competing working level requirements. Most large DBMS development organizations possess three to five year backlogs. Perhaps Office Automation is the vehicle that brings to pass the Management Information System that really serves management. A good office automation system manned by a team of facilitators seeking opportunities to serve end-users could go a long way toward defining a DBMS that serves management.

This paper will briefly discuss the problems of the DBMS organization, alternative approaches to solving some of the major problems, a debate about problems that may have no solution, and finally how office automation fits into the development of the Manager's Management Information System.

OFFICE AUTOMATION/SCOPE

Office automation has many facets, but the rise in administrative costs has forced industry to seek more aggressive ways of increasing administrative productivity just as has been done for decades on the assembly line. Of course, office work is not a well defined integrated process with measurable raw material and countable units of output. Therefore, the office productivity axiom assumes that if each office task can be completed faster and with more accurate information, then the composite of all the tasks will result in greater overall productivity. Even harder to measure are the real benefits such as increased profitability or reduced or avoided expenses. At NASA, productivity is measured in terms of more work done by fewer people, but the amount of work is hard to measure. Increasing launch rates are measurable, but the work involved in new space station challenges is hard to compute or even estimate. Even so, it seems logical to assume that an integrated office environment will produce efficiencies similar to the integrated assembly line. The task of automating the office in itself has potential for increasing efficiency, but every facet must be carefully considered to obtain maximum benefit without disruption and to create an atmosphere conducive to the process of favorable change. Since organizations and people tend to resist changes that create confusion and chaos in the work place, a highly structured evolutionary process must be projected. Office automation must harmonize for the benefit of the organization through increased productivity in the total management information system.

OFFICE AUTOMATION and the LARGE INTEGRATED DATA BASE MANAGEMENT SYSTEM (DBMS)

The Dynamic Evolution of the Large DBMS

It is well known that even the first computers performed simple repetitive tasks effectively. Any process that must be done over and over by the same identical method is an excellent candidate for computerization. Equally important is the computer's efficient storage and recall of data. Once stored, information can be retrieved, sorted, and reported to highlight important trends that would have been lost in most manual systems. Processing data can be a complicated mathematical model or a simple procedure that manages data to support an organization performing a job. The computerized mathematical algorithm is rather easy to imagine, but the simple procedure in support of a job can be clarified by example. For instance, the job of performing maintenance on computer hardware seems routine enough for an example of a simple procedure. The basic information is the problem report number, the work order number, the description, and the identification of the hardware component or part. Adding dates provides a history of work performed for the maintenance technician, performance information for the maintenance technician's supervisor, and identifies resolved problems and design changes for operations and design personnel. If the organization is relatively large and there are many computers operating in similar configurations, (e.g., the consoles supporting the STS subsystems in KSC's firing rooms), then the technician must be identified and the location of the hardware established. The operations personnel want timely data, so the simple computerized procedure becomes the on-line "Automated Line Replaceable Unit Tracking System." It now keeps track of the location of all spare parts, parts sent to the vendor for repair and expected due dates, etc., etc., etc. It automatically flags the on-line "Problem Reporting and Corrective Action System" when problem reports are closed. It automatically flags the on-line

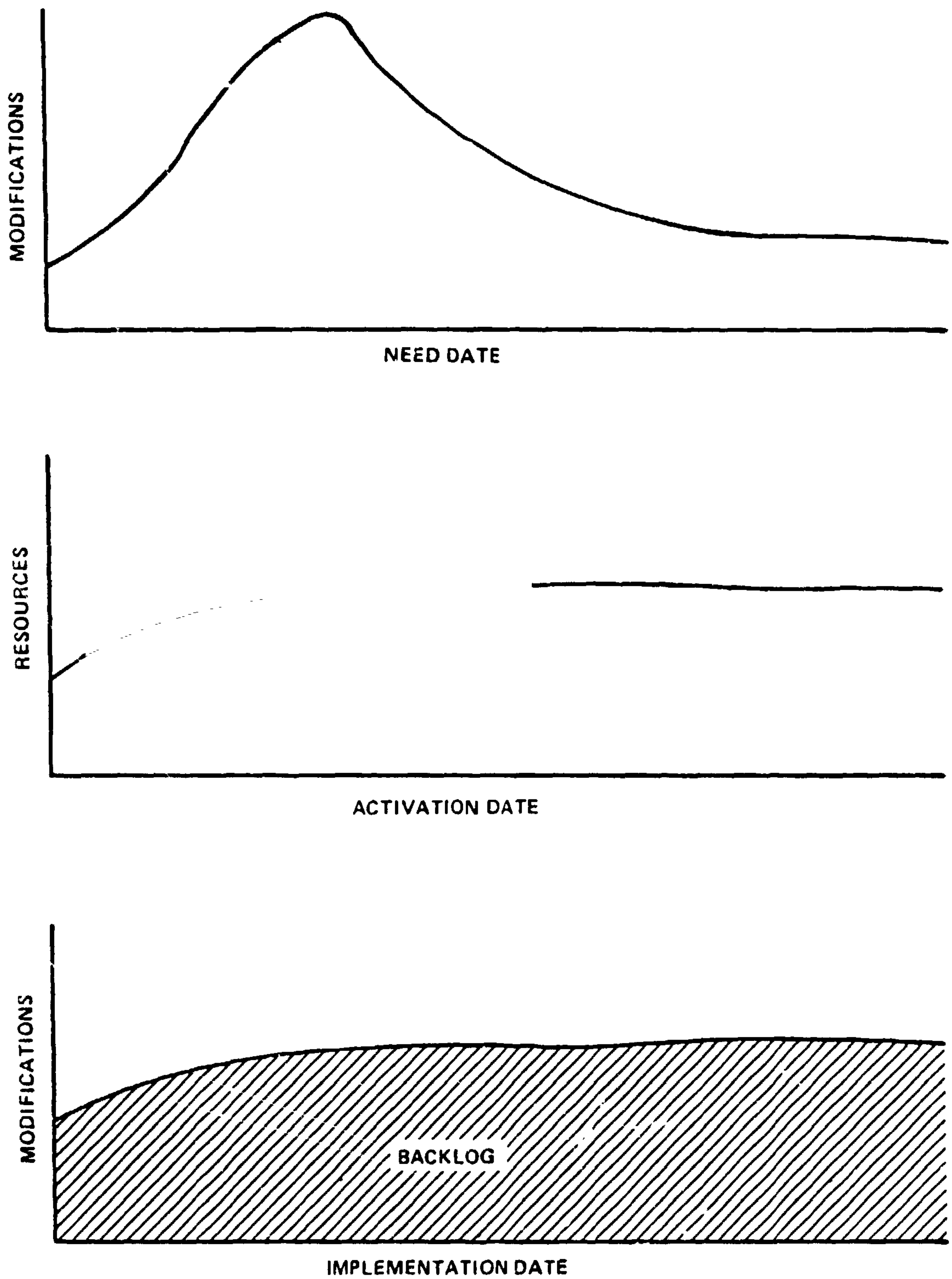
"Configuration Management Data System" when design changes are complete. It automatically flags the "Shuttle Inventory Management System" when the stock of spare computer parts is low. It interfaces with the "Automated Ground Operations Scheduling System" to schedule the work and the needed resources. Two of the systems that are notified of significant events are not on the same computer. The simple procedure has quickly grown into a sophisticated integrated networked system of DBMS's that keep track of hundreds of pieces of information that are entered by people in different NASA and contractor organizations and are protected by elaborate security procedures that ensure autonomy for the authorized organization. Since these computer programs essentially follow the flow of procedures defined to perform work, they are directly affected by each change to the procedure. Even adding volume with no logical change can affect the computer programs. The complicated mathematical model is beginning to look simple and the simple procedure is beginning to look complicated.

The Problems That Resist Solutions

What is the simple solution to large DBMS that cannot keep up with the dynamic nature of work flow procedures? Can the work flow procedures be made less dynamic? Can the computer resources be increased to accomplish more timely modifications? Both approaches are valid but are not simple or easy in a large organization.

First, examine the approach that controls the dynamic nature of work flow procedures. KSC has accomplished a major milestone along this path by combining a large number of small contracts into two large contracts for the base operations and the STS processing. A third large contract will handle cargo processing. The model of computer maintenance in the firing rooms involves the first two major contractors. By reducing the number of contractors, the work flow procedures are significantly diminished. When responsibilities are concentrated from five or six contractors to one contractor, the computer program becomes simpler. However, it must be changed. Along with the scramble to consolidate, KSC must seize the opportunity to streamline the operation. It seems that there are so many changes to the procedure that the computer programs may need a major rewrite. In the quest for stable work flow procedures, a major seismic tremor has been generated that will send shock waves through the computer systems for some time. However, as with ground faults seeking equilibrium, a more stable future computer base is the eventual derivative.

The second approach that attempts to pour more resources into the computer department so that modifications can be made quicker and easier, can certainly reduce the backlogs. However, a number of practical issues limit a total solution by using this approach. Buying major upgrades to computer systems is a very time consuming task due partly to the government procurement regulations. Increasing the staff is sometimes even harder due to the shortage of computer personnel. These two constraints prevent sizing the resources to equal the task. As Figure 1 shows, the limited resources applied to the requested modifications tends to flatten the need date curve into an



MODIFICATIONS > RESOURCES=BACKLOGS

Figure 1

implementation curve that closely resembles the activations of resources curve. Almost all of the requested modifications become backlogged items.

Where Are the Priorities - Where Should They Be?

The computer systems that have been described are Level IV work procedures. Information from these data bases feed computerized systems at Level III (e.g., Artermis schedules) and Level II (e.g., "Inter-Center Problem Reporting and Corrective Action"). The Level II data bases are used for program management, the Level III for planning and integration, and the Level IV for implementation. When the computer systems are down, the ability to get the job done is impacted at all levels. When the requested modifications are backlogged, the jobs take longer to perform. Impact to the computerized procedure directly affects the productivity of the work force at each level. The dreaded impact to workforce productivity tends to place a priority on modifications that benefit the work force rather than the modifications that benefit the managers. The reports generated from the data bases provide data to the people who do the work. Reports designed to identify trends that would be useful in making management decisions are not prevalent. Normally, professional and technical people provide management with oral and written reports that summarize progress or identify problems or issues. The data bases that support the work force could also provide valuable information. Unfortunately, these reports in their current state are usually bulky and hard to interpret. Sometimes the information is scattered across systems and computers and is very difficult to integrate. On top of all of these problems, they must be mailed or hand carried. Often the information is badly dated by the time it hits the mail drop.

The Office Automation Alternative

Office automation may be the answer to the modification bottleneck and the awkward management reporting system. If managers or their executive staffs had access to personal computers equipped with software tools to manipulate data, and these tools were networked to the large DBMS, then reports could be tailored to the individual manager and delivered electronically to the local office printer. As the staff becomes more familiar with the information in the DBMS and learns more about the power of the tools available through the personal computer, ad hoc reports designed by the staff can generate timely responses to immediate requirements for information. By expanding the hardware and software tools, both managers and workers can tap the information to suit their needs without impacting one another.

THE OFFICE AUTOMATION SOLUTION

Two Obstacles That Can Be Eliminated

In order to be effective, two major problems outside the office automation system must be solved. First, the various mainframes that host the large DBMS are either currently overloaded or operating marginally during periods of peak utilization. If office automation demands are to be met, then long range mainframe utilization patterns need to be studied and adjusted to accommodate the traffic. The office automation system could provide central hardware that would relieve a portion of the loads on the mainframes. The second major problem that needs a solution is the outmoded KSC communication plant. NASA and contractor personnel are concentrated in two major areas that are six miles apart. The Kennedy Switched Data Network (KSDN) that is currently being installed will provide the communications backbone between the major buildings and population centers. This system is basically a multiplexed twisted pair solution that will maximize the utilization of the existing cable plant. It will serve the communications requirements until growth pushes the Center toward a fiber optics replacement. Local area networks as part of the office automation system would solve some of the rigidity of the KSDN's twisted pair solution. The current 45 day lead time required to attach end user equipment to a twisted pair cable plant could be eliminated by providing local area network outlets in each room. The local area networks within major population areas and the KSDN between areas would network end users to any destination desired.

The Goals of Office Automation

There are a number of committees throughout NASA devoting their time toward achieving increased productivity through improved management information systems. Figures 2 and 3 identify the NASA Goals and the NASA-wide information system steering groups. Office automation assists in the achievement of all of these objectives.

On the local level, KSC must improve the effectiveness of NASA personnel in order to meet the increasing demands of the Shuttle multi-vehicle processing, Space Station planning, Shuttle/Centaur modifications, and various new support requirements. An integrated office automation system provides for increased productivity through the following general objectives:

- Provides more timely and integrated information access.
- Improves communications between workers.
- Implements a wide range of cost effective office automation technologies and applications.
- Facilitates decision making.

KSC's Approach to Office Automation

KSC's approach toward achieving an integrated office automation system has been to focus the activity through the Office Automation Task Team (OATT) and the ensuing Office Automation System (OAS) Source Evaluation Board. Since inception in March 1983, the OATT has conducted site visits of installed systems, reviewed the literature, canvassed the KSC community, consolidated the requirements, and defined the specifications. The OAS Source Evaluation Board issued a request for proposals in January 1985 and a source selection is scheduled for August 1985.

NASA GOALS

Presented By James Beggs on March 23, 1983

- PROVIDE FOR OUR PEOPLE A CREATIVE ENVIRONMENT AND THE BEST OF FACILITIES, SUPPORT SERVICES, AND MANAGEMENT SUPPORT SO THEY CAN PERFORM WITH EXCELLENCE NASA'S RESEARCH, DEVELOPMENT, MISSION, AND OPERATIONAL RESPONSIBILITIES.
- MAKE THE SPACE TRANSPORTATION SYSTEM FULLY OPERATIONAL AND COST EFFECTIVE IN PROVIDING ROUTINE ACCESS TO SPACE FOR DOMESTIC AND FOREIGN, COMMERCIAL, AND GOVERNMENTAL USERS.
- ESTABLISH A PERMANENT MANNED PRESENCE IN SPACE TO EXPAND THE EXPLORATION AND USE OF SPACE FOR ACTIVITIES WHICH ENHANCE THE SECURITY AND WELFARE OF MANKIND.
- CONDUCT AN EFFECTIVE AND PRODUCTIVE AERONAUTICS PROGRAM THAT CONTRIBUTES MATERIALLY TO THE ENDURING PREEMINENCE OF U.S. CIVIL AND MILITARY AVIATION.
- CONDUCT AN EFFECTIVE AND PRODUCTIVE SPACE SCIENCE PROGRAM WHICH EXPANDS HUMAN KNOWLEDGE OF THE EARTH, ITS ENVIRONMENT, THE SOLAR SYSTEM, AND THE UNIVERSE.
- CONDUCT EFFECTIVE AND PRODUCTIVE SPACE APPLICATIONS AND TECHNOLOGY PROGRAMS WHICH CONTRIBUTE MATERIALLY TOWARD U.S. LEADERSHIP AND SECURITY.
- EXPAND OPPORTUNITIES FOR U.S. PRIVATE SECTOR INVESTMENT AND INVOLVEMENT IN CIVIL SPACE AND SPACE-RELATED ACTIVITIES.
- ESTABLISH NASA AS A LEADER IN THE DEVELOPMENT AND APPLICATION OF ADVANCED TECHNOLOGY AND MANAGEMENT PRACTICES WHICH CONTRIBUTE TO SIGNIFICANT INCREASES IN BOTH AGENCY AND NATIONAL PRODUCTIVITY.

Figure 2

NASA-WIDE INFORMATION SYSTEM STEERING GROUPS

Group	Function
EIS - Electronic Information Services Working Group	Exchanges information for office automation between Centers and Headquarters.
AIMCO - Automated Information Management Council	Coordinates the development and implementation of Agency-wide ADP Systems. Membership includes representatives of all Centers plus Headquarters.
PSCN - Program Support Communications Network	Establishes guidelines and procedures to ensure nd-to-end interoperability and security for the Program Support Communication Network. This includes coordinating Center plans for gateways and support.
ICC - Intercenter Committee on ADP	Provides agency-wide oversight of ADP activities with emphasis on policy matters. Membership includes all Centers and Headquarters.

Figure 3

Practical experience with networked office automation systems has been obtained through a leased pilot OAS that is networked as well as connected to a system of data phones in key management areas. A personal computer loan pool has been established to promote the use of automated techniques. As with most government and non-government organizations, KSC has previously spent its office automation dollars on word processors for the office support personnel. Now that communications networking for stand alone units is becoming more available, the future targets for increased productivity are the managers and professionals who account for 80% of the total office personnel costs. While stand alone personal computers can increase the productivity of this group to some extent, the timely integrated reports from the large DBMS will provide a major portion of their decision support system.

Without listing every office automation technology that KSC expects to get, there have been a number of features that have been identified as critical to system acceptance by the KSC community. The office automation system must have a graphics package suitable for generating visual aids of moderate complexity, must have an integrated approach to the office systems functions, must be user friendly and responsive, must have a powerful electronic mail and filing system, and must have a comprehensive data base manager and communications capability. A major goal is to provide the networking functionality to the KSC contractors' office automation systems. Adequate training is viewed as a major key to user acceptance and system success.

Office Automation Expectations

Integrated information serving all levels of the work force and management is KSC's expectation. Planning and reporting are expected to shift from "anticipatory" to "on demand." Planning will shift from analysis to simulation. Reporting will shift from historical trend projections to real time control. Information will become more accurate, more detailed, and more available. People at all levels will become more productive.

On the other hand, the management of expectations is a critical success factor for office automation. How fast can new technologies be absorbed without disrupting the work force? Technology is a moving target - there will always be more tomorrow. There is a critical need to promote the acceptance of lags between the creation of technology and its implementation and between commercial availability of technology and meaningful user absorption. The KSC implementation plan seeks to avoid disruption, protect investments, secure acceptance, justify costs, provide functionality, and prevent obsolescence. Office automation is a process rather than a project. The office automation user for the first time will have the opportunity to solve the cumbersome manual procedure through automated methods. As the work force experiments with the tools that are available through office automation, they, the end user, will invent the office of the future through the natural selection of the useful features.

BIOGRAPHICAL STATEMENT

During her 21 years with the John F. Kennedy Space Center as a mathematician/electronics engineer, Georgia H. Brock has accrued experience across the spectrum of the information management discipline from computer systems analysis to management of large STS ground operations data bases. Her current assignment is to manage the project planning, engineering, and implementation of the KSC centerwide Office Automation System.

N86-15175

IMPROVING MANAGEMENT DECISION PROCESSES THROUGH CENTRALIZED COMMUNICATION LINKAGES

Don F. Simanton and John R. Garman, Johnson Space Center, Houston, Texas

ABSTRACT

Information flow is a critical element to intelligent and timely decision-making. At NASA's Johnson Space Center the flow of information is being automated through the use of a centralized backbone network. The theoretical basis of this network, its implications to the horizonal and vertical flow of information, and the technical challenges involved in its implementation are the focus of this paper. The importance of the use of common tools among programs and some future concerns related to file transfer, graphics transfer, and merging of voice and data are also discussed.

BACKGROUND

One of the cornerstones of quality and productivity is good informed decisions. The National Aeronautics and Space Administration is a civilian agency of the U. S. Government which has been engaged for over 25 years in research and development for air and space flight. The Johnson Space Center (JSC) in Houston, Texas, as one of NASA's nine field centers, has become the leading center in project and program management and space flight operations. Data systems have supported the decision-making processes at the Center since its inception and have continued as an integral part of the Center's activities for over 20 years. The last 10 years have brought rapid growth in computer technologies which in turn has enabled ever-increasing sophistication in the use of computers in the operational and management decision-making process. Capitalizing on these technologies is not only a challenge for JSC in striving for increasing quality and productivity in its products and activities, but is a major necessity due to the increased scope of JSC responsibilities. JSC is the lead NASA center for both the new Space Station Program and the on-going National Space Transportation System or "Space Shuttle" program.

In order to ensure an integrated approach and to provide direction to the growth of data processing at JSC, a strategic planning committee for automatic data processing (ADP) was established in 1984. Many of the concepts included in this paper are a result of the work of that committee which was presented in a formal report in the Spring of 1985.

INTRODUCTION

Information flow requires three basic elements: (1) a need to transfer information, (2) a physical connection, and (3) understandability. For example, consider two persons speaking to each other over a telephone. First, they must wish to have a conversation. Second, they must have a connection (i.e., the phone must be in order, the line must not be busy, and both persons must be present). Finally, they must be able to understand each other, as in speaking the same language and having a similar knowledge about the topic being discussed.

Transferring information in a data processing environment utilizes a similar process that also involves all three attributes. This paper deals primarily with the first two steps in the transfer: the need and the physical connection. More specifically it deals with the theoretical basis of the need and the application of that theory at JSC together with the theory of the management of a network and the way management has been accomplished at JSC. The tasks left to be accomplished and the subject of understandability will be touched on at the end of this paper.

using an adaptation of Robert Anthony's analytic model of an

THE NEED FOR INFORMATION FLOW

In an ideal organization, information flows unimpeded both horizontally (laterally) and vertically through the management structure. This flow can be best expressed by using an adaptation of Robert Anthony's analytic model of an organization [1] shown in figure 1. This model includes three levels of management structure: the strategic level, the tactical level, and the operations level. The information needs of each of these levels differs considerably. For example, the operational level is concerned with detailed information, the tactical level with summary information, and the strategic level with trends and projections.

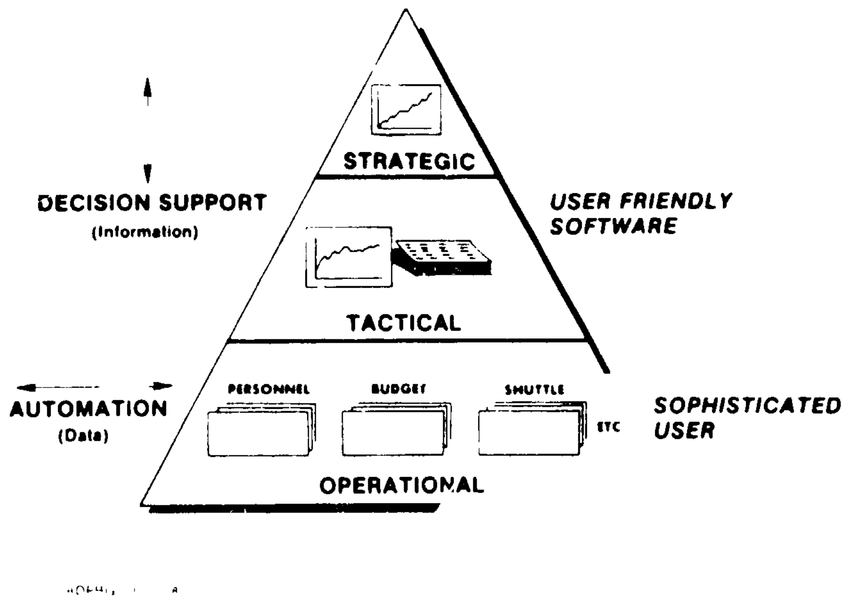


Figure 1.- Organization information model.

Traditionally the data processing industry has concerned itself with the information needs of the operational, or lowest, level. This is the level of "automation" where machines are used to enhance, or in some cases to take over, processes performed by people. Data processing has done well in this area, particularly in taking over mundane tasks involving data manipulation and in providing higher levels of accuracy and quicker responses than are possible in a totally manned environment. People using data processed at this level are familiar with the processes and the data processing required for their specialized functions and are normally characterized as sophisticated users of data processing.

At the tactical level the data processing industry is not as well established. Typical products today are standard summary charts produced by overnight "batch" (noninteractive processing) jobs. This type of reporting offers little flexibility in information available to users. However, this situation is being addressed by a new generation of application development tools, termed fourth generation languages, which have recently evolved into viable commercial products. These languages permit information queries on a relational basis thereby allowing questions to be unstructured and interactive as opposed to the rigidity imposed by the "hard coded" batch report approach. It is this unstructured aspect of the languages that has given them the name "decision support" languages. For managers can now request more than data. They can request decision information, i.e., data relationships or information from data processing reports which meets specified criteria. These languages are also more "user friendly" than those found at the operational level. This characteristic enables less sophisticated users to be effective "programmers of applications." It transfers some of the workload or "cost of ownership" of application software from providers to users, which in turn creates higher productivity and efficiency.

Until recently, the data processing industry has had little more to offer above the tactical level. Standardized summary charts were the extent of the available technology for strategic planners. Trend data could be produced but based only on previously defined criteria. Fourth generation languages and specialized packages which produce trend data and allow "what if" questions are the beginnings of what promises to be a set of powerful tools for the strategic level.

The model created above gives two driving forces for providing communication linkages within a given organization. One linkage is horizontal and primarily supports automation in the operational arena. The other linkage is an emergent one and provides a vertical flow of data through the organization. There is also third driving force, not clearly shown in this model. This force is one of providing common tools for common uses.

The Johnson Space Center can be viewed in several ways. It may be viewed from a project sense wherein there are two main projects and host of smaller ones (the main projects being the Shuttle Transportation System and the Space Station). It may also be viewed as an organization consisting of project offices, an administrative directorate, an engineering directorate, and an operations directorate. A third view might be to consider it as a collection of engineering systems, operations systems, and information systems. Figure 2 shows how these systems relate in an integrated fashion.

A tendency in any organization is to organize vertically, such that all functions needed by an organization are integral to that organization. For example, all organizational elements have need for a budget system. Thus, vertical organization at JSC provides that for each organizational element the budget system be contained within that element. This leads to separate and distinct budget systems for the project offices, the administrative directorate, the engineeering directorate, and the operations directorate. To make matters worse, these separate budget systems might also be duplicated by the program (Shuttle and/or Space Station). Hence, this structure is referred to as a "4 X 3 structure" in its tendency to create 4 X 3 sets of systems for each required function across different systems.

In the center of figure 2 [3] appears a logo for the JSC Center Information Network (CIN). The logo implies a concept whereby the 4 X 3 problem is avoided by interconnecting the data processing systems to allow the use of a shared supporting system across organizations and projects. This is the "common tools for common purposes" concept, which is the third driving force for centralized communications linkages. Conceptually it is the inverse of the more traditional federated or "departmental" systems approach. Instead of bringing complete sets of unique applications and information to each user group, all user groups are provided access to common applications. While the information structure remains highly federated ("you can't see my department's budget until I'm ready to submit it," i.e., move it up the triangle), the interfaces and bridges required for both lateral access and vertical integration are significantly reduced.

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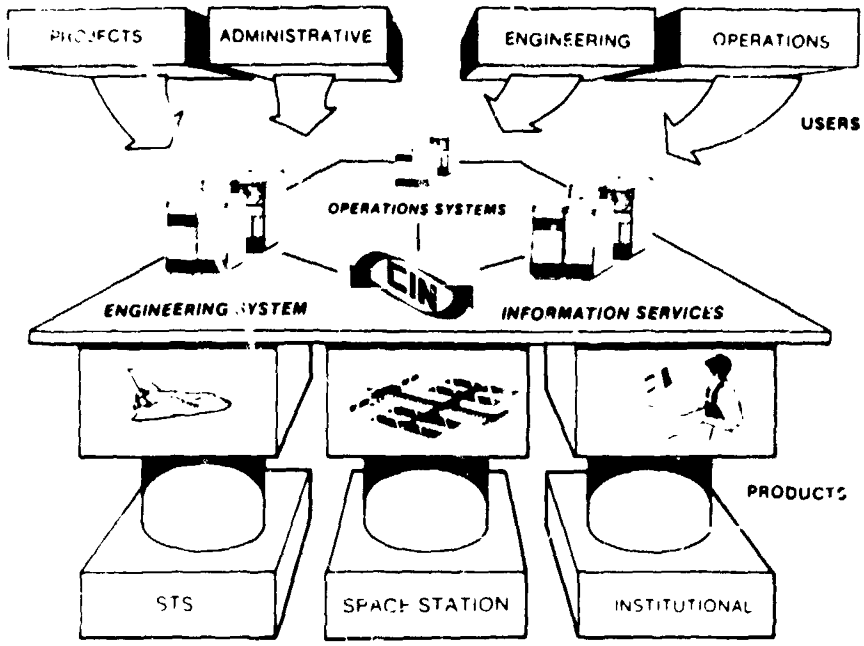

Figure 2.- "Four by three" structure.

CREATING THE PHYSICAL CONNECTION

Over the last year the forces described above have created at JSC a great emphasis to build a multinetworked series of interconnections enabling any element of the Center's data processing equipment, particularly users' workstations, to communicate with any other element of data processing equipment, particularly that which hosts common applications. Because of the universal nature of the three drivers listed above, it is anticipated that this networking will be extended to all of NASA's centers within the next two years.

The Theoretical Basis of Interconnectability

JSC uses six principal ways to network and manage data processing equipment [3]. These are:

- Connecting equipment of like architecture via front end communications processor backbone linkages when a single organization has complete control (centralized management) of all parts of the network, including attached systems software.
- Connecting equipment of like architecture via front end communications processor backbone linkages with centralized management of the environment limited to control of the network only.
- Connecting equipment of different architectures via hardware and/or software bridges.
- Connecting equipment of like architecture via separate front end backbone communications processors such that there is severability between networks.
- Connecting a terminal to more than one network via multiple interfaces at the terminal.
- Connecting networks by using a limited bridge.

Each of these methods is illustrated in figures 3 through 7 (the latter two methods are both shown in figure 7). In these diagrams the network area of responsibility is depicted by the rectangular outline in the center. The user community is shown on the left, and the host processors (applications and information) are shown on the right. The fixed components of the network are the controllers (to which the terminals attach), the backbone wiring, and the front end processors. The variable components of responsibility are the bridges and the operating system software.

In figure 3, called "Class A," the provider of network services is also the "owner" of the operating system within the host processor. This arrangement consolidates complete control (and service) over the management of the network, and the user need only be concerned with the terminal and the application running on the host.

The "Class B" situation in figure 4 differs from that of Class A in that the "ownership" of the host operating system is severed from the consolidated management control of the network. This situation accordingly requires a degree of coordination and interface as the network managers no longer have complete control of all of the components necesssary to make the network operate. The network-related systems software within the operating system must be considered the property of the network manager, who must retain approval authority for changes to that software.

Both Class A and Class B have dealt with two like (architecturally compatible) processors. "Class C" in figure 5 presents two computers of dissimilar architecture. In this case a protocol converter is needed to "bridge" the two architectures. This bridge may be "one-way" whereby one network accesses the processor of the other network but not vice versa, or it may be "two-way" whereby terminals on either network may access either network's processors.

The network shown as "Class D" in figure 6 shows a different method of interconnecting two networks. In this diagram a given host has two front end processors, one of which is connected to two separate networks. The networks shown are of like (compatible) architectures but could easily involve bridges to dissimilar architectures. The advantage of this arrangement is that the secondary network connection may be severed by "downing" the front end processor. An example of this arrangement is its use at JSC to ensure that there is no outside access to Shuttle mission supporting processors during a mission. During nonmission periods access is enabled in order to bring in development and maintenance terminals.

"Class E" in figure 7, for one example, is characterized by two networks connected in such a way that each network is not fully aware of the other. In this example in the first method a terminal has connectivity to both networks by the use of two sets of interface cards. The second method shown portrays a limited "file transfer only" bridge between the networks. These are termed method 1 and method 2, respectively.

Connectivity Issues

The bridging of multiple vendor networks raises questions of vendor cooperation. This issue is one that must be addressed both from a software product's point of view (some bridge implementations work only if certain products are installed on the other vendor's machine) and from a maintenance and problem-troubleshooting perspective. Obviously, cooperation is required during installation and also whenever a problem occurs which does not clearly belong to a given network.

When government and contractors share a common network there exists a need to provide strict access control both to application programs and to processors which may be on the network but which need not be accessed in the course of doing business. Such control may be achieved with the type of connectivity method chosen (e.g., Class E is much more restrictive than Class B), by the use of user ID's which have limited processor access, by the use of application passwords, or by a combination of all of these.

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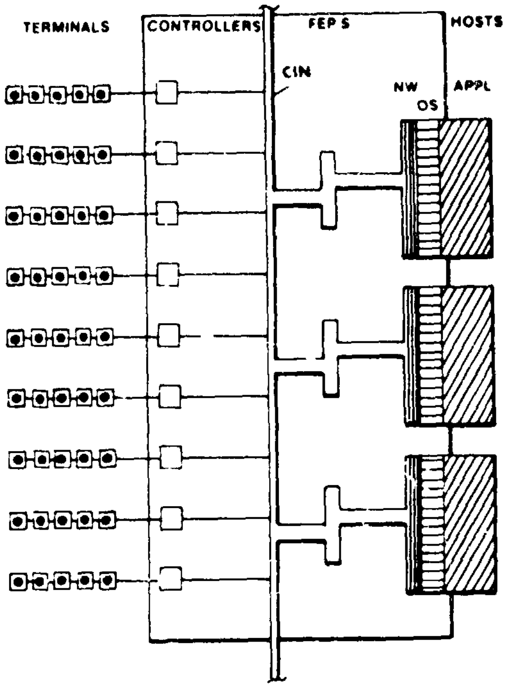

Figure 3.- Class A connection to CIN.

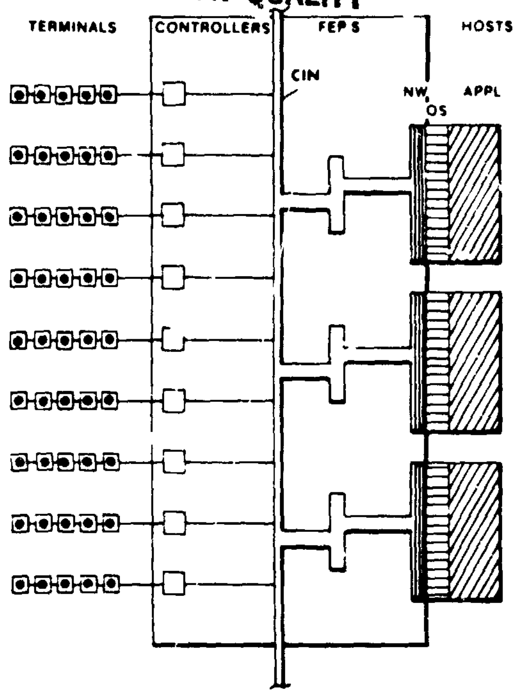

Figure 4.- Class B connection to CIN.

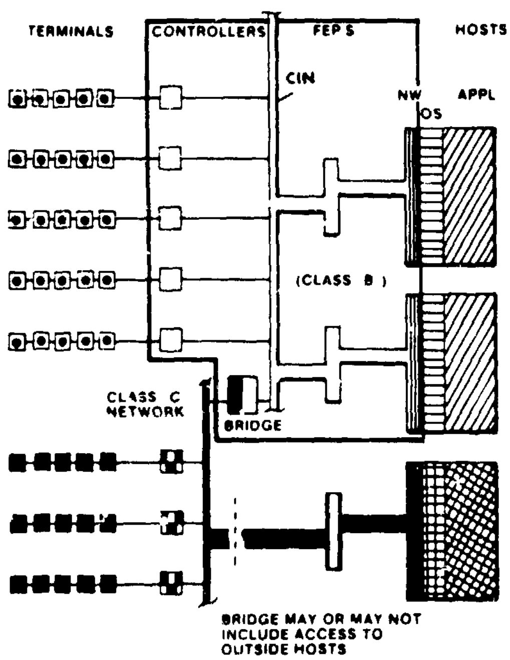

Figure 5.- Class C connection to CIN.

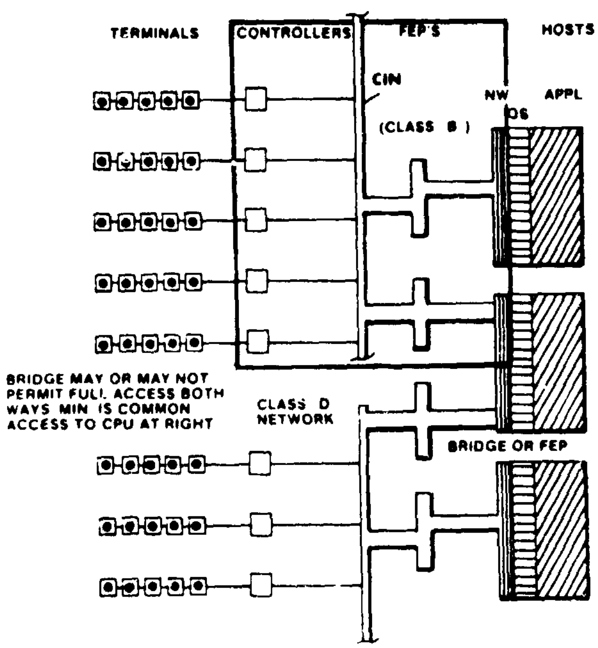

Figure 6.- Class D connection to CIN.

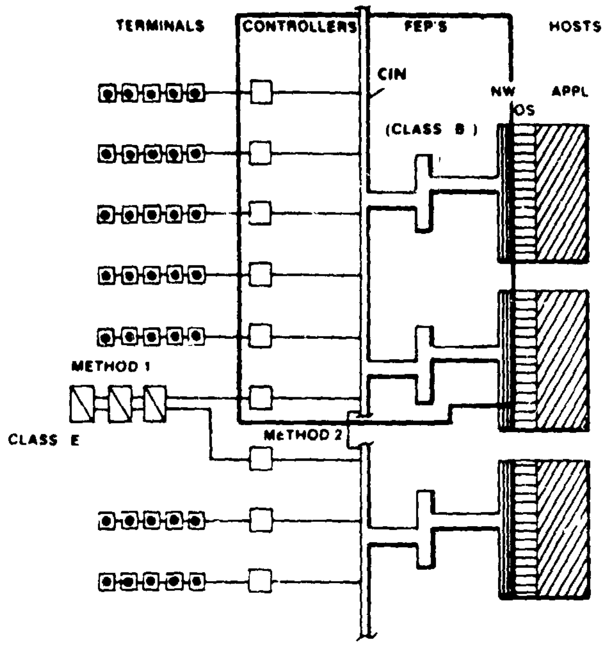

Figure 7.- Class E connection to CIN.

Security is always an issue with extensive networks, especially those which have interfaces to public telephone networks (and most large networks have at least one such linkage). The convenience that access to a public telephone network provides is of great value. Infrequent users can dial in via telephone from nearly anywhere and conduct business. The problem is that so can any "hacker." Protection measures commonly utilized include callback requirements, the limited distribution of access numbers, network passwords, and application passwords. Nevertheless, the network with an interface to a public telephone network has wide exposure to a misuse of information.

Connecting special-purpose local area networks (LAN's) is an emergent technology. In these cases the interface to the LAN appears as a terminal to the backbone network. Yet the LAN itself may comprise a number of terminals networked together. If multiple sessions can occur simultaneously across the interface, the topology of the two networks appears similar to that shown as Class C except that no processor is involved on one side of the bridge.

An extension of the LAN concept is that of connection to a wide area network (WAN), a network that connects multiple networks together over very high-speed linkages. The public telephone system is an example of a very large WAN. NASA is currently interconnecting all of its major field centers over a WAN named the Program Support Communications Network. This network uses the X.25 packet switching conventions over a network of both leased and dedicated T-1 carriers.

Building the Center Information Network

Examination and analysis of the many separate networks existing at JSC in early 1984 led management to conclude that the best way to integrate the networks was to interconnect and build on the existing IBM networks and to standardize on IBM's system network architecture (SNA) as the foundation for expansion and integration with other networks. The choice was made based on three factors. First, already in place was a substantial set of SNA networks at JSC. Second, most major vendors have or are buiding bridges to SNA. Third, SNA corresponds closely, albeit arguably, to the open systems interconnection (OSI) m· ·el. The OSI seven-layer network model is a reality toward which all vendors are wo ng, with completion expected in the 1990's.

The setting of the SNA as a standard having been accomplished, the current backbone network integrates multiple vendor products (e.g., IBM, Sperry, DEC, Xerox) covering most of the Center. Each of the six theoretical types of networks are currently either in use or planned for use at JSC. Where possible the network paths are two-way; however, currrent industry offerings limit some of the paths to a one-way terminal connection. This limitation is expected to be lifted in the next year for most vendors. A policy of "buy it, don't build it" has also been established for network growth. Although waits have occurred for needed technologies in some areas, the course of events during the past two years has proven the wisdom of the policy. In each case the required capabilities have appeared on the market prior to the time JSC could have developed an equivalent function "in-house." The product has also been far less expensive than would have been the case for in-house development.

TASKS TO BE ACCOMPLISHED

The tasks facing JSC are still enormous and pose a challenging environment. Networking is simply the first step which, furthermore, has yet to be completed.

An immediate goal is establishing true two-way connections. Transferring data files is still more constrained than is desirable and thus is not yet a widespread capability. As of the writing of this paper there is no standard for document interchange (unless standard ASCII is considered) Revisable form documents created in one brand of word processor may be electronically transmitted from one organizational element to another but they are illegible upon receipt, almost as if a speaker were conversing in Greek but the listener knew only English. Substantial need exists in this area for a dictated de facto standard supportable by many vendors.

Graphics data transfer is in even poorer condition as exchange capability from vendor to vendor is almost nonexistent. Yet graphics data is destined to play an important role in the Space Station, hence it is imperative that the various NASA centers be able to exchange graphics data if NASA is to have a well-coordinated Space Station Program. In the Shuttle Program, paper has been used as the transmission media for graphics data. In this era of increasing responsibility and decreasing budgets, however, the productivity and quality gains enjoyed through the use of data systems for engineering and technical management are becoming mandatory elements of major programs planning and costing. Finally, voice and data in combination is just over the horizon, according to the major data processing vendors. Yet no plans are yet extant to provide vendors' standards for voice and data in combination.

To accomplish these tasks, for most of which solutions remain to be found, JSC management has chosen the tactic of implementing a strategy rather than a plan. Such an approach may seem strange to an engineer in that a strategy implies certainty about an objective but uncertainty as to how to achieve it. A detailed plan does not in fact exist. Rather, prototype efforts will take place, successes will be built upon, and failures will be discarded.

Figure 8 depicts this concept of a strategy-driven approach to building and integrating data processing over a common network. An excellent description of this process may be found, incidentally, in Bernard Boar's *Application Prototyping* [2]

SUMMARY

In order to provide management with the information required for intelligent and timely decision-making, JSC ADP strategic planning has recommended the use of a

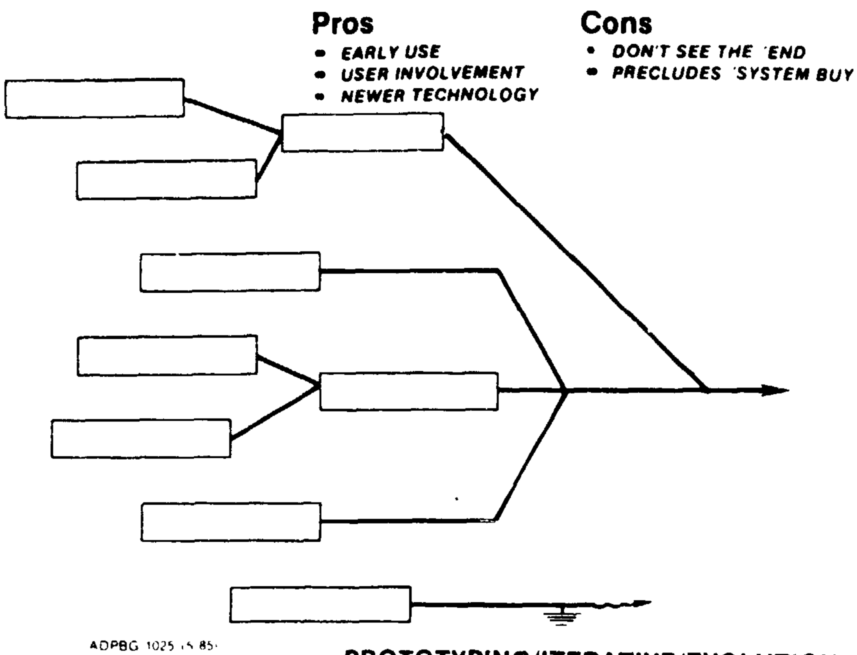

Figure 8.- Strategy-driven approach.

common network strategy. This strategy has been adopted and a theoretical plan for network management has been developed. A common architecture has been selected to ensure that connectivity exists among all organizational elements and to provide the basis for transferring data and information to all levels of management. This universal access to information combined with common tools will create new capabilities of information access to the tactical and strategic levels of management and will further promote the flow of information at the operational level of management.

The products currently supporting implementation are "state of the art" vendor products that engage only the initial aspects of the networking problem, those dealing with connectivity. Hence the network engineering task remains a challenging and path-finding exercise. Yet the network is an iceberg with but its tip showing. There remain the problems of understandability, of transferring graphics data, and of the integrated transfer of voice and data. As the networking problem evolves, corresponding management challenges will emerge from which new strategies will evolve for dealing with the problems of centralized communications linkages.

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BIOGRAPHICAL STATEMENT

Don F. Simanton is the Chief of the Systems Planning Branch of the Data Processing Systems Division at NASA's Johnson Space Center. He has been responsible for the engineering of the Center Information Network at JSC. He also was a member of the JSC ADP Strategic Planning Committee.

John R. Garman is the Chief of the Data Processing Systems Division at the Johnson Space Center. He was a member of the JSC ADP Strategic Planning Committee and was a principal in the implementation of Shuttle avionics flight software and the tools used in its development.

R&D PRODUCTIVITY ASSESSMENT

N86-15176

A PERFORMANCE MEASUREMENT SYSTEM FOR ENGINEERING SERVICES

Richard L. West, McDonnell Douglas - Houston

ABSTRACT

This paper describes a performance measurement system being developed by McDonnell Douglas Technical Services Company-Houston. Based on the Family of Measures concept proposed by the American Productivity Center, the measurement system provides both a means of monitoring performance and a resource to support management decision making. The process of performance indicator development is discussed and typical indicators are described.

The paper concludes with a summary of some of the lessons learned in applying productivity measurements to engineering services tasks and in automating data collection, evaluation and interpretation.

BACKGROUND

McDonnell Douglas Technical Services Company-Houston (MDTSCO-H) built its foundations at JSC on a small task in 1965 to convert the Gemini Mission Simulator to an Apollo Procedures Trainer. Since that time, MDTSCO-H has provided engineering and operations support on Apollo, Skylab, the Apollo Soyuz Test Project and the Space Shuttle Program. Over 1000 personnel are now a part of the Houston Operations, providing support to JSC under the Space Transportation System Engineering and Operations Support contract and supporting McDonnell Douglas Space Station Phase B studies. Ninety percent of the current employees are engineering and technical people performing non-routine tasks for the nation's space programs.

In 1982 the company proposed to NASA a streamlining program to reduce STS costs and improve mission effectiveness. In October 1982, that initiative was formalized under the STS Engineering and Operations Support Contract [2]. In early 1983, McDonnell Douglas corporate self-renewal initiatives were implemented and formed the basis for the current Quality and Productivity Improvement Program at MDTSCO-H [3]. One element of that Quality and Productivity Improvement Program is the Performance Measurement System discussed in this paper.

MOTIVATION FOR A PERFORMANCE MEASUREMENT SYSTEM (PMS)

The MDTSCO-H PMS is based on a definition of performance improvement that includes improvement in both quality and productivity. Development of a PMS as a key part of the Quality and Productivity Improvement Program was motivated by a number of factors:

- An effective PMS provides a highly visible indication of "how goes it" and a resource for management decision making.
- It allows management to diagnose the past, control current performance, and plan for the future.
- It allows management to evaluate the effectiveness of performance improvement initiatives by correlating changes in performance indicators with implementation of those initiatives.
- Finally, and perhaps most important, it provides a means for keeping everyone in the organization informed and involved in the continuous improvement of performance.

With such a list of payoffs for a PMS, the motivation for its development and implementation was clear. But, although the motivation was clear, the approach to development and implementation in an engineering services environment was not.

PMS DEVELOPMENT

The initial effort to develop a PMS at MDTSCO-H was undertaken by the Performance and Productivity Panel of the Quality and Productivity Improvement Council (QPIC). The council is comprised of the top three management levels at MDTSCO-H and is the focal point for quality and productivity initiatives [3].

In reviewing available literature on quality and productivity measurement, the Performance and Productivity Panel found extensive references related to a production manufacturing environment. In such an environment productivity was easily defined as output divided by input - widgets per dollar or widgets per hour. Quality was defined in terms of scrap - defective widgets per thousand.

Early efforts to apply such definitions to an engineering services environment proved difficult. How does one measure productivity in an environment where most products are unique; where the ascent flight design for one mission may be significantly more complex than one for a superficially similar mission? How does one quantitatively define scrap in such an environment? After several false starts the panel was introduced, through an American Productivity Center seminar, to the family of measures concept proposed by Carl G. Thor [4].

The APC Family of Measures Concept

Mr. Thor pointed out that "it is necessary, much more frequently than in a factory, to use a collection of measures rather than a single measure for a particular (professional) department." The reference provided an example of how the family of measures concept could be applied to an engineering department. This family of measures concept was adopted by the Performance and Productivity Panel. The reference further suggested a participative approach to the development of performance measurements. That approach became the nucleus for the panel's PMS Development Plan.

PMS Development Plan

The development plan outlined an approach for development of a hierarchical set of performance indicators beginning with definition of top-level (division-level) indicators by the QPIC. The top-level indicators provided a context for definition of related lower-level ones. These lower-level indicators were augmented by others unique to the particular organizational element for which they were developed.

Development of Top-level Indicators

The Performance Measurement System was intended to provide both hard and soft indicators of performance. Hard indicators included the quality, productivity and timeliness of products, and quantitative measures of fiscal performance. The soft indicators focused on performance on corporate initiatives in areas such as participative management, employee development and recognition, and other factors of quality-of-life in the workplace.

Corporate initiatives defined the major areas of performance to be measured. The QPIC began detailed development of candidate indicators for those areas using the Nominal Group Technique [4]. After an initial round-robin brainstorming and "light" editing, the resulting list of indicators was further edited, organized into categories by the director and published for further, detailed review by the full QPIC. The initial set of division-level indicators was baselined and implementation begun only after thorough discussion, redefinition, additions and deletions.

Resulting Top-level Indicators

The Division-level indicators (figure 1) consist of 31 indicators in seven categories: Business Development Effectiveness, Fiscal Health, Staffing Adequacy, Contractual Performance, Organizational Climate, Organizational Productivity/Quality of Work, and Technology Posture. A final indicator, Self-Renewal and Continuous Improvement, is calculated as a weighted average of scores in the seven categories and provides an assessment of overall performance at the division level.

FIGURE 1

INITIAL MDTSCO-H PMS DIVISION-LEVEL INDICATORS

BUSINESS DEVELOPMENT EFFECTIVENESS
- New Business Funds Expended per Dollar Sales
- Percent of Market Captured
- Additions to Backlog
- Sales as Percent of Sales at Stake

FISCAL HEALTH
- Sales
- Earnings
- Direct Labor Rate
- Overhead Rate
- Cost per Manyear Equivalent
- General and Administrative Rate

STAFFING ADEQUACY
- Percent Staffed
- Years Since Degree
- Percent of Staff with Advanced Degrees
- Grade Level Distribution

CONTRACTUAL PERFORMANCE
- Percent Authorized Hours Delivered
- Performance Evaluations (CPAF Contracts)
- Fee Deviation from Nominal (Fixed Price Contracts)
- Overrun/Underrun of Contract Value

ORGANIZATIONAL CLIMATE
- Attrition Rate
- Absenteeism
- Problem Solving Team Involvement
- Formal Awards and Recognition
- Percent of Time Spent in Training
- Workplace Visits and Boss Talks
- Percent of Workforce Trained in Juran-Deming Techniques
- Percent Supervisory Openings Filled from within

ORGANIZATIONAL PRODUCTIVITY/ QUALITY OF WORK
- Value of Streamlining Savings
- Employee Suggestion Awards
- Resources Required for Flight Preparation
- Accepted Juran Project Recommendations

TECHNOLOGY POSTURE
- Percent of Contracted Work Involving Advanced Technology

SELF-RENEWAL AND CONTINUOUS IMPROVEMENT
- Weighted Average Improvement in Indicators

The Organizational Climate category illustrates some of the soft indicators mentioned earlier. For example, the "Workplace Visits" indicator (figure 2) represents a measure of the level of "management by wandering around" (MBWA) as discussed by Peters and Austin [1]. While not an end in itself, the indicator is expected to allow assessment of the effectiveness of MBWA in the MDTSCO-H organization when correlated with other measures of organizational climate.

Hierarchical Development of Lower-Level Indicators

With division-level indicators defined, the next level of the organization - Engineering and specific Projects - began definition of their PMS indicators. Some were defined automatically as a flowdown from the division-level indicators (figure 3). Additional indicators, each specifically tailored to a particular organizational element, were defined using the same nominal group technique described earlier for division-level indicators. For example, indicators unique to the Software Engineering Department include software development productivity and conformance to software standards.

FIGURE 2

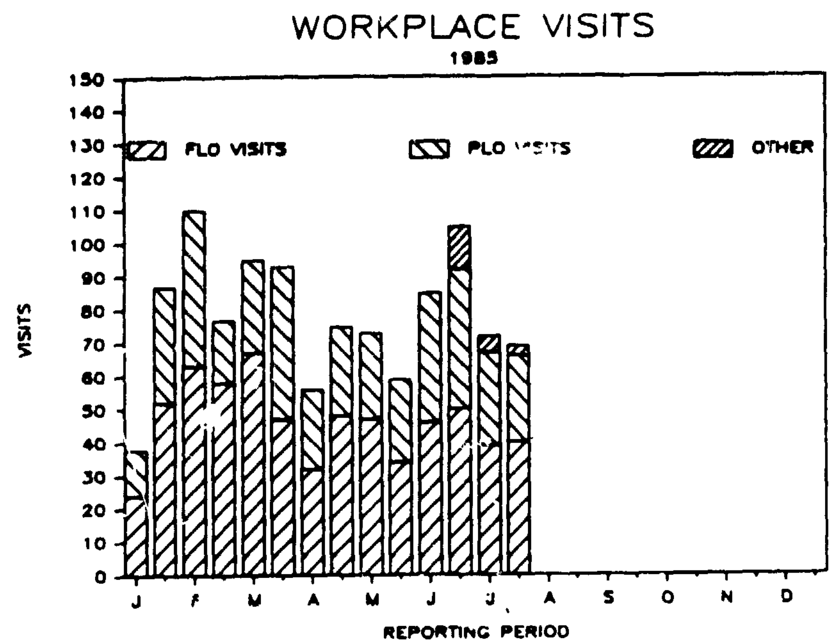
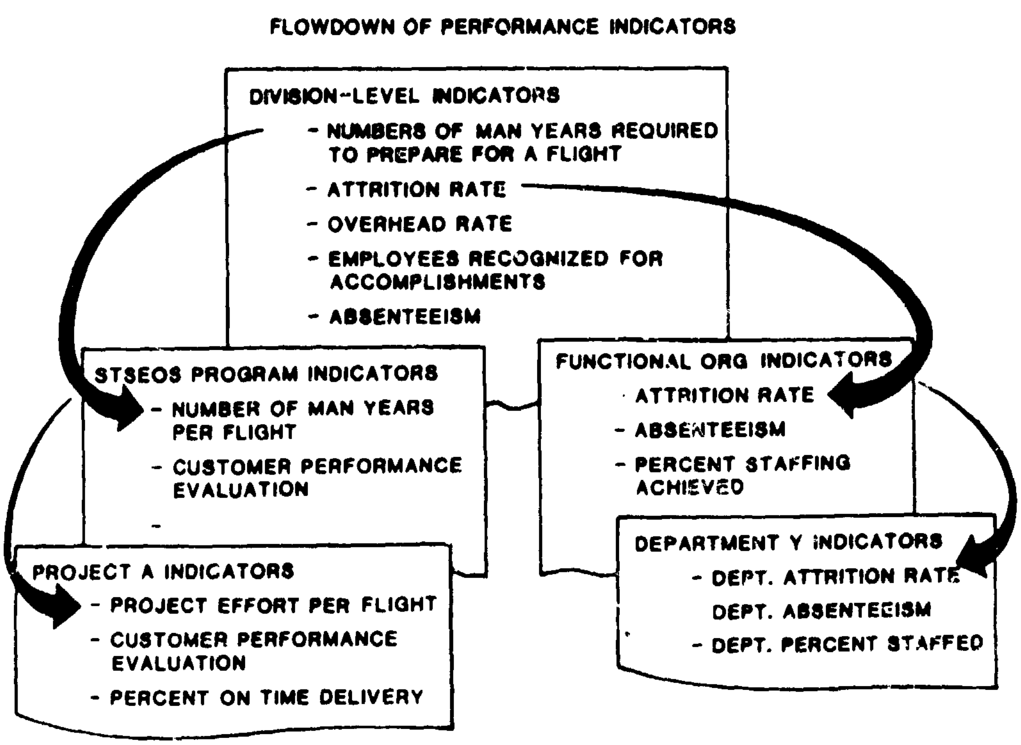


FIGURE 3



LESSONS LEARNED

Since definition of the division-level indicators was completed only last Fall, and the lower-level indicators even more recently, there are a number of lessons still to be learned. Experience to date with the MDTSCO-H PMS does allow some generalizations to be made, however, about what seemed to work effectively:

- Start at the top. This not only demonstrates top-management commitment but forces careful top-level thinking before involving a large number of people. In addition it provides the required top-level definition of indicators which lower-level indicators must support through the flow-down process.

- Once the initial definition is complete, begin implementation with a few selected indicators rather than tackling the whole list at once. Experiment. Try it out. Then use what was learned to expand implementation to the complete list.

- Don't restrict indicators to those that can be plotted as control charts. Control charts may apply for most indicators in a production manufacturing environment; in a non-routine knowledge-based engineering environment, statistical boundaries for control chart limits may not be available.

- Don't feel constrained to cast indicators in concrete. Review them periodically. Delete and add indicators to insure that the PMS really measures those factors that are key to the current and future success of the organization.

AUTOMATION

Attempts to automate the generation of PMS indicators have included several CSPEC-related activities for DoD applications and commercial software packages. Most of the division-level indicators are currently plotted using graphics programs on personal computers. Some of the indicators use a standalone program; others, depending on the complexity of calculations involved, are generated with spreadsheet programs which include an integrated graphics capability. Hierarchical measures are well suited to computer-generated spreadsheets and a number of such products are available which allow efficient consolidation of lower-level indicators to generate higher-level ones.

Generally speaking, however, the recommended approach is to concentrate initially on definition of meaningful indicators and not commit too early to automation of an immature set of measures.

A future goal is to automate as much of the PMS process as economically feasible. Expert systems may also prove to be of assistance in decision making using the indicators. For the present, however, the MDTSCO-H PMS is primarily a hands-on, manual system, under internal evaluation.

CONCLUSION

The MDTSCO-H Performance Measurement System represents an effort to measure performance for an engineering services organization. In addition to measuring the usual hard parameters such as sales, return on investment, etc., the system is designed to provide an indication of performance in other areas of corporate initiatives.

The family of measures concept and use of the nominal group technique were found to be effective means for defining performance indicators at all levels of the organization. The current indicators represent a beginning. They, like the organization whose performance they measure, will evolve as MDTSCO-H presses forward on the path of continuous improvement.

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BIOGRAPHY

Richard West is a Principal Staff Engineer with McDonnell Douglas Technical Services Company-Houston. He has 26 years of experience in the aerospace industry. In his current assignment as Assistant to the Director, he is responsible for coordinating the development and implementation of Division-Level indicators for the MDTSCO-H Performance Measurement System.

IMPROVING ENGINEERING EFFECTIVENESS

N86-15177

SOME KEY CONSIDERATIONS IN EVOLVING A COMPUTER SYSTEMS AND SOFTWARE ENGINEERING SUPPORT ENVIRONMENT FOR THE SPACE STATION PROGRAM

Charles W. McKay
Rodney L. Bown
University of Houston Clear Lake

ABSTRACT

The space station data management system involves networks of computing resources that must work cooperatively and reliably over an indefinite life span. This program requires a long schedule of modular growth and an even longer period of maintenance and operation. The development and operation of space station computing resources will involve a spectrum of systems and software life cycle activities distributed across a variety of hosts, an integration, verification, and validation host with test bed, and distributed targets. This paper identifies the requirement for the early establishment and use of an appropriate Computer Systems and Software Engineering Support Environment. This environment will support the Research and Development Productivity challenges presented by the space station computing system.

CONTEXT AND CHALLENGE

The Space Station Program is different from past NASA projects in that it will provide the capability to support a permanent manned presence in space. The computing resources will provide an end-to-end information system that will evolve over approximately 20 years and remain operational for an indefinite period. At maturity, the Space Station Program will involve networks of computing resources located on the ground, in low earth orbit, in higher orbits, and hopefully on a permanent manned station on the moon. There will be vehicles operating between the earth, multiple space stations, free flying platforms, moon and deep space. Such a program is likely to require the largest number of processors ever embedded in an integrated end-to-end system. These processors must work cooperatively and reliably to maintain the system's integrity and quality of services in spite of their physical separation in space. More than ever before, the key to building and operating an adaptable, reliable system is believed to be the early establishment and use of an appropriate Computer Systems and Software Engineering Support Environment. This environment will support the technical response to the research and development challenges of the NASA space station computing system.

*Ada is the trademark of the US Government, Ada Joint Programming Office

APPROACH TO THE PROBLEM

Parallel Research

The space station data management system can be divided into three functional areas:

1. Network Communication Services (NCS)
2. Network Information Services (NIS)
3. Network Applications Services (NAS)

This functional division will maximize the opportunities for parallel research in related areas of concern. This approach is illustrated in Figure 1 which shows three types of Local Area Networks (LAN's) expected to be in day-to-day use by year 2000.

The scenario of Figure 1 exhibits Space Station #1, Ground Support Station #27, and Manned Orbital Transfer Vehicle #3. Each local area network is shown to be functionally divided into clusters. Each cluster is made up of three functional components: NCS, NIS, and NAS. The lowest layers of the NCS component can be connected to a local area network media (eg, a fiber optic ring) to a gateway to another LAN or to a transmitter/receiver to remotely located LAN's (eg, a radio frequency link or a laser beam link). These lowest level NCS connections form stable interface points, if they conform to emerging International Standards Organization's Open Systems Interconnection (OSI) model.

The mort challenging (and important) stable interface point for the purpose of facilitating the parallel research activities is the one at the junction of the three cluster components. A definition of the software and hardware protocols, that govern exchanges among the three components should allow researchers to combine the best of their work for study. This assumes that each group of researchers applies modern principles of computer systems and software engineering with regard to: layered design, management of abstract objects, and provision of fault tolerance within an environment containing both real time and data driven applications.

Proposed 1990 Environment

The best baseline for a 1990 software engineering support environment is a mature Minimal Ada Progamming Support Environment (MAPSE). However this minimal toolset is insufficient by itself. By 1990 there should be a commonly accepted model and vocabulary for the project data base and for enforcing the configuration management policies. This common model and vocabulary make possible the development of: a reuseable component library applicable to every phase of the life cycle; highly automated technical tools which reenforce methodologies appropriate for the various life cycle phases; and highly automated management tools which complement the technical tools.

As shown in Figure 2, this proposed 1990 environment should support the continual evolution of the system engineering requirements. When enough of the system engineering requirements are sufficiently understood, work can proceed in parallel to begin to determine the software engineering requirements. Continuing this highly iterative feedback process, the work can progress to determine the hardware engineering requirements. Throughout all three activities there is a need to manage people and logistics. As summarized at the bottom of the Figure, this is a highly iterative process of considering systems, software and hardware where all information for all phases of the life cycle are input into a CAIS (Common APSE Interface Set) conforming project database with well understood configuration change management. The engineering process is aided by a highly automated set of advance technical tools. In turn the appropriate use of the advanced technical tools are reenforced by a highly automated set of complementary management tools. This envronment will also support the changing maintenance requirements over the entire life cycle of the data management system.

Working Definition

The upper half of Figure 3 proposes a working definition for the software engineering process just described (adapted from Ross, Goodenough, Irvine, 1975 [4]). The key to this definition is the recognition of the five goals of software engineering (ie, not just "correct"). It is most unfortunate that the rush to produce code which can be demonstrated to pass acceptance tests often produces software at costs which are typically less than 20% of the life cycle costs of the software. Over 80% of today's software costs are incurred in maintenance and operation attempts to modify the software to meet changing requirements, to repair the software, and to tune the software. The difficulties associated with modifying software in a safe and reliable manner that is correct, efficient and understandable were among the principal concerns of the designers of the MAPSE and CAIS.

The bottom of Figure 3 shows the traditional view of the major phases of the software life cycle depicted in the textbooks. However the top half of Figure 4 is believed to be a far more realistic view of the highly interactive life cycle phases for projects such as space station. As shown, the work commences with the analysis of systems engineering requirements. At some point the system requirements are sufficiently understood to enable work to begin in parallel on the software engineering requirements. This highly iterative work is fed into the project data base possibly producing changes in the preceding work. These effects ripple through the other phases of the work. When the software engineering requirements are sufficently understood a third parallel activity (the analysis of the hardware requirements) can also begin.

It is important to realize that the effects of these iterative interactions can be stimulated from any point along a continuum of requirements analysis activities. At one end of the continuum we deal with "illuminated" issues (things we understand very well). Typically we analyze and represent such requirements in a highly procedure driven fashion. This gives rise to the 'myth' of proceeding in distinct steps from one phase of the life cycle to the next phase in a stairstep or waterfall sequence of activities. Unfortunately these are the easy issues to deal with. At the other end of the continuum are the "dark" issues. Typically the analysis and representation of such requirements cannot begin in the same procedure driven fashion as the activities at the illuminated end. These nonprocedural activities are more likely to be driven by insights gained from intuition, inference and investigation. Rapid prototyping, simulating, and artificial intelligence techniques can be very useful in gaining these insights.

STEPS TO THE 1990 SOLUTION

Minimal Toolset

The minimal toolset is exhibited in Figure 5. The MAPSE depicted in the upper part of the figure consists of the services of a KAPSE (Kernel of the APSE) which interfaces to the other CAIS conforming MAPSE tools and the project data base. The six functional divisions of the MAPSE tools which sit on top of the KAPSE are: the compiler, the editor, the linking loader, the command language, the debugging tools and configuration management tools. It is important to realize that the MAPSE toolset is relatively independent of methodology and will provide the most help to the software engineer during the development phase of the life cycle.

Advanced technical tools are needed to reeforce specific methodologies appropriate for earlier and later phases of the life cycle. Unfortunately an integrated set of tools appropriate for the life cycle of a project such as the space station does not exist at this time. Three steps are essential in order to meet the 1990 goals mentioned earlier.

The Steps

The first step is to establish a minimum baseline to begin the development of the system and software support environment. This would include a mature CAIS conforming MAPSE. The second step is to identify and select appropriate methodologies for all phases of the life cycle. This includes methodologies for identifying and developing those reuseable components which have a high potential for return-on-investment. The third step is to build the reenforcing tools which facilitate and reward the appropriate use of the methodologies. This step is divided into two essential parts. The tools to reenforce the technical methodologies must be reasonably well understood before the complementary advanced tools to support management can be developed.

Slice of Life

Figure 6 shows a slice of the life cycle [3]. Essentially this view is applicable to any phase of the life cycle or any step within any phase. It begins with a representation of the problem (or a proposed representation) which is now ready to be transformed according to some methodology into a new representation which is closer to the solution of the problem. The representation is fed into the project data base and appropriate verification and validation techniques are applied to insure that the new representation conforms to the letter and the spirit of the previous representation. The verification and validation results also enter the project data base and feedback is used to fine tune earlier steps. The bottom of Figure 6 applies this view macroscopically to the phases. Initial concepts of the problem space are transformed into a requirements analysis document. The requirements analysis document consists of two major divisions: the "shalls" which must be demonstrated at acceptance test time and the "shoulds" which are vital to the life cycle success of the project but which cannot be dichotomously demonstrated on a pass-fail basis at acceptance test time.

The "shalls" of the requirements analysis document are transformed by an appropriate methodology into a design specification document. The design specification document specifies in annotated, compilable Ada package specification form: what processing is to be demonstrated at acceptance test time, how well the processing is to be performed and under what circumstances the processing is to be performed. The design team can then consider the various design alternatives which would meet the design specifications. The design alternatives can then be evaluated in the context of the "shoulds" of the requirements analysis document. A professional engineering judgement is used to select the best design alternative.

Application of the Slice of Life

The model of the slice of the life cycle can also be applied in a more microscopic sense to steps within the various phases. For example, the bottom half of Figure 4 shows an expansion of the requirements analysis phase for large complex systems. Each of the four overlapping activities can be subdivided into four parts: analysis, partitioning, allocation, and synthesis [2].

For example, the first activity can begin with an analysis of how many types of local area networks are appropriate to accomplish the goals of the space station program. This may result in a first pass at partitioning the computing requirements among local area networks to be located on the ground, on space station, on free flying platforms, and on other types of local area networks. As shown in the figure the principal requirements analysis team can continue their work while a selection of task forces can now begin the analysis of their particular LAN assignments. One team may analyze the LAN requirements for space station while other teams analyze the requirements of other entities. Each of these task forces will eventually reach the point of partitioning their work into various computing requirements.

The task force focusing on the space station may determine that a fully mature space station would have "N" clusters of computing requirements (eg, a guidance, navigation and control cluster; a health maintenance facility cluster; and others). As a result of this partitioning, new task forces can be assigned additional parallel activities to begin a more detailed analysis of the requirements for each of these computing clusters. At some point the further partitioning of the requirements of each of the clusters is analyzed in the context of the whole program so that common denominators can be factored into cluster components such as Network Communication Services, Network Information Services and Network Application Services.

The second phase of the life cycle is macroscopically shown at the bottom of Figure 6 as the second transformation step which leads from a requirements analysis document to a design specification document. However this phase can be subdivided into a more microscopic expansion of the design specification steps as shown in Figure 7 [1]. The second step of this phase is particularly important to good systems and software engineering. This step produces a representation referred to as the abstract functional specification. A characteristic of a good abstract functional spec is the separation of engineering concerns that allows the more difficult issues to be analyzed with respect to risk and the probability of impact by future change.

Those "dark" issues identified to be "at risk" can be identified in the project data base and can quickly be assigned to feasibility task forces. For each of these issues, the feasibility task force should begin by doing a saturation study. The purpose of the saturation study is to determine if a solution to the issue has been found by others and if the solution is documented and accessible to the team. If the team can convince their peers that they now know how to solve the problem, the issue may be removed from the "at risk" list in the project data base. The feedback from the project data base then allows this issue to progress to the next transformation. In many cases, however, the issue identified will not have been solved in the same context as the current application or there is insufficient information available.

The team may proceed to the consideration of detailed scenarios. It is possible that structrued-walk throughs of detailed scenarios may succeed in convincing the team and their peers that the issues are sufficently understood to be removed from the "at risk" list. Unfortunately a number of these walk throughs succeed in improving the team's understanding of the problem but not in convincing them they have a satisfactory solution.

Rapid Protyping

It is then appropriate for the task force to build a rapid prototype. The rapid prototype is not a rapid prototype of the entire system. Instead it focuses on the separate concern which was considered to be at risk. If the understanding that emerges from work with the rapid prototype convinces the team and their peers that the issue can now be removed from the "at risk" list then the next transformation step can begin. Upon some occasions a rapid prototype may be a less appropriate approach than a simulation. Even more frequently the rapid prototype may require interactions with simulations of the remainder of the environment. This is an area which is not well understood at the present time.

THE 1990 ANSWER

To summarize the preceeding sections, a computer systems and software engineering support environment appropriate for 1990 implies a mature, CAIS conforming MAPSE has been extended to provide the following: an integrated and highly automated support environment consisting of a life cycle data base, a project library with a large collection of reusable components, good configuration change management, advanced technical tools, and advanced management tools for use with distributed hosts, distributed targets, and an integration, verification and validation host with testbed.

ACKNOWLEDGEMENT

This work has been supported in part by NASA Contract Number 9-17010. In addition to their colleagues at NASA Johnson Space Center and the University of Houston Clear Lake, the authors gratefully acknowledge the support of the participating contractors and manufacturers which make the work of the Joint NASA/JSC UH CL APSE Beta Test Site possible .

APPENDIX 1

The NASA/JSC UH-CL APSE Beta Test Site was established in September 1983. The test site team has grown to 25 organizations supplying 76 researchers. There are 64 tasks underway. The task order for the teams is titled:

"Research in the Application of the Ada Programming Support Environment to the Life Cycle of Large, Complex, Distributed Computing Applications"

The purpose is stated in the task order as:

"The research will address the application of the Ada Programming Support Environment to large, Complex, distributed computing applications (such as the Space Program) with a

- long schedule of modular growth (eg, 10..30 years) and a
- longer life cycle

involving

- distributed hosts
- distributed targets, and an
- integration, verification and validation host and test bed.

In particular the research will focus upon the issues which are not well understood (ie, 'dark' issues) in the computer systems and software engineering of such applications. The goals of the research are to

- identify and
- illuminate these 'dark' areas and to
- reduce the areas 'at risk'."

APPENDIX 2

Terse definitions of space station computing terms are listed below:

Ada* Augusta Ada Bryon, Countess of Lovelace, daughter of Lord Byron was the assistant and patron of Charles Babbage and worked on his mechanical analytical engine. (The world's first programmer). Also the high level language of the U. S. Department of Defense. *Ada is a registered trademark of the U. S. Government Ada Joint Program Office

APSE	Ada Programming Support Environment
CAIS	Common APSE Interface Set
GAN	Global Area Network
ISO/OSI	International Standards Organization Open System Interconnect (The seven level network communications model)
JSC	Johnson Space Center
KAPSE	Kernel APSE
LAN	Local Area Network
MAPSE	Minimal APSE
NAS	Network Application Services
NCS	Network Communication Services
NIS	Network Information Services
RAN	Remote Area Network
UH CL	University of Houston Clear Lake

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Charles W. McKay

Professor and Director of the High Technologies Laboratory at the Univ. of Houston Clear Lake. Dr. McKay is responsible for directing the research and development efforts of the Joint NASA/JSC UH CL Ada Beta Test Site. The test site team consists of approximately 25 companies and 75 principal investigators. This team is researching the application of the Ada Programming Support Environment and Software Engineering Principles to the NASA Space Station.

Rodney L. Bown

Associate Professor and the Technical Coordinator of the High Technologies Laboratory at the UH CL. Dr. Bown is responsible for coordinating the technical activities of the Joint NASA/JSC UH CL Ada Beta Test Site.

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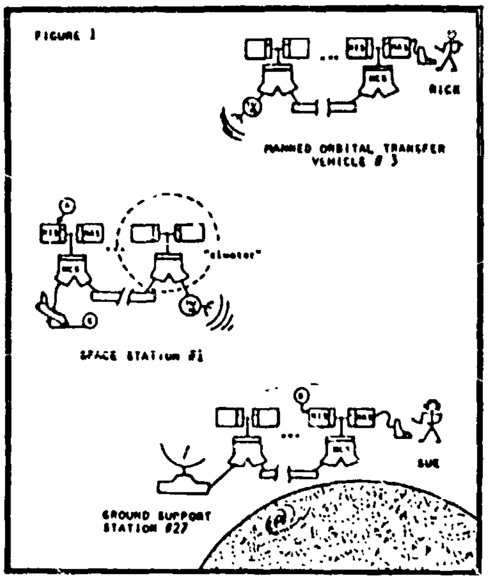


PROPOSED SCENARIOS FOR SPACE STATION SYSTEMS
by Dr. Charles W. McKay

LEGEND
NIS: Network Information Service
NAS: Network Application Service
NCS: Network Communication Service
TX/RC: Transmitter/Receiver

FIGURE 2

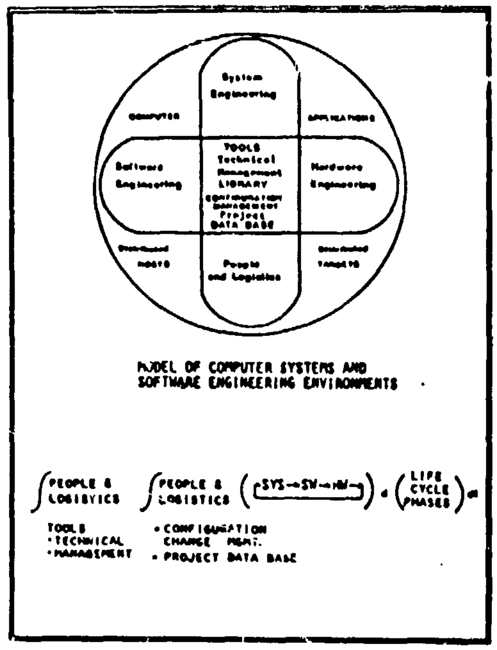


FIGURE 3

A WORKING DEFINITION

(PROPOSED AS A STEP TOWARD THE SOLUTION)

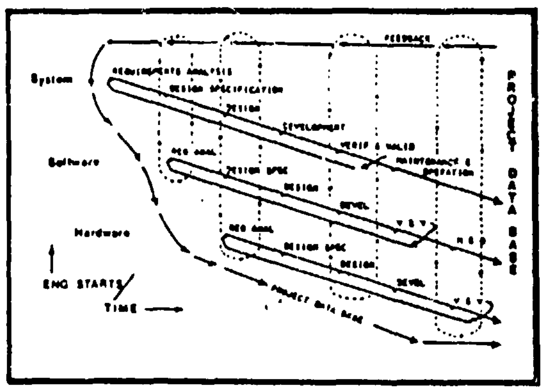
Software Engineering: the establishment and use of sound engineering principles, methods and tools to support processing which is:

- Correct
- Modifiable
- Reliable
- Efficient
- Understandable

} Goals of Software Engineering

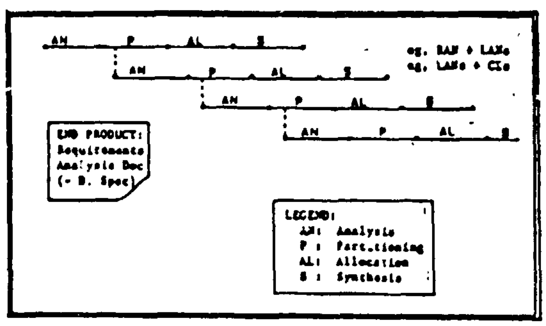
throughout the life cycle of the application.

FIGURE 4



MAJOR PHASES OF THE SOFTWARE LIFE CYCLE:

	(from the perspective of) Developer:	Customer:
• Requirements Analysis	10%	
• Design Specifications	10%	
• Design	15%	
• Development	20%	20%
• Verification and Validation		
. Module level	25%	
. Integration	20%	
• Maintenance and Operation	0	80%



REQUIREMENTS ANALYSIS PHASE 'BLOW UP': SYSTEM LEVEL

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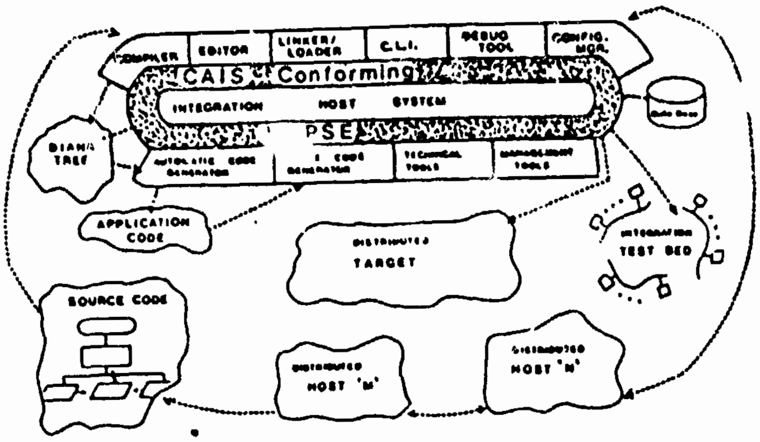
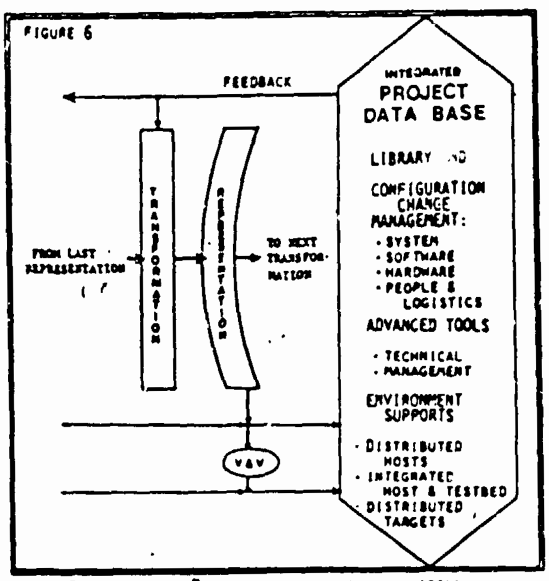
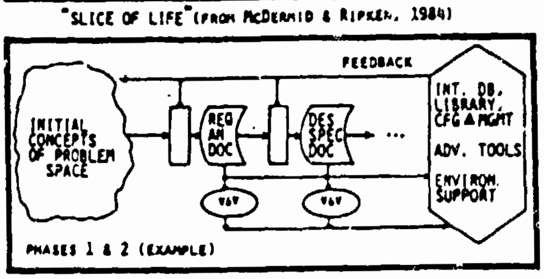
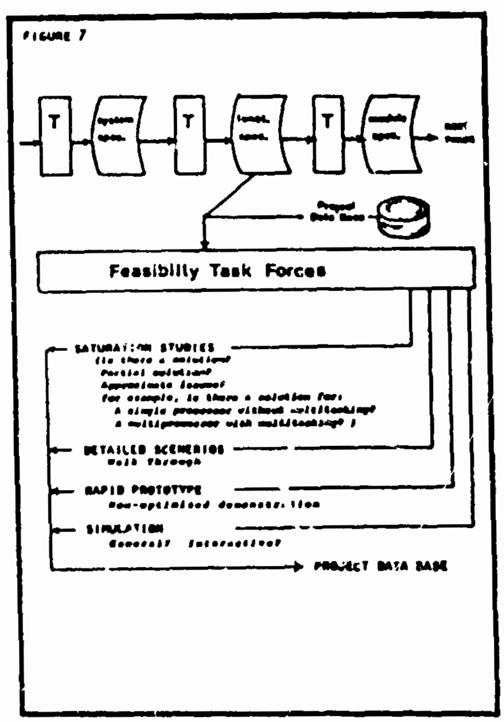


FIGURE 5



"SLICE OF LIFE" (FROM McDERMID & RIPKEN, 1984)





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N86-15178

PRODUCTIVITY IMPROVEMENT IN ENGINEERING AT ROCKETDYNE

R. M. Nordlund, S. T. Vogt, A. K. Woo

Rockwell International/Rocketdyne Division
Canoga Park, California

ABSTRACT

The Rocketdyne Division of Rockwell International has embarked on a productivity improvement program in engineering. This effort included participation in the White Collar Productivity Improvement (WCPI) project sponsored by the American Productivity Center. A number of things have been learned through this project. It seems that any productivity improvement project should be employee driven. The Rocketdyne project was essentially started as a result of a grass-roots effort to remove some particular hindrances, and employee enthusiam was a prime factor in the continuing progress of the effort. A significant result was that awareness of problems at all levels increased. Many issues surfaced in the diagnostic phase, and were then noted and discussed. This process added legitimacy to issues that had previously been merely unspoken concerns. The initial feelings of many members of the pilot group was that significant changes would occur relatively quickly. It is now recognized that this will have to be an ongoing, long-term effort. A wealth of insight is contained in the pilot group, and keeping all those people involved ensures their continuing contribution to increasing their own productivity. An added benefit to keeping a large number of people involved is that as changes are proposed and tried, there is increased acceptance because those affected have contributed to the changes. Thus, it is evident that this degree of employee involvement has made Rocketdyne's program successful.

DISCUSSION

The Rocketdyne Division of Rockwell International is a company of approximately 7000 employees. The primary products of this division are liquid rocket engines. Rocketdyne designs, develops, and manufactures low volume, sophisticated rocket engines and related technology products that are often in the public eye. This type of company and this type of work commands an engineering staff comprised of dedicated and very capable individuals.

American business and culture has entered into an era when productivity in the work force is in the forefront of its attention.

Costs of doing business, and staying in business, are high and will only increase. The primary survival technique is to become as productive as possible. This is especially important at Rocketdyne, where expensive and low volume products are sold almost exclusively to government agencies that recently have gained a renewed cost containment focus and are willing to change contractors to spread out the available funds.

Rocketdyne, along with other members of the aerospace industry, was hit extremely hard in the early 1970s. Companies were forced to drastically cut back by reducing the size of the facilities and the number of employees. A few years passed while regrouping and working to develop new products. Due to key contracts such as the Space Shuttle Main Engine, Rocketdyne began to grow and expand. As a result of this growth and expansion, a large fraction of the present engineering staff is young. This has created an interesting bimodal work force of older employees who were retained throughout the earlier layoffs and the newer, younger employees.

The productivity influence in this environment manifests itself differently on individual employees. Changes to increase productivity are generally changes to the traditional or comfortable way of operation. Resistance to change varies between people, but typically increases with age and/or experience. Thus, the bimodal employee age profile stratifies employees in response to change.

In addition to this employee stratification, there are significant differences in personal insights, values, cultural background, job history, and work ethics. The combination of stratification along different lines and simple personal differences has created a nonhomogeneous engineering staff that is not bound to traditional lines of thought. The lack of continuity throughout the engineering staff is reflected by a lack of subscription to the company line. In light of the industry requirement for a more productive work force, this cross section of employees has been primed for response.

The most straightforward means toward increased productivity in the work force is in the manufacturing or production area. Because of this, Employee Action Circles (Quality Circles) were fostered and developed among the manufacturing personnel. These groups were directed toward problem solving and streamlining the manufacturing process. Realizing the relationship between good engineering and a smooth and efficient manufacturing process, the idea of similar problem solving groups within the engineering department was suggested.

In May of 1983, a first line manager in the Engineering Design Technology Department was asked to coordinate such a group with the help of a Quality Circle facilitator. Because Employee Action Circles were viewed as a blue collar activity, this white collar group was called a Nominal Group Technique (NGT) group, after the methodology to be used in the problem identification and solving process. Involvement with the group was voluntary, and invitations were extended to the members of the manager's unit. The purpose of the group was to look at ways to increase the employees' productivity.

News of an employee group formed to legitimately raise and address common productivity concerns spread throughout the engineering department. There were numerous productivity sore points among the engineers, and an NGT group was viewed as an opportunity to have a say in making the organization function more effectively. The timing was fortunate, for there were lingering doubts about management initiated productivity programs that had recently been attempted. Earlier activities, such as an intimidating personal time usage study summarized in pie charts and productivity increase news bulletins the engineers were instructed to write on a quota basis, had left a bad taste among the engineering staff. An NGT group appeared to be a way engineers could creatively address and identify productivity obstacles, and then work toward their elimination.

More than a way to help the company become more competitive, profitable, or more secure in its business sector, interest in increased productivity was seen by the engineering staff as a way to eliminate or reduce frustration and obstacles standing in the way of doing the challenging and interesting work they were hired to do. Increased productivity would mean the ability to be free to perform at a high level, and not be distracted or hindered in that pursuit. There were personal goals to attain, so interest was high.

The first NGT group completed its activity with a summary report in November of 1983. That report addressed such issues as unnecessary analyses, organization and retrieval of records, noisy working areas, and the avenues pursued to initiate a favorable change for each issue. During that time period, two other groups were allowed to form from an individual unit with the direction and help of the first-line manager and a facilitator. Those groups worked on various problems through approximately June of 1984.

The NGT groups were focused at short range, addressing problems affecting efficiency and morale with much energy and emotion. Many of the issues were met with responses from management that there was no budget to implement the suggestion, or that it was contrary to the present company operating policies. To a degree, these responses confirmed some of the employee frustrations with the system, and they deepened some resentment toward management's attitude. NGT groups were authorized to meet and submit recommended changes, but there was no management commitment to respond. There was no overall plan or direction to the NGT program, resulting in very limited goals being achieved.

In May of 1984, the American Productivity Center (APC) contacted the Rockwell corporate Productivity and Planning Department regarding the White Collar Productivity Improvement (WCPI) Program. The WCPI, a research project conducted by the APC, was one of the programs selected by Rockwell to attack the productivity issues among its white collar employees. The Rocketdyne Division was chosen to be the site of one of the WCPI pilot groups. It was then decided that the pilot group at Rocketdyne would be off to a head start if it utilized an employee base that had already demonstrated an interest in increased productivity, so the pilot group was centered around the groups with NGT experience.

The director of the Design Technology Department at the Rocketdyne Division endorsed the project and introduced it to the pilot group. He was then appointed to another position within the division in the beginning of the project, and the department was left under the direction of an acting director. In retrospect, the project was somewhat hampered by the absence of a full-time department director. Some lack of authority from the top was felt when decisions were required to expedite changes. The pilot group at Rocketdyne, comprised of about eighty people divided into six units, performs analyses that support all of the programs in the division. This pilot group is one of the biggest in the APC project.

The WCPI methodology consists of six phases: Diagnosis, Objectives, Measurement, Service Redesign, Team Development, and Technology Parameters. This approach is different compared to the traditional productivity improvement programs that concentrate on increasing output, which are more appropriately used in a blue collar, production-type working environment. The white collar working environment involves a unique interaction between quality, efficiency, and effectiveness. The WCPI methodology provides a logical framework for an organization to review and enhance its operations. An organization looks at its functions, determines the reasons for performing its services, gets feedbacks on the performance, finds ways to improve its services, and assembles the people and equipment necessary to accomplish the tasks.

The human dynamics and operational practices of the pilot group were surveyed in the diagnosis phase. This provided a baseline for the project. Everyone in the pilot group filled out a survey questionnaire developed by the APC. One-to-one interviews of a cross section of the pilot group members and their users were conducted by a neutral party. This survey showed that the pilot group provides state-of-the-art technical analyses, is highly motivated, and enjoys the technical challenges. Three sensitive areas that the pilot group as a whole felt could be improved were the working environment, lateral and vertical communications, and efficient use of computing equipment and peripherals. This survey did not uncover any issue that was unknown to a majority of the pilot group, but it documented the concerns that were mere verbal complaints before. Although the project was viewed with skepticism, a volunteer steering committee for the project consisting of both first-line managers and technical staff was formed. Involvement teams were also formed to attack the three previously mentioned productivity hindrance areas.

The diagnosis phase set the stage for this project. The committee and the involvement teams got people involved in the beginning of the project, and they were free to explore solutions. The involvement teams proposed and effected some changes within the pilot group. The resultant changes were accepted readily because people affected were directly involved in formulating the changes.

The six units reviewed their functions during the objectives phase, and then determined the purposes for performing them. This effort resulted in the purpose and mission statement of the entire department. Every unit's manager determined the main services performed by the unit, and the staff in the unit brainstormed the objectives of the services. An NGT method was used to rank the objectives of each service. The service objectives were then reviewed by the users.

Going through this phase gave everyone in the unit a better sense of direction and perspective. This exercise showed people how they fit in the whole organization, and how their contributions affect the progress of the tasks. This phase took more time than anticipated to complete. Much time was spent in discussing why certain services were performed. The process could have gone quicker if the manager had set the objectives also, and then had them reviewed by the unit and the users. After all, the manager should set the goals for the unit. The objectives are a good tool for managing and prioritizing tasks performed in the unit, and they are especially useful for indoctrinating new staff. The review by the users was essential because it gave the unit a sense of the expectations placed on them. The process promotes communication between the users and members of the unit.

Measurements were formulated to measure the service objectives. It was desired to develop measurements that are simple to make, not time consuming, and not traceable to any individual. The steering committee felt the measurements should consider efficiency, effectiveness, quality, timeliness, employee attitude, motivation, resource usage, and user satisfaction. The objectives from the six units in the pilot group were combined to form a list of common group objectives. Measurements were formed to measure these common pilot group objectives, so less time would be required by each unit to develop and make the measurements. The project stagnated somewhat at this point because the steering committee was puzzled over the appropriate measurements to be made. A lack of expertise to formulate the appropriate measurements was felt. A separate productivity improvement project within Rocketdyne had an expert in measurement on staff, and it had taken them one year to develop and validate a survey of eight questions. With the completion of this phase approaching, the steering committee decided to p[illegible] ahead. They took the information at hand and derived a user survey, an analyst survey, and a list of measurements for the individual units. The measurements were reviewed by the units, so each unit could tailor the measurements.

Measurements are usually the stumbling block of most white collar productivity projects. Individuals are generally wary and reluctant to submit to measures of their productivity. The steering committee was concerned about how management would use the measurements obtained. Recognizing that there is no perfect list of measurements, the steering committee was deemed to be the most qualified to formulate them. Familiarity with the operations of the pilot group helped formulate the measures. The questions in the surveys were similar to the questions in the other productivity improvement program survey. This was a starting point from which the measures can be refined at a later date. Effort is in progress to obtain the formulated measurements.

Each unit constructed flowcharts depicting the way its services were performed in the service redesign phase. The hindrances became visible, so they presented opportunities for improvement. The hindrances from the units were combined to form a list of common group bottlenecks that could be attacked collectively. Some service changes to streamline operations were proposed to management. Service redesign is an ongoing process, since there are always new situations that present new ways to operate more efficiently.

The Rocketdyne White Collar Productivity Improvement project is ongoing. The above summary describes the first pass through the APC methodology. As a result of the enthusiasm generated by the Design Technology pilot group, three more pilot groups within Rocketdyne were formed. Other units within the Division have shown interest as well. Rocketdyne's desire is to make the WCPI methodology a continual process.

There have been a number of changes that have occurred as a result of this productivity effort. One of the most significant changes at Rocketdyne has been an increased awareness on the part of employees and all levels of management. In many cases, problems that were uncovered had been in existence for a long time. The process that was used during this program legitimized these issues, and created a framework for discussion and resolution. Although this process can occur at any time in an organization, a directed effort such as this encourages the kind of thoughts and exchanges between members of the staff that often leads to resolution of the problems. Awareness seems to be a real key in creating the kind of climate in which productivity improvements can be considered.

Another key to the success of any white collar productivity improvement project is that the project must meet the needs of the employees and be desired by them. Concurrent with this, however, there must be full management support. This is not to say that management must be heavily involved in the process, or directing the effort. Any such project that is so overshadowed by management that the employees do not feel a part of it will be only marginally successful at best. An effort driven and sustained by the employees, on the other hand, will by definition have the energy and interest necessary to get the best return for the time spent. Since each individual manager perceives the increased productivity benefit to his area differently, support will never be uniformly available. Some managers will even be openly hostile. But as an effort progresses, opportunities will become available for these people to be convinced of the value of the project. An effort should be made to communicate all of the successes and improvements that occur along the way, because success breeds interest. The continuing success of the proje will be dependent on getting as much management support as possible.

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A fairly common fallacy in many organizations is that productivity improvement is a discrete type of effort. Programs with fixed time periods are often established in the hopes that permanent, beneficial changes will occur. It seems that a more realistic view is that productivity improvement needs to take place in an environment of ongoing effort. The very nature of the process, including the important role of heightened awareness, is one of long-term commitment. In this kind of environment, problems and impediments to efficiency are constantly being ferreted out. Solutions to these problems are constantly in work. In the ideal case, the search for better ways to do things becomes part of the organization's standard operating procedure. At Rocketdyne, the idea that productivity improvement is an ongoing effort has given individuals the impetus to continue working on problems for which there are no short-term solutions. It also erased some of the bad feelings created by past efforts that strove to obtain significant productivity improvements without a sustained effort.

In any organization, the most important assets are the people. The knowledge of how things work, and how they could work better, resides in these people. They are the collective wisdom of the company. It is important to let these people contribute to the solutions of their own problems. In many organizations such as Rocketdyne, people are highly motivated and desire to do their jobs as completely and efficiently as possible. They can be expected to approach the opportunity to improve things relating to their jobs with enthusiasm. The wealth of insights into the workings of the organization is a resource that should not be wasted. In addition, keeping these people involved helps to ensure that they will accept the changes that result from their effort.

CONCLUSION

Rocketdyne applied the American Productivity Center methodology to a pilot group in the Engineering Department. The methodology provided a framework for the establishment of an ongoing effort to improve white collar productivity. In addition, the effort has provided an outlet for employees with a legitimate desire to improve procedures affecting their jobs. Another benefit in having an ongoing productivity project was that many lingering but unspoken concerns became legitimate issues. Extensive inputs from users were obtained. Communication at all levels was enhanced. Work on improving productivity will continue, but there have been accomplishments to date and a system has been put in place to facilitate future efforts.

BIOGRAPHIES

R. M. NORDLUND - was graduated from the University of Washington located in Seattle, Washington, in June 1980 with a B.S. in Mechanical Engineering. Since that time he has worked in the Aerothermodynamics Department at Rocketdyne, and is now a Lead Engineer working on Space Shuttle Main issues.

S. T. VOGT - received both B.S. and M.S. degrees in Mechanical Engineering from Purdue University. He has spent the last three years at Rocketdyne in the areas of analytical heat transfer and experimental aerodynamics. Prior to that, he spent three years at Hughes Aircraft Company in the Missile Systems Group.

A. K. WOO - received his B.S. degree in Aeronautical Engineering from California Polytechnic State University, San Luis Obispo. His position at Rocketdyne is in the area of rocket engine performance analysis. Prior to joining Rocketdyne, he was a student trainee in Flight Testing Engineering at Edwards Air Force Base.

N86-15179

IMPROVING ENGINEERING EFFECTIVENESS

JANET D. FIERO, CONSULTANT

ABSTRACT

America's quality of life is attributed by many to the technological advances made possible by our scientists and engineers. In the 1980's factors are occurring to force U.S. industries to recognize that: 1) our engineers and scientists are a critical resource and 2) this resource is not being used to its full potential. America's industrial giants are experimenting with many approaches to improving productivity in manufacturing but are still mainly "wringing their hands" regarding engineering organizations.

As an internal consultant at Motorola, Inc. this author was selected to investigate methodologies to improve engineering productivity. This paper will review the rocky road to improving engineering effectiveness utilizing a specific semiconductor engineering organization as a case study. The organization had a performance problem regarding new product introductions. With the help of this consultant as a "change agent" the engineering team used a systems approach to through variables that were effecting their out put significantly. This paper will discuss the critical factors for improving this engineering organization's effectiveness and the roles/responsibilities of management, the individual engineers and the internal consultant

INTRODUCTION

Motorola, Inc., an international leader in commercial and industrial electronics, generated $5.5 billion in 1984 sales. The company, headquartered in Schaumburg, Illinois, manufactures a wide range of electronic equipment. Products include systems and components ranging from cellular radio telephones and two-way FM radios to data communication products and semiconductors.

Approximately 100,000 employees work for five distinct operating segments in 110 countries. Each segment, known as a sector, is divided into groups or divisions depending on the size of the organization.

The Japanese have captured an increasing segment of many industrial markets in the last 20 years. These include steel, consumer electronics, automobiles and hardware. The Japanese have targeted three specific markets which Motorola serves directly or indirectly: semiconductors, communications and computers.

In 1983 the Semiconductor Products Sector of Motorola, Inc. identified *engineering productivity* as a critical strategic issue facing the organization. An Executive Vice-President assumed the role of champion. A sector-wide committee was formed to gather data on productivity issues and make recommendations. After the problems were identified and prioritized the committee recommended that a manager be assigned full-time to address the issues. In 1984 Janet Fiero was selected as Manager of Engineering Productivity. This decision was based on her success at developing the corporate Total Quality Improvement training strategy.

Approximately 60 engineers and engineering managers were interviewed resulting in several projects using different approaches. The project involved with improving a division's new product introduction record was selected as the basis for this paper. This case study best depicts the potential success of such an improvement effort.

NEW PRODUCT INTRODUCTIONS

Recognition of the Problem

The vice-president of a particular semiconductor division began having a series of meetings to improve the division's new product introduction record. Three Product Managers, a Marketing Manager, a Planning Manager and a Manufacturing Manager reported to this V.P. Design Engineering reported into the Product Managers. Through a long and introspective process the management team explored why the current level of performance relative to new products was not meeting their expectations. The initial tendency was to spend their meeting time trying to find individuals responsible for the slippage in schedules. The management team resisted this tendency to "search for the quilty" and looked for the factors that had changed relative to their previous success record of new products.

- --Circuits had gotten larger, exponentially larger, and resources had increased linearly.
- --Check and balance system had slipped. Resources had left and had not been replaced
- --Criteria for successful prototype had become much tighter.
- --Allocation of resources had shifted from new products to existing products (i.e. from long term to short term).
- --Demand for new markets runs counter to economic times. In good times like 1984 the demand for new products was less. Internal priorities focused on "milking" existing products rather than developing new ones.
- --Rapid growth of the division had resulted in people who were inexperienced at their current level. Design Managers in particular had moved rapidly from "hands-on" work to the management of the design process. These people needed effective, job-related training.
- --The design organization had been decentralized and flexibility to allocate resources for special projects like CAD applications was limited.
- --New CAD and project management tools were being developed by central research but existing tools were not being maintained or enhanced.
- --The number of interfaces for the design engineer had increased. The matrix structure of the organization was more complex.
- --The organization had become more internationally oriented.

Analysis of the Problem

Introduction of the concepts of the Performance System helped the vice-president and his direct staff to step back, gain perspective on their problem, and reach some appropriate actions. This Performance System was developed by Dr. Geary Rummler of Summit, New Jersey. The system is based on distinquishing the difference between the performer and the performance. The diagram on the following page illustrates the principles of the Performance System.

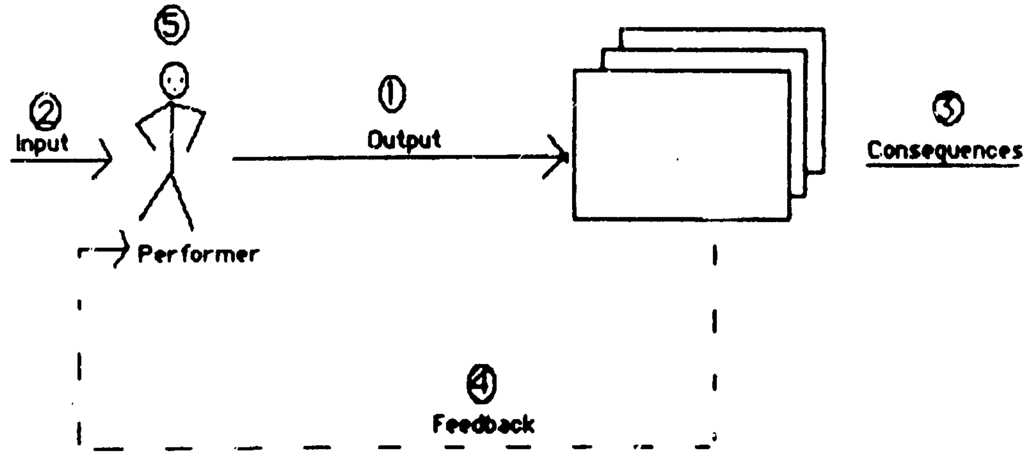

Figure 1   The Performance System

It was imperative for the top management team to recognize that poor performance of the Design Engineering Department regarding new product introductions might have resulted from a breakdown in any of the five components of the performance system. In one meeting the V.P. and his direct staff reviewed the following questions relative to the 5 components:

1. The Output
   --Is there adequate and appropriate criteria (standards) with which to judge the design team's performance?
   --Do the Design teams know what is expected of them?
2. The Input
   --Is there a clear or sufficiently recognizable indication of the need to perform?
   --What interference is there from incompatible or extraneous demands?
   --Are the necessary resources (budget, personnel, equipment, etc.) available to perform?
   --Are the products adequately specified and defined for the design teams?

3. The Consequences
   - --Are there sufficient positive consequences (incentives) to perform?
   - --Can we eliminate the negative consequences (disincentives) to perform?
4. The Feedback
   - --What kind of feedback exists as to how well (or how poorly) the job is being performed?
   - --Is the feedback timely and appropriate?
5. The Performers
   - --Do they have the necessary knowledge and skills to perform the job?
   - --Do they have the capacity to perform both physically and emotionally?
   - --Do they have the willingness to perform (given the incentives available)?

From this analysis the division management team decided the output most critical to their ongoing success was to design products with much fewer reworks or "passes." The team recognized they had been focusing the organizations priorities on today's profits rather than tomorrow's products. This appeared to make the design group's performance less important. They admitted that inadvertently they might be rewarding rework by giving priority and attention to those who were most delinquent. There was little tracking or feedback about the status of various products and the number of passes that had occurred. With the realization that the performance system was breaking down in a number of places the management team "rallied around the flagpole" making First Pass Success the overriding goal for 1985.

Early Actions by Management

1. The Output-- 100% First Pass Success goal on new products was made public to all members of the organization. The 1985 goals reflected goals that supported this superordinate goal. Some delinquent products were terminated.
2. The Input--Two areas which received immediate attention were marketing plans and CAD software packages. Both of these areas required the clout of the V.P. to improve the quality of the service.

3. The Consequences--Incentives were instituted for designs that functioned on the first pass. Attempts were made to remove priority from delinquent product designs.
4. The Feedback--Tracking systems were implemented. Design reviews held during the development cycle were revised. A higher level of management began attending design reviews.
5. The Performer--New expertise in CAD applications was added. Existing personnel were trained in Project Management Skills. Design Management began working with the internal consultant to analyze the Performance System within the design engineering group.

Early Actions by Design Managers

Five Design Managers met to redesign the methods and procedures in which they created their outputs. The methodologies used do design yesterday's products were not working well today. The design managers moved through a process that allowed them the insight to revise their procedures The events occured as follows:

- Defined the output (First Pass Success) in terms of functionality, D.C. & A.C., electrical, manufacturability, and schedule.
- Identified interim outputs and corresponding standards.
- Identified their "customers" (i.e.the departments that received their output)
- Negotiated with the "customer" to determine if they agreed with the standards of the output which would become their input. For most this was a first! All department began to trust that if they received quality inputs they could meet their schedule committments.
- Listed all the tasks necessary to produce the design outputs. Redesigned the sequence of the tasks for maximum effectiveness.
- Redesigned the meetings that monitored new products. A process for technical design and business trade-off decisions was implemented. Cross-functional champions of new products were identified and brought into the review process earlier to be part of the trade-off decisions.
- Identified inputs to the design process, specified standards and communicated these to the appropriate departments.
- Initiated and monitored checklists specifying required check points.
- Wrote individual Performance Appraisals to include First Pass Success standards.

- Requested that departments effecting new product introductions move through the same process as the design group. This process would define: what service or product they produce; what inputs they needed; and how they would know if their "customer" was satisfied.

Organizational Mapping

The process used by the Design Managers was an application of the concepts developed by Geary Rummler entitled "Organizational Mapping Process". This process is based on the premise that organizations operate as systems, consisting of subsystems (functions/departments) requiring specific inputs and outputs in order to meet the organization's (system's) objective. An organization's effectiveness is usually a function of how well these organizational subsystems are linked or connected. System "disconnects" are frequently at the root of organizational performance issues.

Organization Mapping is an effective and efficient process with a visual format which represents an organization as a system and guides a management team through a focused analysis to effective action plans. A flow chart is the visual that depicts how the inputs and outputs of each function interface to produce the final product.

The Organization Mapping Process has been used with teams ranging from a president and vice presidents to peer work groups addressing such critical business issues as:

- the implementation of a new division strategy;
- the implementation of a division reorganization;
- the improvement of the product design process;
- the improvement of manufacturing yield, quality, cycle time, inventory ,cost and delivery;
- the merger of functions;
- the design and start-up of new funcitons.

The Organization Mapping Process results in

- a cross-functional, comprehensive plan for addressing the Critical Business issue.
- the potential for a stronger management "team."
- a common process for addressing cross-functional issues in the future.

Project Hindsight

Progress was made in the organization described in this case study. In 1984 only 12.5% of the new products were First Pass Successes. In 1985, if the remaining months hold true to the new trend, over 50% of the products designed will meet First Pass Success standards. That's the good news. The bad news is that the extra effort required to set up the systems and procedures to ensure First Pass Success has caused a 25% reduction in 1985 new product introductions. This case study is a clear example of an American management team making a long-term investment. The team almost buckled under due to the painful short-term consequences. Now they realize that the long-term gains will come.

Hindsight shows the project could have been done more efficiently and effectively. Looking backwards and learning from mistakes is not considered a worthwhile activity in most companies. For significant improvements to be made we must accept and even reward critiquing. Rewarding the individual or group who uncovers a problem is much more productive than searching for the guilty and shooting them.

The design engineering group did an excellent job of listing all the tasks that they "should" do in order to ensure First Pass Success. It would have been helpful to make a list of all the other tasks they do that detract from the list of good intentions. McDonnell Douglas Electronics Company launched an improvement project similar to this one. Two lists were created: value-added tasks and non-value-added tasks. A goal was made to decrease non-value-added tasks(i.e.waste). This effort, coupled with other improvement activities, allowed engineering resources to decrease through attrition during a growth year.

The design group at Motorola recommended to their interfacing departments that they map their organizations specifying the standards for inputs and outputs. This action was followed through by some but not all departments. Thus the innovative improvement activities of the design group were not being reinforced by the larger system. The lack of division-wide buy-in to the new methodology left the design group feeling totally responsible for the performance though many tasks were outside their control.

Many other factors affecting new product performance were identified and not fully resolved. These included improvements in: the product planning process; the goal setting process; engineering computing tools and support; and training needs assessment.

The role of internal consultant in this project was awkward and ambiguous. A contract between the consultant and vice-president would have clarified the roles and expedited the project. To be effective an internal consultant must negotiate with the client the following:

- an understanding of the problem
- the scope of the project
- the client's expectations
- the consultant's expectations
- agreement on deliverables and timeframe

SUMMARY

External forces facing American industry today demand internal changes. Change is necessary but very difficult. Each of us has noted at one time or another " The only constant thing around here is change." Change is often a reaction to external factors. Change is not often enough due to a proactive choice. This case study shows an organization undergoing change. This change was painful. The individuals advocating change were resisted. but progress was made. We all have filled our notebooks at conferences with innovative ideas that back in the "real" world fail in the implementation. The complexity of the change process must be appreciated before you venture back home to implement the pearls of wisdom received today.

Suppose research validated a theory that people at an optimum weight are more productive then people who are overweight. You, as a conscienscious manager, request that the personnel organization select the best weight reduction program with all necessary training components. You agree to send necessary folks to the events. The first problem may be to get the personnel organization to agree to help you. The second may be getting anyone to attend the "events". You can always make them go, but, will the objective of weight loss be achieved? Most of us recognize we have areas that need improvement-losing a few pounds, stopping smoking, or exercising more. Few of us do anything serious about it until a significant event, such as a heart attack, strikes us down.

Must we wait for a corporate "heart attack" in our companies before we choose to implement change? Is *reaction* our only choice? Managing a crisis is easy. Managing improvement is difficult. One is reactive. One is proactive. When managing a crisis the problem is well defined and the resources to be allocated are obvious. When managing improvement the problem and opportunities are numerous and ambiguous, plus resources scarce due to previous crisis allocations. The successful managers of tomorrow will be those who clean up ineffective systems and create new systems that improve the output. CONTINUOUS IMPROVEMENT must become a way of life for companies to move from surviving to thriving. Improvement requires change. Change will never be popular. As you listen to these ideas and go home to advocate change recognize the task at hand is not easy. If you feel resistance you are probably effecting change. Good luck!

JANET D. FIERO
IMPROVING ENGINEERING EFFECTIVENESS, INC.
CONSULTANT

Janet D. Fiero is a consultant to industry on how to manage for quality and productivity improvement. She started her business, Improving Engineering Effectiveness, Inc. in 1985. Her areas of expertise include Statistical Engineering Applications, R&D Organizational Analysis, and Engineering Training Development. She has 5 years of experience in training and performance improvement management at Motorola Inc. and 12 years engineering and management experience at Motorola Inc. and Fairchild Semiconductor. Janet graduated in 1968 from Pennsylvania State University with a BS degree in Biochemistry and is currently pursuing an MBA at Arizona State University. She is a member of ASEE, IEEE and the Technical Education Consortium.

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'Software Productivity Improvement Through Software Engineering Technology'

Frank E. McGarry

ABSTRACT

It has been estimated that NASA expends anywhere from 6 to 10 percent of its annual budget on the acquisition, implementation and maintenance of computer software. Although researchers have produced numerous software engineering approaches over the past 5-10 years; each claiming to be more effective than the other, there is very limited quantitative information verifying the measurable impact that any of these technologies may have in a production environment. At NASA/GSFC, an extended research effort aimed at identifying and measuring software techniques that favorably impact productivity of software development, has been active over the past 8 years. Specific, measurable, software development technologies have been applied and measured in a production environment.

Resulting software development approaches have been shown to be effective in both improving quality as well as productivity in this one environment.

INTRODUCTION

The Software Engineering Laboratory (SEL) was established in 1977 by Goddard Space Flight Center (GSFC) to investigate the effectiveness of software engineering techniques as applied to the development of ground support flight dynamics systems. The goals of the investigation are (1) to understand the software development process in a particular environment, (2) to measure the effects of various development techniques, models, and tools on this development process, and (3) to identify and apply improved methodologies in the GSFC environment. SEL research should provide the knowledge to enable GSFC to produce better quality, less costly software.

To accomplish these goals, the SEL studies software for satellite mission support during its development life cycle. This software is developed by the Systems Development Branch at NASA/GSFC, which is responsible for generating flight dynamics support software for GSFC-supported missions. The software includes attitude determination, attitude control, maneuver planning, orbit adjustment, and general mission analysis support systems.

The SEL continually monitors and studies all Systems Development Branch software, which includes software developed both by GSFC employees and by contractor personnel. This data covers software development projects that started as early as 1978 and as late as 1985; and the SEL anticipates that data will continue to be collected and studied in the future. Approximately 50 projects, which range in size from 2000 lines of source code to over 150,000 lines, have been involved to date.

While investigating projects totaling more than 2.5 million lines of code, SEL personnel gained insight into the software development process and began to discern trends in the relative effects of various techniques applied to the software projects. This report:

- Describes the motivation and background of the SEL.
- Relates the concepts and activities of the SEL.
- Summarizes the results of SEL research.
- Reports the status, conclusions, and recommendations of the SEL.

APPROACH

Extensive efforts have been made during recent years to devise improved software development techniques. This work generated numerous tools (e.g., precompilers and programmer workbenches), cost and reliability models, and methodologies (e.g., structured programming and top-down design); all were supposed to improve the development process. Early evaluations of the effectiveness of these techniques were incomplete and/or inconclusive. This may have been due, in part, to an unrealistic assumption that the software development process could be isolated from the environment in which it occurs. However, no element of the development process can be understood outside the context of related factors.

For example, productivity in some environments may be constrained by staffing patterns. Thus, the possible beneficial effect of a productivity-enhancing methodology may remain unrealized and unrecognized because of an inappropriate allocation of manpower.

The SEL approach to software engineering research is holistic. Its four components are a problem statement, an environment, a process or activity, and a product (software). The development process is subdivided into seven sequential phases of activity. A goal of SEL, then, is to refine the definitions of the model elements and to define their relationships.

The first step toward this goal is to understand the software development process currently in operation and its environment. Important attributes of the software problem and products must also be investigated. Such an understanding provides a baseline from which the effects of attempted improvements can be measured and allows the identification of strengths and weaknesses so that efforts can be focused on the areas of greatest need.

Beyond understanding the current process and environment, the SEL is interested in improving that process and environment. The SEL recognizes a four-step procedure leading to more effective software development. The steps are to:

- Become aware of the development techniques available
- Evaluate the available techniques to determine those most effective
- Engineer (customize) those "best" techniques.

This procedure can become the basis of a regular system of self-evaluation and improvement, whereby as new techniques become available, they are tested and incorporated in the software development process.

OBJECTIVES OF THE SEL

The overall objective of the SEL is to understand the software development process and the ways in which it can be altered to improve the quality and to reduce the cost of the product. However, the SEL has defined some intermediate objectives within the previously defined areas of concern that will help meet that general goal. These objectives fall into two classes: experimentation and communication.

Experimentation involves evaluating existing software development technologies and developing new technologies. Specific objectives of the SEL are to:

- Conduct controlled experiments
- Evaluate software development methodologies
- Evaluate software development tools
- Analyze cost estimation models
- Analyze software reliability models
- Develop a set of software quality metrics

The results of experimentation must be incorporated in the software development process to improve it. This process requires communication between researchers and developers. Specific communications objectives of the SEL are to:

- Devise software development standards
- Develop software management guidelines
- Provide real-time feedback to development teams being monitored
- Maintain contact with the software engineering research community

Clearly, the objectives of the SEL reflect its multistep approach to software engineering, as described earlier.

SOFTWARE CHARACTERISTICS

The general category of flight dynamics software includes applications to support attitude determination, attitude control, maneuver planning, orbit adjustment, and general mission analysis. Most of these programs are scientific and mathematical in nature. The attitude systems, in particular, are a large and homogeneous group of software that has been studied extensively. The attitude determination and control systems are designed similarity for each mission using a standard executive support package as the controlling system.

Typically, attitude systems read sensor measurements from a telemetry stream and determine the attitude of the spacecraft from this data. Depending on the types of the data available and the accuracies required, the size of these systems may range from 30,000 lines of code to about 120,000 lines of code. All these systems are designed to run in batch and/or interactive graphic mode. Some existing software can be reused for each new system, since there are always some similarities to past systems, especially in the high-level design. The percentage of reused code ranges from 10 percent to an upper limit of nearly 70 percent.

All applications developed in the flight dynamics area of GSFC have development time constraints corresponding to launch dates. Most of the software discussed in this paper must be completed (implying completion of acceptance testing) 60 days before the scheduled launch. If the software is not completed, required capabilities must be deleted or redefined, and an alternative version of the intended system must be defined to ensure that the mission can be supported in some limited fashion.

The development process normally begins approximately 16 to 24 months before a scheduled launch in order to be completed 2 months in advance of launch. This development period is divided into phases typical of the standard software life cycle.

STUDY RESULTS

The data provided by the SEL has formed the basis of numerous software engineering studies. The software development tasks from which data was collected for the SEL data base are comprised of over 50 flight dynamics projects developed over 8 years. All data collected by the SEL is assembled in a computer data base to facilitate its access by researchers and managers.

Two very strong effects were identified early in the SEL investigations and have been confirmed in the literature (Reference 1). That is, variation in programmer abilities appears to be the most powerful influence on the productivity and quality of software development. In addition, the nature of the local computing and work environments seems to be a significant determining force on the process. Any valid experimental design which is attempting to study effects of additional parameters such as methodology must account for or eliminate these effects.

METHODOLOGY EVALUATION

A software development methodology is the regular application of a set of specified techniques to part or all of the software development process. The methodologies and techniques studied by the SEL can be classified into five groups. The groups and some examples of each are listed below:

- o Design Techniques
  - Top-down structured design
  - Tree charts
  - Data flow diagrams
  - HIPO charts
  - Process design languages
- o Design Evaluation Techniques
  - Strength and coupling analysis
  - Connection matrices
  - Program correctness proofs
- o Structured Implementation Techniques
  - Top-down structured programming
  - Structured languages
  - Code reading
  - Walkthroughs
- o Management Techniques
  - Chief programmer teams
  - Design reviews
  - Librarian functions
  - Independent test teams
- o Documentation Techniques
  - Automated documentation systems
  - Structured code

The SEL's approach to evaluating methodologies has been to co[illegible] and quality data from similar projects that employed differ[illegible] development methodologies (semicontrolled) experiments). The [illegible]ive effects of the methodologies on the product can then be obser[illegible] and the useful techniques identified. Controlled experiments would be the ideal means of collecting data for these analyses. However, the cost of duplicating any large development effort precludes that strategy.

The inability to make complete comparisons of the projects studied has delayed the derivation of definitive conclusions from the data. However, some effects are apparent A summary of the early results of methodology evaluations is presented in Table 1. A superficial examination of this table suggests the reasonable conclusion that most techniques that do not significantly increase the programmer's and/or designer's workload but that provide a higher level of organization to his/her activities have a positive impact on the development process.

TABLE 1. SEL METHODOLOGY EVALUATION: SOME CONCLUSIONS

Results of Evaluations

Cost Effective	Cost Unclear	Not Cost Effective
Formal Test Plan	Code Walkthroughs	Simulated Constructs
Process Design Language (PDL)	Top-down Design	Axiomatic Design
Code Reading	Top-down Code	Code Analyzers
Formal Training	Chief Programmer Team	Large Problem Statement Languages
Librarian	Code Auditors	Independent Verification and Integration
Structured Analysis		
Configuration Mgmt.		Reliability Models
Design Formalisms	Requirements Languages	Automated Flow-charters
Formal Design Reviews	Automated PDL	
Structured Code (Precompilers)		
Iterative Refinement	Resource Estimation Models	

More rigorous techniques have been applied to the analysis of some subsets of the SEL data on methodologies. Table 2 shows the results of a study of the effects of methodology on productivity. Essentially, it confirms the SEL's earlier conclusions.

TABLE 2. RELATIONSHIP BETWEEN PRODUCTIVITY AND VARIOUS FACTORS

Factors	Correlation
PDL	0.26
Formal Design Review	0.62**
Design Formalism	0.38
Design Decision Notes	0.62**
Design Walkthrough	0.28
Code Walkthrough	0.19
Code Reading	0.58
Top-Down Design	-0.19
Structured Code	0.02
Librarian Use	0.52*
Chief Programmer Team	0.62**
Formal Test Plans	0.51*
Heavy Management Involvement	-0.09
Formal Training	0.58**
Top-Down Code	0.29

*SIG.<0.05
**SIG.<0.01

In addition to experimenting with and measuring the above mentioned technologies, the SEL has gained insight into additional areas which may have major impacts on the overall productivity as well as quality of software development.

Productivity for large vs. small systems

The common belief by many software managers and developers is that as the size of a software system increases, its complexity increases at a higher rate than the lines of code increase. Because of this fact, it is commonly believed that in the effort equation

$$E = aI^b$$

where E = effort of person time
where I = lines of code

that the value of b must be greater than 1. The projects that the SEL has studied have been unable to verify this belief and instead have found the value of b to approximately .92 in the SEL environment. The fact that this equation is nearly linear leads to the counter intuitive point that a project of 150,000 lines of code will cost approximately 3 times as much as a 50,000 lines of code project instead of 4 or 5 times as much as is often commonly believed.

(Further details can be found in Reference 2.)

Productivity Variation

Another characteristic that the SEL has been interested in studying has been the variations in programmer productivity. Obviously one would want to increase the productivity by whatever approach found to be effective, but first we must clearly understand what the baseline characteristics of productivity are (minimum, maximum, average, difference between small and large projects, etc.); only then will we know if we have improved or not in the years to come.

As has been found by other researchers in varying environments, the productivity of different programmers can easily differ by a factor of 8 or 10 to 1. The SEL did find that there was a greater variation (from very low productivity of .5 l.o.c./hour to 10.8 l.o.c./hour in small projects. The probable reason for this is that newer people are typically put on smaller projects and the SEL has found extreme differences in the relatively inexperienced personnel.

Reusing Code

As was stated in the introduction, projects being developed in the SEL environment typically utilize approximately 30 percent old code. Although it is obviously less costly to integrate existing code into a system rather than having to generate new code, there is some cost that must be attributed to adopting the old code. The development team must test, integrate and possibly document the old code, so there is some overhead. By looking at approximately 25 projects ranging in size from 25,000 lines of code to over 100,000 total lines of code and ranging in percent of reused code from 0 percent to 70 percent, the SEL finds that by attributing a value of approximately 20 percent overhead cost to reuse code the expenditures of the 25 projects can best be characterized. Now the SEL uses the 20 percent figure for estimating the cost of adopting existing code to a new software project.

Development Resources

Another area of concern to the SEL in defining the basic profile of software development, was that of staffing level and resource expenditure profiles. Many authorities subscribe to the point that there is an optimal staffing level profile which should be followed for all software projects. Such profiles as a Rayleigh Curve are suggested as optimal. Chart 8 depicts characteristics of classes of projects monitored in the SEL and shows the difference in productivity and reliability for groups of projects having different staffing level profiles. Although the Rayleigh Curve may be acceptable for some projects, the SEL has found that wide variations on these characteristics still lead to a successful projects. The SEL has also found that extreme deviations may be indicative of problem software.

Resources Allocation

One set of basic information that one may want to understand is just where do programmers spend their time. When the SEL looked at numerous projects to understand where the time was spent, it found that the SEL environment deviated somewhat from the old 40-20-40 rule. Typically projects indicated that when the total hours expended were based on phase dates of a project (i.e., a specific data defined the absolute completion of one phase of the cycle and the beginning of the next phase) the breakdown was less than 25 percent for design, close to 50 percent for code and about 30 percent for integration and test.

When the programmers provided weekly data attributing their time to the activity that they felt they were actually doing, no matter what phase of software development they were in; the profile looks quite different. The three phases (designs, code, test) each consumed approximately the same percent effort and over 25 percent of the time was attributed to 'other' activities (such as travel, training, unknown, etc.). The SEL has continually found that this effort (other) exists, and cannot easily be reduced, and most probably should be accepted as a given. The SEL has found it to be a mistake to attempt to increase productivity merely be eliminating major portions of this 'other' time.

Cost Models

In addition to the studies made pertaining to various measures for software, the SEL has also utilized the cost data collected from the many projects to calibrate and evaluate various available resource estimation models. No attempt was intended to qualify one model as being any better than another. The objective of the studies was to better understand the sensitivities of the various models and to determine which models seemed to characterize the SEL software development environment most consistently.

In studying these resource models, nine projects which were somewhat similar in size were used as experimental projects. Each of the models was fed complete and accurate data from the SEL data base and each was calibrated with nominal sets of projects as completely as the experimenters could. Summary results indicate that, occasionally, some models can accurately predict effort required for a software project. The SEL has reitterated what many other software develops and managers claim. Cost models should never be used as a sole source of estimation. The user must have access to experienced personnel for estimating and must also have access to a corporate memory which can be used to calibrate and reinforce someone's estimate of cost. Resource models can be used as a supplemental tool to reinforce one's estimate or to flag possible inconsistencies.

More detailed information on the SEL studies can be found in Reference 3, 4, and 5.

Effects of MPP on Software Development

In an attempt to determine if the utilization of Modern Programming Practices (MPP) has any impact (either favorable or unfavorable) on the development software, a set of 10 fairly large (between 50,000 l.o.c. and 120,000 l.o.c. and fairly similar projects (same development environment, same type of requirements, same time constraints) was closely examined. These projects had been developed in the SEL environment where detailed information was extracted from the projects weekly and where each project had a different level of MPP enforced during the development process.

The MPP's ranged from various design approaches (such as PDL, Design Walkthroughs, etc.) to code and test methodologies (such as structured code, reading, etc.), to various integration and system testing approaches. All the possible MPP's were rated and scaled as to the level to which the practice was followed for each project (the rating was done by the SEL researchers by the software developers). The only purpose of this exercise was to depict trends and not to prove that any one single practice was more effective by itself than any other.

The level to which MPP's were utilized were plotted against productivity against error rate. The application of the MPP has favorably affected productivity by about 15 percent for these experiments. Results of software reliability vs. MPP is very questionable. The SEL is continuing analysis of additional data.

(More details of this effort can be found in Reference 6).

Conclusions

Several points stand out among the results of the research performed in the SEL. These two points are as follows:

1. The software development process can be improved through the application of selected methodologies. This general conclusion was derived from observations made during the past several years. Productivity rates have steadily increased through the years with the application of more refined methodologies. Even with the additional overhead of data collection and special training, a steady improvement in the development process is evident.

The amount of improvement attributable to any given methodology is very difficult to quantify, but the history of the SEL indicates that almost any of the disciplined methodologies available will favorably affect the process by about 5 to 10 percent over the absence of any such approach. A methodology that is particularly well suited to a specific environment could enhance productivity by as much as 20 percent. Optimizing the organizational structure of the people supporting the project can produce an additional improvement of 10 percent.

2. The greatest need is for the rational application of the available technologies, not for the creation of new technologies. During the past several years, the SEL has learned that there are no shortages of well-defined methodologies and tools. The deficiency of current practice is in the utilization of the available software technology. Software implementers have been slow to evaluate and adapt these approaches to their particular environments.

Software technologies should not be accepted without critically examining their effects and without understanding the environment in which they operate. However, the evidence is conclusive that the software development process can be substantially improved through the application of appropriate technology.

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IMPROVING PRODUCTIVITY THROUGH ORGANIZATIONAL DEVELOPMENT

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IMPROVED PRODUCTIVITY THROUGH INTERACTIVE COMMUNICATION

Phillip P. Marino
Bendix Field Engineering Corporation

ABSTRACT

New methods and approaches are being tried and evaluated with the goal of increasing productivity and quality. The underlying concept in all of these approaches, methods or processes is that people require interactive communication to maximize the organization's strengths and minimize impediments to productivity improvement.

This paper examines Bendix Field Engineering Corporation's organizational structure and experiences with employee involvement programs. The paper focuses on methods Bendix developed and implemented to open lines of communication throughout the organization. The Bendix approach to productivity and quality enhancement shows that interactive communication is critical to the successful implementaiton of any productivity improvement program. The paper concludes with an examination of the Bendix methodologies which can be adopted by any corporation in any industry.

Bendix Field Engineering Corporation's (BFEC's) international reputation in the technical field has remained an industry standard for more than 35 years. Quality service, combined with effective competition in the world market, has contributed to BFEC's distinction as a preeminent supplier of engineering and support services in the electronics and aerospace industry.

In a field as dynamic as the technical service industry, with a multiorganizational structure, BFEC has maintained its position by unremitting efforts to enhance quality, productivity and cost effectiveness of the services provided to its many customers.

BFEC has long had a 'working smarter' concept which reflected the corporate commitment to engineering excellence and productivity improvement. Many factors have contributed to productivity and quality enhancement, but the most crucial and indispensable element is the quality of service provided by our skilled engineering and technical professionals supported by our progressive management team and dedicated work force.

The purpose of this paper is to present methodologies BFEC created and adopted to augment a successful productivity and quality enhancement program.

BFEC's Productivity and Quality Enhancement Program did not start last year. The foundations of the program have been in place for years. These foundations include statistical concepts and accountability, goal setting, and measurement of performance against goals.

In the labor-intensive service industry, for example, productivity can be directly related to absenteeism. BFEC has constantly searched for ways to reduce absenteeism so that productivity may be increased. Records of absence rate and associated costs have been maintained since 1960. In 1976, an alarming trend of increased absence was noted. Armed with a long history of absence statistics, the Absenteeism Reduction Program was developed. The program begins with management reports of absence trends by individual departments, and includes research information, company determined standards of performance, recognition of employees with outstanding attendance records, rewards, publicity of the program, and goals for each element, department, directorate and the corporation as a whole. As a result of the implementation of the Absenteeism Reduction Program, absence was reduced from 2 52% in FY 76 to a rate of 1.91% for CY 84 (refer to Figure 1). BFEC has avoided spending over $3.2 million dollars in lost wages alone during the past 9 years.

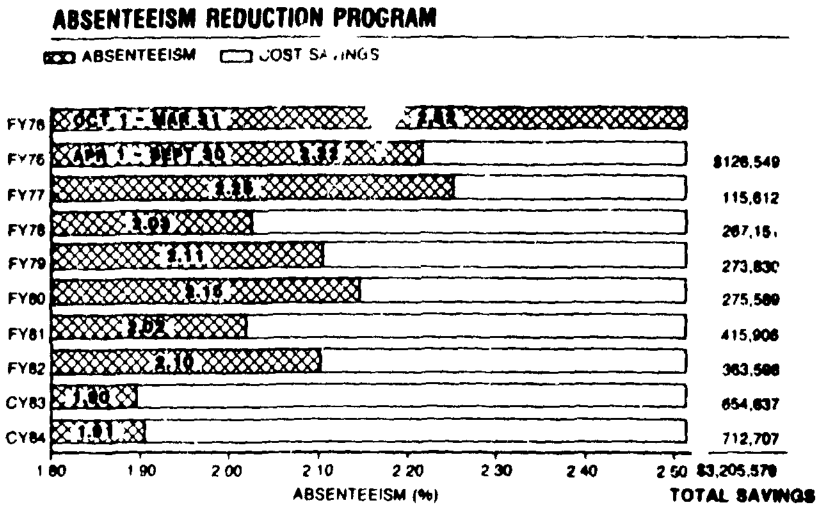

FIGURE 1

Another example of the continuous emphasis on productivity and quality enhancement is the Cost Reduction and Suggestion System. Established in 1963, the program has motivated employees to seek better ways to perform their jobs while maintaining or improving the quality and reducing the costs associated with performing their jobs. Figure 2 depicts the cost savings of more than $18 million since 1981.

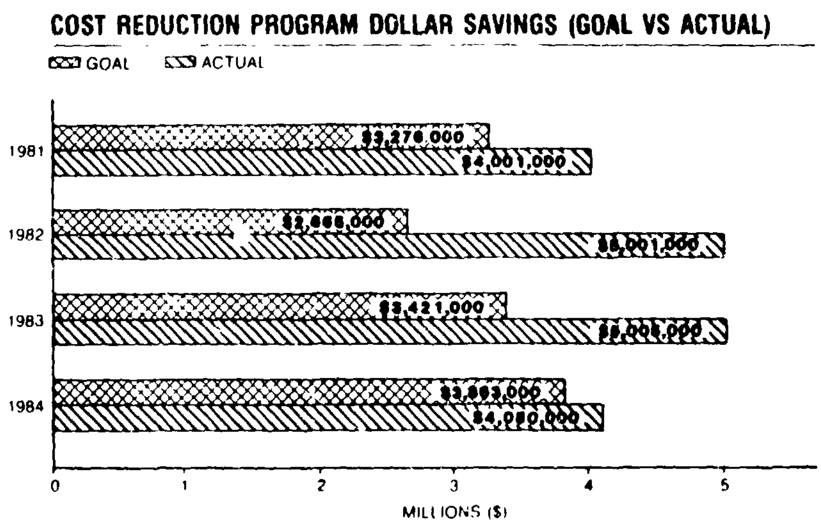

FIGURE 2

An illustration of the corporate commitment to quality, productivity and cost effectiveness is demonstrated by one of our contracts with NASA (figure 3). Originally implemented in 1978, this contract began with a staff of 420 employees. After the contract was awarded, it was converted to BFEC's first Mission Contract. On contract renewal in 1983, our tasks had been expanded to include maintenance of approximately 50 computer systems and peripherals in addition to control center maintenance and operations duties at the Goddard Space Flight Center. BFEC's attention to zero-based staffing analysis, cross

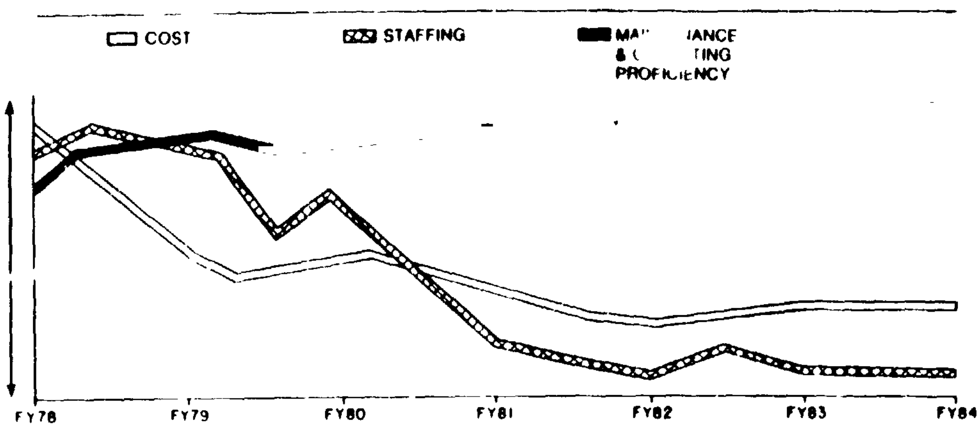

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FIGURE 3

training, and cross-utilization of personnel, plus streamlining of operations allowed the new contract to begin with a staff of 84 fewer employees than the original contract. All of this was accomplished through transfers and normal attrition and exclusive of all NASA mission precipitated staffing changes. Personnel reduction also resulted in lower costs while, at the same time, keeping maintenance and operation proficiency at above average levels.

> "We believe that each generation of products and technology should surpass the excellence, ingenuity and performance of its predecessor and that all our products and service must reflect the integrity that is one of our most precious assets."

These words, from the Bendix Creed written over 40 years ago, challenge each employee to practice productivity improvement and quality enhancement as a way of life. The employees are constantly challenged to learn something new every day. BFEC's President remarks that "a day when you don't learn a better way of doing your job is wasted day". With these types of challenges, BFEC took steps to consolidate and formalize the Productivity and Quality Enhancement Program in 1984.

The first step was taken by the President with the establishment of the Productivity Council, a group of seven individuals from various major departments who were committed to the basic tenet that a formalized quality and productivity improvement program is essential for BFEC to remain a leader in providing engineering and support services. The initial group became the product champions of the productivity cause within their respective organizational units.

They did not charge ahead without understanding BFEC's past performance -- both achievements and failures. The council studied and learned from corporate experiences.

The council was aware of a major Bendix Corporation campaign for productivity improvement in 1980. During that campaign, the Productivity Committee did research, provided training to management in national and international trends in productivity, developed a catchy theme and poster design, and conducted a short term productivity suggestion program. This short term program resulted in over $500,000 in cost reductions in a three month period, but the program was not sustained because there was no continuing long term commitment and because a consolidated productivity improvement and quality enhancement program had not been established.

In 1978, Bendix introduced an objectives-based performance planning and review system (PPRS). This program included over 16 hours of training for managers in the flow or process involved in planning and measuring performance. The PP&RS, as it is now known, is used throughout the company, but initially there was some reluctance to fully implement the philosophy of the program. Rather, there was an attempt to fill out the associated forms, and not practice the management philosophy it espoused.

In an effort to be more productive, the PP&RS was the subject of reevaluation in 1982. As a part that study, a special task force asked for and received information from employees, supervisors and managers about their reactions to the system. The task force found that, although the program did improve communication, documentation for the system was limiting and the task force suggested a more free-form format. As a result of the study, employees began to implement the philosophy of the program more effectively.

The council learned that major programs cannot be implemented fully on a dictatorial basis. It also learned that when managers, supervisors and employees have an opportunity to participate in the structuring of a program, and have an active role in the development of a program, there a greater acceptance -- even ownership of the concept.

With an awareness of PFEC's accomplishments, an awareness of programs which were deemed to be less than successful, and a realization of the basic employee need to be part of a developing program, the Productivity Council began the task of formalizing the Productivity Improvement and Quality Enhancement Program for BFEC.

The council developed a logo for the emerging program. The logo is bascially a star, the symbol of achievement and excellence. But more than just a star, it is people joined together to represent the entire employee population working together as a team. Neither a star nor people joined together as a team are new concepts; but the final product --this logo-- is distinctive.

The next step in the formalization of the BFEC Productivity Program was to discuss the long standing productivity and quality commitment with all levels of employees, from executives to entry level employees. The Productivity Council compiled the statement of BFEC Productivity philosophy with the following primary components:

- Improving communications and cooperation vertically and horizontally within the corporate hierarchy and adopting a more participative style of management

- Educating all management personnel and employees in techniques designed to identify, evaluate, and solve problems

- Continuing the quality improvement process aimed at "doing it right the first time" for tasks performed within all organizations

- Using statistical techniques throughout the company: operational statistics, cost control, management, absence, safety, etc.

- Expanding opportunities for employee participation in the improvement of services supplied to BFEC's customer

- Encouraging supplier or subcontractor participation in the quality/productivity improvement process and providing assistance and direction, as required

The Productivity Council recognized that an effective program required active participation from all employees at all levels of the organization. The President and two key Vice Presidents were chartered with the responsibility for the final administrative and budgetary decisions as the Productivity Program's Executive Committee. The Productivity Council would continue to consist of a Director and representatives from key operational and administrative organizations. Individuals from each department volunteered to serve as Department Productivity Coordinators. Employees were surveyed and given an opportunity to participate in BFEC's adaptation of the productivity improvement process. The council evolved a significant and unique role for a vital group of employees -- the managers and supervisors.

The council quickly recognized that one potentially effective approach to augment organizational performance appeared to be a merger of quality assurance methodology and behavioral science theory. The council researched and examined existing literature on the subject and contacted companies that had implemented or were in the process of implementing productivity improvement programs The council developed the Productivity Enhancement Team (PET) concept, and tried the concept out in one department as a prototype. This department was chosen because it had a long record of productivity and quality commitment demonstrated by marked open communications, an effective team of managers, and a desire to be innovative.

Research revealed that most existing productivity programs centered around manufacturing concerns. The measurement of success was typically based on productivity or quality enhancements to a product or consumer item that could be easily measured. However, research into motivation and employee involvement principles indicate that these manufacturing-oriented productivity programs could be transferred with some customization to the service industry. Through an iterative process, traditionally structured productivity improvement methods were tailored to meet the needs of the BFEC organization.

The growth of the PET program has been controlled during its evolutionary phase. Each PET is made up of volunteers, from four to ten members, who meet on a regular basis to discuss productivity improvement, problems, concerns, and solutions. Employees have been enthusiastic about joining and working in these employee-run teams. They work on problems appropriate to their job responsibilities.

Success of PET teams is linked to certain key elements. The voluntary nature of the PET is an important ingredient in developing employee support, commitment, and enthusiasm. The voluntary nature of the program is rooted in the basic concepts of motivation and employee involvement. PET members learn to work as a team, which not only encourages problem solving but also encourages joint effort and collaborative ways of working. This 'team effort' is a new experience for many employees who typically perform tasks alone or in a limited exposure to others.

The most significant aspect of the PET process is the structure in the program. Many employees have little experience and few opportunities to participate in effective structured problem analysis or to work successfully in group settings. During BFEC's PET training, employees undergo six weeks of orientation to widely accepted productivity improvement methodologies including: problem definition; brainstorming, data gathering; cause-and-effect analysis; Pareto analysis; preparation of data check sheets, graphs, and charts; and presentation techniques. The purpose of this training is to ensure that all PET's operate within the same guidelines, using a specific approach to problem solving with the goal of presenting a solution to a work related problem to supervisors and managers in a method which easily demonstrates that the problem and recommended solution were thoroughly evaluated.

As BFEC implemented the PET process in a controlled environment, it became apparent that supervisors and managers had a very important role in this evolutionary program. The supervisors of the first PETs had mixed reactions. Some were apprehensive because the PET identified problems which the supervisor thought should have been recognized and solved by the supervisor. Some supervisors were fearful that the PET would usurp their authority.

The Productivity Council discovered from its research and practical experience that a productivity program such as the one described cannot succeed without involvement from management. To achieve this involvement and support often requires a drastic change in traditional management attitudes.

True change cannot be dictated or mandated. It must be truly embraced by the highest level of management and communicated throughout the company. Communication and training starts with the company president and proceeds to directors, program managers and senior managers, department managers, and supervisors.

The council contacted various vendors of management development and training and vendors who specialized in productivity programs and quality of worklife programs. They asked for ways to develop meaningful roles of supervisory and management personnel.

The vendors submitted proposals for 4 to 16 hours of training, during which the supervisors and managers would experience the PET process and discuss their reactions to the group process. The council felt that something was missing.

They looked and found a resource who talked about the process of change. They realized that to achieve true system-wide acceptance of the PET process, managers and supervisors would have to not only support and endorse the structured PET techniques, but demonstrate these techniques in their day-to-day interaction with employees.

Given BFEC's long standing pattern of productivity improvements and proven methods of cost efficiency, we only had to provide general guidelines for supervisors and managers. The Productivity Council compiled the Productivity Procedures Manual which incorporates existing programs, procedures, reporting channels with the PET techniques, recognitions and rewards.

Let's review the steps taken by the Productivity Council. They established the PET program, a structured process for small groups of employees to discuss work related problems, research these problems and present well researched and documented solutions to management. Throughout the PET process, supervisors and managers maint n close contact with the PET through receipt of the minutes of each meeting, by responding to PET member requests for technical information, data, and support, by participating, as guests, at regular PET meetings and by evaluating and responding to PET recommendations.

Realizing that department management may not be able to implement a PET solution due to budget or manpower constraints, the Productivity Council further opened a new line of communication between employees and the highest level of management by providing the PET with the opportunity to make its presentation directly to the council. The council then has the responsibility to approach the Executive Committee which has the ultimate power to provide additional budget, manpower and materials.

The Productivity Council has further developed a forum to open lines of communication between supervisory and managerial employees by requiring an annual departmental productivity plan. This plan is not designed to respond to the needs of the Productivity Council. It is designed to cause the department director, managers and supervisors to meet together and, using PET-type techniques (brainstorming, problem-solving, etc.), develop specific measurable productivity and quality goals and objectives for the year. The Council does not expect, nor does it want, a glossy productivity plan which is outside the current and established work of a department. It seeks the documentation of goals and objectives which are part of the way the department does business.

In the formalization process, the council opened lines of communication between employees by providing the structured productivity improvement techniques. It is important to examine the lines of communication and the formal and informal channels for communication. From this examination, BFEC can share with other service groups its experiences in re-emphasizing productivity as a way of life within an organization. BFEC has opened informal lines of communication between employees and managers by providing an opportunity for employees to study work problems and recommend solutions to management; opened lines of communication between executives and managers and supervisors by providing a forum for the determination of departmental productivity and quality goals and objectives; and opened a new formal line of communication between employees and the highest level of management by providing a PET with the opportunity to make a management presentation directly to the Productivity Council.

The BFEC Productivity Council has tried to involve all employees, at all levels of the various organizations, in the productivity improvement process. All of our approaches, methods and processes require people and people require interactive communications to be optimally effective.

Together, management and employees must communicate to maximize the organization's strengths and minimize impediments to productivity. People need to know their role in accomplishing the company's goals and objectives and they must be able to communicate to management their desire to accomplish these goals.

People are the strength of the organization and, therefore, the mainstay of the productivity and quality effort. They help the organization use its resources more efficiently and effectively for the betterment of the company and its customers.

What has happened in the last year and a half is systematic formalization of the process throughout the organization. Components of the BFEC Productivity Improvement and Quality Enhancement Program include research, reviewing past achievements and failure, learning from other companies and from our own experiences, adapting structured methodologies of effective productivity improvement programs from typically manufacturing entities to the fluid, responsive, mobile world of the service industry, and formulating a program which involves personnel at all levels of the organization.

The ideas and methods in this paper are not new. They are distinctive. They are like the BFEC productivity logo -- a star composed of people interacting. Individually the pieces are well known but together distinctive and a symbol of a renewed vigor to work together, to work more innovatively, to work smarter.

(Phillip P. Marino, Senior Manager of Software and Engineering Services, began his career with the Bendix Field Engineering Corporation as the Software Quality Assurance Manager. He is now responsible for all software and systems engineering services on the Mission Operations Support Services Program for NASA real-time spacecraft control networks. His prior corporate experiences include Corporate Systems Manager for the largest import automotive distributorship on the east cost, responsible for all ADP activities for the corporation. Further experiences include over 16 years in data processing with the Maryland Department of Transportation, Department of Health, and Department of Education, culminating as Deputy Director for the Department of Education. Mr. Marino holds an Executive MBA degree from Loyola College of Baltimore, Maryland.)

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SOCIO-TECHNICAL INTEGRATION OF THE WORKPLACE

George L. Carter
Manager, Socio-technical Engineering

Westinghouse Manufacturing Systems & Technology Center
Columbia, Maryland 21046

ABSTRACT

The objective of socio-technical theory and design is to provide the best match between the social system and the technical system. The achievement of a best match makes optimal use of the resources of both systems.

Implementation of this theory is best served when there is involvement by the "user" organization. The "involvement" relative to the introduction of new technology in the organization is extremely significant. Employee involvement is critical to effective participative management. Because this style is considered to be "new", many managers lack the experience in dealing with such an approach to management.

The trends toward participative management and employee involvement have taken various forms. These have included quality circles, semi-autonomus teams and adhoc action teams. It is noteworthy to point out, as these processes have evolved, the role of a facilitator has become more prevelant.

The facilitation of the socio-technical design system will use the tools of industrial engineering and will be managed using a style which has been structured under behavioral science principles.

The successful integration of new technologies into the business organization today will be predicated on the socio-technical system which has been developed.

SOCIO-TECHNICAL INTEGRATION OF THE WORKPLACE

Socio-technical theory originating in the 1950s looked at work effort as a system of technical and social components.

> "Socio-technical design is based on principles from two different worlds between which a fundamental split exists. The technical world is organized around rational principles of efficiency, while the phenomenal world within which humans live their daily lives is organized around psychological principles based on cognition and emotion. The principles by which one world is organized are not necessarily or even likely to be the same as those by which the other world is organized.
>
> The objective of socio-technical design is to bridge the two worlds through a "best match" between a social system organized around phenomenal-world principles and a technical system organized around technical-world principles. The achievement of a best match makes optimal use of the resources of both systems. The resources of the two systems are optimally used when the two systems are members of the socio-technical system.
>
> A work group is self-regulating to the degree that group members define themselves as system contributors rather than job-holders." (Susman 1976)

Performance, relative to this theory, is most effective when the social and technical components are well matched to each other. This match does not just happen--it must be properly planned and implemented. This implementation is "best" served when there is involvement by the "user" community or organization.

The involvement of the "user" relative to the introduction of new technology in the organization is extremely significant. For decades the organization of the workplace had been predicated on the principles of scientific management. This system is still routed in the drive for more output per hour, or breaking down each job into its simplest, most repetitive specialized tasks, with the shortest possible learning period. Scientific management had concentrated on the technical exclusion of the social.

This management philosophy generally considered that the worker involvement was of limited value in the organization. This is no longer true.

Employee involvement is critical to effective participative management. Because this style is considered to be "new", many managers lack the experience and know-how in dealing with such an approach to management. Sometimes the concept is viewed by managers and supervisors as a threat in terms of conventional power and authority. The impatience of some managers to achieve the short-term economic gains while dealing with a sensitive new product that requires long term commitments forecasts, at best, an uneasy pathway to meaningful results.

We can anticipate, therefore, that the worker participation in the development of these kinds of new programs to improve the so-called "quality of work life" will manifest itself in a step-by-step effort to enhance the welfare of the workers and to uplift their human dignity. For the present and forseeable future, worker involvement in decision-making will more readily spring up with regard to the more immediate and noticeable aspects of the working life. Managing the job is more immediate and urgent. The workers' concern for the managing of the enterprise is best measured by the immediacy of the impact on the worker himself.

The trends towards participate management and employee involvement over the last several years have taken various organizational forms. These have included quality circles, semi-autonomous teams and ad hoc action teams. Participants in these organizations for the most part have been voluntary. It is noteworthy to point out, however, as these processes have evolved, the role of a "facilitator" or "third party consultant" has become more prevalent. One can logically conclude that as participative management philosophies grow, the role of the facilitator and third party consultant will, likewise, grow.

It should be noted, however, that the role of the facilitator should, in time, become a management style and philosophy and not a position identified with a "program". "Programs" traditionally become the "flavor of the time" and succumb to new programs that take their place.

In one organization in which I was associated, a large quality circle activity prevailed. The quality circle facilitators of the organization each had in excess of twelve circles in progress at any given point in time. The organization had a need for more circles, but was hesitant about adding additional new facilitators. To address the problem, "ownership transfer" was instituted.

The process called for the quality circle team leaders which were work section supervisors, to be trained to become facilitators, and secondly, a member of the quality circle to become the team leader. The original facilitator became a member of the Operation Manager's staff and functioned as an advisor and consultant to the facilitator.

This "ownership process" accomplished two purposes:

1. Allowed the establishment of additional quality circles without the hiring of more facilitators

2. Provided the first line supervisor with a "facilitation" management style which helped to develop a participative management environment in the organization.

The effectiveness of the circles to enhance the organization became significant when the objectives of the organization were shared with the "circles", and the subsequent projects of the circles dealt specifically with supporting and accomplishing the objectives, thus providing a focused activity for the circles.

A second organization which I was familiar, was organized specifically to utilize the participative management concept. The organization was structured around semi-autotomous teams. Instead of the traditional first-level supervisor, the teams had team leaders or facilitators. The facilitators provided the necessary training and technical support to the teams so they could accomplish the established goals and objectives of the organization. The roles of the "team" members changed regularly from "production workers" to support functions such as production and quality control.

The team leaders of the organization had professional classifications and had come from industrial engineering, production, quality, and test backgrounds.

The effectiveness of these organizations has been, for the most part, dependent on the training given to the participants. The training provides analytical and problem solving skills used traditionally by industrial engineers.

The industrial engineer played a primary role in the scientific management of the organization, both from administration of the process and the controlling functional responsibility.

With the advent of the socio-technical process, the industrial engineer will again play a major and significant role. This basic logic is credible, however, there is one basic flaw.

Traditionally, the industrial engineer lacks training in the behavioral sciences which is essential in effectively interacting as the "third party consultant". The role significantly changes from the traditional "tell them how" to the "suggestive" approach as a technical resource to the participative group.

For the present time and immediate future, specialized training in the behavioral science principles and application must be provided to the industrial engineers.

This aspect of education is not presently required in most traditional Industrial Engineering curriculums.

Success of the socio-technical theory is predicated on a participants environment which involves the commitment of the "user". The greater the amount of user awareness and commitment to the process, the lesser amount of resistance to change and the new technology.

It is very difficult to develop a participate approach in an organization when the members have been operating independently of another. Now, to use their individual personalities, work habits, and ideas toward a group goal is a very ambitious undertaking. There's no denying the beneficial impact that genuine participation can produce and the positive repercussions it will have in other areas.

In adopting a participative concept philosophy, the most often asked question is, "What is in it for the organization's members--and what benefits can the organization obtain? We will first take a look at the research that supports why organization members want to participate.

The often-used cliche that we hear, in justifying a participative concept today, is that "people tend to support what they help create." This statement is perhaps becoming more of a truism, as we gain more and more experience working with people in a participative environment.

The establishment of meaningful goals and objectives is an important function of any participative concept. "Some goals are set by the individuals pursuing them, some are set with the participation of others, some are set exclusively by others. Generally speaking, individuals most actively pursue the goals they set themselves. Involvement in goal setting might take the form of units produced per day, per month, or per year. The establishment of a productivity objective, a reduced scrap level, or a reduced rework percentage can be goals also.

What does all this involvement promote? If there is an acceptance and commitment by both participants and management, a climate of cooperation, understanding and genuine teamwork will prevail. To be successful in promoting teamwork in an organization, members of the group must perceive that higher level management is really interested in and committed to fostering a climate based on open communication and mutual trust.

When discussing a participative concept with individuals who are interested in what it is, or getting input from employees on what they think of a participate concept, an often-heard question is: "What's in it for the company? Obviously, there must be some benefits or you wouldn't be trying it!"

The answer to this question is--Yes, there can be significant benefits, if recognized that a participate concept is an on-going process that changes as frequently as the weather--mainly because there are people involved. Because people are involved, and for the advantages to be fully realized, it must be approached from the standpoint that employees are truly ready and capable of making positive and constructive contribution.

The benefits derived, in some instances, may be measurable in dollars and cents, while, on the other side of the coin, benefits less measurable, but very significant. More specifically, measurable benefits reported by organizations adopting a participative concept have experienced the following:

1. Lower Absenteeism, which can be related to additional product shipped and on time deliveries.

2. Lower Turnover, less time and money spent on training new people.

3. Higher Quality can be a result of the employees having a positive attitude about the importance of their task. A satisfied customer can generate repeat orders and job security.

4. Meeting Product Targets in an atmosphere of enthusiasm and commitment.

5. Achievement of Productivity Goals, which, in turn, lower product costs. The other side of the coin that is less measurable in terms of dollars and cents, but very significant from a humanistic standpoint, is that you capture a bigger part of the whole person. Perhaps the most important benefit of all this is simply the change in environment that, characteristically, occurs when a participate concept is attempted. The plant floor can become a strikingly different place from the days when work was just a routine grind.

As previously mentioned, the development of the participate environment is not something that happens quickly--however international competition and Japanese management styles have done much to bring about the awareness of the behavioral sciences effect on management styles in business today. As large numbers of organizations encounter successes in behavioral management applications, expertise will continue to be integrated in the organization.

The industrial engineer has traditionally over the years provided the interaction and communication link between management, technology and the worker. The role today has not changed; however, the process and culture have. As management gains greater familiarity with the behavioral sciences, management attitudes will change and thus enhance the cultural change. The behavioral sciences are now being regarded as results-getting tools and will thus be expected to produce hard, measurable improvement.

The conflict between traditional industrial engineering and behavioral sciences and their practitioners is disappearing. In a quest for greater productivity and efficiency, I.E. will put less emphasis on its traditional approach of work simplification and will view overall efficiency in light of what the behavioral sciences say. Working from the other direction, behavioral scientists will need the skills of industrial engineering to develop useful hard measurement.

Change, and the management of change will be most significant in expediting the process. Because the development of high technology is so rapid, it is almost impossible to maintain the knowledge of the employees to the level of technology. Because of this, two major areas of the organization need to be addressed:

1. Organization has to be modified, changed, whatever to accept the new technology

2. Retraining of the people relative to the new technology.

The industrial engineering organization is best suited to deal with the change problem as it affects the organization. Recognizing that the industrial engineers must have prior training to become effective facilitators and third party consultants--two approaches can be taken to address the organization needs for coping with technological change--ergo-the Socio-technical process.

One approach might take in assessing the needs of a new requirement, in comparison to the existing organization, is called functional organizational analysis. This approach utilizes a third party facilitator, but it brings into play all of the participants or members of an existing organization. First take the existing organization and break it up by its specific functions.

As these particular function are broken out, they are further broken down by their specific responsibilities and the necessary tasks required to achieve these responsibilities. At this time, we are looking at an existing organization as opposed to the one that will be accepting the new technology. This gives the members of the organization an opportunity to see if, in fact, the responsibilities are still required for the job that has be done today.

As these functions are analyzed, we have the organization point out the skills necessary to accomplish the specific responsibilities that they have been analyzing. The members, at this point in time, build a skills inventory of the functional organization that presently exists. These are the skills which are deemed necessary to have the organization function properly in today's environment. This information also will provide a framework of reference when going through the organizational analysis needs for the new technology.
After the functional organization has had an opportunity to be informed of the technology that is going to be introduced, it's possible to then go through a functional organizational analysis using the same type of approach that was used on the existing organization. The only difference here is working with the technologist. One can now define the new responsibilities of the functions that are going to be required to operate the new technology.

As these functions, responsibilities, and tasks are defined, it's now possible to develop a needs analysis of the organization to satisfy the function with the new technology. At this point in time, the needs analysis, or skills required can be compared to the existing skills in the organization. Further analysis will determine skills which are now obsolete, which have to be retrained, or new skills that are necessary to accomplish the operation of the function with the new technology introduced.

The organization should also recognize, at this time, the new skills necessary or new tasks that didn't exist before. The process allows the review of the organization and the required skill tasks that existed before to see where there are possibilities for job blending, skills blending, and areas where one can build on existing skills, where there is a natural progression. If there is no natural progression, then it's going to be necessary to establish programs that can retrain the individuals so that they can, in fact, function within the new organization and the technology that has been introduced.

With this type of information, it's possible to start the necessary training plans for retraining or training the organization to accomplish the end result, that being, the introduction of the new technology.

The second major area to be addressed is the training of the people for the new technology. This training can be placed into two different categories:

1. Training that is necessary when the technology involves a large number of people, such as the implementation of a large integrated factory business systems technology

2. Where the technology involves a small group of people, the training may be for a piece of automated equipment or for the implementation of a robotics system.

The development of the training process required that certain objectives be met:

1. Training of the personnel to be involved in the technology must be enmass, thus allowing a short cycle time from the training to the application of the technology.

2. Training must be proficiency based, not pass/fail, so as to ensure expected performance.

3. Training must have "technologist" and "user" interaction and involvement.

4. Training documentation must be modular and transportable.

5. Training must not be a burden to the "user".

6. Training and technology must have subsequent "user" ownership and control.

Although the training involves different numbers of people, there is a commonality between both types of training. This commonality is that both must have involvement of the organization and the users that will be trained. The training process is called the socio-technical integration process. It involves the introduction of the new technology to the factory floor and is a three-part process:

1. Documentation of the technology.

2. Development and training of the master trainers.

3. Process is the actual training of the people themselves in the new technology.

The documentation of the first step covers the documentation of the new technology so that it can be interpreted into user manuals or manuals that will be used by the people in application of the new technology. These manuals are developed in modular form in that they can be broken down by functions and tasks which will be performed.

The user manuals become the text which will be used during the teaching phase, lesson plans are developed in the same modular manner as the manual. These lesson plans are developed to teach each module.

The second area deals with the training of master trainers, who will subsequently train the trainers. These master trainers, for the most part, are those technologists who developed the technology. The technologists use the structured lesson plans when teaching the trainers, it structures them and provides assurance that the same information that they are teaching is taught the same way time and time again.

Because these technologists are not professional teachers, it is necessary to put them through a training program themselves, so that they, in turn, can teach the trainers. This program is a two-step process, the first being a two-day program that deals with the principles and theory of how to teach in an industrial organization.

The second step of the teaching process is a training program which deals with the actual hands-on teaching of one's peers in a two-day training program. After the individual has done some teaching, they have an opportunity to critique themselves, with an instructor, and discover their areas of skills or weaknesses. These become the areas of concentration during the teaching process.

Prior to the training of the trainers by the master trainers, the trainers also receive this same type of how-to-teach training. This process was designed because of the large numbers of people to be trained. It was decided that the proper way to do this would be to train the supervisors of the subsequent users. These are the people that will actually be applying the new technology.

By using the supervisors as the trainers, it allows you to get the pyramid effect relative to the teaching of a large number of people in a short period of time simply because each of the supervisors would then, in turn, teach their own people. Because the supervisors and their employees have to maintain the normal everyday work, the training has to be in the total control by supervisors. By giving control of the teaching process to the supervisor, it allows them to teach when it best suits them. This allows the supervisors to establish the priorities of what modules they want taught first. Secondly, it also allows them, when they feel that someone hasn't properly learned a specific task, to take that person to the training area and give them some reinforcement or some retraining to maintain iob proficiency.

This approach further provides the supervisor with the capabilities to subsequently retrain or train people for rotation and train new people coming into the organization.

As previously mentioned, the process, both the functional organizational analysis and the subsequent training process, is developed around the user The purpose of that is to ensure the commitment of the user to the process. To have this commitment, the user must play an integral part in the development of the subsequent implementation of the technology. They must be there during the planning stages, not just handed a finished package at the end of the process. When using this approach, the implementation process can be accomplished in a much shorter time, and is much smoother when going into the organization.

The successful implementation and integration of new and advanced technology in the business organization today, is predicated on the cultural environment developed by the socio-technical component balance.

George L. Carter is Manager of Socio-technical Engineering at the Westinghouse Manufacturing Systems and Technology Center in Columbia, Maryland. He is responsible for the introduction and integration of advanced manufacturing technology (robotics, automation and computer management systems) into the workplace.

Other positions he has held within Westinghouse include; but, are not limited to, Manager of Corporate Industrial Engineering, Operations Manager and Plant Manager.

A graduate of Baltimore University and Mount Saint Mary's College, he holds a B.S. in Industrial Management, Masters in Business Administration and Doctor of Laws degree.

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INFORMATION FLOW AND WORK PRODUCTIVITY

THROUGH INTEGRATED INFORMATION TECHNOLOGY*

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Submitted by:

Rolf T. Wigand, Ph. D.
School of Public Affairs
Arizona State University
Tempe, AZ 85287

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INFORMATION FLOW AND WORK PRODUCTIVITY
THROUGH INTEGRATED INFORMATION TECHNOLOGY*

Rolf T. Wigand, School of Public Affairs
Arizona State University, Tempe, Arizona

ABSTRACT

The author reviews the work environment surrounding integrated office systems. He synthesizes the known effects of automated office technologies and reviews their known impact on work efficiency. These effects are explored with regard to their impact on networks, work flow/processes, as well as organizational structure and power. Particular emphasis is given to structural changes due to the introduction of newer information technologies in organizations. The new information technologies have restructured the average organization's middle ranks and, as a consequence, they have shrunk drastically. Organizational pyramids have flattened with fewer levels since executives have realized that they can get ahold of the needed information via the new technologies quicker and directly and do not have to rely on middle-level managers. The author stresses the point that power shifts are typically accompanied with the introduction of these technologies resulting in the generation of a new form of organizational power. These effects and trends can be seen as an evolutionary step toward more flexible, decentralized and less defined organizational structures, resulting in a fluid organizational structure whose design is based on the changing needs of the organization.

INTRODUCTION

Office automation conjures images of legions of secretaries typing away in front of video display terminals. But the term implies no longer just word processing. Instead it is conceived today as a web of new technologies, including computers, PBXs, voice mail, electronic messaging, facsimile devices, conferencing systems, and others. The new

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information technologies affect the access to and then flow and distribution of information throughout an organization and, eventually, the resulting changes can lead to drastic changes in the organizational structure itself.

It is fairly recent that organizations have begun to view office automation efforts in a comprehensive context instead of in terms of individual technologies. Although approximately 87 percent of 89 companies in nine countries stated that computerized information flows play a very important role in at least one corporate activity and even though the extent of computerized information use is expected to rise to 92 percent by 1986 [34, p. 67], several authors [e. g., 18, p. 57; 41] claim that organizations have hardly tapped five percent of the possibilities utilizing integrated information technologies in office settings. At stake for organizations is an opportunity to speed up communications, reduce paper flow and achieve productivity gains throughout the entire organization. Consequently, the integrated automated office is fast becoming a reality. It is quite obvious that only by integrating various office automation technologies into one coordinated system--an orchestrated system--will today's office be truly efficient and effective. There are three broad classes of integration that can be identified: (a) the integration of information, (b) the integration of user interfaces, and (c) the integration across systems.

A well-planned, integrated office automation system demonstrates five characteristics:

1. It incorporates executives, managers, and support staff.

2. It transmits reliably fully integrated electronic documents--text, data, voice, as well as pictures--and stores them electronically across systems at high speeds, be it local or otherwise.

3. It is a host-based system designed around a central computer and a common architecture. As a consequence, end-users can gain easy access to common data bases, edit documents and transfer them between similar and dissimilar devices, including equipment from different manufacturers.

4. It is a real-time management information system, giving its users access to all information in the organization and enables them to transmit information to their colleagues, wherever they may be.

5. It has flexible configurations, an open architecture, transparent connectivity, compatibility, intelligence, full-functional capability and, when appropriate, desktop functionality.

Within just the last two years, a number of technologies have become available on the market that *in toto* seem to make the integrated office come true. They range from voice mail systems via local area networks to integrated communication satellite services. It seems that the growing sophistication of networks is currently the most important element that will make the integrated office a reality. Without such networks few of the real benefits of the integrated office can be realized.

Much of the needed technology exists today, although refinements are necessary to tie the individual elements of the automated system together. An integrated office system is more than just the sum of its parts and it is specifically the applications that matter most, not the devices. Planners and users alike must learn to understand that they are not a single-cell unit, but that they are part of an interdependent community. In this sense then an integrated office system is not defined by its hardware, but by its software. This software in turn should allow dissimilar devices to communicate among each other and make the system easy to use. In accordance with this line of thinking, there appears to be a growing recognition that the management of information and effective communication are as important, if not more so, to organizational success as are products and services.

The Work Environment Surrounding Integrated Office Systems

One can identify three classifications of office workers as prospective users of an integrated office system: (1) those making limited transactions account for 33 percent of the workforce, (2) full-function professionals amount to 27 percent, and (3) specialized professionals constitute five percent of the workforce. The remaining 35 percent are white-collar workers who are not potential system users due to the specialized nature of their organizational activities [41, p. 28]. In 1983 there were 53 million white-collar workers in the United States and 35 million were potential users of integrated offices systems, but less than five million had only desktop devices available to them [41, p. 28]. Even today truly integrated desktop systems have enjoyed very little penetration in most organizations, a shortcoming that is likely to change rather drastically with the massive advent of personal computers on workers' desktops. One must consider, however, that while striving towards automated integration, such desktop devices must be linked at least via a local area network and ideally linked with a central mainframe computer in larger organizational settings. Within this environment office systems are moving toward the integration of any function that can be carried out by a number of technologies.

The market for telecommunications equipment and services in the United States is certainly a most promising one. It is expected to reach $150 billion annually by 1987, a 50 percent increase over current spending [19, p. 22]. Sales of communications technology hardware alone has reached $60 billion in 1983 according to Arthur D. Little estimates and will increase to $90 billion annually by 1988 [44, p. 59]. Information processing has also grown into an enormous industry, accounting for $33 billion in services in 1983--the last year for which figures are available--and it is projected to account for $88 billion in 1988 [17, p. 57]. Office automation--according to some estimates--has reached only a small segment of the 14 million U. S. businesses with revenues less then $10 million [23, p. 126]. Office costs have been estimated to increase at a compounded annual growth rate of 15 percent [1, p. 26].

Such market potential is also reflected in the various activities which typically can benefit from the use of communications equipment. For example, Xerox reports that in 1981 a total of 850 billion pages of business documents were produced in the United States compared to an anticipated 1.4 trillion pages in 1985 [36]. This latter figure is expected to be produced and handled by centralized in-house and contract printing (38 %), by centralized data processing centers (34 %), by office machines (15 %) and by distributed forms of data processing (13%). Over twenty-one trillion pages of paper are now stored in the United States based on studies by Frost & Sullivan [28, p. 53]. The same report claims that for each of the eighteen million U. S. office workers, there are four file drawers with 4,500 documents a piece. Furthermore, office workers are creating new documents at the rate of one million per minute. This translates to the annual creation of 4,000 new documents per office worker. At the same time this individual files ten pieces of paper each day, amounting to a daily total of 180 million pages. Within the time span of a year, this makes up 46 billion, 800 million pages. There is no doubt that paper is still the number one information-carrying medium in the world despite recent dramatic inroads of office automation systems.

When analyzing how managers tend to spend their available time gives additional understanding about the potential of integrated office automation systems. Managers in over 20 studies--too numerous to detail here--spent when averaged 38.29 percent (SD = 17.45) of their time in face-to-face settings, 10.50 percent (SD = 8.00) of their time is spent on the phone, 14.58 percent (SD = 7.73) reading and 14.57 percent (SD = 5.95) of their time is occupied by writing. Similar studies report that 46 percent of the manager's time is spent in meetings or with telephone calls, 25 percent is spent with administrative tasks, 13 percent with document creation activities and the remaining 16 percent fall into the analysis and other category. Others have reported that only seven percent of the manager's time is spent with primary functions (decision-making) and that 78 percent of available time is spent with various communication activities such as receiving, storing, filing, retrieving or transmitting information [Cf., e. g., 10, p. 40]. Professionals spend about 20 to 30 percent of their day just searching for information [43, p. 78]. Secretaries spend 25 percent of their time away from their desks and about 18 percent waiting for work, i. e. they are either unavailable to those they support or just idle [43, p. 78]. Others claim that only 20 percent of a secretary's day is spent typing. Secretaries are interrupted approximately 45 times a day [43, p. 79]. Such data should be seen in light of the fact that the cost of dictating and transcribing the "average" letter amounts now to $8.10, a 6.6 percent increase over the 1983 cost of $7.60, according to the annual survey of the Dartnell Institute of Business Research [8]. It is still quite common that the majority of office tasks are not analyzed and proceduralized and, many times, when procedures exist they are either ignored or out of date. Quite frequently, people in the office perform tasks which are clearly marked for lower paid personnel as can be observed when a manager or professional stands in line waiting for the photocopying machine.

From the results of a recent study on the contents of telephone messages conducted by AT&T [33, p. 36] we know that less than ten percent of the messages are "complete." Except for the category of "no message" calls, these phone calls will trigger at least one more call, even though it is highly probable that a complete message would have enjoyed higher productivity results. This AT&T study found that in terms of message content 46 percent left name and number, 26 percent left name, number and purpose, ten percent left their name only, nine percent left a complete message and nine percent left no message. It should be noted, however, that 82 percent of these telephone messages constitute really no more than a "call report" due to the interpersonal barriers of third-party message taking. Similar results have been reported by Hirschberg, et al. [9]. Asten [1, p. 31] estimates that U. S. business has currently a $15 billion "pink slip problem" (for telephone messages) and that 64 percent of the many millions of return telephone calls made are actually displaceable.

Technology has been advancing manufacturing productivity for centuries, but relatively little has been accomplished for the information and services sectors of U. S. industry. These sectors constitute over 50 percent of all four labor sectors and the 'information business' accounts for 60 percent of the nation's economy [Cf., e. g., 22, p. 30]. With the information and services sectors being the largest ones, it is here where labor saving methods will pay off the most. Numerous productivity-enhancing office automation technologies have already or will produce large advances in productivity. One estimate that information flows are increasing at an annual rate of ten percent and since over half of the U. S. work force is now processing information, it makes eminently sense to automate increasingly information processing and transmission functions. Otherwise, we are likely to choke on information overload as the statistics below may suggest.

It is most surprising that investments in office workers have not been considerably higher. Blue-collar productivity increased more than 80 percent during the 1960s, yet U. S. white-collar productivity increased merely fout percent during the same time span [40, p. 64n]. It is generally estimated that $30,000 in start-up equipment, services, and training are required to support just one knowledge worker [13, p. 69], the term frequently used to denote managers, administrators and professionals as a group. Poppel [29, p. 147] reports from a Booz, Allen & Hamilton study that more than $1 trillion went for salaries and support of white-collar workers in 1982 and $600 billion of this figure went to compensate knowledge workers. Some experts predict that by the year 2000, 119 million people--amounting to nearly 90 percent of the U. S. work force--will be white-collar workers. By 1990 at least half of all office workers in the U. S. will use a word processor, a data processor, or some variant thereof [24, p. 72]. Secretaries and typists represent only 8.7 percent of total office salary costs, while professionals and managers make up 68 percent [14]. It is estimated that word processing systems could eliminate 3.8 percent of all office costs if they replaced every typewriter, the savings yielded from automating professionals and managers would be substantially higher. According to Kearns [14], interpersonal communication, analysis and decision-making make up 47.2 percent of all office expenditures. In spite of those figures though, by early 1980, only 15 percent of major U. S. businesses reported having more than five qualified, full-time office automation professionals on their staffs [29, p. 154]. As the cost of automated office equipment has declined and become more accepted in the executive suite, it appears that the race is on to make white-collar workers considerably more productive.

Work Efficiency Due To Office Automation Efforts

A wide variety of office automation technologies are available to be used for various organizational activities. They could be classified into four phases of product preparation, i. e. input (conversion of ideas or thoughts into verbal or written communications, production (processing or manipulating ideas or thoughts created and/or stored during the input phase), output (the generation of an electronic, optical, or hard copy document) and distribution (transmission or movement of output documents or data). The tools in this sweeping electronic upheaval are the interlocking parts of a communication network that was inconceivable just a decade ago. These technologies include the following:

Communication satellites
Computer conferencing technology
Computers (including personal computers, desktop workstations and terminals)
Electronic mail
Facsimile
Networks
Optical character recognition
PBXs (telephones, including cellular and mobile telephones)
Records management technology
Teleconferencing technology
Teletex
Video disks
Videotext
Voice messaging, voice recognition and voice activated technology

The limited space here would not allow to address all known positive and negative effects for each of these technologies. In order to overcome this difficulty an effort is being made to summarize these findings for office automation settings, especially integrated office automation, as much as possible. Rice and Bair [32, p. 189] present a broad summary of key productivity findings and benefits of office automation and grouped them into five areas:

1. Control: requiring less information to perform a task, better planning, providing a more effective response.

2. Timing: reduced waiting time for a meeting to commence or for another department to respond to an inquiry; reduced time spent in decision-making, initiating action, or responding to the environment; increase flexibility of work schedule. Uhlig et al. [38, chapter 3] elaborate on the role of these components of a cybernetic communication system in improving productivity. The other three areas involve the form, transformation, and by-products of communication activities.

3. Automation: the replacement or elimination of manual processes, such as constant revision of mailing lists, that do not contribute to increased effectiveness. ...

4. Media transformations: time, energy, and errors in transferring information from one medium to another may be reduced. For example, a company memo may pass through many media--oral, tape, typewritten, handwritten, revision, typewritten final, photocopies, and mail--before the content is entered into someone's calendar.

5. Shadow functions: unforseen, unpredictable, time-consuming activities that are associated with accomplishing any task, but do not contribute to productivity, including telephone tag and unsuccessful attempts to retrieve information from a personal file. ...

These class categories are, undoubtedly, useful. On the other hand, they are at such a high level of abstraction that they are of little direct utility for the practitioner. An attempt is made to summarize key work efficiency findings for office automation settings. They are presented in Table 1. These and other studies have investigated the impact of information technology upon organizational settings. Space limitations do not permit additional elaborations on those specific results.

TABLE 1

Work Efficiency Impacts of Office Automation Settings

Research Reference	Work Efficiency Impact
Bair (1974)	Changes in communication patterns: decreased face-to-face contact andincreased vertical communication
Bair (1980)	Reduction of telephone shadow costs
Bamford (1978, 1979)	Decreased document turnaround time and increased document output
Bullen et al. (1982)	Improved work flow with time saved
Canning (1978)	Increased volume of communications
Conrath & Bair (1974)	Reduction in telephone and face-to-face communication; increased upward communication flow
Cramer & Fast (1982)	Considerable secretarial time saved
Crawford (1982)	Decline in menial, clerical tasks
Curley & Pyburn (1982)	Greater organizational productivity when seen as more than a way to increase secretarial output
Dahl (1981)	Annual cost savings and 8% increase in knowledge worker time
Dunlop et al. (1980)	Striking productivity gains from 50-100+ percent in document preparation
Edwards (1978)	Change in working based on ability to work at home
EIU Informatics (1982)	
Rank Xerox	Large reductions in telephone use, 1 hour/day labor saved for attorneys
German Computer Services	Joint information sharing and editing
British Dept. of Education & Science	50-100 % productivity gains in word processing after 6 months
England-various organizations	Many sites did not reach cost-justifying word processing productivity levels
British travel agents	Word processing output rose 150 %
Scotland	Word processing output rose 150 %
Engel et al. (1979)	5-25 % knowledge worker and 15-35 % secretarial time saved
Gardner (1981)	Decreased turnaround time in document preparation and scheduling
Gutek (1982)	More creative, challenging, complex, organized work
Helmreich & Wimmer (1982)	High User Acceptance
Johansen et al. (1979)	It takes longer to transmit the same amount of information in electronic print form than transmitting it verbally
Kalthoff & Lee (1981)	Use of micrographics system resulted in minimum of 30 % saving of annual operating costs; reduction of 90 % or more in space requirements; more rapid information retrieval (25 % to several hundred percent faster); increased file security and document integrity; substan-

Table 1--Continued

Research Reference	Work Efficiency Impact
	tially decreased duplication and distribution costs
Kaplan (1980)	Use of dictation equipment resulted in 6.25 to 12 % time savings per day
Kerr & Hiltz (1982)	Agreement on the group's decision tends to be lower in computer conferencing groups. When groups have longer periods, the level of agreement seems to improve in such groups.
Leduc (1979)	Changes in communication patterns: ability to work at home and increased vertical communication
Lippitt et al. (1980) Miller & Nichols (1981)	Reduction in memos and phone calls
Melton (1981)	Improved communication and decreased information float
Mertes (1981)	Cost and time savings via central library
National Archives and Records (1981)	Concept, scope, and potential of office automation ill-defined in government
case processing	Reduced backlogs, more timely and accurate reports
electronic messaging	Too few terminals--no benefits identified
optical character scanning	More cost-beneficial than word processing
National Bureau of Standards (1980)	Use of stand-alone display text editors resulted in an average of 75 % to 133 % productivity improvement if used for original and revision typing; average 104 % to 181 % if used for revision only
	Use of word processing impact printer (letter quality) was 148 % to 533 % faster than electric typewriters' capacity
	Use of data processing printer (matrix) was 1,184 % to 3,554 % faster than electric typewriter for a matrix, 40-120 cps printer; 4,813% to 6,417 % faster than electric typewriter for a 150 to 2,000 lines per minute (line) data processing printer.
	Use of micrographics enjoyed a 25 % savings in retrieval/access time
	Use of facsimile (fax)--the transmission of an 8 1/2" by 11" page took 30 sec. to 6 min.; when 6 min. compared to 2 days for mail to arrive, fax was 480 times faster
Panko & Panko (1981)	Many perceived benefits--more for managers and professionals using system directly than for secretaries; highest benefit for long-distance communications
Picot & Reichwald (1984), Picot et al. (1982)	A tension exists between a favorable attitude toward technological innovations in offices and skeptical view of the specific personal consequences to be faced when technological change in offices occurs. On the one hand, a large

Table 1--Continued

Research Reference	Work Efficiency Impact
	majority (80 %) articulates a positive opinion on new office technology; on the other hand, wide-spread fear (60 %(of unfavorable consequences for own work situation exists. Substitutability and choice of communication channels were studied
Rice & Case (1982)	Reduction in paper and telephone traffic; increased work quantity and quality; but depends on "media style"
Rice et al. (1984, p. 192)	For electronic messaging, benefits: permanent, searchable record; fewer meetings are needed; control of time to respond; independent of time zones and geography; quick delivery; easy to distribute widely; speedy response; upward communication is encouraged; can serve as channel substitute; potential for reduction in travel; medium for creation, transmission and receipt of message are the same; fewer nonverbal constraints; - drawbacks: potential for information overload, misunderstandings can occur, people may be inhibited by machine, much useless information can be distributed due to ease of use
Rice et al. (1984, pp. 137-140)	As compared to computer conferencing, it takes less time to arrive at a decision in face-to-face groups. When the studies had time limits, this fact also takes the form of less consensus because the computer conferencing groups have had less effective time in which to consider the problem.
Steinfield (1983)	More timely and accurate information, increased coordination
Steward (1983)	13 % daily time saving; 35 % increased document output
Talbot et al. (1982)	Less time in communication activities
Tapscott (1982)	Changes in communication patterns: decreased telephone usage and meetings
Tucker (1982)	Implementation failure primarily due to shortened initial analyses phase
Uhlig et al. (1979)	Reduction of telephone shadow costs
Witte (1980, 1977)	By means of new communication technologies, decentralized autonomous groups could pursue their work effectively without risking organizational disintegration
Witte (1976), Szyperski (1979)	New structural configurations for innovative organizational decision-making could emerge
Yankee Group (1978)	Use of electronic mail resulted in a 40 % reduction in dissemination time
Zouks (Cited in "Computers Rescue," 1980)	Use of personal (professional) terminal resulted in 50 % productivity rise

Note: Some of the above references and impacts were first compiled by Rice and Bair (198?, pp. 211-213). Due to space limitations only the newly added research references are cited in the reference section.

Goldfield [7, p. 66] classifies work efficiency and office productivity studies according to the nature of the issues involved and the associated problems by organizational layer, as represented in Table 2.

TABLE 2

Classification of Work Efficiency and Office Productivity Studies

Organizational Layer	Description	Problems
Top Executives	Most expensive, greatest contribution	
	Conceptual thinkers	
	Decisions critical for strategy	Highest taboo area
Managers	High salaries	Difficult to identify need
	Control of Operations	Tasks varied
	Decisions critical for implementation	Stiff resistance to automation
Professionals	New target group	Qualification critical, difficult
	Technical skills	Task specialized
Support Staff	Easiest to quantify and cost justify	Often least significant savings opportunity
	Most frequently automated	

Of particular concern to those interested in integrated office automation systems are various structural changes and changes that can occur with organizational power that are due to the introduction of newer information technologies.

<u>Squeezing the 'Organizational Sponge': Structural Changes Due To Information Technology</u>

The computer has changed the office environment just like the automobile has changed the city. Integrated office automation is a revolutionary development in the transfer and general dissemination of information and data. It clearly has the power to shake an organization from the top to its very foundation. An effective integrated office automation system may result in the restructuring of one or several organizational units ranging from minor adjustments to the eradication of a unit.

Several authors have argued that new structural configurations could emerge within organizations employing newer information technologies [37, 47, 50]. Already as far back as 1958, Leavitt and Whisler predicted that the design of large-scale hierarchies will be changed from a pyramid toward a bell formation in line with changing distributions of power and authority within the organization. Most organizations enjoyed a relatively rapid growth since World War II and with such growth, middle management grew even faster. In the 1970s, the U. S. economy absorbed a rapidly expanding labor force and created 19 million new jobs, whereas most western European nations' economies were at a standstill or suffered declines in the post-OPEC era. In effect, the nation had put the Baby Boom generation, born in the 1940s and 1950s, to work and these Baby Boomers are now reaching middle age. Working women at an age of 35 and older have been instrumental in allowing business to expand since World War II. Women have seized two-thirds of the more than 20 million jobs created in the past decade, accelerating the shift from manufacturing to services [49, p. 80]. Middle management together with professionals and technical people constituted the fastest growing sector in the occupational groups in the last 30 years.

Typically middle management was to take policy decisions received from top management and translate them into profitable revenues. Staff-level middle management was expected to advise their superiors on marketing, strategic planning, manufacturing and engineering issues. At an increasing pace middle managers became the collectors of information that they in turn analyzed, interpreted and then moved along to top executives. From these type of activities the middle manager came to dominate line operations. During the last few years, however, it appears that the function of middle management has changed and that much of this change is due to recently introduced information technology [3, 5, 21, 23, 42]. This technology is rapidly reorganizing the kind of work people do and, at the same time, reorganizing our organizations as well. New patterns of communication and interaction become possible and, as a consequence, our established communication networks within organizations change [cf., e. g., 26]. The newer information technologies make it possible that a greater amount of information is made available to more and more people in an increasingly timely manner. Such changes, no doubt, can influence decision-making patterns and can result in organizational power plays.

Rather recently, at least since 1982, the middle manager's role was turned upside down. Middle management has been reduced in significance and numbers because its basic function of communication has--at least in part--been assumed by machines. The vast in-roads made by the newer information technologies appear to have restructured the average organization's middle ranks and, as a consequence, they have shrunk drastically. Maybe the first results of this radical phenomenon could be observed after the most recent recession in that many laid-off middle managers--until recently a rather stable and secure position within the organizational hierarchy, earning anywhere between $25,000 to $80,000--were not rehired.

Frequently, top executives viewed middle management as an organizational sponge sitting solidly in the middle of the organizational pyramid. If one pushed the elastic sponge a little bit from above or below, not much happened. But if one tried harder and squeezed the sponge some action occurred, although --just as with real-life sponges--once the pressure subsided, sponges have a tendency to assume their old shape, size and volume. Now--it appears--new means have arrived to deal with this phenomenon.

As more and more top executives recognize that much of the information previously collected by middle managers can be secured quicker, cheaper and more thoroughly by computer-based devices, they have started to view much of the middle management layer as redundant. Many now view these information gathering, analyzing and interpreting tasks traditionally carried out by middle managers as considerable cost centers, high in overhead and making relatively small, directly-attributable contributions to profits. They are realizing in accordance with their Japanese competitors that less means more. Many bureaucratic functions can be replaced by information technology. In addition, since much interaction between a manager and his/her subordinates can be carried out nonsimultaneously via electronic media, a manager can take on direct responsibility over several more individuals. This, of course, could result in fewer managers at the intermediate level, but it might imply additional positions at the remaining levels. Jennings [21] claims that one-third of the 100 largest industrial companies are reducing management and that there are clear signs that other corporations will follow. Analogously, during the first quarter of 1983 the U. S. Bureau of Labor Statistics reported that unemployment among managers and administrators in non-farm industries was the highest since World War II. The latter report did not even include those managers who took advantage of early retirement programs and similar incentives.

Even old-line companies have made cuts in their middle-management staffs: Firestone and Crown Zellerbach, e. g., cut their middle-management staff 20 percent, Chrysler did the same with 40 percent [21, p.52]. Similarly, a few leading edge companies have reported significant structural changes due to new information technology: The chairman of Hercules, Inc. cut the levels of management between himself and Hercules plant foremen from a dozen to six or seven. FMC Corporation reports its amalgamation of sales districts and, in many cases, cut out a level of management. FMC installed a voice-mail system and the resulting reduction in cost for long-distance calling alone paid for the voice-mail system. Citicorp introduced a sophisticated information system to improve customer service and make account and market information available to its corporate clients more quickly. This step allowed Citicorp to reduce its staff--70 percent of whom were formerly clerical--from 2,650 three years ago to 2,150. This bank has now been able to move its customer service operation closer to its clients since information can now be transmitted electronically. More than 90 percent of its employees were based in New York in 1979 vs. only 50 percent today [23, p. 118]. Similarly, General Electric laid off eight percent of its white-collar work force in November 1984 at its vast Appliance Park Complex in Louisville amd GTE Corporation, whose total payroll has fallen to 183,000 from 200,000 in the past two-and-onehalf years, has been cutting layers of management and combining jobs to boost white-collar productivity [45].

It has been estimated that by the year 2000, computerization will have caused only a moderate reduction in total jobs. The likely losers, however, are expected to be white-collar clerical and managerial positions. Clerical jobs are said to decline from 17.8 percent of the work force (in 1978) to 11.5 percent in 2000. Although there will be major growth in the professional sector, the need for managers will fall off [16].

Together with economic necessity and technological forces it appears that middle management is affected by such developments in a number of ways. The corporate structure tends to be changing in that broader information gathering can be accommodated and that data can flow to top executives and managers directly without the editing, monitoring, interpreting carried out by middle managers. Many times, the analysis of such activities provide an opportunity to examine what workers actually do. A redesigned organization is likely to pull together and merge under just one organizational umbrella department such units as office automation, management information systems (MIS), data processing, word processing and telecommunications. These efforts may result in the creation of a new group of information managers. They, in turn, would be responsible for the use and protection of valuable data and, in a sense, they would become the custodian of organizational information. Information centers, as such newly created organizations are called, are growing at a rapid rate. Of 160 large North American corporations questioned in mid-1984 by the Diebold Group Inc., 80 percent stated that they had set up information centers this year (up from 67 percent in 1983) [23, p. 124]. Numerous industry experts predict that end-user computing is going to be the dominating means of providing information support and will result gradually in a major organizational change.

As a result of these changes, the management pyramid has begun to flatten with fewer levels and, as a consequence, employees make more lateral moves and their expectations tend to be lowered since fewer organizational layers means fewer chances for promotion. Any changes in the organizational structure are today largely perceived as a by-product of the new information technologies. Eventually the structure of departments and divisions will change as they increasingly share information for operations and decision-making. One data base, e. g., may support several departments and others could be merged and integrated to make full use of relational data base features. These trends may suggest that middle management positions become less secure and more competitive. Furthermore, organizational structures will experience a gradual shift from the typical pyramid to a shape resembling a diamond. The clerical function is likely to be distributed organization-wide.

A New Organizational Power

The effect of automation on organizational power can be observed in a number of ways [50]. As more and more timely information becomes available to a larger number of people, this increased availability of information can result in changes in the decision-making patterns and power bases of organizations. Organizational power can be defined as the ability to exert influence and bring about desired outcomes, including (1) the ability to resolve uncertainty and solve problems, (2) the power of expertise and (3) diminishing job specialization [Cf., e. g., 2, p. 34; 35, pp. 306-328; 25, pp. 2-3]. With the newer information technologies available in organizations, political power associated with the control of information becomes more and more distributed in most organizations. Some, however, experience the opposite for certain technologies, i. e. control can become more centralized. Access to information via these new technologies makes greater centralization of power and control in organizations possible, since top management is enabled to make decisions quicker and by themselves that would otherwise have to be delegated.

Routine activities can also be related to decision-making power [2]. Task routinization reduces uncertainty in a job and, in turn, provides an avenue to reduce uncertainty for someone carrying out this task. Furthermore, task routinization makes possible the reduction of unknown entities, reduces the complexity of the task at hand, requires fewer skills and makes those executing the task more replaceable. It follows then that those who carry out routinized tasks have less power with limited or no decision-making authority in their work environment. These are usually also the reasons why employees may resist office automation efforts. In part depending on the structure of the task and the degree of required specialization, a secretary may, e. g., resist a change to word processing when this individual was accustomed to performing variable tasks.

Frequently, the strongest resisters when a new technology or procedure is introduced are almost always the middle managers. There are good reasons for this though: they equate their power with the number of people they supervise and anything that changes this is likely to threaten them. They are often left out of direct involvement with the new technology and, as a consequence, they do not experience the direct benefits themselves. Usually they have been promoted because they understand the <u>current</u> procedures better than their subordinates. Kearns [13, p. 70] claims that "The trouble with a lot of white-collar people is that they think the reason they are employed is that they are experts."

On the other hand, the newer information technology can strengthen the power of individuals or entire organizational units. In part depending on how the equipment is utilized, individuals or units could be perceived as being irreplaceable which always was viewed as an important source of power. Some individuals or units may be able to use information technologies while others are not or have not yet received such technology. Until the technology becomes widely available as a resource, the parties involved can enjoy a certain degree of leverage or power due to the access to and control of the technology.

Such information technology makes it possible for individuals or units to carry out many more tasks. As a result, the degree of specialization is reduced in many organizations and individuals or units can take on additional responsibilities which may imply a loss or possibly an increase of organization power. Furthermore, such developments are likely to make organizational units more interdependent with others which can be accommodated more easily and can make increased information exchange and sharing possible due to the available information technology. Overall, as specialization is reduced, this should have positive results on various organizational conflict situations and power struggles since information is now largely distributed as opposed to being available to only certain individuals or units. It will be more and more difficult to control absolute, i. e. undistributed, information when on-line information systems and joint databases are used.

Conclusion

As organization charts are redesigned, as chains of command are simplified and as the new structures are implemented, the balance of power is changing and shifting in our organizations largely as a result to information technology. Rigid, hierarchical structures are redesigned resulting in leaner, more flexible and responsive organizations with fewer management levels and more direct information exchange between the top and bottom layer of the organization. Organizations are creating environments in which performance determines compensation and a relative high degree of freedom to improve performance becomes the psychological reward.

The phenomenon described here may be observable only in a few large organizations so far, but it is expected to hit many more within the next few years as they automate their offices. This trend can be seen as an evolutionary step toward more flexible, decentralized and less defined structures, resulting in a fluid organizational structure whose design is based on the changing needs of the organization. IBM, e. g., is one organization that has long had this type of organization in place. Organizational structures serve both to differentiate and the integrate the components of complex organizations. Organizations do not achieve and maintain effectiveness by technology alone. Studies have shown that the effectiveness of an organization is contingent upon the degree of fit it achieves between the technology and its structural design. Since organizations are not things, but people, it is ultimately people who will be changed by the impact of information technologies. As organizational structures change, the distribution of power will change as well. This problem is unquestionally organizational and cultural within its respective setting. Deal and Kennedy [6] predict the arrival of the "atomized organization," meaning that telecommunication networks and common culture, i. e. not the organization chart, will link the "atoms." It seems that ways must be found that improve the flow of information to the right people and to produce true entrepreneurial opportunities for managers who want such opportunities within their organizational framework. This implies that integrated information technology must be applied creatively to change the way organizations carry out their activities and use this technology to their own competitive advantage. In most organizations the technical experts responsible for managing information systems have tended to treat office administration less as a strategic weapon to win a competitive advantage and more as a productivity tool to improve the performance of clerical and managerial workers. They have viewed office automation products as simply a means to computerize old procedures. Executives must analyze how they can use new information technologies to help restructure the organization and and pare down unnecessary organizational layers. The question to ask is, 'How would I change my organization to make it more effective with information technology?' rather than, 'How can I use office automation procedures to make my employees more productive?' In the past, many managers merely focused on making individuals more productive by overlaying electronic systems (e. g., word processors, [illegible]onal computers, EDP) onto the existing bureaucracy. Before we can address the issue of integrated office systems, however, we must come to realize that an integrated system requires integrated management. An organization must first evaluate its structure, for the lack of integrated management will continue to affect the success of an integrated system after its installation. Organizations should not expect long-term gains when they understand the technology, but they do not understand themselves. Integrated information technology systems applied in this suggested way are likely to turn out to be the single most important opportunity for private and public sector organizations until 1990.

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"TRAINING MANAGERS FOR HIGH PRODUCTIVITY" GUIDELINES AND A CASE HISTORY

Robert M. Ranftl, Hughes Aircraft Company

ABSTRACT

Hughes Aircraft's 13-year productivity study clearly identifies management as the key link in the entire productivity chain. This fact led to the establishment of a long-term series of seminars on personal, managerial, organizational, and operational productivity for all levels and sectors of line and staff management.

To inspire the work force to higher levels of productivity and creativity management, itself, must first be inspired. In turn they have to clearly understand the productive and creative processes, fashion an effective productivity improvement plan with sound strategy and implementation, create an optimal environmental chemistry, and provide the outstanding leadership necessary to propel their organizations to achieve full potential.

The primary goals of the seminars are to (1) ignite that spark of inspiration, enabling productive action to follow, (2) provide participants a credible roadmap and effective tools for implementation, and (3) develop a dedicated commitment to leadership and productivity throughout the management team.

PRODUCTIVITY STUDY

Hughes Aircraft -- a high-technology organization of some 77,000 employees--initiated a study in 1973 on means of optimizing productivity in technology-based organizations (See Box). The results of this continuing study, now in its thirteenth year, clearly stress that management, itself, is the key link in the entire productivity chain.

MANAGEMENT'S CRITICAL ROLE

Skilled, responsible management and superior productivity are inseparable; we are entering a far more demanding era requiring greater

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professionalism among managers. Tomorrow's manager, in addition to being technicaly qualified in his or her field, must be a respected, people-oriented leader skilled in the latest techniques of behavioral science and sound business practice. In the past, many managers were able to "get by" on their technical expertise alone. This, however, will not be possible in the future.

The critical tie between an organization's management and the organization's productivity is evident in the definition of productivity, itself. Basically, productivity is the ratio of valuable output to input, i.e., the efficiency and effectiveness with which available resources — personnel, machines, materials, capital, facilities, energy, and time — are utilized to achieve a valuable output.

Virtually anyone could manage if resources were unlimited. However, as we are all well aware, this is seldom, if ever, the case and, therefore, the challenge of creative management is to get the job done optimally with the available resources. And, looking forward in time, there will very likely be fewer rather than a greater abundance of resources at management's disposal, thus creating an even greater challenge.

Inherently, all resources are bipolar, i.e., they can be fully engaged and productively utilized, or, just as readily, they can be underutilized, permitted to lie fallow, or counterproductively abused. The "bottom line" of an organization's endeavors depends primarily upon the effectiveness with which management deploys the resources at its disposal. Management's primary responsibility--its fundamental reason for existence — is, and always has been, the deployment or "stewardship" of available resources. Thus, management is clearly the key link in the entire productivity chain.

Further confirmation of management's critical tie to productivity is evident when one considers personal productivity. The Hughes study showed that personal productivity does not correlate significantly with such factors as IQ, excellence of education, schools attended, curricula pursued, grades achieved, or specialized courses taken since graduation. These factors are extremely important since they indicate a person's qualifications, aptitude, and potential to perform, i.e., they represent one's credentials. Therefore, such factors are of great significance when hiring someone into the organization. However, study participants consistently pointed out that among qualified individuals, differences in productivity primarily depend upon two key factors, namely, attitude and motivation -- first and foremost, the attitude and motivation of management, and that, in turn, reflected downward and coupled with the attitude and motivation of the work force.

To achieve high productivity, it is particularly important that every member of management be highly skilled, positively motivated, and totally committed. Correspondingly, the same posture is necessary relative to the entire work force. But, it must be remembered that the psychological work environment is a critical factor in this regard, and it is management who establishes the psychological work environment. (See Figure 1 regarding an optimal psychological work environment.)

It is management who gives the challenging assignments or lack thereof; it is management who establishes the equity (fairness) within the organization or lack thereof; it is management who exhibits genuine interest, encouragement, and appreciation or lack thereof, maintains equitable incentives and rewards or lack thereof, etc., etc. As can be readily seen, management not only directly determines its own attitude, motivation, and productivity, but through its managerial style and technique, and the associated psychological work environment, is extremely catalytic in influencing the attitude and motivation — and therefore the productivity — of the entire work force. (See Figure 2 regarding Productive Managerial Style and Technique.)

Still further confirmation that management is the key driving factor relative to an organization's productivity is evident in another study finding which showed that the overall productivity of an organization depends heavily upon its management personnel and the top five percent of the staff, i.e., people who deal largely in the realm of creative and innovative ideas, judgment, major decisions, and actions. Participants did not diminish the importance of high productivity on the part of everyone else in the work force, but the point they clearly made is that it is the managerial personnel and the top five percent of the staff who set the pace for productive operations, i.e., it is their ideas, judgment, direction, actions, example, etc. that set the pace for organizational productivity down the line.

If space permitted, many additional proofs that management is the key link in the entire productivity chain could be provided. Suffice it to say, management definitely is that link.

LEADERSHIP

Of all factors, leadership has by far the greatest leverage on productivity. Ultimately, the destiny of any organization hinges on the caliber of its leadership. Although many managers have distinct leadership abilities in certain aspects of their jobs, very few qualify as outstanding leaders. The few who do are unusually competent, dynamic, confident individuals who somehow "have it all together." They are the "uncommon leaders" potentially capable of creating a renaissance within their respective organizations.

Of significance, leadership is entirely the outgrowth of self-development. No two leadership styles are the same — each style is and should remain unique to each individual. Furthermore, a good leader in one situation may not be a good leader in a different situation. Also, the type of leader needed depends specifically on the group to be led. Yet, even the same group may require a different kind of leadership at different times in its evolution.

Fundamentally, leadership and management are uniquely different entities, with the intrinsic value of "outstanding leadership" orders of magnitude above and beyond "effective management." Many individuals score satisfactorily as managers who run orderly, profitable organizations and stay on par with the competition. The key question is whether those organizations are operating anywhere near their full potential. Unfortunately, in the vast majority of instances, they are not and very likely neither are the organizations with which they are competing.

That broad gap separating status quo from full potential can only be bridged by outstanding leadership. Such leaders and the organizations they manage, compete with themselves; they do not permit others to pace them. In competing with themselves, they set their standards particularly high, and then drive themselves to achieve and transcend those standards. Neither do they permit the environment to box them in. What to others may appear to be adversity, uncommon leaders look at as challenge and opportunity to change and build. Although realists, they have a strong, positive, life-enhancing bias.

Rather than being merely goal oriented, leaders live by values, purpose, and commitments, far superior to and transcending finite goals. They actively share their values, purpose, and commitments with others, stirring others into action. Thus, uncommon leaders create an excitement and share that excitement with their followers, permitting them, also, to rise to higher levels. The followers hope some of the benefits of the endeavor will rub off on themselves; this, in turn, happens and synergistically the overall effort results in an unpolarized win/win situation wherein all parties involved productively come out ahead.

Leaders not only seek improvement in their organizations; they continually seek improvement in themselves. They are highly creative, particularly with respect to themselves and their lives; literally, they are talented artists who make themselves their own greatest masterpiece. In essence, they are on a self-propelled collision course with their own destiny.

Being very people-oriented, leaders value and welcome the abilities and potential of their followers. In contrast to fearing and competing with their subordinates, leaders seek out and enlist their subordinates' full efforts, encouraging them to also expand to their limits. Thus, in an organization embodying outstanding leadership, there is minimum rigidity, fear, politics, and gamesmanship; intrinsic, not extrinsic motivation is the norm. There is both high productivity and a high esprit de corps.

In summary, leaders bring out the best in people and organizations. This is largely because leaders elicit strong, positive, emotional reactions, and people fulfill their needs and grow under effective leadership. Such leaders are highly proactive and flexible, focusing on the horizon and beyond, continually alert to symptoms, portents of change, and opportunities. Their never-ending search is to discover the possibilities and potential in everyone and everything encountered. They have an uncanny knack of cutting through complexity, providing practical solutions to difficult problems, successfully communicating these solutions to others, and instilling enthusiasm and a "can-do" attitude. Through such leadership, organizations are dynamically transformed -- there is a strong sense of mission and excitement with people and operations propelled to peak performance. (See Figure 3 for the Profile of an Outstanding Leader.)

HUGHES AIRCRAFT'S APPROACH TO ACHIEVING FULL POTENTIAL

Hughes Aircraft Company is taking an aggressive, multifaceted, systems approach to achieving full potential; focus is on total quality, with primary attention to product quality. The company believes that to produce a high quality product, emphasis on quality must be inherent in every facet of the organization and every segment of the product's evolution, i.e., quality must be foremost in the mind of every manager and employee — it must be designed, planned, and built into the product.

The company feels that, collectively, its management and employees are by far its most important resource in achieving full potential; therefore, particularly great emphasis is being placed on this facet. Other important facets include focus on effective marketing and contracting practices, IR&D, optimization of design processes, value engineering, product effectiveness, improved manufacturing technology, integrated CAD/CAM, effective procurement practices, employee involvement programs, performance and cost-improvement systems, upgrade of facilities and equipment, etc.

The company's overall operations improvement effort is orchestrated by a corporate-chaired council membered by senior representatives from each of the major operating activities throughout the company. The scope of this article, however, is not to encompass the overall improvement efforts within Hughes, but to focus on a particularly critical element, managerial productivity.

MANAGERIAL PRODUCTIVITY

Hughes recognizes that the key element in achieving and sustaining high productivity and product excellence is its management team. Therefore, it is striving to develop the most productivity-conscious and productive management team possible. To help accomplish this objective, the position of Corporate Director of Managerial Productivity was created. Basically, the charter of this position is to develop the highest caliber, totally committed, productivity- and quality-conscious management team possible. The primary vehicle in achieving this end is training.

PRODUCTIVITY COURSES

The initial productivity training thrust at Hughes was a long-term series of voluntary, after-hours courses for line and staff managers. Four basic courses were provided, comprised of 25 class-hours each. The four courses focused respectively on (1) personal productivity, (2) managerial productivity, (3) organizational and operational productivity, and (4) effective means of combating counterproductivity. A particularly valuable adjunct to these courses was that either the Chief Executive Officer or President of Hughes Aircraft Company personally joined each of the classes for one of the ten evening sessions.

After personally teaching more than 1,000 hours of such classes, the author recognized that a more streamlined approach would be necessary in order to reach all the management of a company comprising 77,000 employees. Furthermore, although the classes were always fully subscribed, it was evident that those managers already predisposed to productivity improvement were more likely to volunteer than those most needing the training.

PRODUCTIVITY SEMINARS

A transition was, therefore, made from voluntary, after-hours, productivity courses to a long-term series of mandatory, off-site seminars on personal, managerial, organizational, and operational productivity for all levels and sectors of line and staff management. The content of these tight, fast-paced, one-day seminars, which are conducted during normal working hours, is a distillation of the 100 class-hours of material contained in the four original productivity courses. The content of the seminars is additive to, and complements the material contained in the study report, R&D Productivity; the author strives to minimize redundancy realizing that seminar participants have either read the report or can do so at their convenience.

The seminars are not intended to constitute a "cookbook" approach to productivity improvement, nor is there any attempt to cast participants into a common mold. Quite to the contrary, at the start of each seminar, the author points out that managers should develop and maintain their own personal style of management, and particularly their own unique style of leadership, adding and subtracting to that style only as they, themselves, see fit. Therefore, the seminars do not present a productivity gospel; rather, they provide a sharing of insights and ideas. The intention is to (1) develop a dedicated commitment to leadership and productivity throughout the management team, (2) provide team members a credible roadmap and useful tools for implementation, and (3) stimulate team members to take effective productivity improvement actions with respect to themselves and the organizations they manage.

Productivity improvement cannot be dictated or legislated from the top. Those at the head of organizations can be highly productive themselves, set noteworthy example, and be catalytic in enhancing productivity down the line. However, peak organizational productivity will only be achieved when each manager stimulates productivity improvement within his or her respective organizational sector, with all subordinates performing productively in their incumbent positions.

To date, the author has conducted more than 100 seminars within Hughes involving several thousand members of company line and staff management. As described below, a typical seminar (8:30AM- 4:30PM) is comprised of four modules of approximately equal length.

Module #1

The first seminar module establishes an awareness, understanding, and common vocabulary among the participants. It deals with the anatomy of productivity, i.e., what is it, why is it crtically important, what are the key factors that impact it, how can it be evaluated, and, of greatest importance on an overall systems basis, how can it be improved.

Module #2

The second seminar module focuses on managerial, organizational, and operational productivity. A number of key counterproductive factors common within organizations are identified and analyzed, with focus entirely on effective managerial techniques of precluding or combating such counterproductivity. Of the many roles and responsibilities of management probed in this module, particularly great emphasis is placed on leadership and means of enhancing it.

Module #3

The third seminar module focuses on personal productivity. A number of counterproductive factors commonly experienced in one's personal and professional life are identified, with the entire emphasis on effective means of precluding or combating such counterproductivity. In conducting this portion of the seminar, the author draws upon more than 30 years of research on productivity, leadership, management, motivation, creativity, and professional self-development. Much of this research focuses on the diaries, notebooks, and personal journals of uncommon leaders and creative giants who have withstood the test of time and uniquely stand out in history. Such materials, never intended for the eyes of others, clearly reveal the core of motivation and creativity that drove these unique individuals to the pinnacles. The author identifies the many common denominators among these individuals and synthesizes these factors into an action plan which one can follow in his or her pursuit of professional self-development and excellence. Because personal productivity and creativity totally complement each other, and since creativity is a key ingredient in leadership, much attention in this module is focused on personal creativity and means of enhancing it.

Module #4

The fourth seminar module comprises a participative workshop on identifying an organization's major sources of counterproductivity and formulating constructive means of combating such counterproductivity. The workshops are completely positive in nature, based on concensus and constructive discontent. The participants recognize that there are already many highly productive factors within the organization (these also are identified); the objective is to make the organization even better.

The workshops have proven very effective within Hughes and the many other organizations for which the author has conducted seminars on a consulting basis. One might assume that most organizations' lists of major counterproductive factors would be very long; however, the opposite tends to be the norm. Nevertheless, those lists, although relatively short, are extremely important and should be judiciously dealt with in the productivity improvement process.

VALUE OF THE SEMINARS

Participants' reaction to the seminars has been particularly favorable; on the anonymous evaluations conducted upon completion, participants consistently rate the seminar highly. Utilizing a scale of 1-6, the overall evaluation of the several thousand seminar participants within Hughes, to date, averages between 5 and 6; the ratings of seminars conducted for outside organizations is comparable. Of particular significance, 97 percent of all the managers who have participated in the productivity seminars within Hughes and the many other industrial, commercial, governmental, and academic organizations for which the author has conducted seminars have recommended that other members of their organization's management participate in subsequent seminars. Through such endorsement, a domino effect is being achieved which is very important when striving to make productivity improvement an integral part of the daily way of life throughout an entire organization.

Further confirmation of the seminars' value is reflected in the thousands of written comments submitted by participants. Typical are:

> "Best seminar that I have attended; really helpful, all people in management should attend."
>
> "A must for anyone who has a desire to become a leader."
>
> "I've applied some of the principles in my daily routine and had the greatest results with excellent feedback."
>
> "This seminar was very successful in motivating me. I believe my increased motivation will be contagious to the people working for me."
>
> "So much information, so well done — a wealth of ideas to integrate into a productivity improvement effort."
>
> "Reawakened my desire to motivate my people to increase our total effectiveness and enjoy the fun of doing it."
>
> "Exceptionally strong reaction — energizing and motivating — I feel as if I will go out and go, go, go!!!

Recently, an extensive sample survey of past seminar participants, both within Hughes and outside, was conducted to determine the long-term, lasting value of the seminars. Although considerable time had elapsed since they participated (several months to several years), the large majority of respondents (more than 80 percent) still look back on the seminars as being highly effective, and feel their personal productivity and that of the organizations they manage has been, and continues to be, enhanced as a result of the seminar.

A CLOSING NOTE

The approach to productivity improvement must be totally professional, avoiding all gamesmanship, fads, and buzz words. A well qualified, highly motivated and dedicated management team — an enlightened, people-oriented management team—that optimally deploys the organization's resources, particularly the human resources, is the ultimate foundation upon which to productively and creatively build.

The productivity seminars — which are continually evolving and improving — are making a valuable contribution in this regard. To inspire the work force to higher levels of productivity and creativity management, itself, must first be inspired. The primary goal of the seminars is to spark that inspiration, enabling dedicated commitment and productive action to follow.

An economic renaissance is critically needed. The effective chemistry for such a renaissance requires a synergistic blending of people-oriented leadership and a stimulating, creative climate. Only under such conditions can — and will — people put forth their best efforts. Management's most important responsibility is to establish the climate necessary for this renaissance and provide the uncommon leadership to "put it all together."

BOX

HUGHES PRODUCTIVITY STUDY

This continuing productivity study, now in its thirteenth year, encompasses not only the traditional research and development functions, but all the key interfacing activities; e.g., marketing, contracts, finance, procurement, manufacturing, information systems, human resources, industrial relations, and support services. To date, the study has involved the active participation of 59 major organizations in industry, government, and education; the services of 28 prominent consultants; surveys of more than 3,500 managers, and an extensive literature search. In addition, particularly valuable source material has been derived from the candid insights of many thousands of managers who have participated in the author's productivity courses and seminars.

A book-type study report, R&D Productivity, was published in 1974 and a second edition in 1978. Although the report focuses on technology-based organizations, the vast majority of its findings are applicable to all types of organizations, and, therefore, the report is used as widely in the commercial, governmental, and academic sectors as it is within industry. Robert M. (Bob) Ranftl has directed the study since its inception and authored the study reports.

To date, more than 20,000 copies of the report have been utilized within Hughes and more than 125,000 complimentary copies have been shared with interested industrial, commercial, governmental, and academic organizations throughout the world. Some 20,000 U.S. corporations — including 95 of Fortune's top 100 corporations — have acquired the report, as well as some 1,000 foreign companies in 50 different countries. A large number of these organizations are using the report in their internal management development programs, and more than 100 universities have adopted it for use in their curricula. The report is retained by more than 700 libraries throughout the world and has been translated into a number of languages.

Hughes will be happy to provide complimentary copies of R&D Productivity to interested individuals as long as the supply lasts. Requests should be addressed to R.M. Ranftl, Corporate Director of Managerial Productivity, Hughes Aircraft Company, P.O. Box 1042, El Segundo, California 90245.

FIGURE 1

OPTIMAL PSYCHOLOGICAL WORK ENV'RONMENT

- Skilled and effective management and leadership with outstanding people in key positions.
- Clearly identified organizational objectives and performance goals.
- Simple organization structure featuring clear lines of direction.
- High standards of staffing.
- Simplicity in all operations.
- A stimulating, open, creative climate where everyone can be oneself.
- Meaningful, challenging assignments.
- A high degree of personal job freedom.
- Minimum constraints, procedures, and red tape.
- A prevailing sense of equity in all operations.
- An absence of fe. politics, and gamesmanship, and the avoidance of any connotation of "insiders" vs. "outsiders."
- The absence of a caste system, i.e., the differentiation between first-and second-class roles within the organization.
- Equitable, parallel promotion ladders.
- An equitable system of incentives and rewards.
- A climate conducive to career planning, wherein job security is directly tied to contribution.
- A prevailing "can do" attitude coupled with the spirit of "thinking improvement into everything."

FIGURE 2

PRODUCTIVE MANAGERIAL STYLE AND TECHNIQUE

- Maintain high performance standards promoting personnel and product excellence.
- Make a genuine effort to understand subordinates; know their strengths and weaknesses, their primary sources of motivation, their career goals, etc.
- Effectively integrate the abilities of all individuals within the organization, matching them to the jobs for which they are best suited.
- Delegate authority, decision making, and control as far down the organization as practical.
- Manage by expectations; set high standards and high expectations, and encourage subordinates to achieve them.
- Involve subordinates in planning, goal setting, and decisions that affect them.
- Let employees demonstrate their capabilities and grow professionally; help subordinates prepare themselves for jobs to which they aspire.
- Maintain light pressure on subordinates to produce, keeping them fully, but not excessively, loaded with work. (This must be done skillfully — mild pressure properly applied can stimulate productivity, but excessive pressure can easily become counterproductive.)
- Avoid (1) treating all tasks as maximum efforts or special cases, i.e., "crisis" management, (2) rush and overtime followed by delay, and (3) surprise and unexpected changes.
- Be available to subordinates through an open-door policy, and make it a point occasionally to informally drop by their work places.
- Provide subordinates feedback on their performance; recognize and reward achievement; cite mistakes fairly and tactfully.
- Make a special effort to help subordinates who are deficient in certain aspects of their jobs.
- Assure that no facet of the organization or individual gets short-changed or overemphasized, representing equitably all subordinates and their work to higher management. (Whenever possible, have the person who originated a unique idea or did a particularly outstanding job be the one to brief management.)
- Be sensitive to factors that cause employee dissatisfaction and frustration; get to the root of such factors and resolve conflicts in a timely manner.
- Serve as a buffer to protect subordinates from many of the daily administrative and operational frustrations.
- Maintain an effective flow of two-way communication, keeping employees informed of the broader aspects of the organization's operations.
- Avoid imposing personal standards on subordinates and "oversupervising."

FIGURE 3

PROFILE OF AN OUTSTANDING LEADER

Sets a particularly positive example as a person. The outstanding leader exhibits characteristics that stamp him/her as a "person of note."

Typical observations:

- Is unusually competent
- Has quality and quickness of mind.
- Is particularly creative, innovative, and nontraditional — a unique individualist.
- Is highly self-motivated, self-confident, and self-directing.
- Has extremely high integrity, values, and standards — stands above organizational politics and gamesmanship
- Has unusually high motives — is dedicated — has a firm sense of purpose and commitment — is never self-serving.
- Has a strong positive orientation.
- Displays total self-command.
- Has a high level of deserved self-respect and self-esteem.
- Accepts the role of leader with appropriate humility — enjoys the role and is clearly accepted as a leader.
- Is willing to work harder than other members of the team.
- Has particularly high vitality, stamina, and reserve energy.
- Is continually searching/learing/developing/expanding/evolving.
- Is a "winner."

Takes a dynamic approach to activities. The outstanding leader approaches tasks with verve and enthusiasm, is always oriented toward improvement.

Typical observations:

- Is action-oriented — has a compelling drive to accomplish and achieve.
- Is quick to size up the merit of people, ideas, and opportunities
- Uses a persuasive personality rather than force of power to get things done
- Is tenacious — perseveres in the face of obstacles — always sees things through to successful completion.
- Is always willing to "stand up and be counted" — makes necessary decisions and do[illegible] what has to be done, even though such a[illegible] may be unpopular and result in adverse [illegible]iticism.
- Continually seeks new and better ways.
- Is a visionary — is unusually skilled at predicting future technological and operational needs and applications.
- Always sees new challenges and new fields to conquer.

Brings out the best in people. Getting people to do their best and to work together effectively is a special talent of the outstanding leader

Typical observations

- Is strongly people-oriented.
- Exhibits great respect for human dignity.
- Is particularly skilled in motivational processes and in dealing with people.
- Has well defined, meaningful goals and successfully inspires associates to help achieve them
- Has confidence in people and effectively communicates that confidence.
- Brings about dynamic synergism within groups.
- Is stimulating and catalytic — instills enthusiasm — maintains an exciting organizational climate — communicates a "can-do" attitude in all actions.
- Helps subordinates achieve their full potential.

Demonstrates great skill in directing day-to-day operations. The outstanding leader exhibits unusual ability in dynamically directing operations for maximum results.

Typical observations

- Conceptually integrates all facets of the operation
- Has a strong sense of timing and limits — accurately senses "when" and "how much" in each situation.
- Has an uncanny knack for cutting through complexity — effectively sorts out irrelevancies and identifies the real driving factors — provides practical solutions to difficult problems and successfully communicates these solutions to others.
- Senses what might go wrong and develops contingency plans.
- Maintains control of all situations, performing with relative ease during times of stress.
- Displays an "elegant" simplicity in all actions.

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NOTE The "Profile of an Outstanding Leader" is actually built on a foundation of two other profiles, the "Profile of a Productive Employee" and the "Profile of a Productive Manager". The composite can be viewed as three concentric circles with the "Profile of a Productive Employee" at the center, surrounded by the "Profile of a Productive Manager" and the "Profile of an Outstanding Leader" circumscribed around the other two Naturally, no single individual collectively encompasses all the traits listed in the three profiles Rather, the profiles provide a shopping list of traits from which one can select [illegible] or her unique pursuit of self-development. Unfortunately, space does not permit reprinting of the two core profile[illegible] [illegible]y can, however, be found in the study report, R&D Productivity. (See Box)

BIOGRAPHICAL SKETCH

Robert M. (Bob) Ranftl is Corporate Director of Managerial Productivity at Hughes Aircraft Company, and is President of Ranftl Enterprises, a consulting firm totally dedicated to helping organizations achieve their full potential. He has provided consulting services and hundreds of in-house productivity seminars to a large number of major organizations, nationally and abroad. Bob is a graduate of the University of Michigan, a guest lecturer at many of the nation's leading universities, and a member of both the White House Conference on Productivity and the Department of Defense Human Resource Productivity Task Force.

HUGHES ADDRESS:

P.O. Box 1042, El Segundo, CA 90245, Telephone: (213) 414-7872

RANFTL ENTERPRISES ADDRESS:

P.O. Box 49892, Los Angeles, CA 90049, Telephone: (213) 471-1804

DESIGNING SPACE STATION FOR PRODUCTIVITY

N86-15185

INCREASED PRODUCTIVITY IN FLIGHT WITH VOICE COMMANDING

WILLIAM T. JORDAN, NASA - JSC

ABSTRACT

Automatic Speech Recognition technology has matured to the point where it can provide a viable means of increasing productivity by naturalizing the man-machine interface. With ever increasing workloads being placed on astronauts, speech recognition may provide an alternative means of system controlling that would reduce the task burden. Voice commanding, allowing "hands-free" operation, can be especially effective during operations requiring simultaneous system control. A flight experiment is under development to demonstrate the operational effectiveness of voice control by commanding the Space Shuttle's Closed Circuit Television (CCTV) system. This experiment will help direct future applications of voice entry to space operations.

INTRODUCTION

Speech recognition has made its way into the consumer market through the personal computers, toy voice-controlled robots, and aids for the handicapped. Other uses include office and factory automation, sortation applications, quality control, inventory management, and speaker verification. Government programs such as Advanced Rotocraft Technology Integration (ARTI) and Advanced Fighter Technology Integration (AFTI) have developed the use of Automatic Speech Recognition (ASR) in military aircraft form helicopters to fighters.

The application of ASR devices can facilitate simultaneous system controlling. This "multi-tasking" occurs frequently in spacecraft operations when a single crewmember must operate more than one system. One such operation occurs during Space Shuttle missions when a single crewperson is tasked with operating both the Remote Manipulator System (RMS) and the CCTV system. The RMS, or payload bay "arm", requires two hand controllers for operation, and payload manipulation is a visually demanding task. Thus, it is undesireable to remove visual and dexterous attention from RMS operations to utilize the CCTV system.

Integration of Automatic Speech Recognition into spacecraft systems is under study at NASA's Johnson Space Center where development of Shuttle Orbiter enhancements and concept designs of Space Station are being conducted. To demonstrate the capabilities of an ASR device in a space operations environment, an experiment will be flown to control the Orbiter's CCTV system by the Voice Command System (VCS).

BACKGROUND

Automatic Speech Recognition (ASR) is the ability to discern and distinguish utterances. This is done chiefly by pattern matching techniques. Every utterance that is to be recognized is represented by a "pattern" that distinguishes it from all other patterns. A spoken word can be processed into a pattern and compared to existing patterns in memory. These patterns can be created by the user repeating words into an ASR device (speaker dependent recognition), or, they can be more generalized, created by combining together the patterns that distinguish the basic phonemes or sounds of a given dialect to represent a spoken word (speaker independent recognition). Once there are patterns representing a set of words to be recognized, an ASR device might recognize words spoken discretely, one-at-a-time (isolated) or might have the capability of recognizing words spoken continuously as in natural speech communications (continuous).

The most reliable state of the art devices are the speaker dependent, isolated word recognizers. However, there are some dependant continuous recognizers that are highly reliable depending on thier application. Most independent speech recognizers can only work reliable with small vocabularies and are most accurate only for chosen dialects of a given language. ASR can be used as a tool for language understanding which involves the formidible task of context interpertation. Language understanding is considered an artificial intellegence task. In the flight experiment, a state of the art dependent recognizer with continuous recognition capability will be used.

SYSTEM DESCRIPTION

The Voice Command System experiment package will consist of a CCTV system interface, a control panel, and an ASR device. Figure 1 shows the placement of the VCS unit int the Orbiter's AFT flight deck.

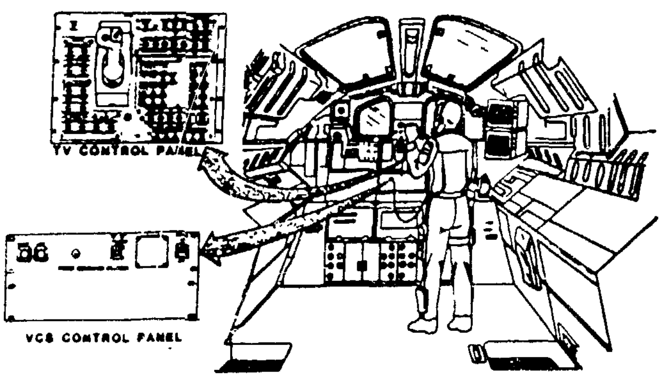

Figure 1 AFT FLIGHT DECK

For minimum impact on system interfacing, the VCS will control the CCTV system by paralleling the switches on the CCTV control panel. CCTV commands include: selecting monitors, cameras, panning, tilting, focusing, zooming, and iris control. These commands result in visual reactions. That is, something happens that can be confirmed visually; selecting a camera will show as a display change on a monitor; panning will show as monitor display panning, and so on. Also, the CCTV control panel has lighted pushbuttons for most commands, so there is a second visual feedback. With this existing feedback, there is no need for a display on the VCS. There will be an audible feedback for confirming recognition or rejection of an input utterance.

Normal crew audio communication is a requirement of the VCS. Thus, there will be an interface to the Shuttle Audio Distribution System. This connection will allow other crewmembers and groundlink to communicate with the VCS operator. A "relax" state of the VCS will allowthis communication disregard the operator's input until a "ready" state is enabled. This will be accomplished by a panel switch on the VCS or by a voice command.

HUMAN FACTORS

The objective of this experiment is to demonstrate the effectiveness of voice entry to increase the efficiency and productivity of the crewmember while reducing the task burden. Since ASR devices are tools to manipulate end systems and are not in of themselves an end system, their effectiveness is measured subjectively by how the operator perceives the system's effectiveness. A technically good speech recognizer may fail because the user did not want it to work or perceived no advantage to using the device. While speech is a natural and convenient method of commanding systems, it is often applied unnaturally. For instance, the constraints of an isolated recognizer to say words one at a time with pauses, may be a hinderance when controlling a system that requires a continuous stream of commands. As an example, the post office might use voice recognition to help sort mail. The operator would take a letter or package, read the zip code and let the computer determine the sorting. It would be less efficient to say the zip code one number at a time rather than the full sequence.

Other factors that influence the acceptability and performance of an ASR device are:

- o Physiological
  - o age
  - o sex
  - o fatigue
  - o dialect
  - o health
- o Psychological
  - o motivation
  - o attitude
  - o stress
- o Environmental
  - o noise
  - o atmosphere
  - o pressure

One unique problem to this application of voice control is the effect of micro-gravity on the human speech mechanism. Possible effects include:

- o No pull on tongue or diaphragm
- o Atrophy of vocal tract muscles for long duration exposure
- o Sinus congestion, which requires gravity for draining
- o Special atmosphere mixture and pressure

An attempt was made to help discern any degradation of speech in an experiment flown on the sixth Shuttle mission. Astronaut Story Musgrave helped conduct an experiment by making voice recordings before, during, and after his mission. Subsequent testing on these recordings did show a drop in recognition accuracy for pre-mission trained patterns on a discrete ASR device. However, with only the one test subject, who was fatigued, and the other error factors like the effects on the tape recorder, the results of the experiment are nonconclulsive. The experiment indicated further testing is required. Recordings are again planned as part of the CCTV experiment on magnetic tape as well as data stored into memory.

Recognition results are best on a dependent ASR device when trained in the environment it is to be used in. The physiological effects encountered during a mission can only be simulated. The micro-gravity environment cannot be. However, the ambient noise on the shuttle has been measured during flight by sound level surveys conducted on the first three Space Shuttle missions. This noise can be recreated for training patterns in a flight-type environment.

SUMMARY

Possible future applications for voice input/output in a Space Station design include:

- o Control of closed circuit television system
- o Information retieval by audio response
- o Systems checkout nad verification
- o Data retrieval during EVA
- o Control of robotics
- o Inventory management
- o Maintenance and repair aid
- o System configuration

Voice entry can be applied equally well to ground operations with similar applications. The technology is evolving to include large vocabularies (10,000+ words) with speaker independency. With the added capability of natural language processing, voice I/O may achieve the man-machine communication ability that resembles the human-to-human commudnication. Yet, such goals are still elusive.

Results from the flight experiment will be measured from the Voice Command System's memory to determine the accuracy of the ASR in flight and from the subjective reporting of the crewmember/operator. This first-time application of voice recognition to a spacecraft environment will be a fore-runner to developing standard voice I/O for Space Station and future NASA projects.

BIOGRAPHY

William T. Jordan received his B.S. in Electrical Engineering from the University of Texas in May 1980. He has since been employed by the National Aeronautics and Space Administration at the Lyndon B. Johnson Space Center in Houston as the Project Engineer on Voice Commanded Systems.

N86-15186

GROUP STRUCTURE AND GROUP PROCESS FOR EFFECTIVE SPACE STATION ASTRONAUT TEAMS*

John M. Nicholas, Loyola University of Chicago
Ronald S. Kagan, LaJolla, California

ABSTRACT

Space Station crews will encounter new problems, many derived from the social interaction of groups working in space for extended durations. Solutions to these problems must focus on the structure of groups and the interaction of individuals. A model of intervention is proposed to address problems of interpersonal relationships and emotional stress, and improve the morale, cohesiveness, and productivity of astronaut teams.

THE CHANGING NATURE OF SPACE MISSIONS

With Space Station, the nature of American space missions will change. One difference is that NASA will be shifting from missions of relatively short duration to operation of a permanent, continuously-occupied platform. Astronauts will be living and working in space for weeks and months. Interplanetary missions of the future will take years.

A second difference is that Space Station will increase the size of the ongoing crew complement. The preliminary design plan calls for six to eight people living and working for 90-day stretches in 300-mile orbit. The number of people in space for extended periods will continuously grow as Space Station is expanded and others are built.

Third, the makeup of astronaut crews will be different. For two decades, NASA selected highly trained and disciplined military test pilots, men who would do as they were told and consistently perform well, even under extremely stressful and hazardous conditions. In time, NASA will rely more and more on industry and academia for its astronauts. Whatever their expertise, one thing is certain: future space crews will be made of Different Stuff, different both from the astronauts of yesterday and different from each other. They will also devote much less time in preparation for space flight, so not only will they be different from the start, they are likely to stay that way as astronauts.

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*Appreciation is extended to Gustave J. Rath of Northwestern University for his helpful comments.

Finally, more decision making and problem solving will be made in space by teams of astronauts themselves. Thus far most work in space has been performed according to schedule and checklist, and with the assistance of Mission Control. As man stays longer in space, more contingencies will arise and more judgement will be required by astronauts.

New Missions, New Problems

As the size of teams and amount of time they spend in space increase, so does the likelihood of dysfunctional group behavior. Behavior of heterogeneous groups of six or more in extended isolation is different than that of two- or three-man homogeneous groups, so problems can be expected that were not seen on earlier U.S. space missions. Informal patterns of behavior common to work groups will arise in space. Looking at small groups in confined, isolated, and hazardous conditions on earth and aboard Soviet and American space vehicles suggests some of the kinds of social/psychological problems expected aboard Space Station. Unfortunately, most observations have focused solely on physiological and psychological responses; few studies, and none in space, have been directed at group behavior.

Consider, for example, research centered on groups of scientists and Naval personnel at remote stations in Antarctica. Among widespread emotional problems reported during winter isolation are sleep difficulties, headaches, "feeling blue," feeling lonely, and irritability and annoyance with others. Studies of group behavior show clear evidence of deterioration in social relationships and work effectiveness, particularly during the latter part of confinement. Groups reporting the greatest decline in teamwork and efficiency also have the greatest persistent difficulty in keeping essential equipment operating, the most frequent open conflict among members, and the lowest morale.

Stress symptoms reported in confined, isolated groups on earth are similar to those observed on U.S. and Soviet space flights. Cosmonauts report that interpersonal hostility starts to develop after about 30 days in space. Hostility also develops between the space crews and mission control; cosmonauts report being relieved when communications with earth were interrupted. Interpersonal difficulties on U.S. flights also produced problems: conflicts on some Apollo missions resulted in faulty or scrubbed experiments; ineffective communication among Apollo crew members caused near-fatal mistakes on reentry following the Apollo-Soyuz linkup [1]; and on Skylab IV, a frustrated, overworked crew went on strike six weeks into the mission.

Space is a high-cost, high-reward environment. Costs include overcrowding and daily reminders of physical danger; rewards include recognition, pride, and adventure. For groups in hazardous conditions such as space, the costs--being physical stimuli--are relatively stable; the rewards-mostly subjective--are unstable. Radloff and Helmreich [8] believe that "pioneering" groups adjust and perform well because the perceived rewards of the mission exceed the costs, but they predict that as time passes, the cost-reward ratio will be altered so that costs exceed rewards. As space travel becomes more routine, rewards may decline more rapidly than the costs. More personnel will be needed, and they will be younger and less-experienced. Not all of them will view space flight with the same sense of accomplishment and adventure as earlier astronauts, nor will they be as prepared. Radloff and Helmreich predict that combined changes in the quality of the personnel and in the perceived reward of routine work in high-cost situations will result in personnel problems and declining teamwork.

Teamwork is important to productivity. Astronauts' ability to work together effectively, and to adopt and develop formal and informal mechanisms to improve their working relationships and group output is vital to the success of Space Station. With the estimated cost of a human work hour aboard Space Station being $80,000, there must be considerable emphasis on productivity. Yet the stresses on teams living and working in space have very high potential for inhibiting communication, instigating hostility and conflict, and reducing productivity.

Current Approaches

NASA is taking a multifaceted approach to these problems, including astronaut selection and training, and human factors design. The U.S. and Soviets use psychological/psychiatric guidelines for the selection of people with the greatest likelihood of adjusting to the stresses of space flight. Both space programs emphasize individual-level solutions to reducing and adapting to stress, including relaxation techniques, meditation, biofeedback, exercise, proper sleep and special diets.

A second approach is ergonomics and human factors--designing and operating a space-habitat that is congenial to living and working in space. This includes attention to anthropometric and architectural details of interior layout, lighting, textures, color, windows, and size and shape of living and working spaces. Private crew-member retreats, control of noise and vibration, programs to encourage sleep, and effective use of diet and music to combat monotony are examples of features being studied.

Selection, training, and human factors address some but not all parts of the problem. First, despite their obvious value, these approaches ignore group-centered problems and solutions. A common, fallacious assumption is that the process used by effective work teams is natural and even simple. But effective teams do not just happen; great skill and understanding is required by both the leader and team members. Even groups working under the best possible conditions on earth suffer from problems which hinder their ability to perform and limit their output. Secondly, current approaches ignore the social environment and individuals' need for "social support." Social support--emotional concern, aid, and information from others--is crucial to making social environments less stressful, more conducive to stress adaption, and more productive [3].

Astronaut crews train intensively under conditions as realistic as possible. They practice responses to routine situations and crisis events. Now we must ask: What kinds of skills and abilities should they have to make them effective in the long-duration, team efforts of Space Station, and how should these skills be acquired?

The technology of applied behavioral science offers interventions to increase effectiveness of astronaut teams. This paper proposes an intervention model to insure that space crews, as teams, are functionally and social "fit" for missions, and remain that way in space.

APPLIED BEHAVIORAL SCIENCE IN SPACE

Applied behavioral science in the Space Station Program aims to improve the interpersonal effectiveness, stresshandling capability, morale, and productivity of crews and their support groups on earth. It includes both proactive and reactive measures--interventions applied in planning and preparing teams for space and again during missions whenever problems arise.

The intervention model is based upon the technology of organization development and the use of social support in stress management. Organization development refers to efforts to improve an organization's problem-solving and renewal processes through use of applied behavioral science theory and techniques (see e.g. [4]). Problem solving is how an organization goes about diagnosing problems and making decisions; renewal means establishing and encouraging organizational creativity, innovation, flexibility, adaptability, and motivation.

Organization development has six areas of emphasis in the Space Station Program: (1) It is preventive work rather than therapeutic; (2) it is an advisory/suggestive approach rather than authoritarian/directive; (3) it places heavy emphasis on instruction to astronauts about relevant aspects of group and interpersonal behavior; (4) it is based on data collection about group performance and behavior; (5) it is oriented toward the Space Station crew (as a team) and its problems rather than individuals; and (6) it places prime emphasis on development of social-support skills and alleviation of social-related stressors, including interpersonal and intergroup conflict, perception distortions, poor communication, and low levels of trust and openness.

Behavioral science interventions focus on the structure of groups and the interaction of individuals. Structure includes the hierarchy and formality of reporting relationships, role definition of group members, and the degree of flexibility of the arrangement to accommodate the nature of decisions and tasks. Structure-centered interventions for Space Station focus on both space crews and Mission Control.

Interaction-centered activities, also referred to as process interventions since they concern the process by which groups interact and work, focus on interpersonal and intergroup communications, conflict resolution, decision making, and trust and openness among group members.

Group Structure and the Technological Imperative

Structural interventions have been used to improve the performance of groups by tailoring the group's size and configuration to alleviate structural conflicts which impede work. Research shows that decentralized groups are more adaptive to the uncertainties of their environment and technology. As work becomes more routine, centralized hierarchies are more effective. This supports the "technological imperative:" group form (its structure) follows its function (or work)[9].

Group efficiency can be improved by adjusting group structural characteristics to suit the work. On a recent Shuttle flight, astronauts on a two-man team ran into technical difficulties while deploying a commercial satellite. After repeated tries, the team was enlarged to include a group on earth headed by Sally Ride. Normal communication through a central liaison was circumvented as Dr. Ride talked directly with the team in space. This new structure, decentralized for intense problem-solving, demonstrates the need for a variety of configurations in space to handle different types of tasks.

Though the necessity for a shift in structure may be recognized at the time, such a shift can cause problems with clarity of responsibilities, stability of lines of authority, and morale. The situation becomes more difficult as lines of authority must rapidly decentralize to allow more creative problem-solving behavior. Such a change might be interpreted as insubordination and be resisted by the flight commander or Mission Control. Future mission teams must be equipped with skills to interpret and work with shifting, alternative group structures.

Group and Individual Process Interventions

The objective of process-centered interventions in the Space Station Program is to build cohesive work teams, improve methods of resolving conflict, and develop good interpersonal, communication, and emotional support skills. Many of the problems and stresses of Space Station work inhere in group process--both within and between space crews and terrestrial support crews. The organization development model deals directly with these problems in ways which individually-focused programs cannot.

Groups which possess a high degree of closeness and solidarity, and a low degree of tension, hostility, and major conflict are said to be cohesive. Cohesion may lead to more investment in the group, more commitment to group issues, a greater sense of personal security, and the desire to be a "good" team member. These alone seem sufficient for wanting Space Station teams to be cohesive, but cohesion is also related to task performance. When groups strive for high performance, the highly cohesive groups perform better. They are also more adaptable to stressful conditions: among military combat units in battle, the more cohesive units generally perform better.

What can be done to increase a crew's cohesiveness? Two contributing factors--frequent interaction among members and group prestige--come already built-in to space station teams. Cohesion may be further enhanced by selecting people more likely to get along--those with similar values, personalities, and norms, and evaluating and rewarding them based on group performance. Other factors needed for cohesiveness--mutual trust and support, and agreement on the thrust and direction of the team--are frequently absent in groups, but these can be developed and strengthened through organization development interventions.

On the negative side, cohesion may cause members to be more concerned with the group than with the purpose for which it exists. Members choose to ignore the negative aspects of the group or are unduly influenced by other members of the group. This malady has been termed "groupthink;" its symptoms and effects have been well-documented [5]. On Space Station, this could lead to crews deviating from mission objectives or ignoring directives from mission control. Occasionally such autonomy may be necessary and desirable. but frequent excursions into group-think could result in poor decisions or even disaster. These problems are acknowledged and dealt with in organization development interventions.

THREE-PHASED PROGRAM

The intervention model uses a three-phased program of training and teambuilding, process consultation, and transition debriefing. Action-research oriented, the program is directed at maximizing mission-team effectiveness and productivity by minimizing dysfunctional group behavior. The intervention techniques, although new to the space program, have shown substantial success in a wide variety of settings (see e.g. [2,6,7]).

Phase 1: Pre-Flight Training in Group Process and Structure

Pre-flight training is necessary to provide crews with learning in group dynamics and structure, leadership, and interpersonal relationships. Some training should be done in unstructured group sessions, where the group is allowed to "evolve," sometimes into an informal structure, sometimes into disintegration. The trainer encourages individuals to explore their feelings, behaviors, the behaviors of others, and the effect of these on the group. This training can be combined with cognitive lectures, structured exercises, and role plays to enhance learning and relate it directly to the mission environment.

To help reduce structural conflicts, crews must also learn concepts of group-structure analysis, including diagnosis, definition of alternatives, evaluation and selection of new structures, and implementation and refinement. During training, crews learn to diagnose group structure, using responsibility charts and network analysis to highlight communication flows, subgroups, and power and control issues. Crews identify the most suitable configurations for each type of task, such as subgroups, liaison arrangements, or "group-leveling" for non-mission activities. Each type of structure is well-defined during training so as to illicit a set of clear behavioral expectations during missions. Selection of a structural arrangement should be endorsed by the leader and have the commitment of the group. Crews would learn how to walk through the pros and cons of alternative arrangements. Even though roles and structures should be well-defined prior to a mission, crews should be able to quickly evaluate and refine the group structure to best suit unplanned situations.

Group training also provides skills needed for astronauts to support one another in space. Among possible sources of social support--work, nonwork, and professional, research shows work-related sources are the most effective in reducing work-related stress [3]. In space, fellow astronauts are at once more accessible, more familiar with and similar in their experience, and more attuned to their unique problems than any external person can be. Nonwork sources of support such as interactive television meetings with family and friends should be counted as contributory stress buffers, but not a major factor in buffering or compensating for the effects of work-related stress in space. Few Americans "naturally" possess good support skills; the competitiveness and task-orientedness of our society generally limit their development. Although emotional support is difficult to "teach" as a skill, group training provides the necessary experience.

Interpersonal and group skills in space will become more important as mankind spends more time there. Notes Cosmonaut Valery Ryumin, veteran of two six-month flights, "We (the crew) must solve our problems together, taking into account the feelings of the other. Here we are totally alone. One must bear in mind constantly the other's good and bad sides, anticipate his thinking and the ramifications of a wrong utterance blown out of proportion." [1]

Pre-Flight Teambuilding

Teambuilding is a proactive intervention to "develop" Space Station crews and group support units into effective work teams and reduce the likelihood of many group problems ever occurring. Teambuilding helps groups to maximize use of members' resources, develop a high level of motivation, reduce hostility and conflict among members, and overcome problems of apathy--including loss of productivity and innovativeness.

Typical teambuilding uses data collection, group workshops, and a consultant to help the group analyze its behavior, diagnose its problems, and develop plans for becoming more effective. Data is gathered from the team through questionnaires, interviews, or process observation about group tasks, group process, and interpersonal conflict. During the workshop, the consultant helps the group understand and diagnose its group process. The group develops a plan for becoming more effective and then works to implement the plan.

Traditional teambuilding must be modified for Space Station since crews will not be stable. Some astronauts will be on board only once, others will be on rotation. The concept of a "Space Station team" must be altered, perhaps to include all astronauts to be sent aloft in the forseeable future and key figures at Mission Control who will be in frequent communication with them. NASA astronauts would be involved in teambuilding sessions as part of their initial training. Then--perhaps every six months--teambuilding sessions would be conducted to include everyone scheduled to be on Space Station and at Mission Control for the following six months.

The likelihood of "too-cohesive" groups developing is lessened by awareness of its symptoms and effects. Pre-flight training provides astronauts and support personnel with skills to recognize and deal with these behaviors, and teambuilding is conducted so that any one "team" is not pitted against other groups with which it shares goals and must interact.

Phase 2: In-Flight Process Observation and Consultation

Process observation uses a skilled third party who observes the group and "feeds" data back to the group. She does not offer "expert" advice, but "intervenes" to help the group use its own resources to identify and solve problems involving the task, the process used to accomplish the task, and interpersonal conflict. The process consultant may be anyone trained in process observation and consultation, including astronauts or former astronauts.

The process consultant is interested in the nature and style of communication, both overt and covert, the functional roles of group members, the extent to which personal needs are shared, activities directed toward holding the group together as a cohesive team, problem solving and decision making activities, the group's understanding and articulating group norms--especially the dysfunctional ones, and the group's understanding and coping with different leadership styles.

A full-time process consultant is unlikely to be onboard to observe groups and provide consultation. One alternative is to monitor crews via radio or television, or collect data from videotapes, televised personal interviews or computer-assisted questionnaires. She would then provide feedback and counseling, in confidentiality, to individual astronauts or entire crews while in space to help them become proficient in self-monitoring and self-correcting their behavior. The feedback signal could be scrambled to insure confidentiality.

How effective will "remote" process observers be? This is difficult to foresee since traditionally the process observer is present with the group. But the time, budgetary, and physical constraints of space flight will require innovation and adaptation for many interventions, including process observation.

Alternatively, one of the astronauts onboard could serve as process consultant. This would be a NASA crew member with other responsibilities--technician, engineer, mission specialist--but who has been trained and has skills in process observation and in giving nonevaluative feedback.

Groups must be familiar with process consultation before it can work. The pre-flight training in Phase 1 is good preparation. Ideally, everyone in the crew becomes a process consultant.

Phase 3: Post-Flight Transition Debriefing

A transition meeting is held at the end of a mission or when crew members are rotated back to earth. Meetings held onboard Space Station would serve several objectives: departing crew would (1) give emotional and performance feedback to associates remaining on the station, (2) obtain feedback about their performance, and (3) inform new crew members of various aspects of the mission. The procedure is aimed at reducing the temporary negative effect of introducing "novitiates" into previously established teams.

Once back on earth, rotated members would meet with support personnel from Mission Control for a feedback session, the intent being to analyze and correct any unresolved conflicts or issues, and reduce the likelihood of similar problems occurring on future flights. The process consultant for the mission should be present to help the group identify (or recall) and work through communication, interpersonal, or conflict issues. Again, process training and members' understanding of process-related issues is a prerequisite for this work.

CONCLUSIONS

A model of interventions based upon organization development and social support is proposed to improve team morale, cohesiveness and productivity, and reduce problems of social interaction and emotional stress. The model uses training, teambuilding, process consultation, and transition debriefing in a three-phased program. Although new to the space effort, similar interventions have been substantially successful in other settings. The arguments and evidence in favor of the model are compelling, while the costs are relatively low and entail no major risks. Implementing the model does not require elaborate equipment nor take substantial time away from work activity. Initial efforts must necessarily be innovative and somewhat experimental, and involve collaboration among behavioral scientists, astronauts, and support personnel at Mission Control.

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JOHN NICHOLAS is an associate professor of Management Science at Loyola University of Chicago and a part-time management consultant. He has a combined background in social and behavioral systems, operations research, and aerospace engineering. RON KAGAN is president of Horizon Office Systems, LaJolla, California, a consulting firm specializing in the use and acquisition of technology in organizations. His experience includes organization development, computing science, and physics.

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SPACE CREW PRODUCTIVITY

- A Driving Factor in Space Station Design -

Harry L. Wolbers, Ph.D.

Manager - Man-Machine Systems

Space Station Program

McDonnell Douglas Astronautics Company

5301 Bolsa Avenue

Huntington Beach, California 92647

(714) 896-4754

SPACE CREW PRODUCTIVITY
- A Driving Factor in Space Station Design -

Harry L. Wolbers, McDonnell Douglas Astronautics Company

ABSTRACT

The criteria of performance, cost, and mission success probability (program confidence) are the principal factors that program or project managers and system engineers use in selecting the optimum design approach for meeting mission objectives. A frame of reference is discussed in which the interrelationships of these pertinent parameters can be made visible, and from which rational or informed decisions can be derived regarding the potential impact of adjustments in crew productivity on total Space Station System effectiveness.

INTRODUCTION

Crew productivity will be the driving factor in determining the cost effectiveness of the Space Station and cost effectiveness in turn will be the key to providing a viable national resource that can meet the evolving needs of multiple users during the coming decades.

The very importance, however, of the problem of maximizing the productivity of the crew within the assigned resources and anticipated operational constraints of the Space Station emphasizes the need to understand the nature and effects of adjustments in crew productivity within the overall operational context of the Space Station Program.

The subtleties of human-machine interactions do not always reflect the obvious. Conventional wisdom, for example, suggests that:

1. Productivity measures of the crew directly reflect changes in the total efficiency of the (space) operation.

2. Changes in productivity can be measured by output per man-hour.

3. Increases in output per man-hour are desirable because they yield decreases in user charges.

These expressions of "conventional wisdom" are not necessarily true. Increasing the productivity of the crew in a given task may require more electrical power, and that in turn may decrease the resources available to support critical payloads and thus degrade the total efficiency of the overall space operation. Increasing the output per man-hour may cause more errors or mistakes in critical operations, leading to poorer overall system performance and higher costs to the potential customers. On the other hand, depending upon corollary factors, either increasing or decreasing crew work load can have a negative impact on productivity in view of the long-term effects of work values on crew morale and psychological well-being. It must be recognized at the outset that for the Space Station designer, productivity adjustments can be appraised meaningfully only within a total system engineering framework. The Space Station designer or system engineer must consider all the interrelationships of all the human and machine elements that are involved in achieving the mission goals and objectives.

In order to analyze the impact of crew productivity adjustments in terms that will be useful to the system designer, organizations and individuals concerned with enhancing space crew productivity must:

- Identify potential ways to enhance overall system productivity.
- Develop criteria to measure changes in productivity in terms of overall system performance, cost factors, and mission success factors.
- Provide insight to the system designers of the successive linkages whereby crew productivity adjustments can affect total system performance, cost, and the probability of achieving a successful mission.

The following paragraphs discuss each of these three key steps.

IDENTIFYING POTENTIAL WAYS TO ENHANCE PRODUCTIVITY

Factors that can affect productivity include both operational issues (such as physical conditioning exercises, training, maintenance, logistics scheduling of activities, organization, etc.), and design factors (such as interior layouts, modularity, lighting, noise control, work station design, etc.).

The methodology used in defining the critical design and operational issues should be predicated upon a detailed consideration of the classes of crew activities that will be required in the Space Station era. These include three key areas: habitation and survival activities; mission and payload-oriented activities; and STS/Ground interface activities. Identification of these activities provides a basis for defining operational issues affecting crew productivity in each activity area and a basis for assessing the productivity adjustments that could result from design changes.

An example of an operational issue might be the time to be devoted to exercise using a particular protocol to maintain specific levels of physical conditioning versus the desire to minimize exercise time and maximize available work time. The operational issue is to define exactly how much the exercise time can be reduced with the particular protocol without significantly increasing the risk of irreversible physical deterioration. A design factor might be to design and validate a different exercise technique such as an on-board human centrifuge, which would offer the potential of being a more efficient exercise procedure than that used in the original protocol.

If such a centrifugation procedure were determined to be effective as an aid to improving crew productivity, then further trade studies would be required to establish the cost effectiveness and the impact on mission success of the new implementation technique.

Another example might be the effect of whole-body showers on crew productivity. Factors that should be considered in a study of this issue might include:

- The proliferation of skin-surface microflora in the absence of whole-body showers - when using hand and face wash and wipes or cloths only.
- The relative amounts of skin infections with and without whole-body showers.
- The effect of whole-body showers on crew morale.
- The amount of water used per unit of shower time and the number of showers allowed per mission.
- Development, production, and installation costs of wholebody showers.
- The impact of whole-body showers on Space Station water logistics.

Still another example might be the effect on the number and location of commodes on crew productivity. Examples of factors that should be considered in the study of this issue include:

- The number of commodes relative to the number of crew members on each work shift.
- Procedures for commode use in case of failure of one or more commodes.
- Emergency provisions for urination or defecation when commode is unavailable.

- Whether or not commodes should be located in other pressurized modules as well as in the habitation module(s) (e.g., in laboratories, such as an animal research lab in which the crew may wear specialized clothing restricted to the lab area).

The intent at this point is to ask the questions: (1) Will changes in the crew operational activity or in the crew organization influence performance and thus impact productivity?; and (2) Will changes in the design concept influence crew performance and thus impact productivity? If productivity adjustments could result from positive answers to questions (1) or (2), these become issues for further investigation.

DEVELOPING CRITERIA TO ASSESS IMPACT OF PRODUCTIVITY CHANGES ON SYSTEM OPTIMIZATION

The criteria of performance, cost, and mission success probability (program confidence) are the principal factors that program or project managers and system engineers use in selecting the optimum approach to meeting mission objectives. The decision maker must base his judgment on knowledge that a particular implementation option can or cannot achieve the desired productivity levels and meet the basic performance requirements. In many cases, more than one implementation option can meet the performance requirements, and it is then necessary to examine the relative costs and success probability associated with each approach.

Performance Criteria

With regard to performance, the limiting factors on direct human involvement are primarily associated with sensing (whether stimuli are within or outside the range of human sensor capability); information processing (whether or not the complexity of the information to be processed requires supplemental aids); and action (whether or not the action required is within the range of human motor responses and time availability).

In a current study being performed by MDAC for the Marshall Space Flight Center entitled, "The Human Role in Space (THURIS)"[1], 37 generic classes of activities have been defined that, when combined in the requi d operational sequences, can be used to describe a broad spectrum of potential space programs. For each of these activities, the limiting factors in terms of sensing, information processing, and motor actions have been defined, and the requirements for human involvement have been described. This generic set of activities was defined by examining a number of space programs and projects, including Skylab, Space Platform, Space Station Missions, and a Life Sciences laboratory.

Each of these activities could conceivably be accomplished with different levels of human involvement ranging from direct manual operation through various degree of automated or robotic support. In the THURIS study, five reference steps were identified along the continuum ranging from direct manual operation at one extreme to completely automated operations at the other. These steps were:

- Manual - unaided IVA/EVA, with simple tools.
- Augmented - amplification of human sensory-motor capabilities (powered tools, exo-skeletons, etc.).
- Teleoperated - use of remotely controlled sensors and actuators allowing human presence to be removed from the work site (remote manipulator systems, teleoperators, telefactors).
- Supervised - replacement of direct manual control of system operation with computer-directed functions, although maintaining humans in supervisory control.
- Independent - basically independent self-actuating, self-healing operations, but requiring human intervention occasionally (automation and artificial intelligence).

As a general statement, response time was found to be the most generally applicable discriminator between the manually controlled modes and the more automated supervised and independent modes of operation. If responses in time periods of seconds or less are required, then the activity is generally best performed in the supervised or independent modes. Applications where speed of response would dictate that the activities be performed in the supervised or independent modes might include launch abort procedures and orbital trajectory corrections. If allowable response times become minutes or hours, and if the spacecrew member is not already loaded then all modes might be applicable and the criteria of cost effectiveness or success probability would provide the more appropriate basis for selec[illegible] [illegible] a particular mode of implementation.

Cost Criteria

In considering the issue of cost, important fa[illegible] the number of times a specific activity is to be performed, [illegible] number of different activities that are required to be perform[illegible] the operational sequence.

Conventional wisdom would suggest that even if a given activity were capable of being performed in a manual mode, the cost of a manhour or man-minute in space is so high that if the activity were required to be repeated a number of times, a crossover point would quickly be reached where it would be most cost effective to implement a more automated approach to the activity performance. In similar fashion, it can be reasoned that the human operator is basically a single-channel mechanism and cannot be expected to perform multiple activities simultaneously, although the activities might be performed serially if the performance time permits.

MDAC has developed costing models that provide comparative data on the relative costs for each man-machine mode in performing single and multiple activities, from one to many thousands of times as a function of the time required to perform the specific activity. Figure 1 summarizes these relationships for three time intervals in terms of normalized "Accounting Units"*

From Figures 1A, 1B, and 1C, a rather significant observation is that the cost level for direct human involvement (manual, augmented, or teleoperated modes) generally remains considerably lower than the cost for remote human involvement (supervised and independent modes) over a large number of times that the activity might be performed (1 to 10,000 times). As may be noted, the cost differentials span two orders of magnitude when only a few activations are required (1 to 10) but narrow to one order of magnitude when the number of activations approaches 1000. For most activities, the manual modes are relatively inexpensive. Even a space station facility charge of $32,500-per man hour, although a significant factor if lengthy times are involved, is still a relatively small cost factor until the frequency of use approaches 1000. Performing activities in the independent, supervised, or teleoperated modes requires, in most cases, a relatively expensive initial investment in support equipment and software, which does not compare favorably with the manual mode unless amortized over a large number of uses.

The more activities that are required to accomplish a specific mission objective, the more time required and the higher the cost. This is true of the manual, augmented, and teleoperated modes of operation. In the case of the operational modes, where human involvement is more indirect (i.e., the supervised ground, the supervised-on-orbit, and the independent modes), the principal contributor to the cost of performing a set of activities is more directly dependent on the cost of the resources and the supporting equipment items required to perform each activity in orbit than on the time required to accomplish the activity. This means that in the modes requiring indirect human involvement, the cost reduction due to the potential of sharing common equipment items and common resources can be a significant factor in the cost equation. Figures 1D, 1E and 1F illustrate the cost relationships when multiple activities and multiple repetitions of a single activity are considered.

In the examples shown in Figures 1D, 1E and 1F if only one activity were required to be performed, it would need to be repeated thousands of times before it would be cost effective to provide some degree of automated support. On the other hand, if a total of 10

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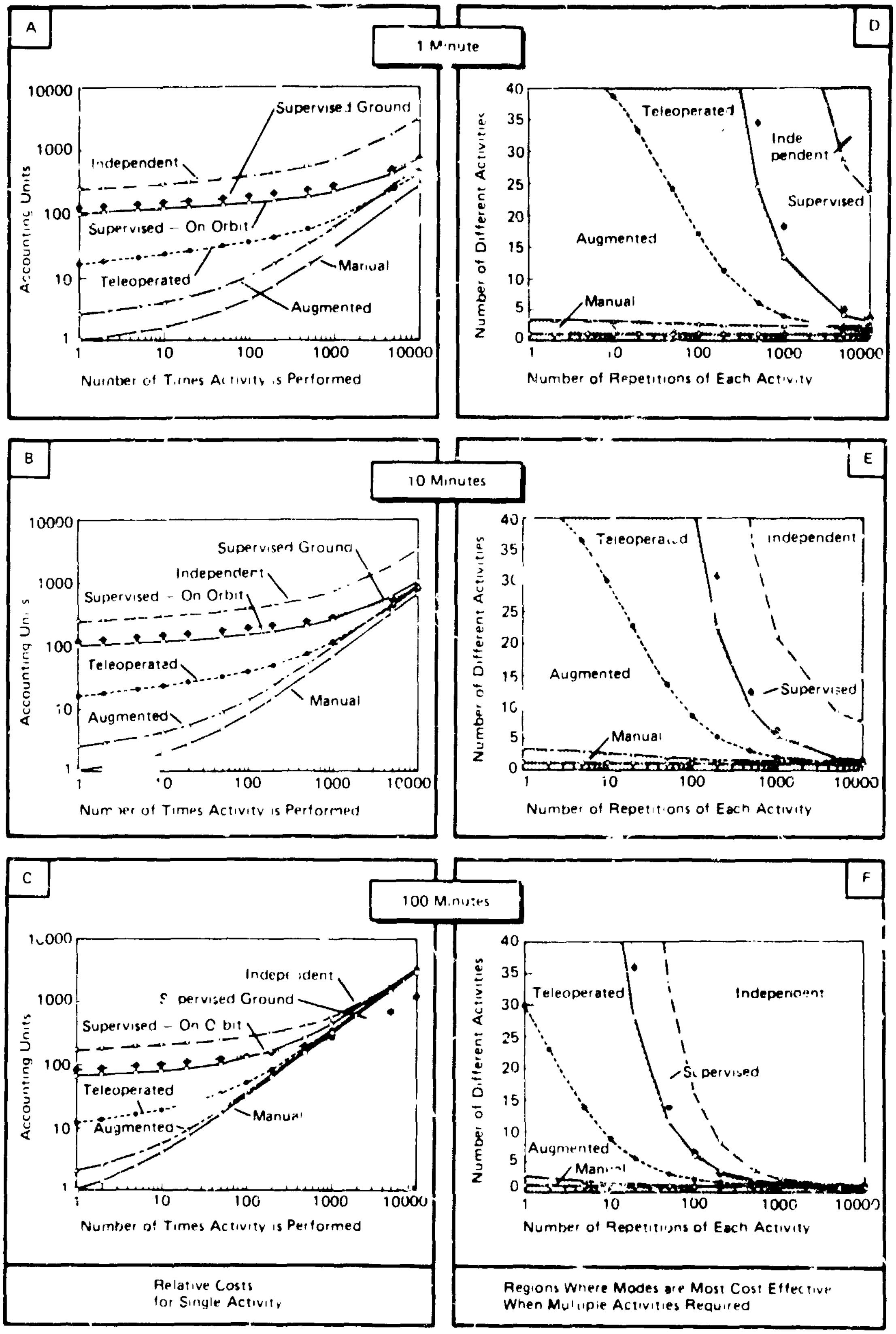
*An "Accounting Unit" is the cost to perform an activity one time in the Manual Mode.

Figure 1. Comparative Costs of Alternative Man-Machine Modes for Three Different Performance Times



activities have to be performed to accomplish the mission objective, and if one of the 10 takes 100 minutes and has to be performed 1000 times, designing the mission objective to be accomplished in the independent mode becomes an attractive option.

Mission Success Criteria

In developing an estimate of success probability, two issues must be considered. One is the issue of human reliability and how the human can best be used to reduce risk; the second issue is the impact of the state of technological readiness on mission success. Techniques are available for estimating the level of technological readiness; the use of the human to enhance success probability is more difficult to quantify.

Although precise analytic techniques exist when predicting the reliability of complex mechanical or electrical systems with components of known reliabilities, and some success has been achieved in predicting human reliability factors in certain well-structured tasks, considerable caution must be exercised in attempting to treat analysis and integration of human and machine error in an analogous manner to the techniques used in dealing with physical systems. The basic problem is that human errors are fundamentally different from machine errors.

When a physical component fails, the system is usually designed so that the failure is isolated and doesn't affect other components. When humans make a mistake, resulting frustrations may increase the likelihood of subsequent errors. Machine failures generally require human intervention to repair or replace the failed component. On the other hand, humans can monitor their own performance and can often correct their own errors before they affect system performance. In physical systems, redundant components are assumed or designed to be independent and, by being placed in parallel networks, can increase system reliability. Redundancy in crew size or presence, however does not necessarily increase reliability and, in fact, the social interactions among crewmembers can lead to common conclusions that may in fact be wrong. On the other hand, the human's perception of the likelihood of specific components failing can lead to a greater sensitivity and awareness for impending failure and the potential for anticipating corrective actions.

While mathematical modeling of human performance may be possible in well-structured tasks, the precise mathematical modeling of human performance for systems in the very early conceptual design phase is an elusive goal.

On the basis of past experience the basic rule when designing new systems should be to consider the human element not in terms of being a component in series with other system elements and having a specific numeric value of reliability, but rather as an element functioning in parallel with the machine components. The human element can enhance system operations by reducing the risk of system failure through the use of human performance capabilities to provide parallel or redundant resources in the form of maintenance and servicing, repair and replacement, and reprogramming of the machine elements.

If this philosophy of machine interface is adopted, then a manual backup will be provided wherever possible, and the more pressing issue in dealing with mission success probability becomes the impact that the state of technological readiness of the hardware required may have on mission success.

ACHIEVING THE OPTIMAL DESIGN FOR THE TOTAL MAN-MACHINE SYSTEM

Lessons learned from the US and Soviet* space programs to date suggest that (1) systems can have indefinite operational lifetimes in space if they are designed to permit the contingency of in-flight repair and maintenance; (2) structures too large to be launched intact can be constructed and assembled on orbit, using man's unique capabilities; and (3) the flexibility and creative insights provided by the crew in situ significantly enhance the probability of successfully achieving mission objectives.

The ability of the crew to manually assemble delicate instruments and components and to remove protective devices such as covers, lens caps, etc., means that less rugged instruments can be used as compared to those formerly required to survive the high launch acceleration loads of unmanned launch vehicles. As a result, complex mechanisms secondary to the main purpose of the instrument will no longer need to be installed to remove peripheral protective devices or to activate and calibrate instruments remotely. With the crewmembers available to load film, for example, complex film transport systems are not needed, and malfunctions such as film jams can be easily corrected manually. The time required to calibrate and align instruments directly can be as little as 1/40th of that required to do the same job by telemetry from a remote location.

Specific experiments and operations no longer will need to be rigidly planned in advance, but can change as requirements dictate. One of the greatest contributions of crews in scientific space missions can be in reducing the quantity of data to be transmitted to Earth. One second of data gathered on SEA SAT, for example, required 1 hour of ground-based computer time for processing before it could be used or examined, or a value assessment made. Scientist-astronauts in situ could determine in real-time whether cloud cover or other factors are within acceptable ranges before recording and transmitting data.

Astronauts can abstract data from various sources and can combine multiple sensory inputs (e.g., visual, auditory, tactile) to

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*The Soviets have been reported to rely heavily on manned involvement in order to repair equipment and subsystems with serious shortcomings in reliable and trouble-free service life.

interpret, understand, and take appropriate action, when required. In some cases the human perceptual abilities permit signals below noise levels to be detected. Humans can react selectively to a large number of possible variables and can respond to dynamically changing situations. They can operate in the absence of complete information. They can perform a broad spectrum of manual movement patterns, from gross positioning actions to highly refined adjustments. In this sense, they are variable-gain servo systems.

Thus, with the advent of permanently manned space studies, there are alternatives to the expensive deployment of remotely manned systems, with their operational complexity and high cost of system failure. Long-term repetitive functions, routine computations or operations, and large-scale data processing functions can be expected to be performed by computers capable of being checked and serviced by crews in orbit, just as they are now serviced in ground installations. In addition, the normal functions of the terrestrial shop, laboratory, and production staff will find corollary activities in the work done by the crews manning the space platforms of the coming generation.

The criteria of performance, cost, and mission success probability (program confidence) are the principal factors that program or project managers and system engineers use in selecting the most cost-effective approach to meeting mission objectives. While the final selection in the productivity tradeoff between performance, an acceptable probability of success, and the resultant cost must rest with the decision maker, these criteria provide a frame of reference from which rational or informed decisions regarding the impact of productivity changes on total system effectiveness can be made.

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Harry L. Wolbers, Ph.D. is currently Manager - Manned Systems Design, Space Station Programs at the McDonnell Douglas Astronautics Company. He has participated in every MDAC Space Station study since 1963. He is also a Professor (Adjunct) in the Department of Industrial and Systems Engineering at the University of Southern California.

HUMAN PRODUCTIVITY IN SPACE STATION

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THE SPACE STATION AND HUMAN PRODUCTIVITY:

AN AGENDA FOR RESEARCH

Claudia Bird Schoonhoven
Department of Organization and Management
San Jose State University
San Jose, California 95192

ABSTRACT

This paper offers a research agenda for analyzing organizational problems in permanent organizations in outer space. The environment of space provides substantial opportunities for organizational research — as we face questions about how to organize professional workers in a technologically complex setting with novel dangers and uncertainties present in the immediate environment. Although organizational theory and behavior have always had important implications for research on human habitation in outer space, research into these issues has been limited because technological and medical issues have been viewed as more critical and thus of higher research priority. It is suggested that knowledge from organization theory/behavior has been an underutilized resource in the U.S. space program. A U.S. space station will be operable by the mid-1990's. Organizational issues will take on increasing importance, because a space station requires the long term organization of human and robotic work in the isolated and confined environment of outer space. When an organizational analysis of the space station is undertaken, there are research implications at multiple levels of analysis: for the individual, small group, organizational, and environmental levels of analysis. The paper reviews the research relevant to organization theory and behavior, and offers suggestions for future research.

INTRODUCTION

The United States is rapidly approaching the beginning of long term habitation in outer space. A space station will be operational by about 1995 and space colonization will be close behind. The construction of the space station will take place in real time, with the astronauts actually assemblying its pre-fabricated modules in space. This achievement will mark a very important event in human history, because it heralds the end of short term space missions and the beginning of humans living and working in space for long periods of time. The ultimate success of this remarkable undertaking will hinge considerably on many organizational factors. The question of whether human beings can physically survive the rigors and real environmental dangers of space appears to have been answered favorably with the success of the U.S. and Soviet Union's "manned" space flights to date. Whether humans as organizational and social systems will survive the transition from work and life on earth to long term work and life in a space environment remains a question for future observation and research. Years of technological, physical, and me.. al data have been gathered, and yet many basic organizational and managerial questions remain unanswered.

Why have basic organizational and managerial questions not been answered? To a large extent this is because they have not been asked, and there are a number of reasons for this, which cross-cut most of the social and behavioral sciences including psychiatry and psychology (Santy, 1983; Helmreich, 1983). (1) A hierarchy of "practical" concerns directed the early research. In the early phases of the U.S. space program in the 1950's and during the post-Sputnik Era, organizational questions were not addressed because the question was survival, not how to organize. (2) The earliest missions had crews of one and then merely a few, and mission durations were counted in hours. Both of these limitations truncated organizational and sociological problems, and thus the apparent need for inquiry. (3) An early suspicion of "doctors" and human scientists developed among the astronauts, largely due to the kind of psychological and medical testing which surrounded astronaut selection procedures. The scenes described in Tom Wolfe's THE RIGHT STUFF and the film by the same name provide the reader with colorful images of these early activities. Psychiatrists and doctors in general are traditional culprits in the lore of pilots, often responsible for grounding military pilots, the group from which the early astronauts were recruited. (4) The study of organizational issues surrounding space missions ultimately involves the study of NASA as an organization and the astronauts themselves. The astronauts are heavily in demand for both training and public appearances, and NASA's administrators have been reluctant to increase the demands on their time and subsequent good will for the purposes of behavioral or social science research. Behavioral research is little understood in general, and this has not hastened the case for organizational research. (5) Social and behavioral researchers strive to maintain the anonymity and privacy of their subject individuals and organizations. While NASA is a large organization, it is nonetheless a single organization. Concerns that disguising its identity would be difficult are understandable. NASA is dependent upon government-controlled funds, and thus is appropriately sensitive to maintaining a favorable public image and legislative goodwill.

All of these issues have inhibited the development of organizational and managerial knowledge regarding human behavior in the space environment. Nonetheless there is growing recognition of the pressing need for this research. Brady, for example, acknowledged that early space missions provided the presumed high motivation among astronauts to "..succeed in pioneering a new frontier" (1980). It is an open question as to what will motivate productive work behavior at the high level NASA has come to expect, given long term missions in a permanent space station, operating under relatively routine work conditions. Sadin has remarked that "..it now seems clear that the stage is set for extending a research analysis of interrelated selection, training, and organizational problems.." (1982: V-137).

It is interesting that despite the concerns like those expressed above, Bluth has remarked that the U.S. space program has never made a formal attempt to establish experiments and record behavioral reactions, nor has it used behavioral scientists in its training programs (1981). In contrast, several American scholars have remarked on the extent to which the Soviets have undertaken social and behavioral research on their cosmonauts. Research findings have been utilized by the Russians in their space program to a far greater extent than in the United States (Bluth, 1981; Connor, 1983). In the sections which follow, we will outline a research agenda developed from an analysis of the existing research and theory on organization and management as it applies to organizing the space station. We will limit out attention to the space station, because space colonization involves more global societal organization and evolution, and these issues are beyond our current scope.

Space Station Analogs: Other Isolated, Confined Environments (I.C.E.'s)

Space stations feasible during the next several decades will be fairly small, have limited habitable spaces, and accomodate six to twelve human residents for intervals of about three months. The space shuttle will service it, transporting limited numbers of people and goods at infrequent intervals spaced to provide adequate provisions. These features of a low earth orbit space station in combination with expensive communication linkages to the outside world, combine to produce an isolated and confined environment, referred to as an "I.- C.- E." With one major exception to be discussed below, relatively few organizational and sociological problems among space crew members have been made public. Nonetheless, a conceptual analysis of the variables operating within future, permanent space organizations suggests that more rather than fewer organizational and structural issues are likely to be encountered. Because a space station will exist within a high danger, hostile external environment, with organizational members confined to relatively crowded physical spaces with little recourse for escape, space craft will continue to be potentially volatile organizational systems.

Considerable research has been conducted looking at small groups in isolated, confined, and stressful environments (ICE's). These are called Earth-based analogs, where analogs are defined as any Earth-based simulation or naturally occuring working or living arrangement which replicates in part conditions of space habitation and flight. The settings studied have included Antartic research teams, submarine crews, oceanographic research vessels, Alaskan oil pipeline construction crews, and undersea research labs. None of these ICE's exactly replicates permanent habitation in space, however, especially the unique stresses of space derived from microgravity and its related influences. When compared to the space station, the analogs contain the variable factors of crew size, degree of isolation, social and educational background of the crew, organization of the crew, nature of the formal work to be done, the historical context, degree of confinement, and what are presently considered to be the "unique" stresses of space like meteor storms and loss of bone density, for example, (Bluth, 1981). They also contain variations in organization structure, goals, and expected outcomes.

Studies conducted on ICE's have identified a number of psychological, social-psychological and group behavior effects associated with the ICE setting, most of which are undesirable from both a mission performance and social desirability perspective. For example, on Antartic stations where confinement of mixed scientific and naval crews varies between six months to a year, there have been three reported murders (Gloye, 1980). Among the navy personel were increases of 40% in stress-related symptoms of anxiety, depression and hostility. Civilian scientists showed the same but less intense symptoms. There was a high, consistent emphasis on personality-oriented rather than task-oriented behavior (Vinograd, 1974). Also see G.E. Ruff, 1959; E.K. Gunderson, 1963; C.S. Mullin, 1960; and Gunderson and P.D. Nelson, 1963, for more detail on the Antaractic experience.

On oceanographic research vessels differences in educational background and formal tasks between ship members appear to be related to group disputes and interrupted mission performance. On one, the merchant crewmen threw frozen scientific samples overboard, eliminating $50,000. in scientific materials, 2 years of scientific investigation, and one doctoral dissertation (Bernard and Killworth, 1974; also see: Miller, Vanderwalker, and Waller, 1971; and Helmreich, 1971). On Polaris submarines on 60-day submerged runs, men reported insomnia, headaches, attacks of anxiety, and depression. Lack of personal space influenced the development of cliques, hostility between them, vulgar language, joking, and pecking orders reminiscent of behavior in federal penitentiaries. (Sexner, 1968) McNeal and Bluth have summarized the ICE symtomology in genuinely hostile environments. These include: boredom, irritability, depression, anxiety, mood fluctuation, fatigue, hostility, social withdrawal, vacillating motivation, tension, and sleep disorders. (1981)

Some would argue that there is high similarity between the ICE symtomologies described above and those produced by stress in general. The organizational behavior literature on the predictors of stress and on the effects of stress on withdrawal, turnover, and other valued organizational outcomes is relevant here. Stress has been defined as any behavioral responses of an individual to adversive stimuli (stressors) which push the functioning of the individual beyond ordinary, non-emergency coping mechanisms (McNeal and Bluth, 1981). The literature on stress management in general may be usefully applied to the space environment as a mechanism for deriving potential coping strategies and a preparedness for social - psychological problems in space.

RESEARCH IS NEEDED on the efficaciousness of coping strategies across a variety of organizational settings, including of course, any which are conceptually similar to the isolated and confined environment of outer space. A major problem with the ICE studies is that they are primarily anecdotal, few variables are quantified, and seldom is there any attempt to specify the effects of specific variables on specific other outcome variables. Carefully designed research is clearly needed here to move beyond the present wholistic conception of an ICE. Future research must break out the conceptually independent but potentially interactive effects of the variables which combine to produce an ICE. For example, psychological withdrawal and subsequent social isolation have been reported on the Antarctic stations. Withdrawal is presumed to be a coping mechanism for physically isolated settings under confined conditions. A question to ask is will an isolated organizational setting where workers are not confined continuously produce the same effect? If extensive activity outside the confines of the organization were possible, would this mediate some of the observed effects?

There is one additional observation which can be made about the ICE studies. Most of the research on long term isolation and confinement in hostile environments describes behavior and interpersonal relationships which do not support optimal mission performance. However, in the largely anecdotal ICE research, there is minimal attention paid to formal structure or design of the organization. Typically it is simply ignored, often because there is so little variation in formal structure in this research with an apparent high reliance on the military command model or variations of it in many of the ICE's. While some organizational variation has been introduced by the oceanographic research vessels and the north slope settings, the actual structures in place cannot be readily ascertained given the reported data. NEEDED RESEARCH: a thorough literature review with an analysis of the organizational designs present is needed on comparative organizational structures under conditions of isolation, confinement, and a hostile external environment as it relates to mission performance and the mental and emotional health of the workers.

The High Funnel: Intra- and Inter-Organizational Links

What also differentiates the space station from other isolated and confined organizational settings is what has been referred to as the "high funnel" (Hays, 1984). At the present, space missions in the United States are closely monitored and supported from the ground. While the intensity of ground support is likely to decrease over time with technological advance, the space station will nonetheless be part of a very large organization with extensive interorganizational links -- metaphorically described as a high funnel. In terms of the total organization, it is as if the orbiting station itself were at the small end of an upended funnel, with the broad end very widely based on Earth. The activities of many individuals, groups, and organizations will converge on a very small, and for its high cost, fairly modest setting.

At the narrow neck of the funnel are first mission support and the astronaut office, both of which buffer and screen inputs to the space station, via mission control functions. Expanding from the neck toward the base of the funnel is the larger NASA as an organization, with its multiple subunits. Spreading widely to the base of the funnel and beyond are representatives of a large number of external organizations: contractors who built the station, concerned agency and governmental groups who fund the space agency, and portions of the scientific and commercial communities whose research and commercial enterprises are conducted on the space station. This latter mega-group is both quite large and not always clearly visible, and yet its presence will be felt. Through communications to and from the space station, technical problems will need to be solved with assistance from contractor's engineers and decisions will be made and refined regarding research during the mission. At this point, one can only speculate as to how the high funnel of extensive intra- and inter-organizational relations is likely to influence the work arrangements and work outcomes in the space station. COMPARATIVE RESEARCH IS NEEDED on the effects of similarly complex "high funnel" organizational arrangements on relative organizational power to affect decisions, control over valued resources, morale and productivity of those positioned at the top of the funnel itself, the space station equivalent.

There is a fairly deep description of the low power of astronaut crews relative to mission control and flight administrators. In former Astronaut Cooper's HOUSE IN SPACE (1976), he describes the expectation that the astronauts would "..screw something up!", given the constraints and technical complexities of the 1973 Skylab activities. This expectation supported the firmly autocratic decision and authority structure which governed the astronauts' work. It was also consistent with the military command structure the astronauts were familiar with, given their mostly ex-military pilot backgrounds. When astronauts were scheduled so tightly by the ground that unanticipated events and unsystematically stowed equipment prevented them from maintaining the schedule, the three Apollo 3 astronauts closed down communication with mission control for twenty-four hours, cleaning and stowing equipment properly, awaiting a newly prioritized schedule from mission control. This event has become an infamous Harvard Business School case, and titled "Strike in Space" (Balbaky, 1980). This is, of course, one of the only publicly known "negative" reactions of astronaut crews during a space flight, and it centered on high funnel, organizational issues: the relationship between the ground organization and the crew in space.

If there is an area that is critical to on-station stress, judging from past experience, it is relations with Earth-based personnel. Stress from this source in the past has involved a combination of high work demands and overspecification of behavior , and these are explicitly organizational issues. However these sources of stress must be dealt with and mediated by more appropriate organizational arrangements, because they influence quality of life for the space inhabitants. Former astronaut, Gerald Carr, reported that "During the Skylab 3 flight, work was mixed into the schedule on our days off. Mid-mission we insisted on a full day free, and that insistence was later labelled rebellion. Like the Russians we had our own frustrations with ground support." (Bluth, 1981a)

When focusing on organization and management issues on the space station itself, the very large Earth-based mouth of the "funnel" could easily be overlooked. This would be a mistake, because most of the reasons for the space station's existence reside in Earthly motives and organizations. Alternatively, one could consider the <u>space station mission</u> as a small organization which <u>includes</u> the immediate ground specialists, managers, and communications personnel as well as the crew itself. This space/ground <u>team</u> could receive collective training on issues of mutual interest, developing cohesion and trust, and be more firmly buffered from outside pressures (Hays and Schoonhoven, 1984). Clearly RESEARCH IS NEEDED on the variety of organizational designs and intervention mechanisms potentially applicable this complex "high funnel" organizational setting.

Organizational Design: Ask the Astronauts

Research is imperative which solicits the ideas of U.S. astronauts and the earth-based managers of space missions regarding the organizational design of future space stations. As of this writing, there is no publicly available data in which current American astronauts were formally engaged in systematic research as expert informants on their organizational experiences, needs, and problems while in space. In contrast an American scholar has been allowed to interview Russian cosmonauts and to publish the results of that research (Bluth, 198_).

Organizational design is an issue which the Russians have explicitly dealt with in their research. In a publicly available, translated collection of papers, Novikov reports on Russian organizational structure in space: "To our view, the strict distribution of duties and responsibilities and refraining from absolute emphasis on a hierarchical structure for a crew consisting of 2-3 people and erasure of the concept of "commander" is sufficiently expedient as a method which smooths the sharpness of such situations. Evidently, one should choose other designations which correspond more to the developed spirit of cooperation and fraternity of people who are carrying out important assignments under extremely complex conditions." (1979: 135)

Stereotypical thinking about the Russian character and apparent heavy reliance on bureaucratic organization would suggest that the Russians would be among the last societies to recommend no commander on a space station. Yet, it is their explicit research into the subject of organizational structure in space which led to the rather counter-intuitive "no commander" conclusion, above.

Regarding organizational design, there are at least two issues here. One is what should the desirable organizational structure be for the crew in space? The second is what should the nature of the ground-station organizational relationships be. This latter question is usually posed within NASA as how much "autonomy" should the crew have from ground control. When these questions are addressed, space operations managers and administrators are concerned about designing space organizations for high levels of performance and for the least cost -- the familiar organizational concepts of effectiveness and efficiency. While neither design question can be simplistically answered, many organizational theorists would observe that prematurely fixed decisions should not be made regarding the proper structure for the space station which are then relied upon in an unquestioned manner as "the one best way" to structure and manage a space station. There is much we do not yet know about structuring for organizational effectiveness, particularly when survival rather than merely effectiveness may be the dependent variable as it is in the isolated and hostile external environment of space. Yet, twenty years of research on the issue has demonstrated that a single way of structuring successful organizations does not exist. Equifinality emphasizes that there is often more than a single path to the same outcome. Several satisfactory ways to structure the situation likely exist. These, with their differing strengths and weaknesses are reviewed in Schoonhoven (1983 and 1984) and crew-based scheduling schemes are developed in Sims (1984).

The systems concept "morphogenesis" reminds us that organizational form is capable of adaptation over time, and yet population ecologists argue that organizations are environmentally selected for survival when structural inertia exists (Hannan and Freeman, 1984). As yet there is no definitive understanding of the relative strengths of what are presently two competing perspectives: adaptive capacity versus structural inertia as they relate to survival of organizations. THIS IS AN AREA OF NEEDED RESEARCH. The space station's structure is presumed to require adjustment to changing levels of technology, modifications in the number and mix of space station missions, shifts in the number and characteristics of crew members, and increasing knowledge of space itself. This is a QUESTION FOR RESEARCH rather than presumption.

Initially there will be only one space station, "the" space station referred to thus far. However several varieties of space stations are likely to be developed in the near future, and they will likely specialize by mission. There will undoubtedly be purely commercial ventures; the enormous costs of space development and missions are expected to be shifted to the private sector with industry basically paying the way in the long run. There are also military applications in space and the likelihood of stations with predominantly military missions. This discussion suggests that different ways of organizing are likely to be appropriate for space stations as a generic set, depending on which goals and missions are pursued, the division of labor, the technology in place, and so forth. Whether new ways of organizing will be required which deviate from the military command model is an open question, even for military space ships. New frontiers often demonstrate the need for structural innovations, and research on earth in technically complex organizational settings with dramatically different goals is a likely target for meaningful research. The recently announced General Motors "Saturn" plant is a case in point.

Were research undertaken in which current astronauts are systematically engaged as expert informants, it is important that data from participants in the more recent shuttle missions be gathered. These missions have been of longer duration, have had larger crews, have had greater specialization and division of labor (mission and payload specialists, pilots, commander) and have been more technologically and scientifically sophisticated. All of these conditions approach the space station conditions more closely than earlier missions have.

Methods for gathering this data should include direct interviews with current astronauts who have made shuttle flights and with mission managers

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for initial insights into the major problems and variables for both on-board and space station - earth organizational issues. These organizational actors are the best sources of contemporary and probable future problems relative to organizational issues. Initial interviews should be semi structured, but open-ended to allow for maximum variation in responses. For a comparative basis, astronauts from earlier, shorter missions with smaller crews will be important sources of data. A representative sample of both sets of crew members can easily be devised from the various missions. Getting official access to these important actors is a different issue, however, just as organazational entree is a concern is most organizational research.

Once this initial data has been gathered and analyzed for trends, explicit hypotheses can be tested using data gathered from video and vocal tapes of past space missions. Both of these data sources exist. A content analysis of such tapes would reveal the extent to which perceptions of astronauts and mission managers regarding organizational issues are supported by a larger data base, sampled under varying crew, workload, and mission conditions. Video and vocal tapes are a rich data source, since they are genuine histories of the actual organizational experience.

A second, although less ideal approach to hypothesis-testing could involve the simulators in which astronauts spend extensive training time. The simulators provide controlled environments which reproduce as closely as possible selected physical characteristics of the space craft. Given a sufficiently realistically simulated work environment, these settings could be used to experimentally manipulate organizational characteristics in order to study the effects of variation in organizational structure on task performance. Flight simulators have been used rather successfully by the military and the commercial airlines to train pilots. It appears that task conditions are sufficiently realistic that value from the training is genuine.

NASA has funded simulation studies relevant to work in space in the past. For example, Brady and Emurian (1978) have studied isolation and confinement reactions among volunteer subjects in laboratory settings. However, among the difficulties with simulated space environments and other isolation studies is that there is no true danger from the simulated space environment to the experimental subjects, and of course a microgravity condition does not exist. Among simulated studies of space using long-term isolation (90-days) it has been difficult to obtain the experimental conditions desired as a consequence. Crews have high awareness of the simulation, produce a high level of performance, generally good morale, and little hostility. The lack of true danger in the benign simulations appears to account for generally favorable outcomes of the experience. (Seeman and McFarland, 1972) Studies of other phenomenon may not depend on the very difficult problem of experimentally recreating genuine isolation and the awareness of confinement, and thus may be more successful than the isolation studies appear to have been. For example, the simulation of a scientific shuttle missions appears to have been successfully executed, and as a consequence, the organizational and psychological aspects of mission management were observable. Results suggested that the social dynamics of planning and integrating the components of missions are critical to success (Helmreich, Wilhelm, Tanner, Sieber, and Burgenbauch, 1979).

Naturally, what one simulates depends on the questions addressed in the research. Important work is being done in three corners of the country in which interactions among commercial airline crew members are analyzed to understand how group dynamics and formally differentiated status influence crew error rates and mission performance. Some of these are simulations; others involve direct observation of working crews in airplane cockpits, at least initially. This is the work of R. Hackman, in process, H. C. Foushee on dyads and triads at 35,000 feet (1984), and a social psychologist, R. L. Helmreich, long active in space-relevant research (1971; 1980; and 1979). What is important is that these researchers have creatively examined empirical settings available for space-relevant research, and in so doing have also made original contributions to their base disciplines as well. Collectively their work provides a good model for the exciting research which awaits the stimulated organization and management investigator.

Space Station as the Ultimate Company Town

Research is also needed on the interactions between the formal (work) organization's structure and the social living structure under conditions of isolation, confinement, and a hostile external environment. The concern is with the social relationships among people who also live where they work. The space station has been described as the ultimate company town (Schoonhoven, 1983: 23). What are the likely interactions between off-duty social structure and the formal organization of the work? How does the interacting set of variables influence: (a) mission performance, (b) the mental and emotional health of the space workers, and (c) individual and collective human productivity? Even the Russians have now demonstrated their interest in the "emotional enthusiasm" of their cosmonauts, because it is presumed to influence "working capacity" (Lomov, 1979: 9).

Recent court cases on Earth involving naval personnel at sea suggest that close personal relationships are likely to develop during long missions, despite formal organizational restrictions to the contrary regarding "fraternization". Privacy needs are likely to develop on long term missions as well, which develop from both psychological as well as social needs. Sexual behavior and tensions must be expected and planned for. Studies of all-male prison environments describe in grim detail that victimization and destructive interpersonal behavior is common when sexual needs are not formally recognized, condoned, and architecturally planned for in a facility.

One may also expect that the formation and dissolution of personal relationships is likely to create additional tensions which undermine productive, cooperative work group behavior. Obviously the prison studies of all-male groups demonstrate that it is not the added presence of women in an organization which suddenly illuminates this issue. It is clear that if officials simply ignore this "delicate" issue, in-mission problems are clearly predictable. Similarly, if traditional cultural mores are presumed to dictate "appropriate" behavior, this may severely hinder the crews' adaptive capacity that will be essential during the longer term exploration of the universe and beyond. We would agree with the psychiatrist, Santy's conclusion, that "We must avoid letting rigid cultural values and customs, especially in the area of sexual mores, prevent research in this area." (1983: 522)

The existence of truncated social roles is a variable which may influence mission performance. Astronauts are currently seen unidimensionally as workers and while in space do not enjoy the usual variety of social interactions as sybling, spouse, child, parent, or jogging partner. In the formal work group one is constantly evaluated. In a family or friendship setting, individuals are accepted more completely and performance pressures are reduced substantially. Bluth remarks that in small confined groups all aspects of daily life are in the presence of the same group of people who are always there. The group must function for both work and friendship, evaluation and nonevaluative support.(1981b) Destablized self-concepts can result from imposed role restrictions, which can in turn influence mission performance. While this is an issue for research, prior work in total institutions like prisons and state mental institutions suggests that extensive visitation rights from family members play a part in depressing undesirable social behavior. Similarly having the equivalent of an open-phone to family and friends, like E.T.'s phone home, is likely to reduce confinement perceptions by introducing more varied role opportunities, alternative sources of evaluation, and significant others for self-concept stabilization. This is speculation, however, and systematic evaluation of existing mediated communications research would be useful here.

Crew Selection: Structure versus Personality

Most of the research sponsored by NASA on crew selection has been conducted from a psychiatric or psychological perspective, because an astronaut's psychological stability was considered of primary importance during the selection process. (See Santy, 1983, and Helmreich, 1983, for reviews of this literature from the two perspectives.) Because the disciplines of psychiatry and psychology both emphasize the individual, most of the research relevant to crew selection in these two disciplines recommends selecting for desirable personality attributes, where androgonous, flexible people-oriented individuals are argued to promote group cooperation and conflict reduction, for example. There is evidence that systematic characteristics of groups, like their sex ratio for example, operate structurally to produce extremes of performance and reduced group effectiveness. This research suggests that sociological characteristics of groups, not merely personality characteristics, may strongly influence desired outcomes on space missions.

Work groups can be described by the extent to which they are numerically skewed by the balance of a dominant, majority social group to a numerically rare, minority social group. When there is a low proportion of the numerically rare, minority social category in the group, a condition of tokenism is said to exist. It has been well documented that tokenism (whether intended or inadvertant) results in high psychological stress for the token members; that performance extremes of over and under achievement are likely; that imbalanced and unstable self-concepts develop for the tokens; that the maintenance of satisfactory social relationships within the group is problematic; that dominant members of the group suffer humiliation when out-performed by the minorities. This latter dynamic undermines the group's ability to encourage excellent performance among all of its members. The consequences of tokenism are reduced performance within the group as a whole. The dynamics of tokenism also help to perpetuate a system which keeps members of the token's category in short organizational supply. This is a structural effect which operates within the social system, independent of selected personality characteristics. The decision to send crews into space with "token" members in their crews can have the negative consequences described above. Sally Ride, the first U.S. woman astronaut in space, and Commander Bluford, the first U.S.black astronaut, both flew under structured token situations. Since the space station will present conditions of long term isolation and confinement, the presence of numerically skewed crews could have serious negative consquences for future space missions.

Based on Kanter's work (1977a), research should investigate when a work group moves from a numerically skewed, rare token-dominant majority structure to a balanced position. This is necessary to inform managerial decisions regarding the appropriate gender, ethnic, and cultural balance of astronauts necessary to crew successful space station missions. This will facilitate recruiting, selection and development decisions for the astronaut corps, and the knowledge will help NASA missions avoid the negative consequences of the dynamics of tokenism: psychological stress; the performance extremes of over and under achievement; more balanced self-concepts; enhanced interpersonal interaction between men and women without the pressure of public humiliation of the dominants and consequent negative affect; the swings of either social isolation or public scrutiny, high visibility, and lack of privacy experienced by tokens.

It is not enough to recruit for androgenous, psychologically stable individuals as has been suggested in some research on the effects of isolation and confinement in hostile environments. Some social categories, like gender and race, are still very important in our society. Women, or members of any other underrepresented category, need to be added to total group membership in sufficient proportions to counteract the effects of tokenism. What the precise numbers are is a matter to be researched. Similarly, if none of the negative effects of tokenism have emerged during shuttle flights, then that is also important information. If the negative effects of tokenism have not emerged, perhaps inadvertantly avoided through NASA's extensive training programs, then the specific variables responsible for the depression of this structural effect should be understood. It is not enough to be fortunate. Expensive long term missions require maximum information from which to make crew assignments.

AN AGENDA FOR ORGANIZATIONAL RESEARCH

Human - Robotic Interaction: Who's in Control?

One of the objectives of the Space Station Technology Steering Committee has been to establish the desired level of technology to be used in the initial design and operation of an evolutionary, long life space station and the longer term technology for application to improved capabilities (R. Carlisle, 1982). Research is currently in proces to develop robotic systems to enhance human productivity in the space station context as one avenue for realizing this objective. Since robots and robotic systems are presently relatively youthful and developing technologies, few organizations have had extensive time-based experience with them. Little serious research has been conducted to document the effects of robots on human performance, safety, productivity, and overall organizational performance.

The installed base of robotic, flexible manufacturing systems has grown substantially in recent years in the U.S. and in Japan. These industrial settings provide naturally occuring variation in robotic systems and organizational arrangements. They could be used to study a number of issues important to the space station's development. Of first concern is the conditions which promote safety of the human participants in the system. Other pragmatic concerns include: what has been the impact of these technological innovations on worker characteristics, including required skill levels and educational attainment; how has the relationship between managers and the system operators changed with the introductionn of intelligent machines; have relationships between members of the work group been modified in ways which impact overall group and/or organizational performance? What are managerial and worker attitudes toward intelligent machines? Do favorable attitudes evolve over time or do they require managerial intervention in the form of specialized training to promote rapid acceptance and efficient utilization of the machines. When we speak of an evolving technological system like the space station, what changes over time can be expected in the tasks or jobs performed by humans in the system? The basic question to be researched is what are the conditions under which strong performance is made possible when intelligent machines become a significant element in the organizational system.

Conclusions

In general it appears that existing research and theory on organization and management can be usefully synthesized to derive insights and predictions regarding appropriate organizational designs and probable organizational and small group behavior one can expect on a permanent, human inhabited space station. However as this review has demonstrated, much of the application of these ideas leaves us with predictions which should be tested, and with much research before us. Many of the questions raised by the relatively novel environmental setting of space can be investigated within earthly organizations. The robotics questions raised above are an example. It would be unfortunate if the U.S. astronauts' experience in space along with their counterpart mission managers were overlooked in the important research ahead. We can no longer rely entirely upon the few Russian studies which have been translated and on extrapolations from anecdotal, unsystematic research in the ICE space analogs for predictions of likely human behavior and mission performance in a permanent space station. There are many areas in which the research and the applied experience of organization theory, behavior, and development are likely to demonstrate high utility in the future success of the space station as an organization. If this article has alerted the reader to new and exciting research opportunities, then one of the major goals of this article will have been achieved.

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- BIOGRAPHICAL STATEMENT -

Dr. Schoonhoven is an Associate Professor of Organization and Management, San Jose State University and has been a Visiting Scholar, Stanford Graduate School of Business during 1984 and 1985. Her Ph.D. is from Stanford University in organization theory and behavior, and she was a NASA-ASEE Summer Faculty Fellow, 1983. Currently in the early stages of research on success factors in semiconductor start-up companies, she specializes in the management of innovation and organizational design.

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POST-IOC SPACE STATION: MODELS OF OPERATION AND THEIR IMPLICATIONS FOR ORGANIZATIONAL BEHAVIOR, PERFORMANCE AND EFFECTIVENESS

Scott Danford, School of Architecture and Environmental Design
James Meindl, School of Management
Raymond Hunt, School of Management
State University of New York at Buffalo

ABSTRACT

The magic, mystery and romance which will surely surround its first years of operation and the careful selection of motivated, dedicated (to NASA) crews will doubtless combine to ensure high levels of productivity among the first several crew generations to occupy space station. However, once space station's operations become routine and the magic, mystery and romance give way to perceptions of its being just another isolated and confined place to go to work, high levels of performance and effectiveness could become problematic. It will be at that point that the crews' environmental context will become an increasingly significant productivity parameter.

In consideration of this, unprecedented (for NASA) and commendable attention is being paid to issues of "crew productivity" during current design work on space station. Unfortunately, this "crew productivity" is being defined almost exclusively in terms of "human factors" engineering and "habitability" design concerns. While such spatial environmental conditions are, of course, necessary to support crew performance and productivity, they are by no means sufficient to ensure high levels of crew performance and productivity on the post-IOC (Initial Operational Configuration) space station. What is being relatively ignored is the role of the organizational environment as a complement to the spatial environment for influencing crew performance in such isolated and confined work settings.

This paper identifies three possible models of operation for post-IOC space station's organizational environment and explains how they and space station's spatial environment will combine and interact to "occasion" patterns of crew behavior - both desireable and undesireable. The paper concludes by suggesting a three phase program of research designed (a) to identify patterns of crew behavior likely to be "occasioned" on post-IOC space station for each of the three models of operation and (b) to determine "proactive"/preventative management strategies which could be adopted to maximize the emergence of preferred outcomes in crew behavior under each of the several spatial and organizational environment combinations.

POST-IOC SPACE STATION

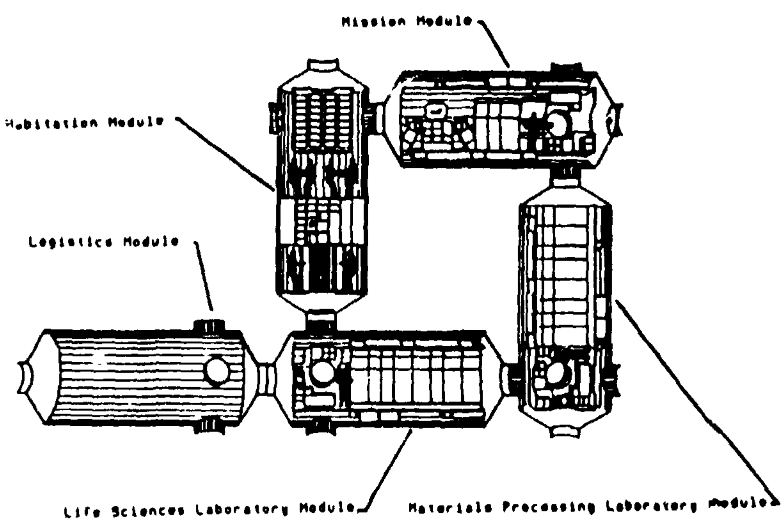
While space station's initial organizational model of operation will likely follow the successful traditions established by over two decades of U.S. manned space programs, legitimate questions can be raised about its long-term appropriateness for what is likely to be a more routine, more commercially-oriented, less glamorous, more isolated and confined post-IOC (Initial Operational Configuration) space station [3]. Once the magic, mystery and romance of space station's initial years of operation fade to leave rather bleak but accurate perceptions of its being just another isolated and confined place to go to work, one can expect the station's environmental context - both spatial and organizational - to become an increasingly important productivity parameter [2].

The Spatial Environment

Fortunately, the spatial component of that environmental context is receiving unprecedented (for NASA) and laudable attention as a potential productivity parameter during the current design work on space station. For example, beyond the expected "human factors" engineering concerns, NASA has begun exploring "habitability" design concerns of privacy, crowding, territoriality, personal space, way-finding, spatial orientation, etc., which would have been considered frivolous or at best largely irrelevant for any of the previous U.S. manned space programs (including, unfortunately, Skylab) [4].

While design work on space station's spatial environment is continuing (and is therefore unavailable for public presentation at this time), the design concept work of NASA's in-house, 300+ member "Skunkworks" team done during the Summer of 1984 is available for illustrative purposes (see Figure 1) [2]. While these design concepts for

FIGURE 1
Illustrative Space Station, Port View



space station's spatial environment were not intended to reflect all state-of-the-art "human factors" engineering and "habitability" design concerns, they nevertheless give some feel for the degree of attention being focused on these concerns as potential productivity parameters for the crews of space station.

But while such features as "zero-gravity body posture" appropriate design, artificial vertical referencing systems, individual private crew quarters, etc., are obviously necessary to support long-term crew performance and productivity, they are still not sufficient to ensure such behaviors. While the spatial environment's influence on users' behaviors is undeniable, there are few who would argue the case in favor of some form of spatial environment (i.e., architectural) "determinism." Rather, the spatial environment is instead viewed as "occasioning" certain patterns of user behavior - but even then only to the degree that other environmental factors are at least not working at cross purposes [1].

Consequently, the design of the environmental context in which post-IOC space station's crews must operate will have to address considerably more than "human factors" engineering and even "habitability" design spatial concerns if high levels of crew performance and productivity are to be not just "enabled" but actually "occasioned." Providing a "productivity occasioning" environmental context for the post-IOC space station will necessarily mean considering those other environmental factors as well. And foremost among those relatively ignored "other" environmental factors in terms of its likely influence on crew performance and productivity in isolated and confined settings like the post-IOC space station is the organizational environment.

The Organizational Environment

Combining and interacting with post-IOC space station's spatial environment features to either compromise or reinforce its "productivity occasioning" potential will be a number of organizational environment concerns. Regretably, despite its virtual certainty as a productivity parameter on-board space station, the model of operation that organizational environment will adopt remains largely undefined and relatively ignored. As a significant complement to post-IOC space station's spatial environment for influencing crew performance and productivity, one might have expected more attention to have been paid to this area - including the possibility of having the organizational environment's selected model of operation serve as one of the prime drivers for the spatial environment's design to ensure (at minimum) their compatibility.

Unfortunately, because the on-going design of space station's spatial environment continues largely outside of any major consideration of what model of operation its organizational environment should ideally adopt, the selected spatial environment will inevitably become the limiting factor in any eventual choice of organizational environment concerns. But while the opportunity to have post-IOC space station's organizational environment serve as a primary consideration in the design of its spatial environment has been lost (with the consequence that certain spatial and organizational environment combinations with strong "productivity occasioning" potential may no longer be possible), there still remains the choice of an organizational environment which can hopefully complement the selected spatial environment.

Assuming that the selected spatial environment will possess the necessary "human factors" engineering and "habitability" design features without which crew functioning would be severely affected (if not undermined altogether), there still remains certain significant (even if constrained) performance- and productivity-relevant decisions to be made about post-IOC space station's organizational environment. Even if the selected spatial environment were to present "human factors" and "habitability" features permitting potentially high levels of crew performance on space station, it would be the organizational environment which would largely determine the degree to which those potentials were or were not realized.

Indeed, with space station likely to be a rather spartan spatial environment for a variety of budgetary, practical or oversight reasons, the burden on the organizational environment to realize fully whatever potentials that the spatial environment provides will be enormous if post-IOC space station is to entertain any thoughts of being a productive, cost-effective enterprise. Consequently, the design of space station's organizational environment, although perhaps not as significant as it might have been had it served as one of the prime drivers for the design of space station's spatial environment, nevertheless remains a critical influence on space station's crew performance and productivity.

ALTERNATIVE MODELS OF OPERATION

Because space station's organizational environment remains largely undefined and relatively ignored, questions about which models of operation might be considered to reinforce the chosen spatial environment's "productivity occasioning" potential remain unanswered. While some might favor a continuation of the successful operational traditions established over the past two decades of U.S. manned space programs, such proposals would seem to ring untrue due to the numerous ways in which post-IOC space station will be substantially different from any of NASA's previous experiences - including the Skylab program. With post-IOC space station likely to provide a more routine, more commercially-oriented, less glamorous, and more isolated and confined experience for its crews than will initially be the case when space station first becomes operational, the appropriateness of continuing to carryover traditional operational procedures from NASA's previous manned space programs can logically be questioned.

The "Paramilitary" Model of Operation

The practice of maintaining an organizational environment designed for NASA's more traditional "paramilitary" model of operation (i.e., NASA/military astronaut-dominated operations in which any commercial activity is performed primarily by the crew on behalf of earthbound clients) may be already becoming obsolete as the private sector begins to book passage for its own employees on shuttle (STS) missions so that they can conduct their own proprietary experiments. Once space station passes through its first few "shake-down" years, the incidence of private sector employees going to work in space to conduct experiments and even to engage in manufacturing activities will likely become the "norm" rather than the current "exception." At that point, NASA's traditional "paramilitary" model of operation could begin to constrain such activity and thereby compromise the commercial potential of post-IOC space station. Consequently, organizational environments based upon alternative models of operation should at least be considered.

The "Host" Model of Operation

One moderate alternative to the "paramilitary" model and one for which there are numerous earth-bound illustrations is the "host" model. Applied to the post-IOC space station, this model would find a smaller NASA/military crew functioning as "host" to on-board civilians engaged in commercial/proprietary activities on behalf of private sector, earth-bound corportations. In such a model of operation the crew would retain full authority over all on-board activities analogous to the authority vested in the crew of a commercial airliner or passenger ship but would generally be reluctant to exercise such authority except under the most extraordinary conditions. Obviously even this moderate alternative to the traditional "paramilitary" model would necessitate a substantially different organizational environment for post-IOC space station to that which NASA has provided to date.

The "Corporate" Model of Operation

A second alternative representing a somewhat more radical departure from NASA's traditional "paramilitary" model of operation would be the "corporate" model. Characterized by NASA's removing itself completely from day-to-day operations to allow the post-IOC space station to become a predominantly civilian, commercial enterprise engaged in proprietary research and manufacturing, this model of operation would see NASA's role return to a focus on advanced research and development activities in keeping with its original charter. Under this "corporate" model of operation, post-IOC space station could become a government leased commercial facility with NASA's involvement restricted to providing selected technical services to private sector occupants on a "by request," fee-paid basis. With NASA's withdrawal from any routine operational roles on-board, post-IOC space station's organizational environment would obviously be a radical departure from that to be found for a "paramilitary" model of operation.

Consequences of the Choice of Model

For each of these three models of operation for post-IOC space station's organizational environment there are both costs and opportunities which make the choice between them less intuitively apparent than it might at first seem. The only thing that is intuitively apparent is that each of these three models of operation for the organizational environment - when combined with space station's selected spatial environment - will inevitably "occasion" markedly different patterns of crew behavior and thereby differentially impact crew performance and productivity.

While the spatial environment will define upper and lower limits on the crews' performance and productivity potentials by its accommodation (or lack of accommodation) of the crews' "human factors" and "habitability" needs, it will be the organizational environment's adopted model of operation - interacting with the selected spatial environment - which influences the degree to which those potentials are to be realized. By its reinforcing or compromising spatially defined "occasions" for various patterns of behavior which will influence the crews' performance and productivity, the organizational environment will necessarily become a significant productivity parameter on the post-IOC space station.

Consequently, the choice between alternative models of operation for post-IOC space station's organizational environment cannot be made arbitrarily, intuitively or based upon some established tradition. The potential consequences for post-IOC space station's crew performance and productivity are too significant to base the choice on anything less rigorous or empirical than that which would be expected for comparable "human factors" engineering decisions.

Beyond the Choice of Model

Moreover, while it is important to realize the potentially significant consequences of choosing between alternative models of operation due to the unique opportunity which each - when combined with the selected spatial environment - presents for influencing "occasions" for specific patterns of crew behavior, it is equally important to realize that each spatial and organizational environment combination actually "occasions" a range of both desireable and undesireable patterns of crew behavior.

Because there is no reason to expect there to be some special or magical combination of spatial and organizational environments for post-IOC space station (or any setting for that matter) which will always deliver the "goods" and invariably suppress the "bads" in "occasioned" crew behavior, steps will surely have to be taken to influence the displays of certain of those behaviors. For that reason, management strategies for encouraging desireable patterns of "occasioned" crew behaviors and discouraging undesireable patterns of "occasioned" crew behaviors will need to be identified for each of the spatial and organizational environment combinations before any informed choice can be made between alternative models of operation for post-IOC space station.

SUGGESTED PROGRAM OF RESEARCH

Even though the era of large scale commercial research and manufacturing activity for space station is still well over a decade away by even the most optimistic estimates, it is important to note that it is already too late for any particular model of operation for post-IOC space station's organizational environment to be included among the considerations influencing the current design work on space station's spatial environment. Because of that lost opportunity, organizational environment options for post-IOC space station are already constrained to those which can be accommodated by the selected design for space station's spatial environment.

Yet while possibilities for certain spatial and organizational environment combinations may have already disappeared, there still remain important (even if constrained) options for post-IOC space station's organizational environment which will still significantly influence crew performance and productivity. To enable informed choices among those remaining organizational environment options, a three phase program of research will be needed not only to understand the patterns of crew behavior "occasioned" by each spatial and organizational environment combination but also to identify effective "proactive"/preventative (as opposed to "reactive"/corrective) management strategies for both encouraging and discouraging certain of those behaviors so "occasioned."

Occasioned Crew Behaviors

Because the chosen model of operation for post-IOC space station's organizational environment - when combined with the selected spatial environment - will significantly influence patterns of crew behavior, it is suggested that Phase One of this suggested program of research first identify those patterns of crew behavior "occasioned" by each of the spatial and organizational environment combinations and then determine the desireability or undesireability of all such "occasioned" behaviors in terms of their impact on long-term crew performance and productivity.

This could be done through full-scale, earth-bound behavioral simulations involving longitudinal study of task performance and effectiveness for each of the alternative spatial and organizational environment combinations. From such research one would know the patterns of crew behavior likely to be "occasioned" by various spatial and organizational environment combinations and those "occasioned" behaviors' probable impact on long-term crew performance and productivity.

Management Strategy Options

With each spatial and organizational environment combination for the post-IOC space station "occasioning" a range of crew behaviors - both desireable and undesireable in terms of their impact on long-term crew performance and productivity - it is suggested that Phase Two of this suggested program of research identify management strategy options which organizations operating in close earth analogs to each of the spatial and organizational environment combinations have employed in dealing with both desireable and undesireable patterns of crew behavior.

By examining readily available, documented experiences in these close earth analogs (e.g., extended underwater cruises in nuclear submarines for the "paramilitary" model; "wintering over" in Antarctica for the "host" model; and isolated Alaskan oil pipeline camps for the "commercial" model), a range of options for influencing patterns of "occasioned" crew behaviors associated with each of the spatial and organizational environment combinations can be identified. From this research one would obtain lists of hypothetically appropriate and inappropriate management strategy options for influencing both desireable and undesireable patterns of crew behavior associated with each of the spatial and organizational environment combinations to be considered for post-IOC space station.

Empirically Informed Choice

Because an informed choice between alternative spatial and organizational environment combinations for the post-IOC space station is only possible when the hypothetical appropriateness or inappropriateness of alternative management strategy options for influencing both desireable and undesireable patterns of "occasioned" crew behavior have been empirically tested for each model of operation, it is suggested that Phase Three of the suggested program of research determine the effectiveness of the various management strategy options.

As in Phase One of this suggested program of research, full-scale earth-bound, behavioral simulations involving longitudinal study of task performance and effectiveness for each of the alternative spatial and organizational environment combinations could be employed to provide an empirical test of the actual appropriateness and inappropriateness if hypothetically appropriate and inappropriate management strategy options for dealing with patterns of both desireable and undesireable crew behavior. From this research one would have a group of empirically-based indicators of the probable effectiveness of various management strategy options for influencing patterns of "occasioned" crew behavior likely to be associated with each of the alternative spatial and organizational environment combinations for the post-IOC space station.

ALL OTHER CONDITIONS BEING HELD CONSTANT

Underlying all this discussion of "alternative spatial and organizational environment combinations for the post-IOC space station" and "on what basis one might begin to make informed choices between them to maximize crew performance and productivity" are three basic arguments: (1) that the crews' environmental context will become increasingly significant as a productivity parameter as post-IOC space station becomes just another routine, isolated and confined place to go to work; (2) that the spatial component of that environmental context will define upper and lower limits for the crews' performance and productivity "potentials" by its accommodation (or lack of accommodation) of their "human factors" and "habitability" needs; and (3) the organizational component of that environmental context will strongly influence the degree to which those "potentials" are ever realized through the model of operation adopted and the appropriateness and effectiveness of management strategies employed within that model of operation to encourage/discourage patterns of desireable/undesireable crew behaviors which (in combination with the selected spatial environment) it "occasions."

Of course, it should be recognized that the aforementioned discussion and basic arguments are rooted in the theoretically acceptable but practically improbable assumption of "all other conditions being held constant." Without doubt one can expect that in the "real world" of post-IOC space station all other conditions will not be held constant and they thereby will introduce an avalanche of uncontrolled complexity into this simple model of environmentally "occasioned" behavior and its influence on long-term performance and productivity.

But such is often the case with empirical research - one begins with an admittedly simple model and gradually adds complexity as pressing circumstances dictate and/or as research-based understanding allows. That is the rationale behind this simple discussion of alternative spatial and environmental environment combinations and how one might begin to make informed choices between them for post-IOC space station. What has been presented is an admittedly simple model of environmentally "occasioned" behavior and that behavior's influence on long-term crew performance and productivity - a model to which complexity can hopefully be added as appropriate research-based understanding and knowledge increase to warrant more complex model building.

And that, in large part, is why it is not too early to begin the suggested program of research now. It is not that the decade or so that stands between now and the post-IOC space station era is such a short period of time in any absolute sense, but rather that, given the current simplicity of our models of environmentally "occasioned" behavior, there is even now barely enough time for the growth and development which our models must undergo if they are to deliver the needed understanding by the date required.

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AUTOMATION AND MISSION OPERATIONS

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THE ROLE OF ARTIFICIAL INTELLIGENCE AND EXPERT SYSTEMS IN INCREASING STS OPERATIONS PRODUCTIVITY

Chris Culbert
Artificial Intelligence Section
Mission Planning and Analysis Division
NASA/Johnson Space Center

ABSTRACT

Artificial Intelligence (AI) is flourishing outside the bounds of its traditional academic environment. A number of the computer technologies pioneered in the AI world can make significant contributions to increasing STS operations productivity. Application of expert systems, natural language, speech recognition, and other key technologies can significantly reduce manpower while raising productivity. Many aspects of STS support lend themselves to this type of automation. The Artificial Intelligence Section of the Mission Planning and Analysis Division has developed a number of functioning prototype systems which demonstrate the potential gains of applying AI technology.

BACKGROUND AND GROWTH OF ARTIFICIAL INTELLIGENCE

The field of Artificial Intelligence had its beginnings over 20 years ago. The original goal was to make the computer "think" like a human; i.e., to make computers solve problems in a fashion very similar to the way humans do. After an initial flurry of interest, the mainstream of the computer industry stayed out of serious research into AI, and the work continued primarily in the academic environment at such places as Carnegie-Mellon University, Stanford University, and M.I.T. Although the original problem has proven to be considerably more difficult than initially anticipated, significant strides have been made towards improving the capability of both computer hardware and software. These developments have application to real-world problems, and in recent years, AI has begun to flourish outside the academic environment. Spurred by the success of a few key technologies, commercial development is placing more and more of the computer advances pioneered by the AI researchers into the mainstream environment.

Artificial Intelligence is generally split into a number of subfields, including: computer vision, natural language, speech recognition and synthesis, robotics, and expert systems. Applications in all of these areas are in commercial use. Other areas, such as common sense reasoning, true computer learning, self-adapting systems, etc., are still not well developed outside the research environment. Although numerous universities are doing work in AI, most of it is at the graduate level or above, and researchers with extensive AI background currently command top dollar in the job market. On the commercial side, much of the current effort has been devoted to providing software (expert system shells, natural language systems, computer algebra) and hardware (vision, speech synthesis, speech recognition, robotics) tools which aid in the development of AI products, thereby, eliminating or reducing the need for expensive AI experts. Numerous companies have formed in the last three years to capture a part of this growing market.

The most common computer language for AI work is still LISP, although PROLOG, C, and Ada have gained some acceptance. PROLOG is widely used in both Europe and Japan. There is no universally accepted LISP standard, but Common LISP is rapidly evolving into a de facto industry standard. Dialects of LISP are available on many machines, from personal computers to mainframes. Computers specially designed to run LISP have done much to improve the performance of the language and are available from a growing number of vendors such as Symbolics, LMI, Xerox, and Texas Instruments. Competition and increased sales are steadily lowering the price of the hardware. These machines also incorporate many software environment advances: windows, pointing devices, high resolution bit-mapped graphics, and object oriented programming capability.

APPLICATION OF AI TO STS OPERATIONS

The Space Transportation System (STS) is rapidly becoming a fully operational program. Many aspects of this program face the challenge of reducing manpower and resources while still supporting a growing flight rate. Meeting this challenge will require increased reliance on automation and higher productivity in all phases of mission support. STS operations, particularly in the areas of real-time support of the Mission Control Center (MCC), system performance analysis, and mission planning have matured to the point where a large amount of expertise has been developed. Due to the nature of the organization, much of this expertise has been recorded in the form of flight rules, procedures handbooks, etc.

Many of the available AI technologies are directly applicable to these NASA operations. Expert systems can be applied to well understood, routine tasks to capture specialized knowledge and reduce manpower requirements. Improved man-machine interfaces using voice synthesis, voice recognition, natural language, and advanced graphics can increase the productivity of the operators.

Many of the MCC tasks involve monitoring data for potential problems or recording information for analysis. Since these procedures are now well understood, and generally well documented, they readily lend themselves to implementation in expert systems where the specialized knowledge can be captured in a computer program. Although systems that adapt and respond to new situations as they are occurring are not available as of yet, expert systems have proven quite capable in well defined problem areas. Expert systems make excellent monitoring tools since they never get bored or tired, are always alert, react faster than humans, and can't retire or quit. Expert systems can provide a wide range of aid; from merely warning controllers of developing problems, to advising controllers on potential responses, to actually correcting problems as they occur. The use of expert systems for these kinds of tasks could potentially free large amounts of manpower.

Another potential benefit of expert systems is a reduction in the effort required to modify the system. Since knowledge is represented and coded in a manner more closely akin to the way humans think, theoretically, it is easier to maintain the information. This theory has been difficult to prove since most expert systems in commercial use are near the beginning of their life cycle. Also, verification of expert systems is still a poorly understood concept. Current techniques involve "training" the expert system in a manner very similar to the way human experts are trained, through repetition and simulation of problem situations. For most NASA applications, it is anticipated that the expert systems would work in parallel with human experts until confidence is gained that the expert system performs correctly and at an expert level.

The increased use of automation in all functions will place a larger emphasis on the manner in which humans interact with the computer. The man-machine interface must become more flexible and less dependent upon the users learning specific procedures and peculiar syntaxes. The emphasis will be on allowing users to work with the computer tools in a manner that is comfortable for the user and not dependent on hardware/software limitations. Natural language processing could allow users to enter commands or information into the system without learning a special terminology. Speech recognition systems could allow users to enter information while leaving their hands free and also avoids typing mistakes. The combination of natural language and speech recognition provides a flexible yet powerful manner for users to enter information into the computer. At the same time, speech synthesis systems can provide for output from the system without requiring direct user attention. Better use of color and advanced graphics systems will also improve the effectiveness of information presented to the user.

PROJECTS OF THE MPAD AI SECTION

The Artificial Intelligence Section, Technology Development and Applications Branch of the Mission Planning and Analysis Division (MPAD) has been actively working on AI applications for over a year. Projects are currently under way which could provide significant productivity gains for STS operations as well as potential applications for Space Station. The Artificial Intelligence Lab currently has in use a number of state-of-the-art hardware and software systems, including: 6 Symbolics computers, 1 LMI computer, a VAX 11/780, a Hewlett Packard 9000, numerous personal computer systems, DECTalk speech synthesis systems, Votan and Kurzweil voice recognition systems, the Knowledge Engineering Environment (KEE) expert system building tool, the Language Craft natural language tool, the OPS5+ expert system tool, and the Automated Reasoning Tool (ART) for building expert systems. These tools have been used in the development of a number of functioning prototype expert systems. Some of the prototype expert systems are applicable to STS operations, including:

Navigation Expert -- NAVEX

An expert system which emulates the decision making process of the flight controllers who work on the high speed ground navigation console during the ascent and entry phases of Shuttle missions. Currently the task requires three people who monitor the tracking data from 1 to 3 radar stations, control the operation of the High Speed Trajectory Determinator (HSTD), monitor the comparison between the onboard and ground navigation systems, and provide status information to the Flight Dynamics Officer. The expert system monitors the same radar data and the output from the HSTD. It will warn the operator of current or impending problems with the data and will recommend potential actions. This system has the capability to reduce manpower requirements from three people per shift to one.

MCC Software Status Expert System -- MCCSSES

An expert system which emulates the function of the Printer Controller in the MCC. This flight controller monitors the on-line printer for error status messages during all flights and simulations. Virtually all the software and hardware in the MCC report error or status information to this printer. The printer controller scans this printout in real time for significant information and the reports it to other flight controllers, primarily the Computer Supervisor. This expert system could potentially eliminate this job and also provide extended capability for error detection, analysis, and correction.

Expert System for the Flight Analysis System -- ESFAS

An expert system which acts as an intelligent front end to the Flight Analysis System (FAS), a set of computer programs used to design many of the Shuttle missions. This system will allow less highly trained users to make use of the FAS for mission design and will provide a friendlier, more powerful interface for experienced users moving on to Space Station projects.

MCC Workstation On-Orbit Navigation

An expert system which will provide advice and control for on-orbit navigation functions.

Navigation Console Shift Scheduling

An expert system to aid in the complicated task of scheduling teams to work on the navigation console.

Most of these expert system prototypes take full advantage of the advanced software environments available on the LISP machines using highly visual interfaces and mouse oriented interaction, as well as speech synthesis. Expert systems applications in more traditional languages and computers are also being explored, including development of our own expert system language based in C. Use of parallel processing for expert systems is also being researched. Along with the expert systems, the AI Section has ongoing work in speech recognition and natural language systems a well.

N86-15191

APPLICATION OF MODERN TOOLS AND TECHNIQUES TO MAXIMIZE ENGINEERING PRODUCTIVITY IN THE DEVELOPMENT OF ORBITAL OPERATIONS PLANS FOR THE SPACE STATION PROGRAM

John S. Manford
Gregory R. Bennett

McDonnell Douglas Technical Services Company,
Houston, Texas

ABSTRACT

The Space Station Program will incorporate analysis of operations constraints and considerations in the early design phases to avoid the need for later modifications to the Space Station for operations. This paper discusses, from a qualitative perspective, the application of modern tools and administrative techniques to minimize the cost of performing effective orbital operations planning and design analysis in the preliminary design phase of the Space Station Program.

Tools and techniques discussed include: approach for rigorous analysis of operations functions, use of the resources of a large computer network, and providing for efficient research and access to information.

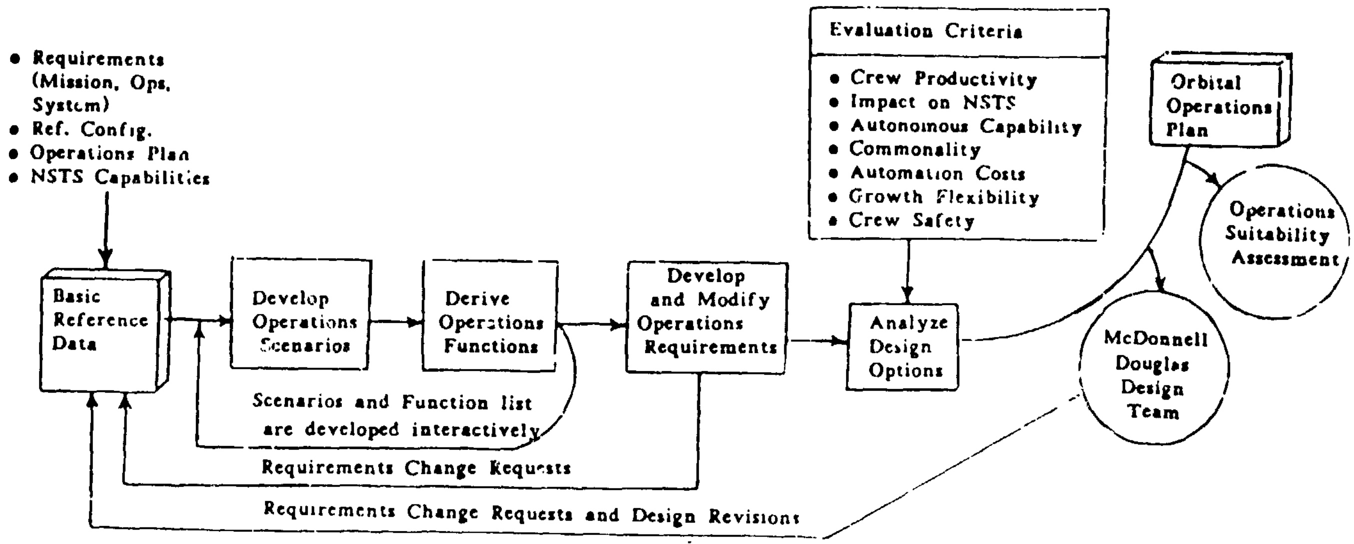
SUMMARY

NASA directed that operations planning be done early in the Space Station program, as part of the definition and preliminary design activities. Our goal in Oribital Operations Planning is to avoid designing in errors that would later have to be corrected, or would reduce the efficiency of operations due to work-around solutions.

Because of the limited availability of analytical modeling tools and the uniqueness of each new manned space flight program, operations planning is the most labor-intensive technical analysis done in the design of manned space systems. Consequently, orbital operations planning is a prime target for productivity improvement.

The basic flow of the task of operations planning, shown in Figure 1, follows the method generally used for development of operations plans for manned spaceflight. Scenarios of the operations, a reference hierarchy of the functions accomplished by these operations, and resulting requirements

Figure 1: Task Flow for Operations Planning



are developed in a iterative procedure, with each activity feeding back into the others.

The operations planning procedure is coupled with the process of preliminary design by providing assessments of the designs to the design organizations, and feeding synthesized products back into the basic reference data. While this approach ensures that operations considerations will be included in the early phases of the design activity, the labor-intensive nature of standard methods of operations planning make the process especially challenging for productive application in a broad-scoped program, such as the Space Station. As the number of subsystems and design options for each subsystem increases, team coordination and information gathering demand more of each engineer's time. Since every technical discipline has to address operations considerations, the operations engineers must exchange information with each design group. So, the effects of the communications overhead costs are amplified for operations planners, who spend the largest amount of time communicating with other groups.

The keys to productivity improvement in operations planning are found in the implementation of these communication activities. Figure 2 summarizes the methods available for streamlining the analysis of the operations of a large number of interrelated systems and communicating with design organizations to accomplish these analyses.

Figure 2: Methods for Increasing Productivity in Space Station Operations Planning

- **Organized Analysis of Operations Functions**
- **Efficient Access to Information**
- **Use of Technical and Management Information System**
- **Standardization of Formats and Outlines**

ANALYSIS OF OPERATIONS FUNCTIONS

By using an organized approach to the definition of operations analyses, the operations planner maximizes use of previous work done in the same subject areas. His efforts are concentrated on analyses most beneficial to the current program. Space Station Definition and Preliminary Design contracts divide the work into several work packages, so each design team is concentrating their efforts on a specific subset of the total systems of the Space Station. This situation requires an especially organized approach, with operations and design analyses organized so that information can be found quickly by the operations planner, by the reviewer, and by the system designer.

Prior to this design study, operations analyses were organized in a mixture of systems, subsystems, and operational functions. The result of the lack of uniformity in this type of organization of the material is that a disproportionate amount of time will be spent searching for data in comparison to the time spent using the data.

By matrixing the operations functions with the systems involved in performance of each function (see Figure 3), we can eliminate a confusion which historically arises in operations planning. Previously, functions and systems were mixed in this type of analysis, so that the general relationships between operations and the systems used in each operation were obscured.

Each function is analyzed to determine which systems are involved, and how each system is used in accomplishing that function. From this analysis, the impact of the operations function on each system's design requirements can be determined. The total impact of all operations considerations on an individual system's design can be found by summing the results of all the functional analyses.

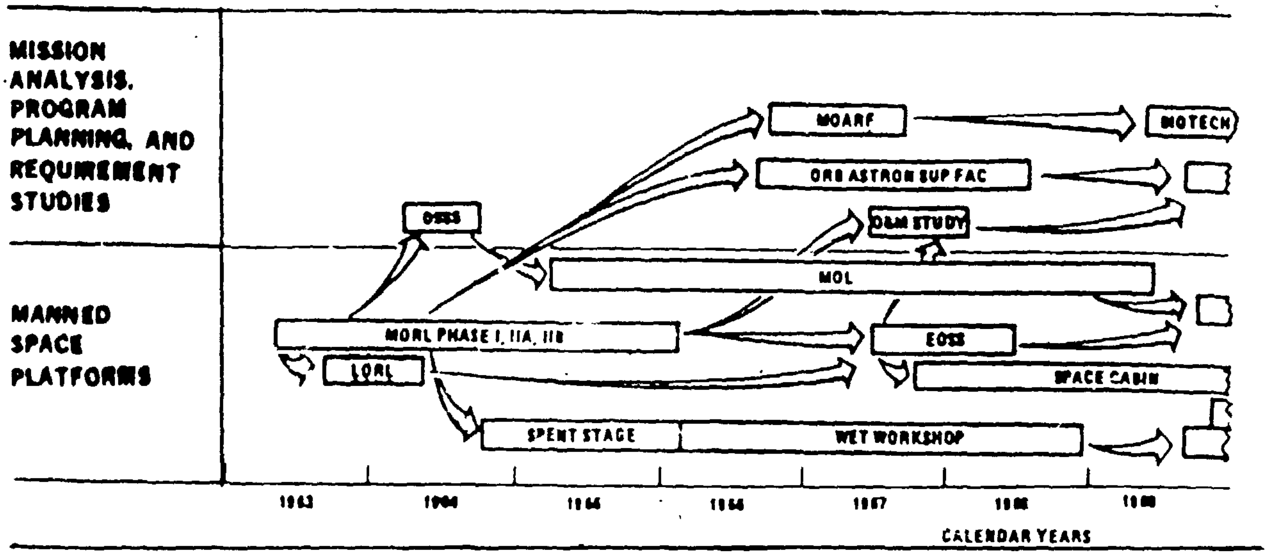
Figure 3: System Affected by Operations Functions

OPERATIONS FUNCTIONS	Space Station Systems: Trusses & Structure	Module Interconnect	Airlock	Heat Rejection & Transport	Guidance & Navigation	Mechanical Systems	Resource Integration	Data Management System	Communication & Tracking	Habitability & Man Systems	EVA Systems	STS Interface & Berthing
Station Assembly	●	●	●			●	●			●	●	●
Station Operations			●	●	●		●	●	●	●	●	
Operations Planning								●	●			
Crew Support							●			●		
Logistics							●	●	●	●	●	●
Flight Operations					●			●	●			●
EVA Operations			●			●				●	●	
Contingency Operations	●	●	●	●	●	●	●	●	●	●	●	●
Payload Operations	●		●	●		●		●	●		●	
Platform Interface	●				●	●			●			

For efficiency, only major design drivers are considered during preliminary design. The resultant operations scenarios are incomplete; however, since the scenarios are developed and modified iteratively with the system designs, they provide a foundation for later phases of the program. Carrying the early work into the detailed design phase avoids additional costs to perform the same analyses again. This process provides the foundation for highly productive development of further documents when the program has reached sufficient maturity to began detailed planning of the step-by-step procedures.

Providing a matrix of operations functions and the subsystems involved in accomplishing each function enables all users to find the data efficiently and conveniently. The function heirarchy is based on current experience and practices in the Space Shuttle program, extended to encompass the

Figure 4: Program Genealogy Chart



unique features of the Space Station. This arrangement closely parallels the organization of NASA personnel and provides a familiar form that allows reviewers to find what they are looking for quickly. Operations planners can assess the completeness of their work and identify the trend of system impacts. And subsystem designers are provided with a quick look at the bottom line of how operations considerations place requirements on their subsystems.

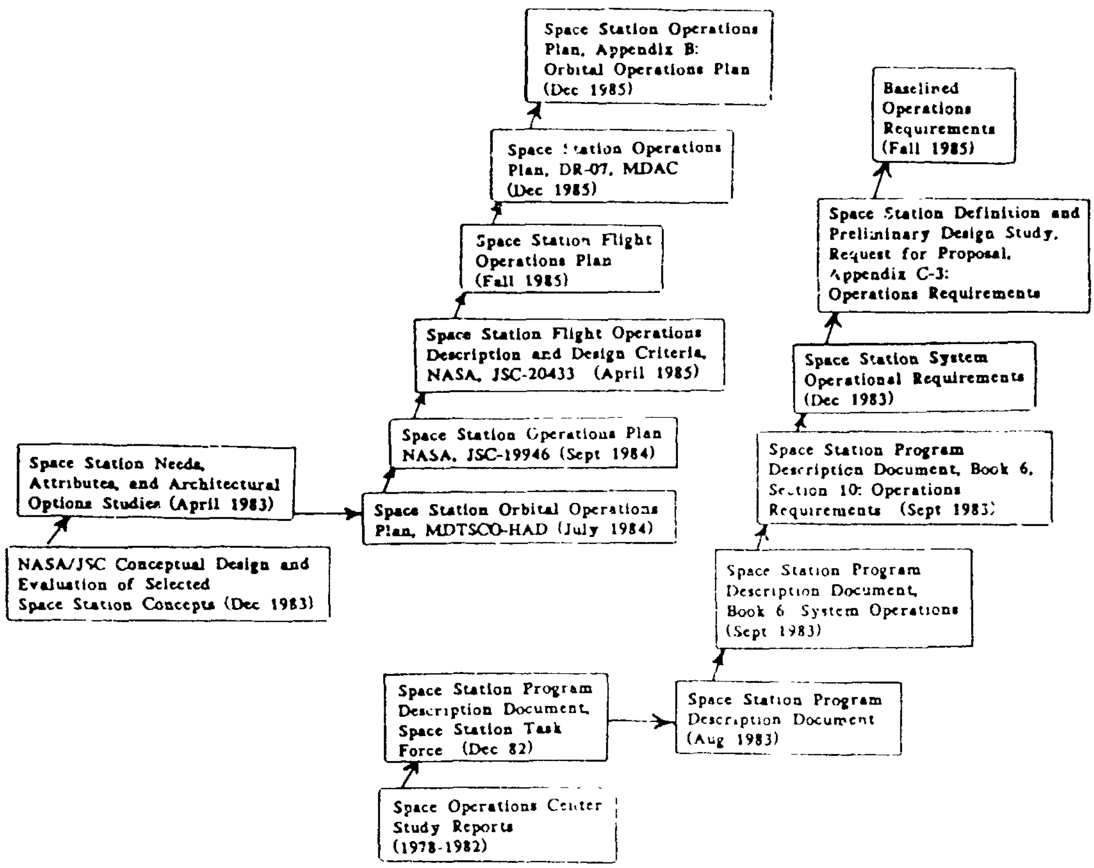
ACCESS TO INFORMATION

Operations planning engineers spend the largest share of their time finding the information needed to do their work. At the beginning of the program, a training curriculum should be developed that teaches the engineers what work has been done before, and where to find the applicable documentation.

The training should include sufficient details on past programs for the engineer to assess the applicability of the past work to the current problem. For example, the basic hierarchy of operations functions of the Space Station have not changed significantly during the past twenty years, though the details, emphasis, and methods of implementation of these functions have changed dramatically.

Genealogical histories are most useful to training engineers to find and assess information quickly: the genealogy of the program, and the geneaology of the available documentation. By representing the interrelationships of programs and documents, by objective and date, a better understanding of the current program's history and applicable documentation is available. Examples for these are shown in Figures 4 and 5.

Figure 5: Genealogy of Applicable Documentation



Besides an elaborate computerized communications and data storage network, a well-organized central libary provdies a cost-effective productivity tool available to a large program. The cost of implementation of a library is usually one research libararian plus the floor space for the facilities. Some of the costs of facilities for storing documentation will be recovered because the presence of the central library reduces the need for similiar furniture to store several duplicate copies of the same documentation at each engineer's work site. The increased productivity from having a library available can run between 25% and 90% of each engineer's time, depending on the program and the engineer's specific work assignment.

Beyond provision of a library and the necessary tools to use the library efficiently, electronic tools can be used to decrease the time spent discovering and gathering information. Methods for using these electronic tools are discussed below under Use of the Technical and Management Information System.

Figure 6: Comparison of Older Methods to TMIS Tools

Previous Method	Replaced by
• Hand-written text and typewriter	• Word processing
• Overnight express mail	• Electronic mail
• File cabinets and bookshelves	• Electronic storage and retrieval
• Drafting boards	• Computer graphics
• Travel	• Video conference

USE OF THE TECHNICAL AND MANAGEMENT INFORMATION SYSTEM

Engineering labor costs at least 100 times as much as a computer's time. (The exact ratio of the cost of adding an engineer to a project compared to the cost of serving an additional computer terminal or adding a desktop computer will vary depending on the tools and computer configurations used in each program.) So, computer systems should be designed so that the machine is always waiting for the man, and not the reverse.

NASA specified that all products of the Space Station definition and preliminary design study would be "delivered electronically to the maximum extent possible". The Technical and Management Information System (TMIS) which resulted from this direction has provided us with an unprecedented kit of productivity tools which have proved their worth in areas beyond the simple electronic delivery of documentation.

Figure 6 compares tools prevously used in operations planning to those available from the TMIS.

Electronic mail has replaced most of the daily technical coordination that otherwise would be done using typed memos. An immediate gain in productivity usually results from having engineers typing instead of writing by hand. When revisions and editing are performed by the engineer himself, without secretarial assistance, he avoids errors that result from miscommunication and from the secretary's interpretation of his cryptic handwriting.

Figure 7: Summary of Data Base Applications

- **Detailed Task Schedules and All Schedule Reports**
- **Budget and Time Tracking**
- **Requirements Analysis**
- **Crew Time, Skills, and Training Requirements**
- **Resource Analysis by System and End Item**
- **Operations Functions Hierarchy**
- **Reference Documentation Listing and Evaluation**
- **Tracking Training of Engineering Personnel**
- **Tracking Task Products and Documentation**

Use of electronic mail also provides a machine-readable form for the contents of each message. The text and technical analyses contained in the day-to-day engineering communications can be merged and formatted into deliverable documentation with minimal additional work. Having text and graphics in machine-readable form eliminates the extensive duplication of effort necessary to produce final documentation from paper copies of the engineering work.

A key feature of the implementation of this philosphy is having the TMIS interface electronically with the word processing facilities at each site. Products of these daily activities are in near-final form when they are transmitted to the word processor for formatting into formal documentation; and they can be transmitted with no additional keystroking required. This procedure can reduce the man-hours required to produce a document by an order of magnitude.

Data Base Features

The centralized TMIS also provides a data base system which is applied to enhance productivity in the areas summarized in Figure 7.

The data bases used in daily technical analyses contain relations of all mission, operations, and system requirements, the function breakdown, the operations scenarios, and design assessments. These data bases are used to create figures for final deliverable documentation from the technical analyses presented to system design groups.

Data bases are also used to reduce the labor overhead in management of the task. One database contains an extremely detailed master schedule for the task from which reports are extracted so all the engineers are aware of short-term and long-term milestones. Other reports from the detailed schedule data base keep the customer informed of when to expect certain products from the study, and still others become inputs to program-level master schedules used to manage the whole team's progress and direction.

Tools can be developed as they're needed

The need for new software tools arises continuously in the R&D environment. The availability of a computer and a high-order language provides the engineers with the basic resources they need to generate these new software tools when the need for them is identified. If at least one of the engineers in each group is proficient computer programming, analyses that would have taken weeks of drudgery with a hand calculator can be dispatched with a small investment in programming time.

For example, in the analysis of the Space Station personnel transportation needs, a few hours of one engineer's time produced a program to model the status of Space Station and Space Shuttle crews and vehicles. The program provides a top-level look at the transportation scenarios for any set of input parameters, such as variations on the Station crew size, maximum stay time on orbit for a crewman, maximum number of people on board a Space Shuttle Orbiter, skills required on board at a specific time, and so forth. Without the TMIS resources, this analysis would have taken longer to produce less rigorous answers. Use of the TMIS also produced documentation-quality output, eliminating artists' time and providing engineers with data in an easily understood form.

STANDARDIZATION

Standardized formats and outlines are used to speed compilation and access to information. Standard froms for each bookkeeping job (such as recording applicable requirements and system effectivity of each operations function) alert designers to the operations concerns that have a significant impact on the design of their individual subsytems.

Standardized outlines also will reduce the amount of time required to review and synthesize the inidividual inputs of each work package. In the Space Station studies, all work packages depend on NASA to assemble these individual inputs and republish them for use by the entire program. The productivity gains from an efficient synthesis process count twice, since a timely turn-around of these data will keep all the work packages focussed on a common baseline and reduce duplications of effort.

These standard formats work well with the data base management features of the TMIS. Relations between requirements, functions, operations scenarios, subsytems, and sections of final documentation are preserved in data bases. Reports from these data bases show up-to-date relationships betwen the data, and immediately identify missing information.

Figure 8: Enchancements to Productivity Tools and Techniques Currently Being Developed

- Database of graphics for building figures
- Automation of including grahics in documents
- Increase number of network terminals and desktop computers
- Flexibility so each engineer can use the machines and tools he's familiar with and still work with a mainframe-based network
- Get all documentation on line, including historical libraries
- Increasing user-friendliness of engineers' tools to reduce training time and efficiency of use
- Standardization of computers used
- Multiple-purpose tools... make tools friendly enough to encourage their use in early design phases
- Common data bases - system designs, simulators, graphics systems, visual generators, logistics planning systems, failure analysis programs, training plans, manifesting systems, stowage tracking

GOALS FOR THE NEXT FEW YEARS

Experience with these techniques for improving engineers' productivity leads to some reasonable goals for building on the available tools. These goals are listed in Figure 8. Each of these goals is at some stage of evaluation and implementation in the Space Station program.

AUTHORS

John Manford is an engineer in the Space Station Orbital Operations group at the McDonnell Douglas Technical Services Company in Houston, Texas. He received his Bachelor of Science degree in Mechanical Technology from the University of Houston in 1981. His work experience prior to joining MDTSCO in March 1985 included product engineering for an oil field wire-line service company.

Greg Bennett is the Task Leader in the Space Station Orbital Operations group at the McDonnell Douglas Technical Services Company in Houston, Texas. He received his Bachelor of Science in Aeronautical and Astronautical Engineering from the University of Illinois in 1973. His 12 years of aerospace engineering experience includes exploratory design of commercial aircraft, simulator development and operations, and space flight operations planning.

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ONORBIT MISSION PLANNING USING THE SHUTTLE TRAJECTORY AND LAUNCH WINDOW EXPERT SYSTEM

Peter R. Ahlf
McDonnell Douglas Technical Services Company
Houston Astronautics Division

ABSTRACT

As the Space Transportation System (STS) enters its operational era, the need for standardized, automated, mission planning computer tools has become apparent. In order to support an increased flight rate without a corresponding increase in manpower, quicker and more efficient methods are needed to perform standard tasks. Also, the problem of losing experienced personnel through attrition creates the need to retain their knowledge and expertise even after they are gone.

To help solve both of these problems, the Shuttle Trajectory and Launch Window Expert System (STALEX) was developed to automate many aspects of early mission planning for space shuttle missions carrying geosynchronous communications satellites. Most of the commercial Shuttle missions planned for the next three years will carry at least one of this type of satellite. The applications of STALEX include payload deployment scheduling, launch window analysis, orbital trajectory determination, and landing opportunity selection.

INTRODUCTION

Recent history has displayed a virtual explosion in the popularity and visibility of artificial intelligence (AI) applications to industry. The AI technique receiving the most attention is that of "expert systems". An expert system is a computer program which duplicates the decision process which a human expert would use to solve a complex problem. Most expert systems are written in relatively new AI programming languages (e. g. LISP). These languages are being supported by a new generation of computers which are designed with emphasis on the machine-user interface.

AI oriented languages are based on a different concept than their predecessors. While languages such as FORTRAN, PASCAL, and Ada are designed to manipulate numbers, languages such as LISP, LOGO, and PROLOG are designed to manipulate characters or symbols. This approach, known as symbolic processing, is conducive to the modeling of decision logic; a process known as knowledge representation.

STALEX is an expert system that is used in the pre-mission planning for Space Transportation System (STS) shuttle flights. It was developed on a SYMBOLICS 3600 computer and is written in a combination of LISP and FORTRAN.

This paper describes, in general, how the use of expert systems and the latest machine-user interfaces can improve productivity. Specifically, the use of STALEX in the early phases of Space Shuttle mission planning is described. To highlight the benefits of expert systems, a close comparison between STALEX and the old analysis tools will be made.

STALEX APPLICATIONS

The STALEX is used for flight design on Space Shuttle missions which carry geosynchronous communications satellites as their payload. For this type of mission, the STALEX performs two major tasks: launch window analysis and scheduling of when the payloads are released (deployed) from the Shuttle.

The launch window is the range of time during the launch day that launch may occur. Satellites impose constraints on the launch time due to their requirements on the inertial orientation of the shuttle parking orbit at the time they are deployed. Because the shuttle orbit does not remain inertially fixed throughout the mission (it is rotating due to gravitational perturbations arising from the oblate shape of the earth) the launch window requirements for a satellite are also dependent upon how long into the mission they are deployed. Each satellite is scheduled for one prime and one backup deployment opportunity. Therefore, each satellite imposes two restrictions on the launch window; one corresponding to its prime deployment opportunity, and one corresponding to its backup opportunity.

There are also restrictions on when during the mission a satellite may be deployed. Orbital mechanics involved for the satellite to reach the desired final geostationary orbit limit deployments to occur once every 90 minutes as the Shuttle passes over the equator. Additional payload requirements limit deployments to occur on only those equatorial crossings which fall within certain longitude bands. Finally, the times of the satellite deployments must also be compatible with the astronaut activity timeline. A few examples of these considerations include limits on the number of events scheduled for any one crew day, the unavailability of those revolutions during the crew sleep periods, and requirements for the amount of time between scheduled deployment opportunities. The mission planner must determine a deployment sequence (a prime and a backup opportunity for each satellite) which optimizes the criteria for the times of deployment and the resulting launch window.

The solution of this problem involves a combination of straightforward numerical analysis and the application of expertise gained from experience. The conversion of the payload requirements for deployment on a given orbit to a launch window requirement is an unambiguous mathematic calculation. On the other hand, the guidelines for scheduling deployments from a crew timeline standpoint, or more importantly, the criteria for selecting the best deployment sequence from a large set of possible solutions, are not hard and fast, and most are not officially documented. In most cases they are simply rules of thumb that are learned from experience. The STALEX combines models of these rules (a process known as knowledge representation) with the numerical calculations needed to determine deployment opportunities and launch windows. Its goal is to allow ease of use, to perform the task quickly, and to consistently choose the same solution as the experienced mission planner.

A NEW APPROACH

The concept of the "expert system" involves a basic divergence from earlier approaches to computer programming. In conventional programming, the computer is used to aid the user in his decision making/problem solving by speeding up numerical calculations. This method, shown in Figure 1, involves the expert in an iterative process of calculation and decision making leading to a solution.

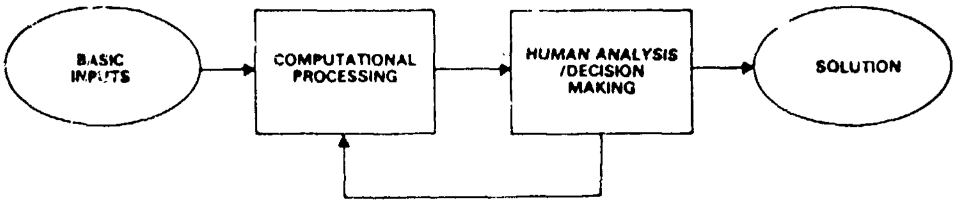

Figure 1

An expert system models the knowledge used by the expert in the decision process, thereby removing him from the loop (Figure 2).

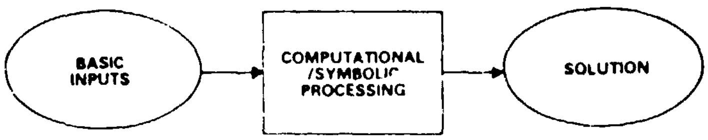

Figure 2

The expert system approach holds benefits from three standpoints. First, if the knowledge of many experts is accurately represented, such a system should theoretically outperform any single expert. Second, the expert system will operate faster and without the human drawbacks such as boredom, forgetfulness, or fatigue. A third benefit is especially applicable to industry and the space program. If an expert system successfully performs as well as the human expert, the knowledge and capability to solve a problem is "captured" and will not disappear when the expert is no longer around. The aerospace business is known to be dynamic in terms of personnel turnaround, and the cost of replacing expertise is thus substantial.

These concepts were used in the development of STALEX with the key goal being that of automation.

AUTOMATION OF THE SOLUTION SEARCH

The task for the flight designer is to select a satellite deployment sequence which meets two criteria. First, the scheduled deployments must meet the crew timeline guidelines. Second, deployment sequence must result in an acceptable launch window. These two conditions do not always result in the same deployment sequence. Therefore, many potential solutions must be identified and evaluated to determine the one which best meets the requirements.

Previously, five separate programs (the Payload Launch Window program family) were used to aid in this analysis. Two of these were used to enter and edit data files which define the payload constraints on the shuttle orbit orientation at the time of deployment. Having constructed these files, the following steps were used to determine the best solution.

1 - Determine available deployment orbits that meet payload constraints by running the Payload Deployment Opportunities Launch Window (PLDOLW) program once for each satellite
2 - Select a deployment sequence that meets crew timeline constraints (a prime and backup deployment opportunity for each payload) from the PLDOLW list of available orbits
3 - Calculate the launch window corresponding to the deployment sequence. For the planned launch date, this is done by running the Composite Launch Window Plotting (CLWPLT) program. For a range of dates around the planned launch date, this is done by running the Payload Launch Window Plotting (PLWPLT) program
4 - If the launch window is unacceptable, or if it may be improved by changing the deployment sequence, select a new sequence and calculate the new launch window by running CLWPLT and PLWPLT over again.

This process was highly iterative. One program had to be run before the user could select a potential solution, then another program had to be run to find if the solution was acceptable. The second and third steps had to be repeated numerous times until the flight designer was confident of having found the best solution.

The major drawback was the lack of automation in these programs. As described before, the final launch window is the result of combining the launch window restrictions derived from several constraints. In running the CLWPLT and PLWPLT programs, the user would specify a constraint, and the program would calculate the corresponding launch window. The user would then specify the next constraint, and again the program would give the resulting launch window. The CLWPLT program would calculate the intersection, or composite, of those previously entered constraints specified by the user. This process is very labor intensive, requiring the user to be constantly entering data and waiting for computer to perform its calculations.

An expert system requires a very different approach. STALEX combines all of the algorithms required for the numerical calculations (steps 1 and 3) with a model of the knowledge used to select and evaluate potential solutions [1]. There are two types of knowledge that must be modelled; the methods of generating possible solutions, and the guidelines for evaluating the solutions. STALEX uses a converging process to generate and evaluate a potential solution set. Beginning with the realm of all possible deployment timelines, a large number are eliminated and the remainder are evaluated. STALEX models the human logic needed to do this by using filters and rules.

Filters are functions which eliminate large numbers of potential solutions by using certain terminal criteria. Failure of this criteria implies that a solution is totally unacceptable. Rules may also eliminate solutions, but they model the less stringent guidelines needed to distinguish an optimal solution from many acceptable solution.

With the computer performing the second step, the human expert is removed from the loop and the entire analysis is automated. This approach lends itself to a more graceful style of data entry. Because the program now performs the entire analysis all of the top level data must be input prior to its execution. The user enters data once at the beginning instead of constantly during the program execution.

QUICK RESPONSE TO MISSION CHANGES

An all too common occurrence in the space program is an unexpected problem causing the definition of a shuttle mission to change. An engine problem can cause several launch dates to slip, or satellite manufacturing delays can cause the payloads on several missions to be remanifested. A typical shuttle mission may see two launch date changes and three payload remanifests before actually flying. In these cases, the launch window and deploy sequence must be recalculated. Reacting to such changes quickly and accurately is imperative in order to maintain a reasonably stable STS mission schedule. The STALEX accommodates this by making use of previous executions of the program to speed up the work needed for mission redesign.

The original PLW program family used one mechanism to save time on repeated executions of the programs. By building files of payload constraints, this data was entered only once. The STALEX expands upon this technique by allowing the permanent storage of an entire mission definition. All of the data needed to determine the launch window and deployment sequence for a mission can be stored in a data base. Should a change occur on a mission, that mission data is read into the program from the data base (rather than re-entered from the keyboard) the change made to the definition, and the analysis performed for the new mission definition.

A NEW USER INTERFACE

Conventional computers communicate with humans by displaying characters or graphics on a display or screen. Humans, in turn, communicate with computers through the use of a keyboard, light pen, or mouse. The method of interaction between the human and computer is called the user interface. The levels of sophistication in computer user interfaces range from the single number display of the hand held calculator, to the advanced CAD/CAM computers which can display three dimensional representations of objects which the user can move or rotate with the touch of a light pen. The capabilities and ease of use of any program are dependent upon the user interface of the host computer.

The original launch window design programs were developed on a Hewlett Packard (HP) 9825 desk top calculator. The term calculator is misleading here: the system included floppy disk drives, a pen plotter, and a dot matrix printer. Its major disadvantage was that the "screen" displayed only one line, not unlike a pocket calculator. This forced the programs to be written in a "prompt/response" style. The single line displays a prompt, requesting a value for a variable or a choice for which program operation is to be performed next, and the user responds. The drawbacks of this type of user interface include:

- o The user can only view a bare minimum of information at any one time
- o The number of characters on the single line prevent all but the shortest prompts or messages
- o The values of program variables are hidden from the user because the single display line is erased with each new prompt
- o The user has minimal control over the flow of the program processes; the prompt/response sequence must be followed identically each time

The STALEX is hosted on a SYMBOLICS 3600 computer. This computer, known as a LISP machine, is one of a new generation of computers designed for AI applications and featuring advanced user interface capabilities. The system includes a large high resolution screen, keyboard, and mouse. The user interface is based on the window concept [2]. A window is a configuration of the computer terminal screen. Each window is divided into smaller sections called "panes". The STALEX makes use of two types of panes; output panes and menu panes. Output panes are sections of the screen where graphs and dynamic text information is displayed. Menu panes in turn consist of three types [3]:

- o Variable value editing menus which display and allow editing of program variables
- o Command menus which allow control of program processes (STALEX displays these in inverse video)
- o Temporary menus which appear following selection from a command menu in order to refine the choice

The STALEX consists of six windows. The top level window is called the Mission Definition Window (Figure 3) and is displayed upon program initialization. This window is designed to allow entry, editing, and viewing of all the basic mission definition data. This data may be

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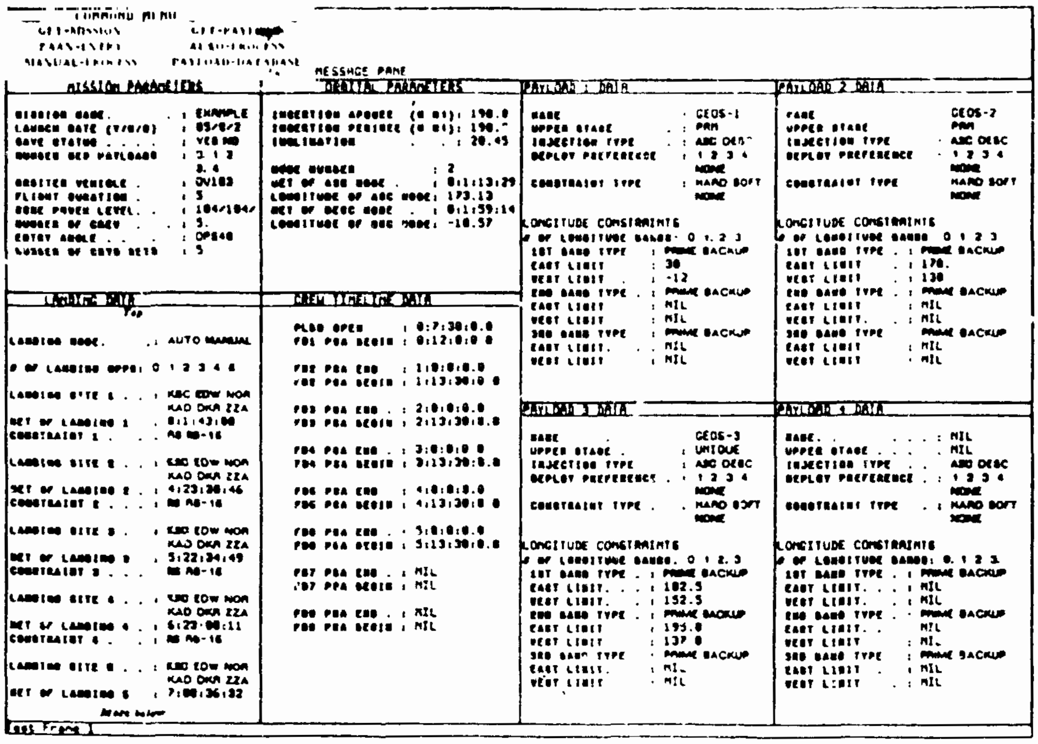

Figure 3

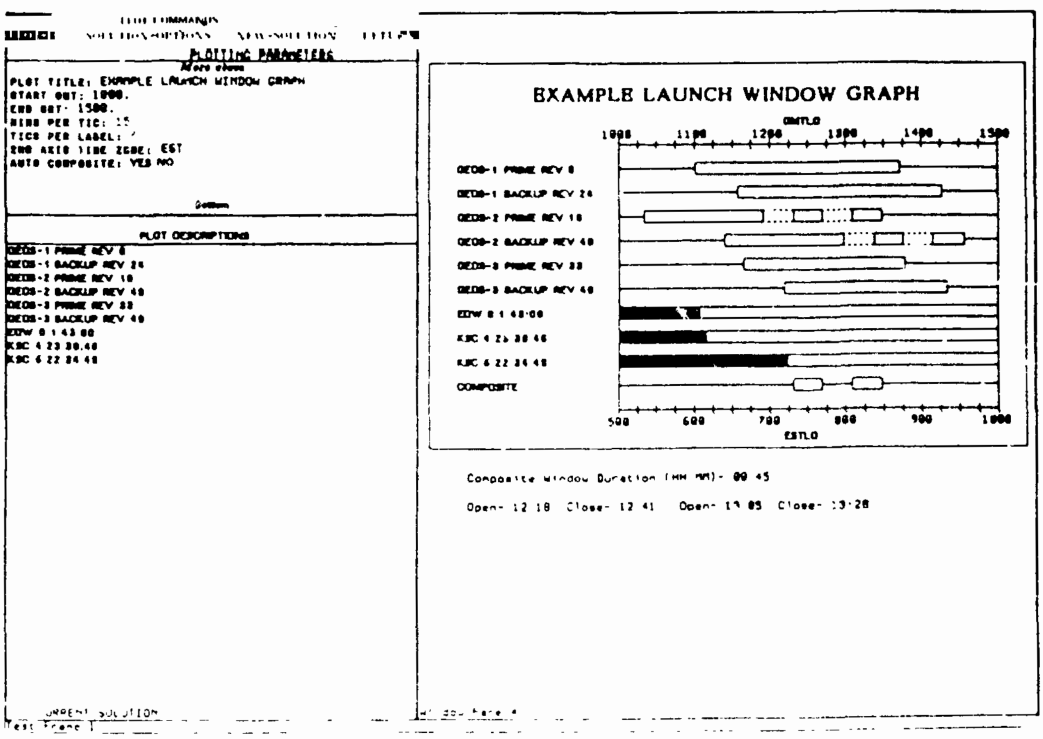

Figure 4

entered manually or automatically loaded from the mission data base. Two other windows are used to enter data into the permanent payload data base, and the remaining three windows display the launch window and deployment sequence solutions. Figure 4 shows an example of the day-of-launch launch window display.

Rather than a prompt/response flow of control, the STALEX is a menu driven program. To change the value of a program variable, the user positions the mouse over the current value, clicks the mouse, and enters the new value from the keyboard. Other menus allow program processes to be invoked by again clicking the mouse on the desired action. This type of user interface has many advantages over the prompt/response concept:

- o All of the basic inputs are logically formatted and visable on one screen
- o Using the mouse to make selections greatly speeds up the editing process and reduces the chance of typing errors
- o All inputs are predefined and are drawn from requirements documents; no design work is needed to calculate the input data
- o Erroneous inputs are trapped at a high level and re-entry is permitted
- o A large set of default data is available and automatically loaded if the user fails to provide all of the necessary inputs
- o The user interface is highly interactive

INTERACTIVE GRAPHICS

The STALEX graphics and graph enhancement capabilities provide additional time savings for the engineer user. A common problem for all engineers is to effectively communicate the result of an analysis. This is especially true for the flight designer who must present the launch window analysis to several NASA mission planning review boards such as the Flight Operations Panel (FOP), the Cargo Integration Review Board (CIR), and the Mission Integration Control Board (MICB). The launch window problem is not easily visualized, and the only method of communicating the results of this analysis is through effective graphics.

The PLW programs plot results directly onto paper. For a typical launch window, this would take approximately ten minutes. If a mistake was made, the process had to be completely repeated. The STALEX displays the graphs on the computer terminal screen, in less than a second. The graph can be enhanced or replotted in a negligible amount of time. When the user is satisfied, the graph can then be "dumped" to a graphics printer. The ability to use interactive computer graphics is dependent upon the capabilities of the computer, not the inherent capabilities of the program. The STALEX also includes such graph enhancement features as automatic region shading, labeling, grid and line drawing, and arrow drawing. These features make heavy use of the mouse to provide a natural and highly interactive graph enhancement capability.

RESULTS

Figures 5 and 6 provide a representative comparison of the time required to perform several tasks relating to launch window and deployment sequence determination using the PLW program family and the STALEX. Figure 5 compares the time required for data entry and graph production tasks. Figure 6 compares the larger analysis tasks which represent a combination of smaller tasks including those shown in Figure 5. The amount of design time is related to the complexity of the mission. The values in Figure 6 are representative of a mission carrying three deployable satellites.

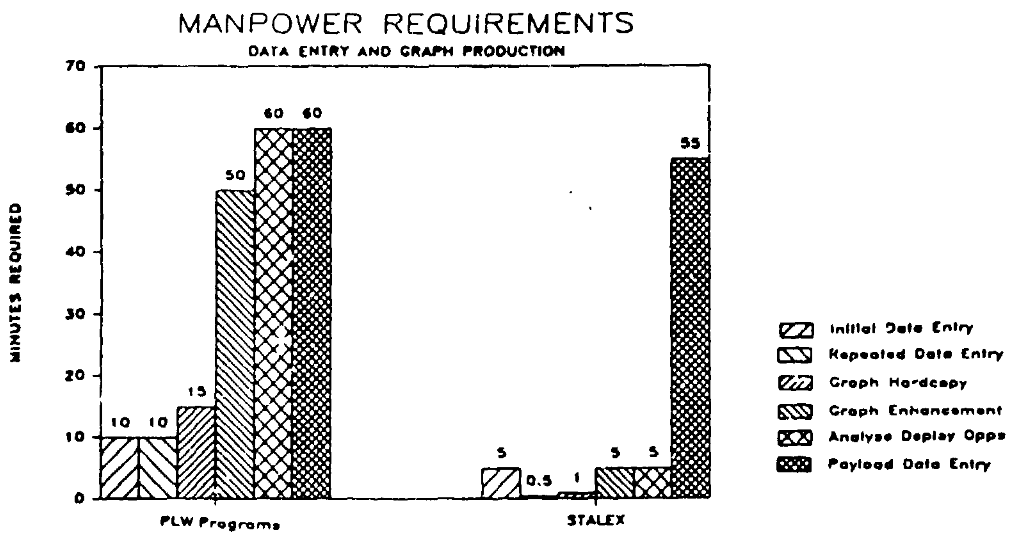

Figure 5

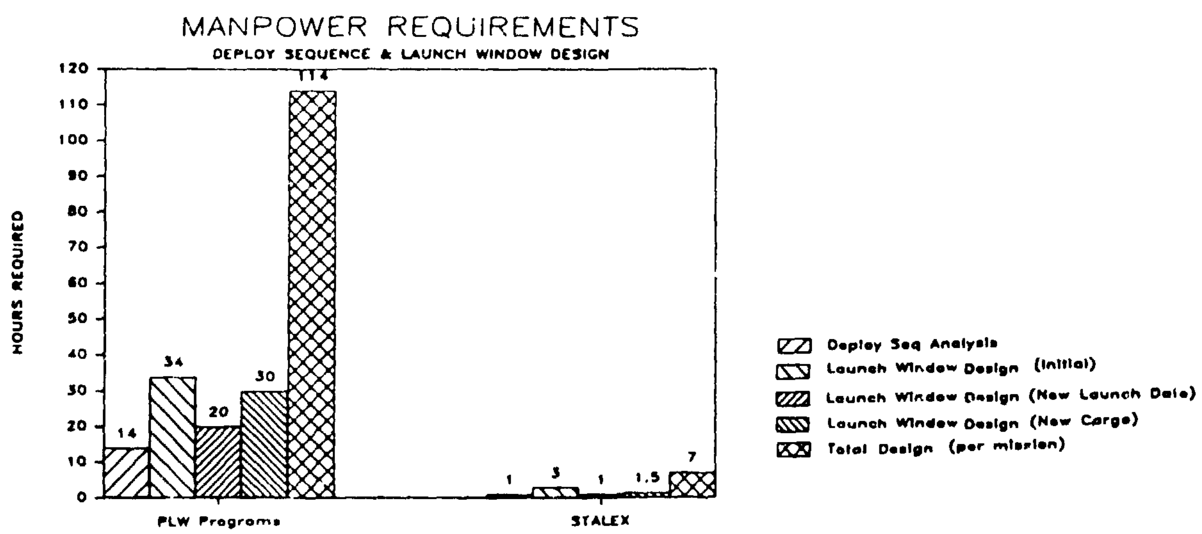

Figure 6

In addition to the obvious time savings the STALEX is usually more thorough in its analysis. For a typical mission carrying three deployable satellites, the STALEX evaluates over 500 deployment sequences and calculates the launch windows for the best twenty solutions. Using the PLWPLT programs, the human expert would examine ten sequences at the most. While STALEX discards over 90% of the solutions it evaluates as unacceptable, it will never overlook an acceptable solution while the human expert might.

CONCLUSIONS

The STALEX is a prototype system. It has been used for launch window design on six space shuttle missions. For three missions it has been used as the sole launch window design tool. It has proven the usefulness and power of applying AI techniques to solving engineering problems.

Experience with STALEX has led to two conclusions. The first is that the use of innovative computer programming techniques to automate design tasks can greatly improve productivity. Expert systems can reduce manpower, improve quality of work, and make the engineers job more rewarding. The second conclusion is that a computer program can only be as powerful as the computer that runs it. The capabilities of the computer (e.g. graphics, user interface, memory, etc) limit the capabilities of the program.

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BIOGRAPHICAL STATEMENT

The author received a Bachelor of Science degree in aerospace engineering from the University of Virginia. He has been employed by the Houston Astronautics Division of the McDonnell Douglas Technical Services Company for two and a half years. He supports the Flight Design and Dynamics Division of the NASA/Johnson Space Center performing flight design integration and orbital trajectory design for Space Shuttle missions.

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AUTOMATED CREW PROCEDURE MAINTENANCE

Paul Hollingshead
McDonnell Douglas Technical Services Company
Houston, Texas

ABSTRACT

Preparing 30 controlled documents for each flight of the Space Shuttle involves 90 people at JSC in processing 200 or 300 changes to existing checklists, and building new procedures. A prototype system is discussed below which stores and displays those precise sets of instructions, including rationale and change history, using readily available hardware. In addition, it provides a simple method of structuring the data in a form for easy understanding and maintenance.

Crew Procedures Attributes

Checklists :

Are the distilled result of much study and decision making by experts in multiple functional responsibilities.

Have a definite process for coordinating and implementing the frequent changes.

Use standard names to refer to switches or indicators, as well as having plain text, and short tables of data.

Must preserve the sequencing of steps to work.

Refer to specific people, times, or pieces of equipment that need to be orchestrated.

Comply to some standard format.

(Notice that the above description applies not only to procedures for Shuttle operations, but to test procedures for many other types of complicated equipment. A subset of those qualities also applies to many contractural documents and interestingly enough, to program source code.)

The Problem

More information is related to a page of procedure than just the instructions listed. There is a background of what the step does, or whose inputs it was based on. In the case of switch labels with obscure abbreviations, it's useful to have the full name shown, with a brief description of action initiated. Some explanation of the rationale for a step (or group of steps) is needed to acquaint a new crew member or flight controller with the steps being performed. In the case of a payload supplied by an outside organization, it may be useful to make a reference to their requirements document as the reason for a particular way of doing things. Few people have the expertise to understand the rationale for all guidelines given in disciplines other than their own. An additional volume, such as a Flight Procedures Handbook is one way of explaining the steps. In the heat of preparing the main procedure for an upcoming flight, it is inconvenient to spend the time needed to keep that separate document up to date.

Much of the information in the checklist isn't easily collected with only manual methods. Engineers specializing in a particular area may want to see only the operation of a particular piece of equipment for comparison with other books or flights. Individual crew members may want to skip steps for the other crew members and pick out the next step he or she should perform. At a given point in operations, it's useful to know just what configuration a panel or system has been put in, and trace the steps that change the setup. Gathering that information by hand is slow and tedious.

Paper distribution for the people involved in change coordination has certain hazards. A fifth generation copy, especially if it was handwritten, can take extra time to interpret. In typical distribution systems the proposed change often spends days being copied and routed. If copies are sent out in parallel, then one person has no way of seeing how other members of the review team have responded. If the change request is routed serially, then changes can't be done quickly, and it can be tough to decipher just which one of four previous people is making any particular suggestion.

Modifying the masters for a book, using mostly manual methods, and distributing copies that incorporate the approved changes can take weeks. Some portion of that preparation time is spent in ensuring that the procedure conforms to an established standard for combining the plain text, switch throws, tables of data, and computer inputs in a consistent manner. Editors also check to see that only approved nomenclature has been used in switch and talkback names. If there are specific numbers used for each step, those may need to be redone, which can ripple through several pages.

For Shuttle missions the last weeks before flight are periods of both intense training and the final editing and printing of the on-board documents. For new refinements or problems found and solved during that final practice, two alternatives, neither of them attractive, present themselves. Either postpone the inclusion of the change until a flight or two later, or go through the extra, often frantic, effort to get the change in the books for the next flight. Flying, or even practicing with an outdated checklist is to be avoided. The increased flight rate demands that the preparation period be trimmed down.

The established method for coordinating changes involves many people, but certainly doesn't reach everyone who is interested in a modification. To someone who has reviewed the checklist, but doesn't work with it daily, the most important feature of a new edition is the changes since its last use. In paper documents, "change bars" indicate that an improvement has been made, but offer no clue as to why, or who requested it. Oftentimes there is a history of changes to explain why a sentence ended up that way. Some changes don't have their own technical justification, but are made merely to be consistent with similar documents. Change bars by themselves leave many things unexplained, and no hint as to where to find the reasons.

Storing the "complete" document means more than showing just enough detail for a trained crew to interpret. Flight personnel that get reassigned, engineers that rotate through and work every third flight, new customers trying to understand how their similar operation might go, or managers that are troubleshooting need to be able to grasp the background and change history in a convenient manner.

The attributes of a checklist that make it a precise and portable document for successfully operating complicated equipment also require a substantial effort to ensure accuracy and completeness. With less and less time between Shuttle flights, and the assumption that Space Station operations will use an entirely electronic flight data file, there is plenty of motivation to apply automation to the process of maintaining procedures.

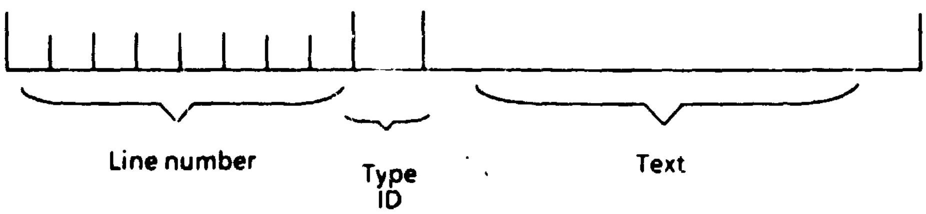
A Solution

Storing the information contained in a procedure in electronic form for rapid distribution is the first step in automating its processing. A microcomputer with floppy diskettes that can be copied in a few minutes works for small groups, while a minicomputer tied into a local area network serves that purpose for a larger operation. Those are both recent alternatives to using a timesharing a terminal tied to a mainframe. A local area network, or remote computers tied by modems over voice grade phone lines have the advantage that not all equipment used has to be identical. The increased flexibilty brings with it the requirement that the files being transferred have a form that different machines can process. If the files can be built using only characters defined in the ASCII (American Standard Code for Information Interchange), so much the better.

ASCII files can be processed by most equipment, but a simple text file doesn't have the structure needed for properly storing all the information that makes up a procedure. The trick is to have a subtle form of structuring the data that will let the goals be accomplished, but still allows quick processing. The chosen method is, of all things, line numbers! Or step numbers, in the case of a pure procedure. Not just plain line numbers (100, 110...ad infinitum) but numbers designed to shorten the process of pagination, showing changes, making a table of contents, or building a list of effective pages.

In contrast to the line number editors that have fortunately been replaced by screen editors, these numbers are used only internally by the program. The step number can be used as a link in a technique similar to a relational database to show and order the steps and tie the text itself, rationale, proposed additions or deletions, all together. The actual steps and the associated information become a database with one of the output forms being masters for publishing the book.

Figure 1 - Record Structure



Each "record" in this database that makes up the procedure has an identical form, no matter what it represents. Of three fields, (see Figure 1) the first is the line number, the second a number which tells what type of information is contained in the text (80 characters, or whatever is appropriate) which makes up the third part. Such a record structure is simple to write out to, or read from, an ASCII file.

One way to construct the line number is to have seven or eight individual numbers in array. The first few might represent the major sections of a book, and successive subdivisions that are used to organize the book. The last two numbers are needed to show the version number of the line, and which segment of the line is represented by the text in that record.

Figure 2 shows an example line as it appears in a checklist, with its associated rationale. If there were more text than could be fit in one record, an additional record labeled as segment 2 could be used. Notice that the actual checklist line and the rationale both have the same line number, but their "types" are different. Table 1 shows an example list of "types" that might be used for the records. The table can be built in whatever manner is convenient.

Figure 3 shows the modified records for a change that has been requested. To show the addition, the original line is broken up into two pieces, and has the version number incremented. The text to be inserted is marked as being a different type, and a separate segment. Using some display technique the proposed insertion can be contrasted with the original text. An additional record is used to show the formal change request number, which can be tracked for that new version. If desired, additional records can be used to show who requested the change, or what it's approval status was.

Figure 2 - An Example Step

Before:

MS1 CRT Report "pin out" times for PIVOT pins

3	6	2	8	3	7	1	1	1	Report "pin out" times for PIVOT pins

The text for that step

3	6	2	8	3	7	1	1	7	MS1

The individual who performs the action

3	6	2	8	3	7	1	1	8	CRT

The equipment used to perform the action

3	6	2	8	3	7	1	1	10	Used by the ground to calculate a
3	6	2	8	3	7	1	2	10	predicted time for the final pin

Rationale for that step

Defining type 5 as a switch name, and type 6 as its commanded position provides a means of checking nomenclature and tracking switch throws. When the procedure is being written, and a type 5 is input, it can be checked against a list of switch names, to be certain that is an existing one. That same list could be used to define all the possible positions for that switch. The structure also allows the handy ability to find and highlight all the callouts for a particular switch or set of switches. Designations for switch panels (or racks of equipment) can be used in the same way. By maintaining the sequence of switch uses, it is possible to tell the present configuration of a panel, assuming you knew what it was when the procedure was started.

Table 1 - "Types" of Records

Type Number	Function
1	Plain text
2	Blank line
3	Inserted text
4	Deleted text
5	Switch name
6	Switch position
7	Individual performing step
8	Equipment used to accomplish step
9	Approval status
10	Rationale
11	ID of change request form
12	Initiator of change request
.	
.	
.	
(etc.)	

Figure 3 - Changes to the Step

After change has been requested:

MS1 CRT Report "pin out" times for PIVOT & KEEL pins

3	6	2	8	3	7	2	1	1	Report "pin out" times for PIVOT
3	6	2	8	3	7	2	2	3	& KEEL
3	6	2	8	3	7	2	3	1	pins

The new line with the proposed addition

3	6	2	8	3	7	2	1	11	SYN DPY - 15

The identification number of the formal change request

3	6	2	8	3	7	2	1	9	Not approved

Status of the change request

A record of type 7 might be the name of the crewman that performs the action. The database can be quickly scanned, finding the particular crewman's steps (the next one or all of them) to be highlighted. On the occasion that different crewmen's steps are put on separate pages, (Commander and Pilot on the right-hand side, Mission Specialists on the left-hand side as is done in some books) they can be easily segregated.

With the different levels of organization embedded in the line numbers, some editing processes can be done automatically. Generating a table of contents requires only fetching the first record within each minor heading, or whatever level of division is desired, and listing those titles consecutively. As changes are made, the list of effective pages can be determined with similar ease. Pagination rules can be defined that will avoid breaking up blocks of related information (paragraphs in plain documents or underlined procedures in a crew checklist) as desired.

Lines need not appear on the page in the order of their line numbers. An ordering table can be maintained by the program to keep track of the sequence in which the steps appear. This table is also used when the screen cursor is moved, to relate that coordinate back to the step being touched.

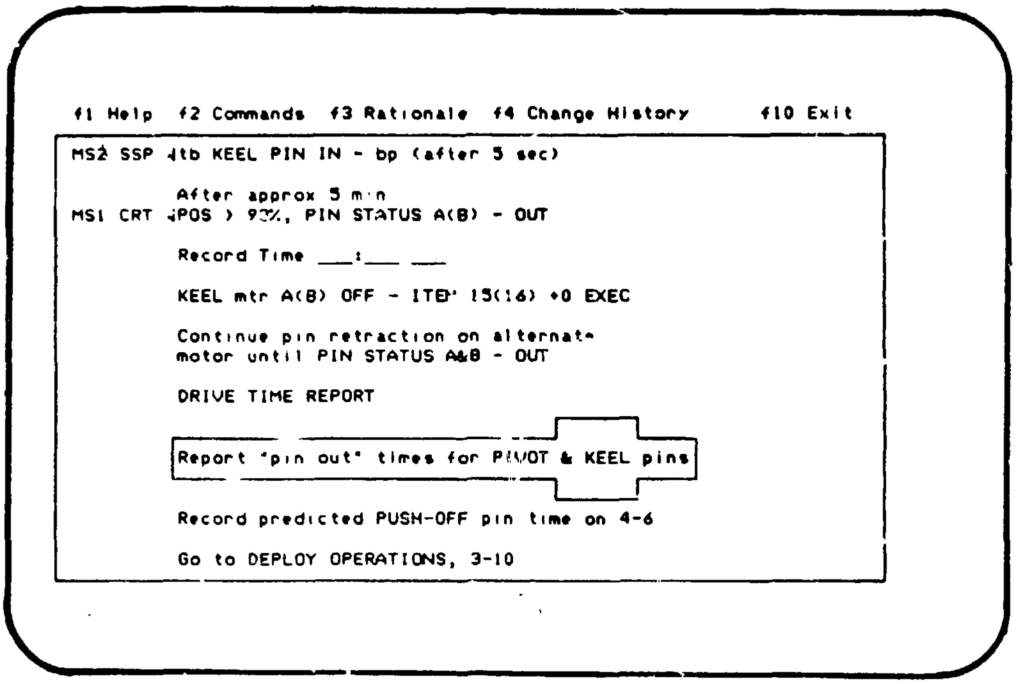
User Interface

That logical method to tie all this information together is nothing really new, or particularly clever. The other half of the solution, the hardware-dependent techniques now available to present the numerous pieces to the crew and other readers in an uncluttered manner, is what makes it worth talking about. Several hundred kilobytes of memory, and fast processors in a package cheap enough to be distributed to individual offices are the key to making an automated solution practical. Microcomputers with enough memory to easily support the use of color and "windowing" software provide a convenient way of displaying the different levels of information that form a checklist.

Additions or deletions can easily be distinguished from unchanged text with the use of colors. A different background shade can highlight the step currently being examined. Hues can also separate the actual procedure being studied from the statusing information and editor command options. If there are a limited set of type fonts used, they can be indicated with a change in color.

For this discussion, windowing is the ability to overlay a portion of the physical screen with a different background color and fill it with ancillary text. This can be done more than once if needed, using different shades, or lines to form a border to separate successive windows. When any particular window is no longer needed, it can be closed with the stroke of a function key, uncovering the information previously shown below it. Windows, in this case, do not allow the computer to be performing distinct tasks simultaneously.

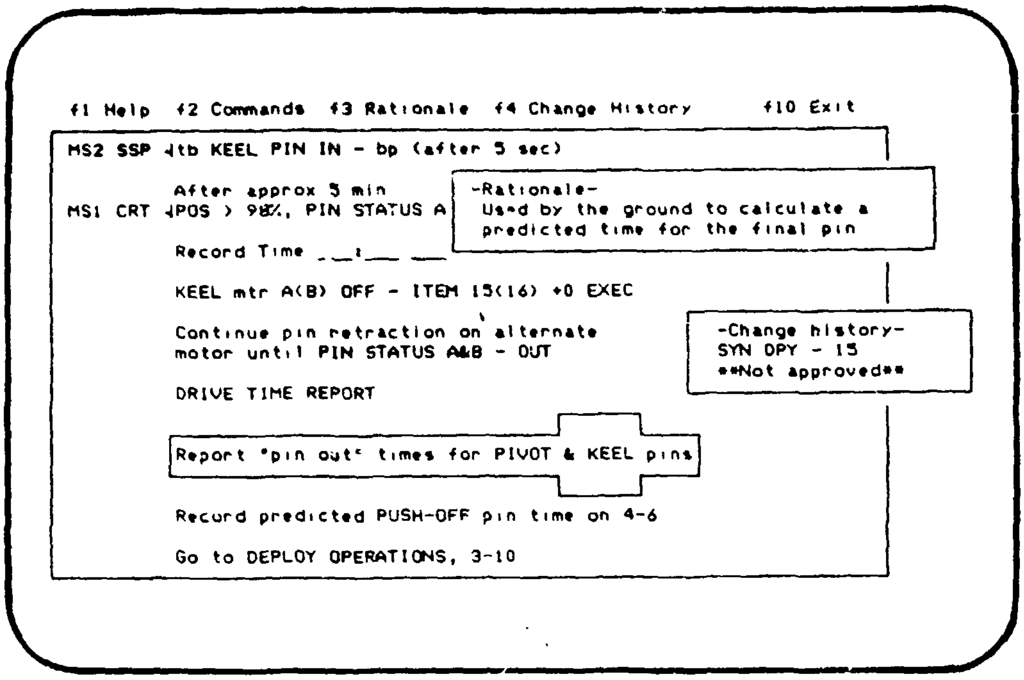
Figure 4 - Editing Display



While working on a checklist, the workstation screen can use the layout shown in Figure 4, though it (and the next figure) can't show the use of color. The main area of the screen is used for viewing portions of a checklist page, with another area needed to show function key use. Command and status area can be kept to a minimum, since a window can easily be called up to give more detail. As the cursor passes over each step, that step is highlighted by a change in background color. (For these figures, lines around the procedure step take the place of contrasting colors to indicate the "current" step.) Though the computer cannot display all of a printed page on the screen at one time, status lines can be thrown up at the top and/or bottom on demand, to identify page numbers or headers that are associated with the page.

A keystroke creates a window containing rationale or a comment provided, or a history of changes to the step, right on the screen as shown in Figure 5. The windows have overlaid the text already present, but like a sheet of paper covering a corner of the book, can be whisked away to reveal the original wording. All the background linked to a particular step can be conveniently shown, as needed. For a particular switch name used in the step, a window might spell out the full name of the function, and notes on its use, since the database can be queried about such things. This is the electronic equivalent of holding your finger at one particular place on the page, and piling other documents on top of it. But what is the advantage of doing it this way?

Figure 5 - Display with Rationale and Change History



When requesting a change to an existing procedure, the engineer can see the up-to-the-minute status of the book, including other changes that are pending. Once his change is made to a central copy of the book, all others interested in the book can see that request, immediately. People at remote locations can see the proposed change, reasoning, and comments as fast as it can be electronically transmitted. Changes since the last edition can be flagged as to whether or not they have been approved by the whole community, or are still under consideration. Since the rules for formatting are contained in the routine for displaying a procedure, the result will be consistent with standard practice. If approved, the changed page itself and the list of effective pages can be updated with checking being the only additional human work.

When a change is proposed, other information about that request can be gathered for tracking by management, if needed. Reasons for the change, books affected, initiator's name, concurrences, dates, and other data can be recorded for use in separate programs.

When creating a new procedure, rationale for the steps can be captured and preserved when the steps are entered, since it is convenient to do. Database-like functions, now available with an electronic document, can also be used when building the checklist. Status information about what panel, software block, or digital autopilot mode is being used can be shown, or added to the top of a new page. The total result can be distributed immediately after creation and approval.

It appears that the burden for building the table of contents and formatting the document falls on the engineer writing the procedure, but that is actually a hidden part of the input process. Windows, if applied copiously, can be used to give clear information about command choices. A "help screen" can be used to explain use of the function keys on the workstation to perform a "block move", for example. In short, the environment can be made simple enough for even an engineer to use!

EQUIPMENT NEEDED

The equipment needed to provide this automated tool isn't particularly fancy. Most business microcomputers have at least the native ability to handle printing letters in different colors with that same palette available for background colors. A rich character set that includes a checkmark, or the graphics characters used to provide borders for tables can make the process easier. Most recent microcomputers have a hard disk, at least as an option, and room for plugging in several hundred kilobytes of memory. For a miniscule cost in purchased software, the basic building blocks are there.

This prototype was built using an AT & T 5300 (an IBM compatible machine) equipped with a hard disk, the full 640 kilobytes of memory, and a color monitor. The language used was Turbo Pascal, sold by Borland International. The windowing software is a package called "Virtual Screen Interface", a product of Amber Systems, Inc. The entire package described has a list price near $5,000.

CONCLUSION

Storing procedures (and other documents that combine the work of several people) for electronic distribution and editing greatly speeds the process of coordinating changes and producing the final book. The methods outlined can be used to show suggested changes and the rationale that supports individual sections of the document. Modern hardware, and innovative software now available provide clever ways to display the information, as needed. By treating a procedure as a database of actions, times, people, and equipment, instead of just a text file, convenient methods can be built to understand the operation. Embedding editing guidelines and procedural nomenclature checks in the program makes the process of creating or changing a checklist faster and easier for the personnel involved.

Mr. Hollingshead is a Senior Engineer in the Orbit Procedures and Flight Data File section at JSC, building satellite deploy procedures and providing automated tools for checklist maintenance. His prior experience includes running and writing instructions for the functional, qualification, and acceptance testing of varied aerospace hardware.

PRODUCTIVITY TOOLS IN STS MISSION OPERATIONS

414

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STREAMLINING: REDUCING COSTS AND INCREASING STS OPERATIONS EFFECTIVENESS

Ronald K. Petersburg, McDonnell Douglas
Technical Services Company, Inc., Houston, Texas

ABSTRACT

The McDonnell Douglas Corporation has a Corporate-wide program to create a management and work environment conducive to increased job satisfaction and continuous quality/productivity improvement. A related activity called Streamlining is an integral part of the McDonnell Douglas Technical Services Company-Houston Space Transportation System Engineering and Operations Support (STSEOS) Contract with NASA/JSC.

The paper will discuss the development of Streamlining as a concept, its inclusion in the STSEOS Contract, and how it serves as an incentive to management and technical support personnel. The mechanics of encouraging and processing Streamlining suggestions will be discussed including reviews, feedback to submitters, recognition, and how individual employee performance evaluations are used for motivation. Several items that have been implemented will be mentioned. Information reported to JSC will be discussed as well as the methodology of determining estimated dollar savings.

Finally, the overall effect of this activity on the ability of the McDonnell Douglas flight preparation and mission operations team to support a rapidly increasing flight rate without a proportional increase in cost will be illustrated.

INTRODUCTION

The Space Transportation System (STS) has provided a vehicle to deliver, retrieve, and service a wide variety of payloads in the near-earth orbital environment. Many design, fabrication, implementation and operational challenges have been met and undoubtedly there will be more to come. The NASA and its Support Contractor team have taken the STS from a developmental environment into an operational era. Support for the early flights was extremely labor-intensive since the flight objectives were designed to systematically verify the operation and flexibility of the vehicle systems. Starting with the fifth flight, however, emphasis shifted to operational objectives with the addition of paying customers and valuable commercial and scientific payloads. This very quickly brought home the fact that the STS must become proven and cost-effective to compete with other delivery systems.

McDonnell Douglas Technical Services Company (MDTSCO), through the Engineering and Operations Support Contract, is playing a significant role in transforming STS from a R & D to an operational system. McDonnell Douglas provides engineering support for flight preparation and mission operations. Recognizing these activities as a significant factor in the cost per flight equation, McDonnell Douglas program management devised a process to provide cost-effective, high quality support in a rapidly increasing flight rate environment.

The approach is called Streamlining and the remainder of this paper will further define the term, discuss how it evolved as an effective quality/productivity improvement tool, define the mechanics of tracking, reviewing, and reporting, and will explain how McDonnell Douglas has developed it into a never-ending process of continuous quality/productivity improvement. Also included will be examples of results and estimated savings.

DEFINITION

An exact definition of Streamlining is elusive and can vary greatly from government agency to agency, company to company, manager to manager, and person to person. There is nothing wrong with this as long as the ultimate goal of such an activity results in increasing productivity without sacrificing quality.

In broad, but appropriate terms, the McDonnell Douglas contract defines Streamlining as *"initiative/innovation in reducing the cost of STS flight preparation and/or increasing effectiveness of STS flights"*.

McDonnell Douglas has not limited Streamlining to direct contract support responsibilities but has provided concepts, ideas, and implementation plans for productivity improvements to benefit the overall STS program.

PROCESS IMPLEMENTATION

McDonnell Douglas determined that four basic ingredients were essential to successfully develop and implement a Streamlining process: 1) Management commitment; 2) Providing the proper environment for the workforce; 3) Incentives for the workforce to participate; and, 4) A system for recording and reporting progress (internally and to the customer). All of these are equally important for gaining management and workforce support and customer awareness and acceptance. They instill a cultural shift toward high-quality products at the lowest possible cost.

Management Commitment

A lack of top-level management commitment to any new initiative can mean failure of that thrust. This is true whether it is only perceived by the workforce or if it is seen by the workforce as being real. Leading by example has been found to be a powerful tool. Continuous encouragement down through the chain of command serves as a constant reminder to the workforce.

Providing The Proper Environment

Engineers and scientists need more than a desk, paper, pencils, access to a computer, and a periodic paycheck to become enthusiastic streamliners. The workplace environment at McDonnell Douglas is made more conducive to Streamlining by:

1) Encouraging skill sharpening through in-house and advanced degree training;
2) Applying paraprofessionals to necessary routine, repetitive, manual operations;
3) Implementing standardization and then automation to known processes and/or product generation;
4) Providing employee involvement through the application of Participative Management techniques;
5) Supporting the formation of problem-solving teams (Quality Circles) in work areas - along with appropriate leader training in brainstorming and other problem-solving techniques;
6) Increasing the availability of micro-computers for general engineering use and providing adequate remote access terminals to large mainframe computers;
7) Making management more visible through boss talks and workplace visits;
8) Reinforcing the concept that there is always a better way to accomplish a task or to improve a process;
9) Assuring the workforce that attention to Streamlining or eliminating their assignment will not jeopardize their future but rather allow their talents to be used for more creative work; and
10) Briefing all new employees on the concept and process of Streamlining as part of the McDonnell Douglas orientation session.

Following are examples of McDonnell Douglas progress or results during the six-month period ending in March 1985:

1) The number of Quality Circles grew from 9 to 22;
2) Strong emphasis on the benefits and proper use of participative management techniques continued through an in-house workshop given to all-hands; and,
3) The use of paraprofessionals on routine/production tasks was increased from 24 to 44.

Incentives to Participate

The vast majority of employees in a professional, knowledge-based workforce are self-motivated to excel at their assignments. At McDonnell Douglas, proven incentives are used to focus the workforce talents on continually improving the process.

Streamlining suggestions that are implemented and result in tangible, and sometimes intangible, benefits are recognized through an employee recognition program. This recognition takes the form of an individual, or group, achievement certificates and/or monetary awards. Also used for incentive are "extras" as part of the overall compensation package - bonus plan payout and special salary reviews.

Other more subtle methods include modest monetary awards through the McDonnell Douglas suggestion program, candidacy for the JSC launch honoree program, recognition by various and other publications; e.g., the company newsletter and local newspapers. Letters or other forms of recognition by the customer and/or end-user have proven to be extremely powerful motivators but are outside of McDonnell Douglas control.

As a measure of the quantity of these motivational methods at McDonnell Douglas, during a six-month period ending in March 1985, the Engineering and Operations Contract recorded the following:

1) More than 200 commendations/awards were made as part of the employee recognition program;

2) Monetary awards of about $3850 for sixteen employee suggestions; and,

3) Twenty letters received from JSC management commending the performance of seventy individuals.

System for Recording and Reporting

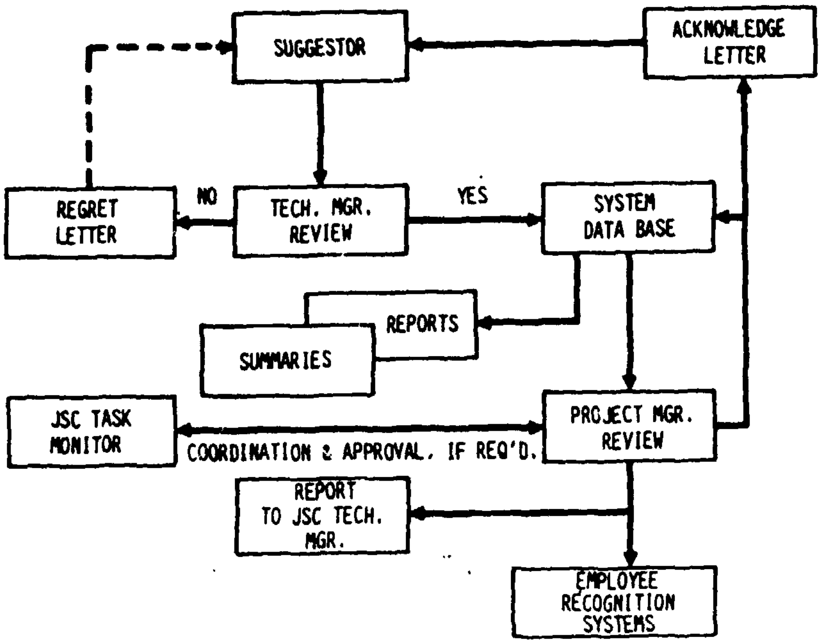
Another ingredient in the McDonnell Douglas Streamlining process is a system to record, track, and report on the disposition of suggestions. It is also necessary to formally review the items for appropriateness and applicability. It is also important to recognize employee participation by direct feedback - keeping the submitter aware of where the suggestion is in the review process flow and, if it is rejected, to supply the reason.

It should be noted that there have been suggestions that required customer acceptance and required changes in policy, rules and/or procedures before implementation. Because of this, the end-user is included in the process.

The process at McDonnell Douglas can be described by a flow diagram, as shown by Figure 1.

FIGURE 1

STREAMLINING PROCESS FLOW DIAGRAM



A micro-computer data base is utilized to provide summary reports plus feedback and acknowledgement letters. It also facilitates regular reporting on the progress of Streamlining to management and the customer.

Another important step in reporting is the interface with JSC's Productivity Improvement Program. McDonnell Douglas has submitted several ideas to JSC which were subsequently implemented and reported on in the JSC Crier newsletter.

STREAMLINING RESULTS

The continuous improvement approach to day-to-day and flight-to-flight activities has generated literally hundreds of Streamlining suggestions/ideas. An appreciable percentage of these have been approved and implemented. Collectively they have been shown to accumulate into sizeable estimated contractor and STS Program savings. Results have been formally presented to the JSC Technical Manager of the McDonnell Douglas Contract semi-annually since October 1982.

It should be noted that there have been implemented ideas that are intangible in nature; i.e., cannot be translated into programmatic dollar savings. Some of these have enriched the quality of worklife, which certainly contributes to employee morale and motivation - and thereby, hopefully, lowering attrition, or turnover. Others have resulted in higher quality products by using procedures/approaches that are designed to significantly reduce the chance for human error.

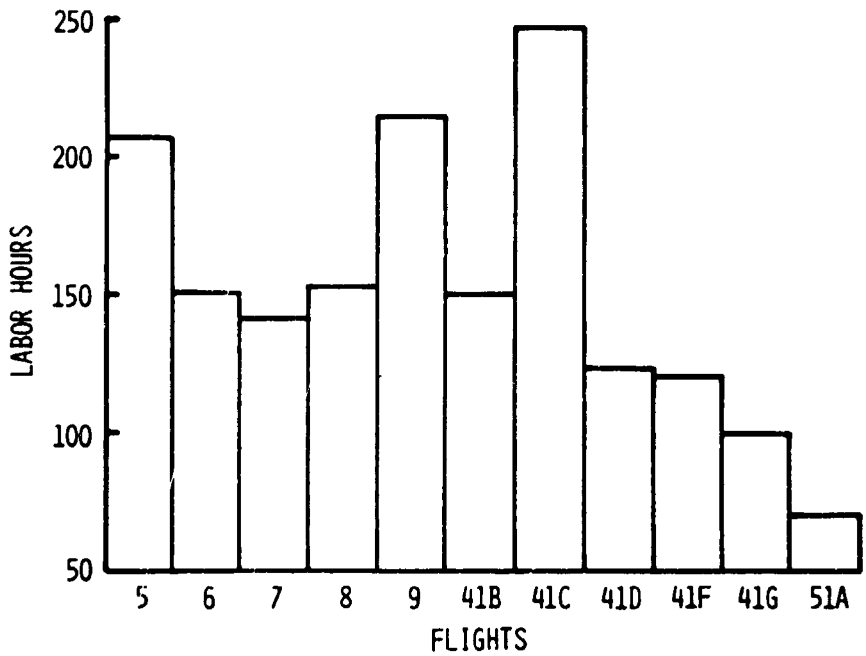
In an environment of a rapidly increasing flight rate, McDonnell Douglas has concentrated a great amount of effort on Streamlining the flight preparation and mission operations support functions. Results of some of the implemented Streamlining ideas are discussed in the remainder of this section.

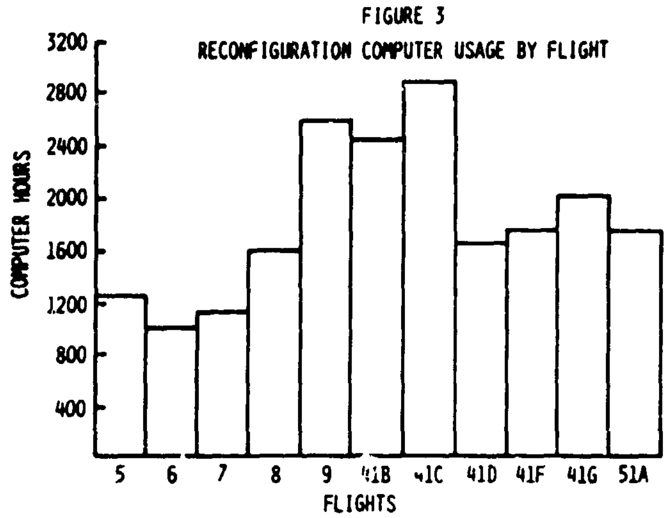
Flight Preparation Results

Data on the McDonnell Douglas - Mission Planning and Analysis Division/JSC flight-to-flight reconfiguration efforts (labor hours and large mainframe computer time) are gathered and monitored to measure the effectiveness of the Streamlining results. Implemented results such as standardized (seasonal) Initialization-Loads, the application of the direct insertion ascent phase, and simplifying the analytical payload integration functions have contributed to the positive trend of flight-to-flight reconfiguration support requirements. Figures 2 and 3 depict the results of such efforts logged for eleven (11) STS flights, starting with STS-5, for labor hours and computer time used, respectively.

FIGURE 2

RECONFIGURATION LABOR BY FLIGHT





This information clearly shows the effectiveness of streamlining the flight preparation process. The data for flights STS-5, -9, and STS-41C are considered "outliers" in that the objectives and/or complexity of the missions demanded considerably more effort in the preparation activities. They were "first-of-a-kind" flights - first direct insertion ascent, first rendezvous, and first high inclination. Some authorities assume both the labor hours and computer time required per flight will level off. This suggests that an increasing emphasis on Streamlining would be a diminishing return situation.

Another dramatic illustration of an increase in productivity is shown in Figures 4 and 5. These figures display the number of missions in the preparation cycle, the total labor hours expended, and computer time used versus time.

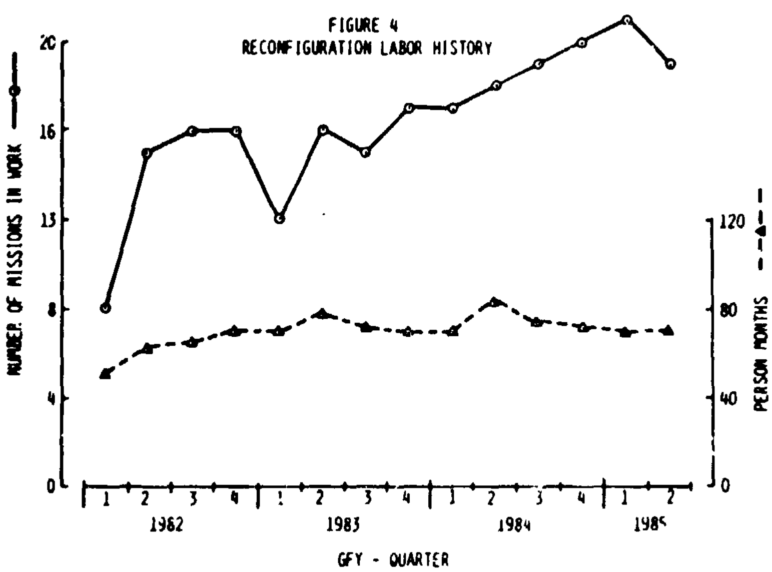
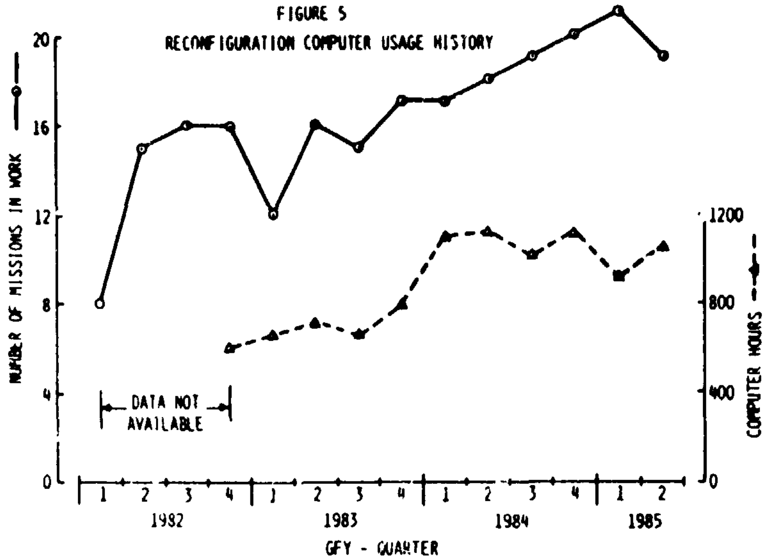


FIGURE 5
RECONFIGURATION COMPUTER USAGE HISTORY



As illustrated, while the number of missions in work has increased significantly, the level of labor required seems to be stabilizing. Computer time requirements, however, are not so well-behaved. It may be that this should be expected and might be indicative of such things as increased automation, mission-complexity, schedule slips, and remanifests.

Mission Operations Results

The McDonnell Douglas involvement in the development of flight procedures, operational products, crew and support personnel training, simulation support, and real-time mission control has been intensively analyzed for potential Streamlining ideas.

One recent accomplishment that resulted from a Streamlining suggestion was the development of a standardized training plan. This satisfies the need for a structured method for developing ground support personnel into technically competent and certified instructors, developers, flight controllers, or flight directors.

The use of existing software tools for the automated documentation of Shuttle Mission Simulator applications software was another example of increasing productivity and greatly reducing the chance for error.

McDonnell Douglas standardized and simplified the Crew Activity Plan. This has allowed proper support of an increasing flight rate without any significant increase in staff.

Increased automation of the Flight Data File (FDF) product generation has eliminated much of the manual efforts associated with this activity. This also allows quick access to the FDF for reports, schedules, and updates.

These are only a few of the implemented Streamlining suggestions in the mission operations support area. The McDonnell Douglas emphasis on productivity improvements will ensure a continuing stream of new ideas and suggestions.

SAVINGS ESTIMATE

Formal presentations are given by McDonnell Douglas to the JSC Technical Manager on a semi-annual basis. These presentations review the entire Streamlining activity for a six-month period, highlight the most significant, and provides an estimate of program savings resulting from implemented suggestions.

The process of converting labor hours, computer time, and other expenditures to program savings in dollars per year is difficult and the accuracy can certainly be challenged. However, a costing criteria has been developed and is consistently applied. The reported savings are felt to be representative. The projected yearly cost savings are determined using a yearly launch rate of 12, two of which are Spacelab and two involve a rendezvous.

The implemented streamlining items reported for the period from April, 1984, through March, 1985 result in an estimated future yearly cost savings of approximately $8.5 $\overline{M}$ (in 1985 dollars).

SUMMARY

Streamlining has proven to be an effective tool to continuously improve the quality and decrease the cost of performing engineering support services activities like those currently underway at McDonnell Douglas.

To be successful, however, several basic ingredients are required. There must be a top-down and demonstrated management commitment, an environment for the workforce which is supportive of the commitment, incentives to encourage workforce participation, and a system for the formal gathering, reviewing, and reporting of progress and achievements. The absence, whether perceived or real, of any of these will jeopardize the entire process.

It has been demonstrated by McDonnell Douglas after a relatively short period of time that this approach to increasing productivity can develop a work environment in which continuous improvement and holding the gains is a way of life.

BIOGRAPHY OF

Ronald K. Petersburg

Program Manager, Engineering and Operations Support, McDonnell Douglas Technical Services Company, Inc., Houston Division, 16055 Space Center Blvd., Houston, Texas 77062.

A graduate of Iowa State University with a B.S. in Aerospace Engineering, he has over twenty-five years of varied industry experience. Sixteen years has been in direct Contractor support of the U.S. Manned Space Program in many engineering, supervisory, and management capacities.

N86-15195

ACTIONS FOR PRODUCTIVITY IMPROVEMENT IN CREW TRAINING

Gerald E. Miller
McDonnell Douglas Technical Services Company, Inc.
Houston Astronautics Division

ABSTRACT

To improve the productivity of astronaut crew instructors in the Space Shuttle program and beyond, the following actions are proposed. Instructor certification plans should be established to shorten the time required for trainers to develop their skills as well as improve their ability to convey those skills. Members of the training cadre should be thoroughly cross trained in their task. This provides better understanding of the overall task and greater flexibility in instructor utilization. Improved facility access will give instructors the benefit of practical application experience. Former crews should be integrated into the training of upcoming crews to bridge some of the gap between simulated conditions and the real world. The information contained in lengthy and complex training manuals can be presented more clearly and efficiently as computer lessons. The illustration, animation and interactive capabilities of the computer combine for a most effective means of explanation.

INTRODUCTION

As the Space Shuttle becomes an operational system, ever increasing numbers of demands of continually greater complexity are being placed on all areas of support. This is easily evidenced by the ambitious launch schedule for the immediate future and the mission scenarios of the immediate past. The current launch manifest calls for a Shuttle mission each month. Assuming an average mission length of five to seven days, it may be seen that twenty-five percent of support personnel's time will be devoted to real time on-orbit support. While simultaneously, the same personnel are tasked with readying the upcoming crew for the next month's launch. Looking back upon previous missions reveals even greater demands. The unforeseen contingencies involving the Westar, Palapa and most recently, the Leasat satellites, demonstrated the reality of unplanned support requirements. Few tasks are as directly affected by these realities as that of astronaut crew training.

Instructor certification plans

Education in the field of hardware/human interactions, which represents the apex of crew training, will require constant productivity improvement if it is to keep pace with the operational world. This translates into better application of existing resources. Of course, the primary resource of any instructor is human. One means of improving the productivity of this commodity is the establishment of, and adherence to, a definite and structured instructor certification plan.

When new employees are hired to become trainers, it is not unusual for them to lack firsthand knowledge of the system on which they are eventually expected to become an expert. This is especially true of the more exclusive systems found in the space business, such as Extravehicular Mobility Units (EMU's), Manned Maneuvering Units (MMU's), or even the Shuttle itself. Incoming instructors cannot be expected to have previous experience with systems such as these, since the systems are unique to a limited section of the industry. A similar problem exists for any area of the industry which deals with relatively uncommon systems. As a result, newcomers often spend a great deal of time and energy in the familiar, "coming up to speed", process. The reasons for this are often quite common. There are always the technical manuals to be read. Such documents are frequently written in a fashion that is tedious to read and usually are not kept current with changing data. There is also very seldom an organized order in which manuals should be approached. There are usually training sessions or classes which may be attended as an observer. Unfortunately, new hires are often inundated by the amount of information covered by an actual training session and are unable to interrupt with questions since the sessions are intended for the crew being trained, not for the observers present. Complicate these problems with the fact that a single source is often not available with which newcomers may gauge their progress, and the impedances to productivity become clear.

A solution to these difficulties can be the development of a definitive instructor certification plan. The concept is quite similar to the curriculum outlines and course catalogs used by universities. All training, whether in the form of manuals or live sessions, should be organized into a coherent, chronological flow. A brief description of what is to be covered and how long is usually required should be included. Particular milestones should be established throughout the plan to mark times when an individual achieves designated plateaus in the field. An example of such plateaus for instructors is that time when a person is deemed an expert in a particular facet of the subject being studied. For instance, in the field of extravehicular activity (EVA), a "Kennedy Space Center Expert" designation is made when all training concerned with the launch facility is completed.

As an example, figures 1 and 2 show the curriculum list and course descriptions for the Kennedy Space Cente- section of the EVA/Crew Systems Instructor Training Flow and Certification Plan.

FIGURE 1
SAMPLE CURRICULUM LIST

KSC EVA SYSTEMS/PAYLOAD EXPERT
LESSON/ACTIVITY SIGN OFF
(Flow Code: T KSC EVA/PL)

SEQUENCE	ACTIVITY	START DATE	COMP DATE	TRAINEE INITIALS	OJT INST. INITIALS
1.	KSC EVA 2101				
2.	QG-101-KSC 1103				
3.	QG-102-KSC 1103				
4.	QG-125-KSC 1103				
5.	QG-126-KSC 1103				
6.	QG-128-KSC 1103				
7.	QG-150-KSC 1103				
8.	KSC EVA WD 2131				
9.	O-EVA EVAL 2131				
10.	C-KSC EVA 2101				

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FIGURE 2
SAMPLE COURSE DESCRIPTION

KSC EVA SYSTEMS/PAYLOAD EXPERT

1. **FCTC CODE:** KSC EVA 2101
   TITLE: KSC EVA Monitor Duties
   DURATION: 1 hour
   SYNOPSIS: This lesson is a briefing on the duties and responsibilities of the KSC EVA Monitor to include an overview of the walkdown at KSC, procedures for coordinating vehicle transportation/logistical support, range safety considerations and scheduling access into the Orbiter, and badging/access training.

2. **STPC CODE:** QG-101-KSC 1103
   TITLE: Fire Protection Safety Orientation
   DURATION: 0.5 hour
   SYNOPSIS: This class familiarizes students in operational areas at Kennedy Space Cener with fire suppression equipment, fixed and portable systems, and the most effective use on different classes of fire.

   NOTE: This class is required for KSC area access badging.

3. **STPC CODE:** QG-102-KSC 1103
   TITLE: Toxic Propellant Safety
   DURATION: 1 hour
   SYNOPSIS: This class provides a general knowledge of the toxic propellants used at KSC. It covers the nature of the propellants and the hazards involved in the use of the propellants. Access control procedures, warning systems and safety equipment are covered. It familiarizes persons with the location, use and limitations of the rocket propellant gas mask and air capsule.

   NOTE: This class is required for KSC area access badging. The refresher class (QG-106-KSC) is required every 3 years.

4. **STPC CODE:** QC-125-KSC 1103
   TITLE: Launch Complex 39 Facility Safety Familiarization
   DURATION: 0.7 hours
   SYNOPSIS: This class provides an overview of the facilities at Launch Complex 39 (LC-39) and the work flow of the Orbiter from touchdown to launch. It covers the safety hazards and hazardous areas at the Shuttle Landing Facility (SLF), Orbiter Processing Facility (OPF), and the Vehicle Assembly Building (VAB). It also covers evacuation signals, egress routes and safety equipment.

   NOTE: This class is required for KSC area access badging.

Upon completion of all necessary requirements, certification as a qualified instructor may be granted. This helps establish self-confidence within the new instructors as well as the confidence of those they will be training. The definition of set criteria for instructor certification not only reduces the time required for trainers to develop their skills, but vastly improves the ability to relay those skills.

Cross training

After an instructor is certified in one area of expertise, the next means of productivity improvement may be applied. That is the concept of cross training. While technical proficiency is best maintained by focusing on a particular field, for instance extravehicular activity, instructors should not be disadvantaged by isolation to a particular subset of that field. The impact of this approach on training effectiveness is to greatly reduce the integrated flow of a task. However, by cross training staff members in the various subsets of their field, a number of productivity improvements will be seen. Among them is the continuity of beginning to end contact by a crewmember with a single trainer.

When a crewmember is being trained for a particular task, the training is usually separated into certain components. This a common approach to solving any complex problem. The individual components, however, commonly are the responsibility of different instructors. The problem of bringing the separate information together is frequently left to the crewmember. Questions concerning the relationship of events in different components must be resolved through the interface between segregated information sources. Productivity is thus hampered when instructors are unfamiliar with the workings of other sections of their task. If instructors were adept in all aspects of their task, which is the expected result for the crews they are training, then continuity could be provided from initial training to real time execution. This can provide crewmembers with a single, authoritative source of information on their expected performance. Also, the instructors' understanding of the overall task will be greatly improved. Due to this improved understanding, the quality of information passed on by the instructor will increase. This is often manifested as a keener insight into the complicated relationships between the mechanical systems being used. Thus, productivity may be improved with respect to the time needed to resolve problems as well as the extent to which problems may be solved.

Further productivity improvement as a result of cross training may be seen in the area of scheduling. As Space Shuttle missions are slated with ever increasing frequency, the scheduling of instructors assigned to a particular mission becomes continuously more delicate. Add to this the demands of unforeseen contingencies, such as salvaging the Westar, Palapa, and Leasat satellites, and the resultant loads placed on training staffs can become overwhelming. By creating a training cadre comprised of members who are equally knowledgeable in all aspects of their task, the negative impact of such demands can at least be minimized. Unexpected work requirements that shift personnel away from scheduled training, as when instructors are needed to develop salvage procedures, can leave crews without instructors. With a fully cross trained staff, loss of productivity can be minimal since other instructors would be capable of taking over for those who were called away.

Improved facility access

With a strong understanding of the system in hand, an instructor's productivity may be further enhanced through improved facility access. This involves making instructors more familiar with the training environment by exposing them to it, not only as instructors, but as students as well. Instructors' ability to convey learning expectations is vastly improved if they have experienced the training session for themselves.

Crew training can, in general, be divided into two types, that which is mentally rigorous and that which is physically rigorous. Often it is some combination of the two, as is acutely illustrated by extravehicular activity. In either case, it is inherently necessary to place the crewmember in environments which are initially unfamiliar, complex, harsh or even potentially hazardous. In most instances, instructors will have studied and observed the facility environment. But rarely will they be given the opportunity to experience the demands it will make on the procedures being developed or relayed. Instructors are consequently forced to plan tasks using conjecture, assumption or speculation that the procedures will be workable. Productivity suffers because cewmembers must often work out techniques from scratch. The instructors are unable to shorten the time required to do this since they lack the experience of practical application. The overall effect can be compared to taking piano lessons from a teacher who understands music theory, but has never actually played a piano.

To illustrate this point, the figure below shows an underwater training session at the Weightless Environment Training Facility (WETF). All of the procedures be-

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ing learned by the crewmembers were developed and conveyed by a trainer. Without exposure to this environment, the trainer must speculate about all physical aspects effecting the task. These may include overall mobility, strength, duration, visibility, manual dexterity within a pressurized suit or many others.

FIGURE 3
WEIGHTLESS ENVIRONMENT TRAINING FACILITY (WETF) SESSION

It is possible to remedy this situation by exposing instructors to the conditions of training facilities whenever feasible. While new procedures are still in the early developmental stages, trainers should undergo instructional sessions identical to those later intended for use on the crews. Thus, once instructors begin presenting these new procedures as facts, they would command a much better perspective of how to approach the task. Communication between the crewmember and instructor would improve since each would possess a common reference of experience. Productivity increases as instructors become better able to convey expectations, and more importantly, techniques to crewmembers.

Integration of former crews

Another means of productivity improvement is the integration of former crews into the training of upcoming crews. This integration may seldom be in the form of an actual instructor. Instead, the role often becomes more that of a consultant.

Techniques fabricated on Earth, yet intended for space, are frequently hindered by the simple fact that they were created under the constraints of planetary limitations. Regardless of the painstaking efforts made to simulate the space environment, many vast discrepencies still exist. As a result of these discrepencies, procedures which work well in simulated space may not in actual orbit. Often, the reverse is true. Tasks which were foreseen as being quite laborious, may turn out to be very simple in space. The constant use of feedback from returning crews thus becomes an excellent means of improving productivity. It has been common practice over the years for all support personnel to make use of the debrief information from former crews. It should be noted, therefore, that what is being suggested is intended to go beyond the passive relay of data to a more active involvement in training sessions. For example, having an experienced crewmember in attendance during a WETF task often provides instructors with immediate feedback for questions concerning the manual manipulation of satellites, on-orbit crewmember work restraints or maneuverability about the payload bay in zero gravity. This accurate insight as to how well the training simulates the real world is invaluable.

Computerized lessons

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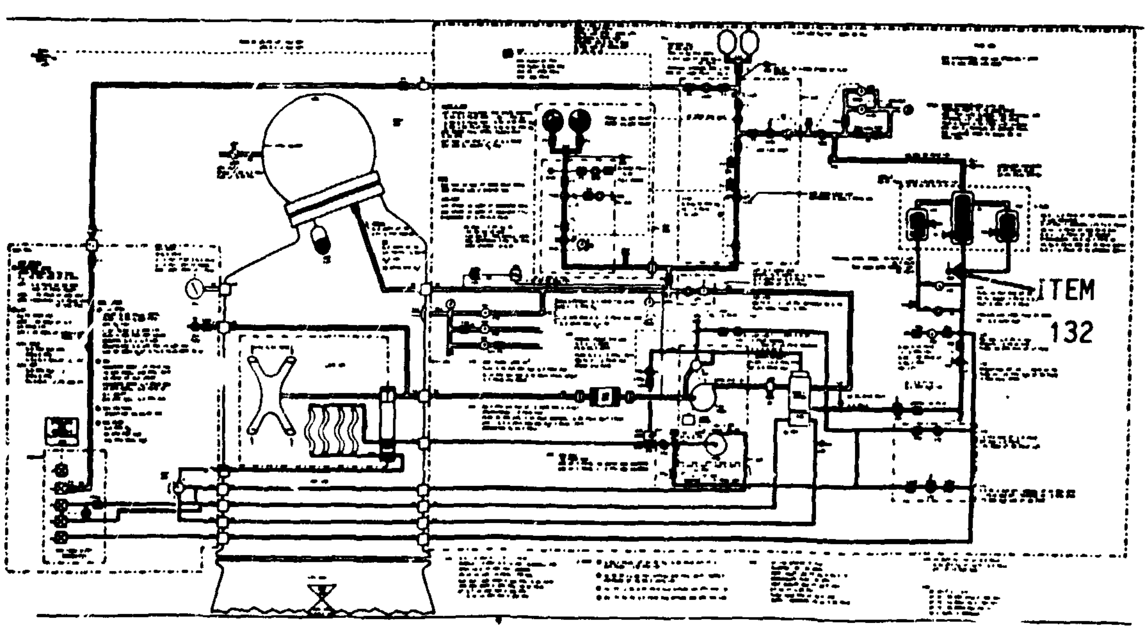
The use of illustrated/animated computer lessons to supplement printed texts can produce an outstanding improvement in productivity. Complex systems are made much clearer when their function can be animated. The immediate feedback and individual interaction of a computer also represent improvements over printed workbook/lecture combinations.

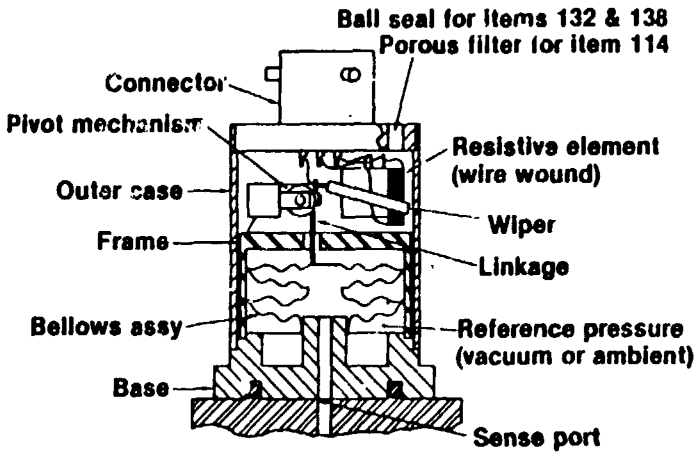
Nearly all Shuttle systems which crews must learn, indeed all space systems in general, are to say the least, complicated. It is also true that regardless of their complexities, the systems must be mastered on schedule. Therefore, training programs are inevitably faced with the problem of how to convey a working knowledge of complex systems while maintaining the highest level of productivity. Traditionally, the initial stages of crewmembers' training consists of many hours spent studying the voluminous stack of technical manuals associated with their given assignments. Such documents are always quite thorough, yet their effectiveness can be greatly improved by supplementing them with computer lessons. For example, figure 4 below shows a schematic diagram of the Extravehicular Mobility Unit (EMU) used by Space Shuttle EVA crews. This space suit diagram is representative of those used in most training manuals.

FIGURE 4
SPACE SHUTTLE EXTRAVEHICULAR MOBILITY UNIT SCHEMATIC



Normally, a schematic such as this will appear in a manual along with detailed drawings to illustrate each of its components. Down to the smallest item, the system is methodically chronicled by diagrams such as the one below. Figure 5 is an expanded view of the pressure sensor called out in figure 4.

FIGURE 5
ITEM 132: POTENTIOMETER TYPE PRESSURE SENSOR



It may be seen that figure 5 illustrates one of the least complex components, representing the smallest fraction of the entire system. Yet, a substantial amount of written text would accompany figure 5 in a training manual to explain the sensor's interaction with the overall system. Expanding this example to the truly complicated components and then adding the requir[illegible] to convey their physical interaction during oper[illegible] of the integrated system, yields an understan[illegible]ng [illegible] demands being addressed. Not only is the printed te[illegible] eeds to do this cumbersome, it is also tedious, non[illegible] and difficult to update as changes occur.

Fully illustrated and animated explana[illegible] of systems such as the EMU can be programmed into computer lessons. Animated representations of flow paths, fans, pumps, motors and electrical circuits in operation can convey their physical interaction faster and more clearly than printed text and static diagrams. Productivity improves further since crewmembers may work at whatever pace suits their degree of familiarity with the system. This is done by establishing level within the programmed lesson. With such an interactive program, the crewmember may request further explanation of particular areas, or move through a brief overview of well known ones. Also, since most complicated texts require the scheduling of a live lecture session to explain them, time may be used more efficiently. This is a result of the fact that most well programmed computer lessons require only a brief discussion with a trainer to clarify points left after the lesson, as opposed to a lengthy lecture. Further improvement in productivity will be seen as system updates occur. When changes occur which effect printed texts, page change notices must be generated and distributed. These must not only be manually added to all existing copies of the text, but hand carried to wherever those copies may be. However, a single change in the program of a computer lesson can complete an update for all who wish to use it, regardless of their location.

CONCLUSION

Productivity improvement in the field of crew training becomes imperative as the Space Shuttle enters its operational phase. Instructor certification plans, cross training, facility access, integration of former crews, and computerized lessons represent some of the means available to increase the effectiveness of instructors. All of the measures discussed have been adopted by the EVA Astronaut Training Office. The value of such measures may be seen in the following statistics. From 1981 to 1985, the EVA training office has experienced a 25% increase in personnel. During the same time period, the number of Shuttle flights being successfully supported annually has increased 600%. It should be noted that all of the actions discussed are applicable to productivity improvement of any form of training, not only astronaut crews.

BIOGRAPHICAL STATEMENT

The author received a Bachelor of Science degree in Aeronautical and Astronautical Engineering from the University of Illinois in January, 1983. Assignment to the Astronaut Crew Training Office was accepted after serving in the software development branch of the Space Vehicle Dynamic Simulation Program. The author is a certified crew trainer specializing in the field of extravehicular activity, particularly as pertains to the operation of Extravehicular Mobility Units.

N86-15196

GROUND PROCESSING OF THE McDONNELL DOUGLAS PAYLOAD ASSIST MODULE (PAM)

C. E. Bryan, McDonnell Douglas Astronautics Company
D. A. Maclean, McDonnell Douglas Astronautics Company

ABSTRACT

This paper describes how the McDonnell Douglas PAM ground processing operations have evolved since they were started at KSC in 1982. The objective of the changes was to reduce the prelaunch testing of the Airborne Support Equipment in order to increase the throughput of PAM systems while not compromising the reliability of the system when functioned on-orbit. The changes that resulted from lessons learned and experience gained from the initial cargo element ground processing, the on-orbit performance of the systems, plus the post-flight refurbishment and recertification of the Airborne Support Equipment have resulted in significant reductions in labor expenditures and work shifts required to prepare a PAM system for flight. Our streamlining efforts are continuing and are expected to yield additional productivity improvements in the future.

THE PAYLOAD ASSIST MODULE PROGRAM

Recognition of the need for an economical upper stage to augment the Space Transportation System's large and heavy payload capability led to the development of the Payload Assist Module (PAM) as a spinning solid upper stage. The stage was sized to provide the capability for boosting a Delta Expendable Launch Vehicle class satellite to geosynchronous transfer orbit after release from the Orbiter in a low circular orbit.

The development of a spin stabilized system represented an orderly adaptation of a family of spinning upper stages which McDonnell Douglas had designed for NASA as the third stage of the popular and well-proven Delta Expendable Launch Vehicle (ELV). The National Aeronautics and Space Administration agreed in 1977 to let McDonnell Douglas develop the PAM system on a commercial basis and offer it to satellite system owners for payloads of the Delta ELV class. The proposed system had the additional advantage of being adaptable to either the STS (PAM-D) or the Delta ELV (Delta PAM), thereby providing the satellite owners with a backup launch capability as the STS was proceeding through the final phase of its development program and the first four STS development flights. The first of 12 Delta PAM launches took place in November 1980. This was followed by the launch of the first two PAM-D systems on STS-5 on November 11, 1982. A growth version of the PAM-D system was given a go-ahead in 1983. The growth version is designated PAM-DII, and it is scheduled to make the inaugural flight in November 1985. The launch record for the first 14 units along with those currently scheduled through mid-year 1986 are provided in Table 1.

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TABLE 1. STS PAM LAUNCH RECORD AND SCHEDULE

STS MISSION	UNIT NUMBER	ASE S/N	CARGO ELEMENT IDENTIFIER	LAUNCH DATE
STS-5	1	01	SBS-C	11-11-82
	2	03	ANIK-C3	
STS-7	3	02	ANIK-C2	06-18-83
	4	03	PALAPA-B1	
STS-8	5	01	INSAT-1B	08-30-83
STS-41B	6	02	WESTAR-IV	02-03-84
	7	03	PALAPA-B2	
STS-41D	8	01	TELSTAR-3B	08-30-84
	9	04	SBS-D	
STS-51A	10	03	ANIK-D2	11-08-84
STS-51D/E	11	04	ANIK-C1	04-12-85
STS-51G	12	02	ARABSAT-A	06-17-85
	13	03	MORELOS-A	
	14	01	TELSTAR-3C	
				PLANNED
STS-51I	15	04	ASC-A	08-24-85
	16	01	AUSSAT-A	
STS-61B	17	03	MORELOS-B	11-27-85
	18*	02	SATCOM-KU1	
	19	01	AUSSAT-B, AUSSAT	
STS-61C	20*	TBD	SATCOM-KU2	12-20-85
STS-61E	21	TBD	WESTAR-VII	03-06-86
STS-61H	22*	TBD	SKYNET-IVA	06-24-86
	23	TBD	PALAPA-B3	

*PAM-DII

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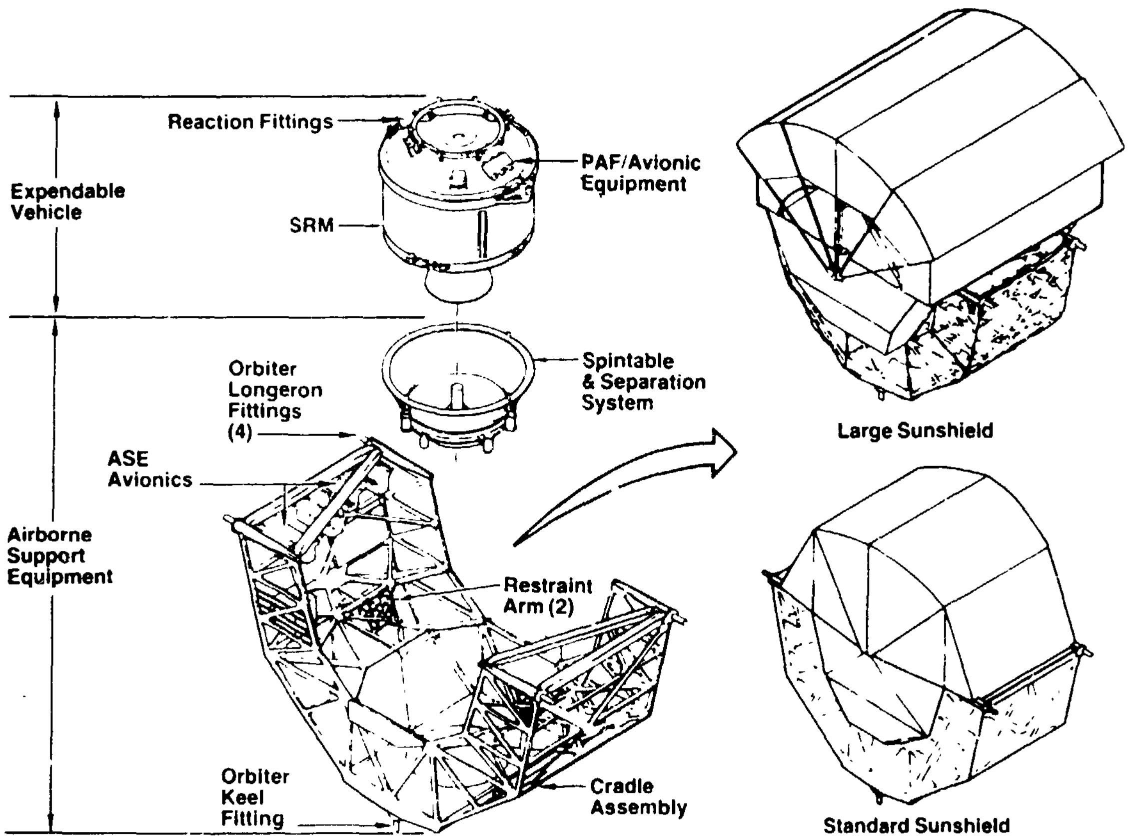
THE PAM SYSTEM

The PAM is a system designed to provide the necessary injection velocity to deliver payloads (spacecraft) from the low earth orbit of the STS Orbiter into higher energy transfer orbits. The PAM flight system includes the consumable expendable vehicle (EV) and the reusable Airborne Support Equipment (ASE) that interfaces with the Orbiter.

The PAM expendable vehicle hardware consists of the solid rocket motor (SRM) and the payload attach fitting (PAF). The ASE includes the cradle, the spintable, the thermal control system, and the avionics equipments required to functionally interface with the Orbiter and flight crew. The PAM flight system hardware is shown in an exploded view in Figure 1.

FIGURE 1. PAM-DII FLIGHT HARDWARE

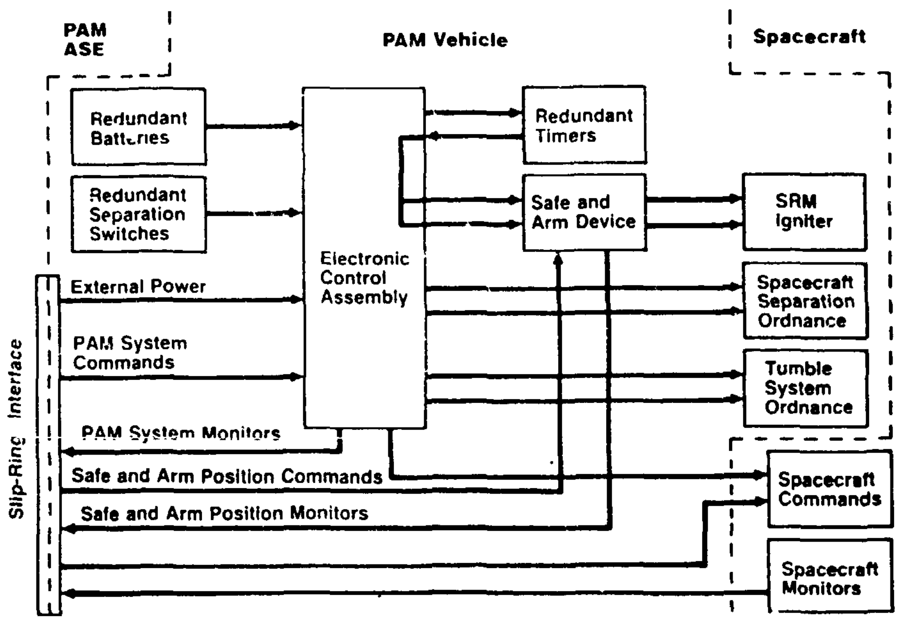


PAM Expendable Vehicle

The SRM is the propulsive element of the PAM vehicle. It is supplied by Morton Thiokol, Inc. and is designed to accommodate a wide range of mission performance requirements. Propellant loading for the baseline PAM-D mission is approximately 4400 pounds. The new PAM-DII SRM is also supplied by Morton Thiokol and has a maximum propellant load of 7155 pounds. The propellant load in both motors can be varied as a mission option.

The PAF provides the means of attaching the spacecraft to the SRM and the mounting accommodations for the PAM avionics subsystem boxes. The PAF structure has two reaction fittings to provide load-carrying paths to the cradle forward restraint arms. These restraint arms are retracted to permit spin-up of the PAM and the spacecraft prior to deployment from the Orbiter. The components for a fully redundant electronic sequencing system (shown schematically in Figure 2) are mounted on the payload attach fitting. The avionics system consists of a timer assembly, an electronic control assembly, and batteries. The avionics system commands SRM ignition, spacecraft separation, and yo-weight release.

FIGURE 2. EXPENDABLE VEHICLE AVIONICS



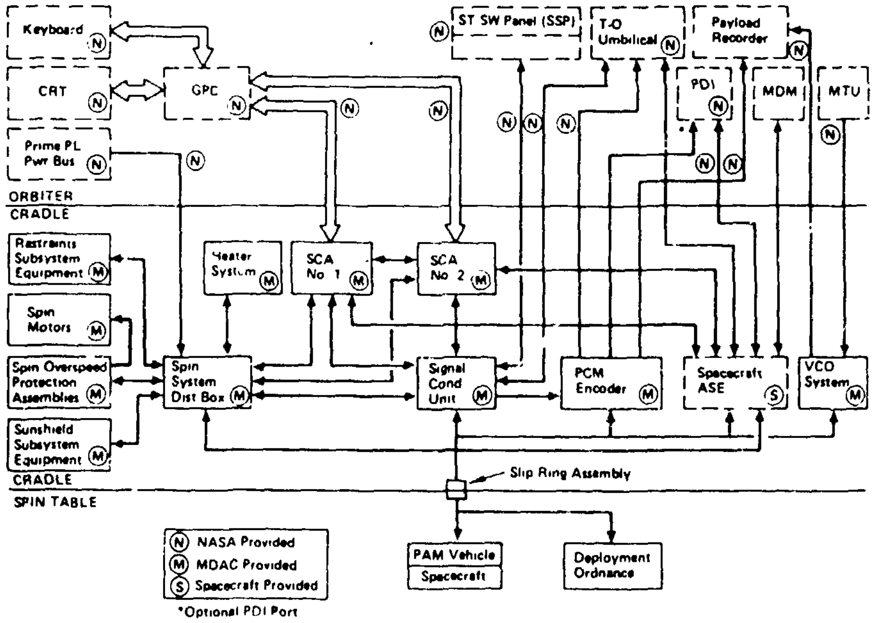
PAM Airborne Support Equipment

The PAM cradle is the aluminum structure which mounts the system in the cargo bay. The cradle is attached to the Orbiter with four longeron and one keel attachment points. The spintable is bolted to the cradle and it serves as the pedestal for mounting the motor to the ASE. There are two motor driven restraint arms on the cradle which provide the forward structural attachments to the Expendable Vehicle Payload Attach Fitting. The cradle also provides mounting accommodations for the sunshield and the avionics equipment.

The spintable provides the rotational velocity to the PAM/spacecraft combination for stabilization after deployment. Spinning is accomplished by redundant electric drive motors, which are capable of providing a selected spin rate in the range of 40-100 rpm for PAM-D or 35-75 rpm for PAM-DII. The PAM expendable vehicle is joined to the spintable by a vee-block clampband. When the clampband is released by the redundant bolt cutters the separation springs on the spintable provide the separation impulse to deploy the expendable vehicle and satellite from the cradle in the Orbiter.

The ASE avionics system, which is common to both PAM-D and PAM-DII, is shown in a functional layout in Figure 3. This system interfaces with the STS Orbiter, the PAM expendable vehicle, and the spacecraft. The PAM avionics accepts and implements commands from the Orbiter General Purpose Computer (GPC) data bus and Standard Switch Panel, distributes Orbiter 28 VDC power to the PAM and spacecraft, provides closed-loop sequencing of PAM systems, and generates system status information for display to the crew and downlisted for real time monitoring in the Mission Control Center at the Johnson Space Center. The microcomputer-based Sequence Control Assemblies are the heart of the avionics control system. The sequence control assemblies (SCAs) are redundant controllers for the sequencing and operation of all PAM equipment in the Orbiter. Certain key steps in the sequence are performed by the Flight Crew (switch panel or General Purpose Computer) due to their safety or timing critically; however, the majority of the detailed sequential steps are handled automatically by the SCA system. The SCA, with the signal conditioning unit (SCU) and the spin system distribution box (SSDB), controls the operation of the PAM heater elements, the opening and closing of the sunshield, and the operation of the restraint arms, spin system, and deployment system. Excess spin rates are prevented through the use of dual overspeed protection assemblies.

FIGURE 3. AVIONICS SYSTEM



ASE Thermal Control System (TCS)

The Thermal Control System consists of multilayered thermal blankets mounted on the cradle to provide thermal protection for the PAM EV and ASE eq. ments. The sunshield is mounted on top of the cradle to provide thermal protection for the spacecraft to control the on-orbit solar input to and heat loss from the spacecraft when the Orbiter bay doors are open. Thermostatically-controlled radiant heaters are installed on the internal surface of the cradle blankets to provide the required heat input for cold STS attitude orientations. The portion of the sunshield covering the top of the spacecraft is a clamshell structure that is opened and closed by a redundant electric rotary actuator operating a wire rope cable system.

PAM ON-ORBIT OPERATION

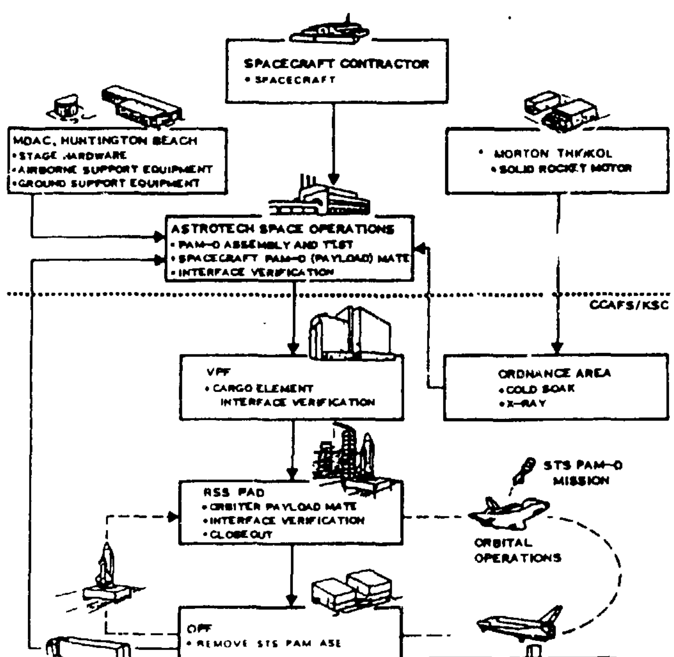
The PAM system is launched with the sunshield clamshells open and in an electrically passive mode. After the Orbiter has achieved the desired 160 to 190 nautical mile circular orbit, the cargo bay doors are opened, the PAM system is powered up by the crew, and the sunshield is closed. After closing, the system is powered down until 60 minutes prior to the nominal deployment time. The Orbiter maneuvers to achieve the proper deployment attitude. The attitude maneuvers are completed by deployment minus 40 minutes. The deployment sequence is initiated by the flight crew at deployment minus 15 minutes. The sunshield is opened, the restraint arm withdrawn, and the spin system brings the expendable vehicle and spacecraft up to the pre-programmed spin rate. At deployment minus 3 minutes, the terminal sequence is initiated by a General Purpose Computer command to the SCA. During the terminal sequence, the ordnance systems are armed, the spacecraft is configured for deployment, and the final deployment command is issued by the GPC. The EV and spacecraft are ejected from the cradle at approximately 2.5 feet per second at the pre-programmed spin rate. When the EV is released, the timing systems on the payload attach fitting start a countdown to initiate the solid rocket motor 45 minutes later. After the deployment is completed, the flight crew initiates the closure of the sunshield to protect the remaining equipment, and powers down the PAM ASE. The PAM ASE is powered up again in preparation for payload bay door close for descent. After powering the system, the sunshield is opened and the system is then secured for descent. Total operating time of the avionics system is usually 60 to 75 minutes on-orbit. Total spinning time is just over 15 minutes.

PAM ASSEMBLY AND CHECKOUT

Preparation of PAM systems to meet NASA manifested mission schedules is influenced by Ground Support Equipment and checkout facility limitations and the four sets of MDC-provided PAM-D Airborne Support Equipment and three sets of PAM-DII ASE. At the initial inception of the launch site testing in May 1982, NASA allocated one of the two checkout bays of the Explosive Safe Area 60 (ESA 60) Facility on the Cape Canaveral Air Force Station for the assembly and testing of the PAM systems. MDC provided a single ground checkout test set. This test set was moved to ESA 60 after being used in the factory for over two years of system integration design verification testing at Huntington Beach, California. The test set, officially identified as the PAM Model 500 Test Set, is a mini-computer controlled "Orbiter simulator" and telemetry ground station. The Orbiter simulation portion of the test set provides high fidelity interface simulation of the Orbiter avionics systems shown in Figure 3. The test set also provides test equipments for monitoring the avionics equipments packaged on the expendable vehicle Payload Attach Fitting.

This multi-purpose test set limits testing to a single test article. The cabling requirements to connect a cradle or an expendable vehicle to the test set make it prohibitive to redirect the short duration testing from one cradle to another or from one expendable vehicle to an alternate. The test set also restricts the testing to either a cradle or an expendable vehicle, not both in parallel. These restrictions, therefore, make serial scheduling necessary. The ESA 60 hazardous processing facility introduced several operational compromises, including limited floor space, which had an adverse effect on the overall operation. Most of these compromises were eliminated when the PAM operations were moved to the Astrotech TICO facility in Titusville in the Fall of 1984. This facility was sized to accommodate the physical needs of the PAM equipment. It offers a separate control room for housing the test set, an overhead hoist adequately sized to allow lifting the entire cargo element with a single hoist, more floor space in the checkout cell, and a dynamic balancing machine in a room adjacent to the test cell. These facility improvements and the inclusion of the dynamic balancing operation to the same building provided an opportunity to consolidate our operations in one location. Figure 4 depicts the flow of PAM hardware at the Eastern Launch Site.

FIGURE 4. PAM HARDWARE FLOW AT THE EASTERN LAUNCH SITE



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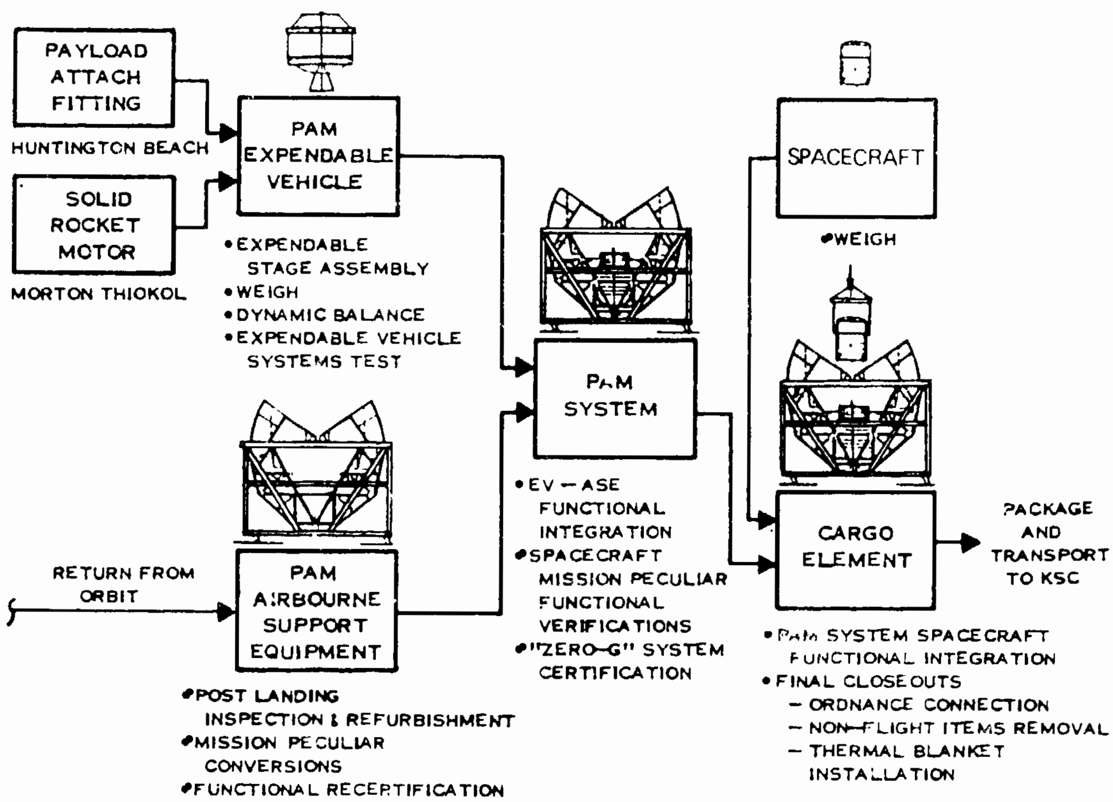
The Astrotech facility is now the central hub for McDonnell Douglas PAM ground processing activities. The PAM elements are staged through this facility as shown in Figure 5. Once the PAM system is completed, the spacecraft is added and the total cargo element is readied for transport to the Kennedy Space Center, Vertical Processing Facility. Upon receipt of the cargo element at the Vertical Processing Facility, NASA and its supporting contractors place the cargo element into the vertical test cell and verify the cargo element interfaces. They then move the total payload complement to the launch pad, install it in the Orbiter, certify the interfaces between the Orbiter and payload, and launch it. At the completion of the mission, the Orbiter and the payload ASE are returned to the Eastern Launch Site where the cargo residuals are returned to the appropriate payload organizations. In PAM's case, the ASE is off-loaded to a cradle support stand, covered and returned to the Astrotech facility for post-landing inspections, refurbishment, reconfiguration, and recertification before it is reloaded with another expendable vehicle for the next usage. PAM Unit 11, prepared for the ANIK-C1 spacecraft, was successfully processed through Astrotech in November and December 1984. This system was launched and deployed from Discovery in April 1985.

FIGURE 5. HAZARDOUS PROCESSING FACILITY OPERATIONS-ASTROTECH-TICO



FIELD TEST PROGRAM EVOLUTION FROM STS-5 TO STS-51D

After processing the first two units for STS-5, an effort was undertaken to make an overall assessment of the effectiveness of the Field test program. This assessment was done in parallel with the operations that had already started for Units 3 and 4 for STS-7. This study took into consideration the results of the performance of Units 1 and 2 on-orbit, the post-landing visual inspection results, and the analysis of the on-orbit telemetry data. Analysis of the labor data showed that approximately 87% of our field costs were associated with the ESA 60 activities. We, therefore, concentrated our efforts on analysis of the ESA 60 (Astrotech) activities. Efforts to improve the operations at the Vertical Processing Facility and Pad were also included. NASA spearheaded the effort to review the on-line operations with MDC, Hughes Aircraft, Telesat and Satellite Business Systems participation. The NASA efforts also resulted in significant productivity improvements, but the most significant gains to MDC resulted from changes made in our hazardous processing facility operations.

As you would expect for a newly designed system, the Field Test program was planned to be extremely conservative. The designated Test Engineering personnel who staffed the PAM Program were by and large reassigned from the on-going Delta Program. Therefore, the Field Test program was heavily influenced by system test techniques which were fundamentally proven. The test program was structured to detect mismanufactured hardware or off-nominal operation of previously tested systems. The testing was developed around the factory to Field concept. All black box and subassembly testing was planned for the factory. Disassembly of hardware was eliminated wherever possible. Final certifications of the system was accomplished at the highest assembly level achievable. All redundancy and logic paths associated with the fail operational, fail safe design were demonstrated. All circuit and software paths would be verified.

The operational systems that were in place in Florida for Delta were also extended to PAM. Test requirements provided by the designers at Huntington Beach were converted to test procedures which included the proven features of the Delta Launch Preparation Documents. The word processing techniques used for the generation of Delta procedures were extended for PAM procedures. The Quality Assurance program and all of the features for verifying the in-process inspection requirements during assembly and test operations were identical. Test team membership, assignments, procedures and responsibilities were not altered. The exposure of our operations and the results of efforts were shared with our customers in the same manner as our activities are shared with NASA quality and technical personnel. At this point in time, the reusable features of the ASE did not alter our test approach. The only impact that reusability imposed was the structuring of equipment log books for maintaining records for multiple usage. When the review team looked at the total test program, it was clear that major changes in our approach to test the reusable equipment should be made. The benefits of successful previous flight operation and the detriments of previous exposure to flight environments were key factors taken into consideration. Our efforts toward streamlining checkout operation were primarily directed toward the Airborne Support Equipment, rather than the expendable hardware. Initial reductions in checkout were implemented gradually over the cargo elements processed for STS-7 through STS-51D.

PAM checkout is structured into four levels of assembly: (1) Airborne Support Equipment; (2) Expendable Vehicle; (3) PAM System (ASE and Vehicle); and (4) PAM Cargo Element (ASE, Vehicle, and Spacecraft). One of the initial gains was to reduce duplication by reassigning some ASE and EV testing until the PAM system level testing was done. Although this could delay discovery of a problem, ultimate reliability was not compromised. Another area of reduction involved the deletion of testing on circuits not used on the specific mission. Previously, the philosophy was to test all flight circuits, used or unused, because they represent a measure of hardware health.

The checkout modification with the most significant productivity improvement was associated with Sequence Control Assembly software verification. For the early missions, checkout included the operation of the total system in a manner which would force the software through almost all possible paths. The purpose was to provide maximum confidence in the flight software despite extensive module and box level validation and verification. When our confidence in software design had been established, the system software oriented testing was replaced by a single bit-by-bit read/verification of the SCA ROM memory in which the flight software is resident, and a read/write verification of each RAM location.

Another major checkout reduction step during this period was the elimination of electrical interface verification testing in the NASA Vertical Processing Facility (VPF) for missions with reflown ASE and a vehicle and spacecraft whose design is identical to that of a previous mission. The major purpose of VPF testing is to detect any potential cargo element/Orbiter interface problems in advance of the final interface verification testing at the launch pad. The elimination of VPF testing on reflown type systems added minimal risk of late problem detection without increasing flight risk. This approach has been used on six of the 16 units that have been delivered to the VPF with no adverse effects detected during subsequent testing in the Orbiter.

CHECKOUT RESTRUCTURING FOR STS-51G AND SUBS

In mid-1984, a second MDAC study team was organized to systematically evaluate the PAM handling and checkout requirements for adequacy and efficiency. The results of the study have been implemented, starting with the STS-51G mission. Although the main emphasis was on the avionics system, structural/mechanical and propulsion systems were also reviewed. The thrust was to further reduce the ASE testing while maintaining very high confidence in flightworthiness. The keys to improved checkout productivity were: (1) the recognition of system hardware/software design maturity through actual flight usage; (2) the recognition that previously checked out hardware that has flown without anomaly requires much less extensive testing than new units; and (3) the recognition that minimizing the exposure of flight hardware to unnecessary dismantling and reassembly to support testing reduces the potential for introducing problems or misleading test results.

This philosophy is more consistent with the early PAM Program planning for a reflight recertification cri' 'ia, and reliance on strictly system level checkout before reflight. It led to essentially eliminating disconnection of wire harness connectors in the PAM ASE system and in the spacecraft ASE system. The test requirements were restructured to specify three alternative levels of recertification, dependent upon hardware history: (1) new ASE and new spacecraft type; (2) reflown ASE and new spacecraft type; and (3) reflown ASE and repeat back-to-back spacecraft type.

Among the checkout reductions which were implemented for recertifying reflown systems are the following:

1. Delete single power supply operation of the heater system, spin brake, and index solenoid. Verify during dual power supply testing.

2. Delete single motor operation of restraints and sunshield. Verify via data available during full-up system, dual-motor operation.

3. Delete resistance and isolation tests of interconnecting wire harness. Verify functionally.

4. Verify only the data bus addresses and commands which are used in flight on the specific mission.

5. Delete slip ring noise testing. Verify circuits by functional test only.

6. Verify SSP circuits functionally only, rather than by voltage measurement.

7. Eliminate slow spin rate testing for missions where this is not used in flight.

In the structural/thermal areas, significant test reductions were possible with the thermal protection system optical properties verification. The performance of the thermal blankets is dependent upon the preservation of the optical properties -- solar absorptance of the external beta cloth and IR emittance of the internal foil layer -- of the multilayered blankets. At the start of the program there was uncertainty as to the effects of handling, solar exposure, the oxidizing environment in space, and contamination collection on these blankets. Following the STS-5 flight, 100 absorptance and 125 emittance measurements were made on the blankets and on special coupons on each cargo element.

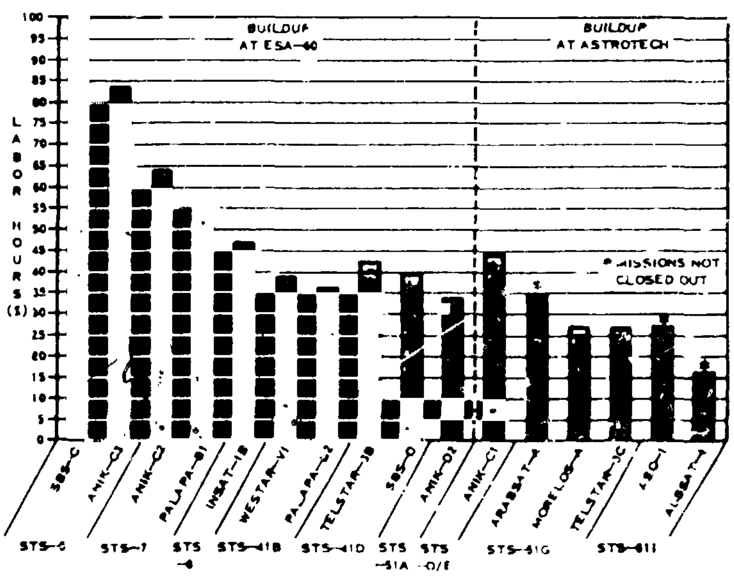
The number of measurements has been systematically reduced to the point where measurements collected from the sunshield flown on STS-51D (Unit 11) were reduced to 75 IR emittance and 15 absorptance measurements, all collected from the coupons. After the return of the ASE from the STS-51G mission, the coupons will be visually inspected only, with emittance and absorptance measurements now required after every third flight unless the visual examinations detect an unexpected surface condition or the flight temperature data indicates unexpected thermal environments.

Requirements for collecting data on the weight of the cargo element that is placed into the Orbiter have been relaxed. During the assembly of the cargo element, the PAM EV and the Spacecraft are weighed individually. Prior to STS-51G, all cargo element weights were collected empirically. In the future, the ASE weight will be analytically calculated based on previous empirical data when the data from the two previous weighing operations indicates the ASE is within five pounds of the predicted. The ASE will be reweighed should changes be made that could cause any significant weight error.

TEST PROGRAM REDEFINITION RESULTS

The results of our efforts to streamline the test program are measurable. Figure 6 shows the reductions in labor hours expended in the preparation of the 16 units we have processed through the Hazardous Processing Facility. Units 15 and 16 have not completed the total flow yet. They have been delivered to the VPF and are scheduled to be launched on August 24, 1985. The ASE set that flew with ARABSAT-A on STS-51G has not completed its post-flight refurbishment work yet, but the trend is clearly shown. Some of the reductions are clearly attributable to the expected efficiency improvements that result from learning, some are attributable to the consolidation of our operations in the Astrotech facility, but the remaining are the direct result of changes in the test requirements. It is our belief that these reductions have increased our ability to provide PAM systems by two to three units per year. Standard schedules at the inception of the ground processing in Florida implied we could expect to process seven units per year on a single-shift basis. We now feel nine or ten units could be provided. We also believe these changes will have no detrimental affects on the in-flight performance of the hardware and will minimize damage to the hardware on the ground. We might also predict future iterations or revisions to our testing once additional performance data is available from the baseline testing implemented on STS-51G.

FIGURE 6. LABOR HOUR EXPENDITURE HISTORY



AUTHORS BIOGRAPHY

C. E. BRYAN

Mr. Bryan is the Unit Chief of Electronics, PAM System Requirements, at the Huntington Beach facility. He was a prime factor in developing the concepts for the coupling of ground and on-orbit pre-deployment checkout activities to minimize system complexity and flight weight, while maintaining adequate verification capability. He holds a BSEE from Vanderbilt University, Nashville, Tennessee, and an MBA in Business Administration from the University of Southern California.

D. A. MACLEAN

Mr. Maclean is the Manager of PAM Launch Operations at the Kennedy Space Center. He has held this position since 1979. He oversees all McDonnell Douglas Astronautics Company efforts for the PAM Program at KSC. Prior to this assignment, he was the Chief Field Engineer for the Delta Program at KSC. He holds a BSEE from Michigan State University.

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SPACE SHUTTLE DESCENT DESIGN: FROM DEVELOPMENT TO OPERATIONS

Timothy J. Crull and R. Edward Hite, III

McDonnell Douglas Technical Services Company
Houston Astronautics Division
Descent Design Section

ABSTRACT

We have supported the Space Shuttle Program at NASA/JSC for the past eleven years, transitioning from development to operations. As partners with NASA we have been responsible for verifying the Descent (deorbit through landing) guidance system, designing the Descent trajectories, and generating the associated flight products.

This paper addresses the emphases which have allowed us to successfully make this transition to STS operations, resulting in reduced manpower requirements and compressed schedules for flight design cycles. These topics include; (1) Continually upgraded tools for the job; i.e., consolidating tools via electronic data transfers, tailoring general purpose software to our needs, easy access to tools through an interactive approach, and appropriate flexibility to allow design c nges and provide growth capability; (2) Stabilizing the flight prof e designs (I-loads) in an uncertain environment; and (3) Standardizing external interfaces (such as target lines) within performance and subsystems constraints of the Orbiter.

INTRODUCTION

The descent design job has changed considerably over the past eleven years. Initially, descent trajectories were custom designed to maximize margins from different subsystem constraints or guidelines. At the same time, the energy potential of the trajectory needed to be balanced to accommodate possible environmental uncertainties.

For the orbiter, the performance of the aerodynamic, thermal protection, flight control & avionics, and structural subsystems all are key drivers in the trajectory designs. Initially, performance margins had to be provided for the uncertainties associated with pre-flight models. Much of this uncertainty has been eliminated from analysis of flight data. Thermal protection and landing gear assembly subsystem performance remain uncertain, but for the most part subsystem performance is known to the tolerance level, i.e., as well as anything can be known. It is important to note that with the exceptions noted above, subsystem performance has been as good or better than expected. This has been a very significant contributor to the progress made on transitioning the descent design job close to an operational state.

This relatively stable design environment allowed developing a very limited number of descent trajectories capable of safely accommodating broad ranges of operational orbiter configurations. Configuration parameters that influence descent performance include weight, center-of-gravity, orbital inclination and apogee, time-of-year, and landing site location. Figure 1 summarizes the progress on developing standard descent trajectories for flights from the Eastern Test Range at Kennedy Space Center. The figure illustrates how only five of about 650 onboard software constants (or I-loads) are routinely reconfigured. Increases in the number of reconfigured I-loads are identified at points A, B, and C. These increases were necessitated by a significant change to the onboard guidance algorithm (A) and significantly different weights that were addressed for the first time (B & C).

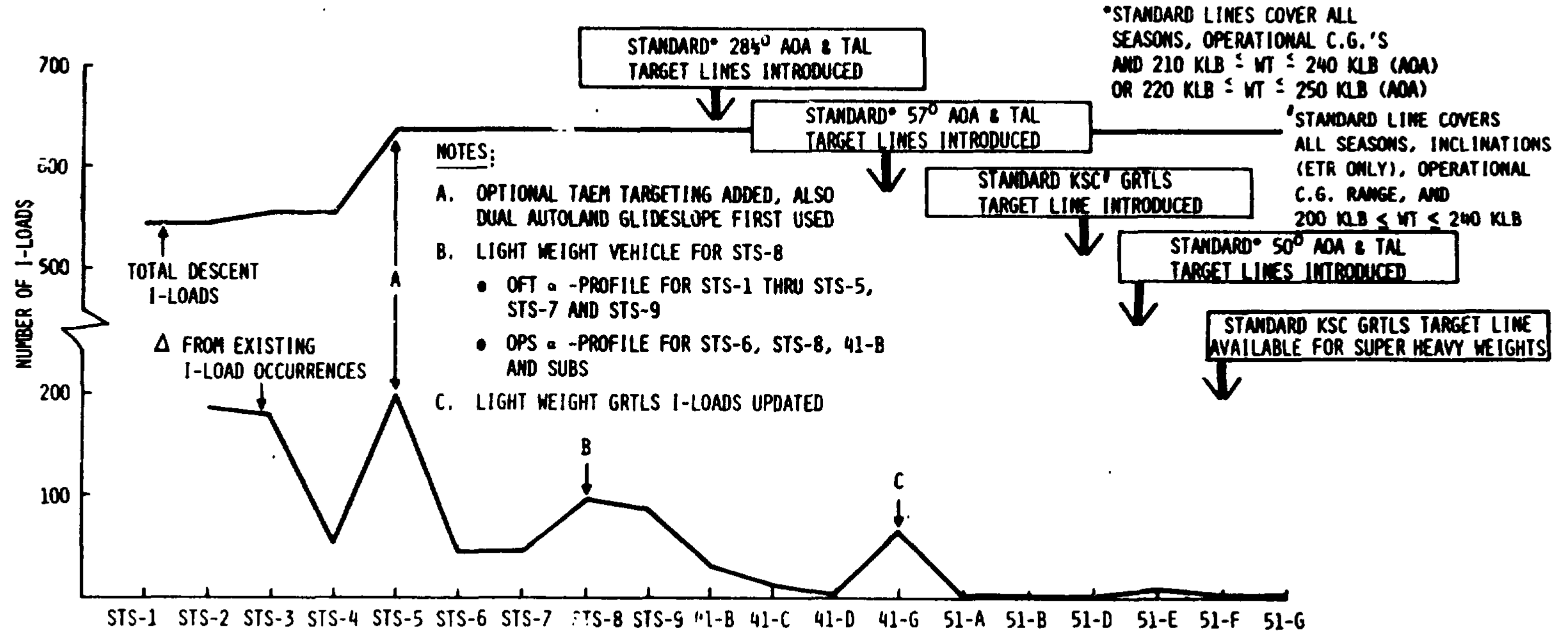
Equally important to I-load design in terms of the magnitude of the engineering job is the design of "target lines" or required initial conditions for the descent portions of the intact abort modes: abort-once-around (AOA), transoceanic-abort-landing (TAL), and glide-return-to-launch-site (GRTLS). Standard target lines were introduced as indicated on Figure 1. Along with standard target lines and I-loads, efforts were directed toward standardizing or eliminating other reconfiguration products as was technically and politically feasible. Taken together, these three efforts significantly reduced the manpower required for flight-to-flight reconfiguration and also (but to a much lesser degree) the Univac computer usage (see bar charts on Figure 1).

The two jobs discussed above, i.e., the "custom" designs for the early flights and the certification of designs, were fundamentally different. The custom designs required repeated cycles of design and test (via digital simulations) to provide a trajectory with the best balance of subsystem performance and energy management. Certifying a design as standard, on the other hand, required the analysis of literally thousands of simulated trajectories. Multiple sets of 100 dispersed atmospheres and varying wind magnitudes from every direction needed to be considered for different weights, centers-of-gravity, months, landing sites, and runway approach directions. Of course, different types of computer tools were needed for these jobs.

The remainder of this paper discusses the evolution of the tools for the job from the perspective of the MDTSCO descent design engineering community. All things considered, the initiatives with respect to tool evolution represent MDTSCO's most significant contribution to affecting the transition to an operational environment. Included will be observations and "lessons learned" on approaches to tool development and configuration control.

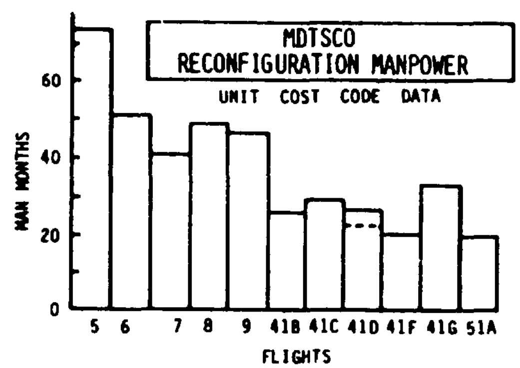
FIGURE 1

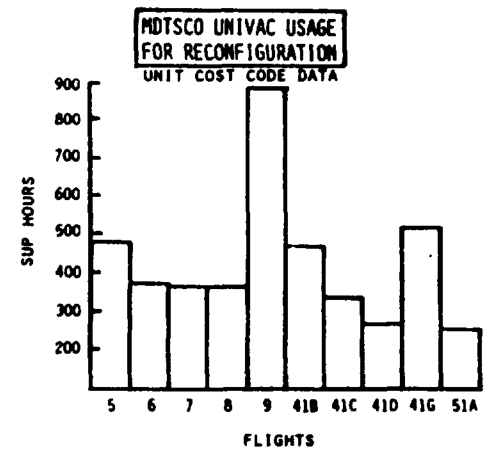
DESCENT STANDARDIZATION PROGRESS



OTHER STANDARDIZATION

- ABORT D-TAPES AND FDF INPUT
- MCC AND ONBOARD DISPLAY INPUTS
- TERMINAL AREA WIND PLACARDS
- RUNSTREAMS FOR MANY PRODUCT APPLICATIONS





TOOL EVOLUTION: FIRST AND SECOND GENERATIONS

Four separate generations of tools have evolved for the descent design job, as depicted in Figure 2. Tools available initially were three and six degree of freedom digital simulations. Considerable effort was dedicated in the 1974, 1975, and 1976 period to developing tools to provide improved means for I-load and target line design. For the entry phase (400000 feet to 2500 fps) batch Fortran programs were developed to map subsystem constraints into the trajectory design plane of interest (drag deceleration versus velocity) and to automate a target line definition process. Desk top calculator programs were also developed to supplement the Fortran programs on the Univac. Design of the lower speed trajectories was done with special purpose simulations and manual processing of the data. In general, this generation of tools evolved as separate entities requiring manual data interfaces (via cards) and manual post-processing (hand plots). Design operations with these tools began to break down as the rate of re-design requests increased; this increase was due to aerodynamic and aero-heating/thermal protection model updates, and mass property changes. Problems encountered with these tools included long design cycles (due to one day turnaround on batch programs) and program setup errors (due to the large amount of data needing to be manually transferred). At the same time, there was resistance to building better tools because all available resources were required for processing the redesign requests.

Not withstanding the workload, prototype modules of an interactive design system for the entry phase were developed on an extra hours basis. The concept of interactive design and testing on demand, with electronic data transfers was demonstrated and "sold"; funding was obtained for development of a complete Descent Design System (DDS). Key features of the system are that it (1) is interactive in that the engineer can iterate design steps to his liking on demand, (2) provides the design and test capabilities to refine a trajectory design from one workstation, (3) provides key data summaries and electronic data transfers to minimize routine manipulations by the engineer, and (4) allows intermediate solutions to be stored so the design can easily be resumed at a later date. It is important to note that the fundamental design process was not changed. Rather, the design steps were modeled as required and then tied together to eliminate trivial operations by the engineer. Subsequent projects in other areas seemingly sought to automate the complete design process and struggled for a long time before being able to claim success. The less ambitious approach used on DDS, where engineering judgement was left with the engineer, resulted in relatively early gains and acceptance. Estimates of the savings provided by the second generation tool (DDS) over the first are presented in Table 1:

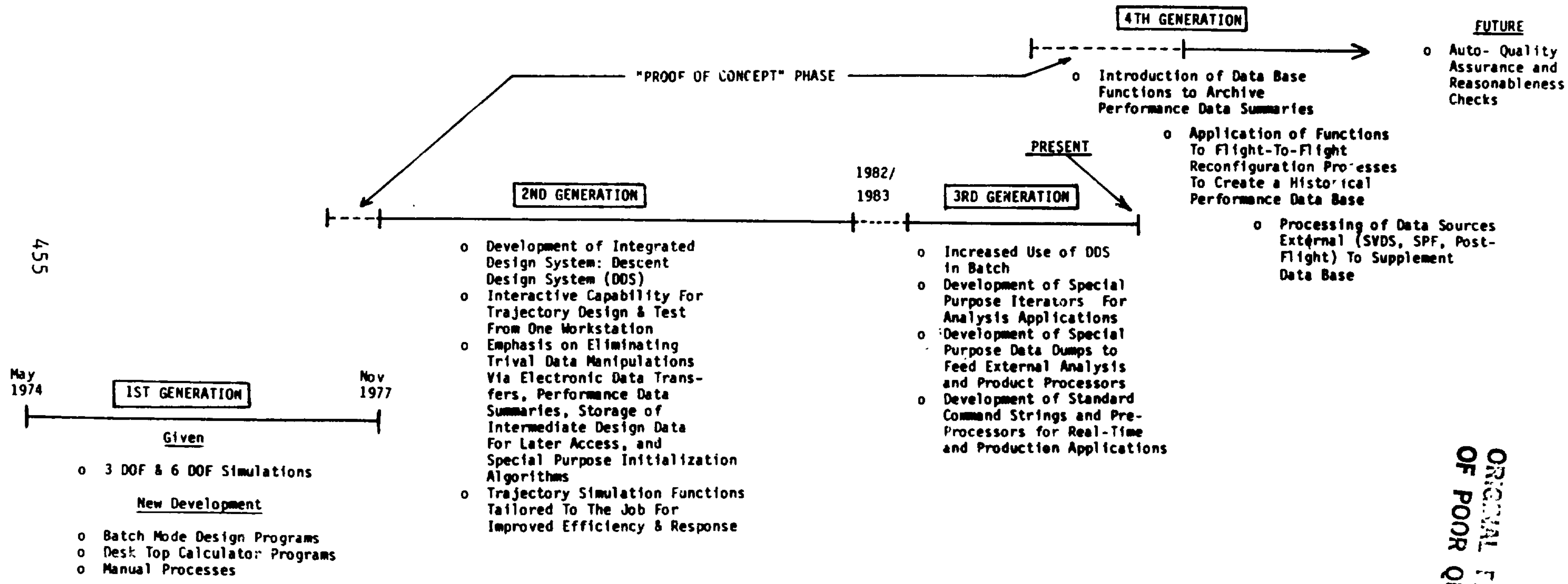
TABLE 1

REPRESENTATIVE TIME SAVINGS WITH THE DDS

		PRE-DDS	W/DDS
ENTRY	MAN-DAYS EFFORT	65	20
	COMPUTER TIME (HRS)	10	4 1/2
TAEM	MAN-DAYS EFFORT	35	14
	COMPUTER TIME (HRS)	5 1/2	2 1/2
AUTOLAND	MAN-DAYS EFFORT	25	10
	COMPUTER TIME (HRS)	6	1 1/2

NEW DESIGN OF MODERATE COMPLEXITY ASSUMED
DATA IS REPRESENTATIVE FOR ORBITAL FLIGHT TEST PERIOD

FIGURE 2
TOOL EVOLUTION FOR DESCENT DESIGN



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DDS Development Process

Development of the DDS was done by two separate groups under separate management. One group provided for requirements development and the other group provided for development of the software. Figure 3 presents the organizational interfaces. Frequent interactions between the designers and requirements developers were crucial. Functional level requirements for each major processor were first reviewed with the design community and the system developers. Concepts were openly discussed and a consensus was reached. Basic architecture of the software, including development of the executive and data storage software, was able to proceed at this point; highly experienced software system developers, i.e., not flight design engineers, produced a system design that proved to be feasible, expandable, and easy to use. It is doubtful the DDS would be as useful as it is today without the sophisticated engineering performed upfront by the software system developers.

Development of this second generation design tool spanned roughly five years and required a total effort on the order of 30 to 35 man-year-equivalents (60% of that being software developer effort and 40% being requirements developer effort). Operational software was first released about a year after development was begun; additional capabilities were then periodically released. A large number of change requests (about 150) were processed in this period of initial use. Responsive processing of these change requests from the user community was maintained throughout this period. This responsiveness was crucial to gaining early acceptance of the system. The requirements and software developers maintained close contact and communicated frequently.

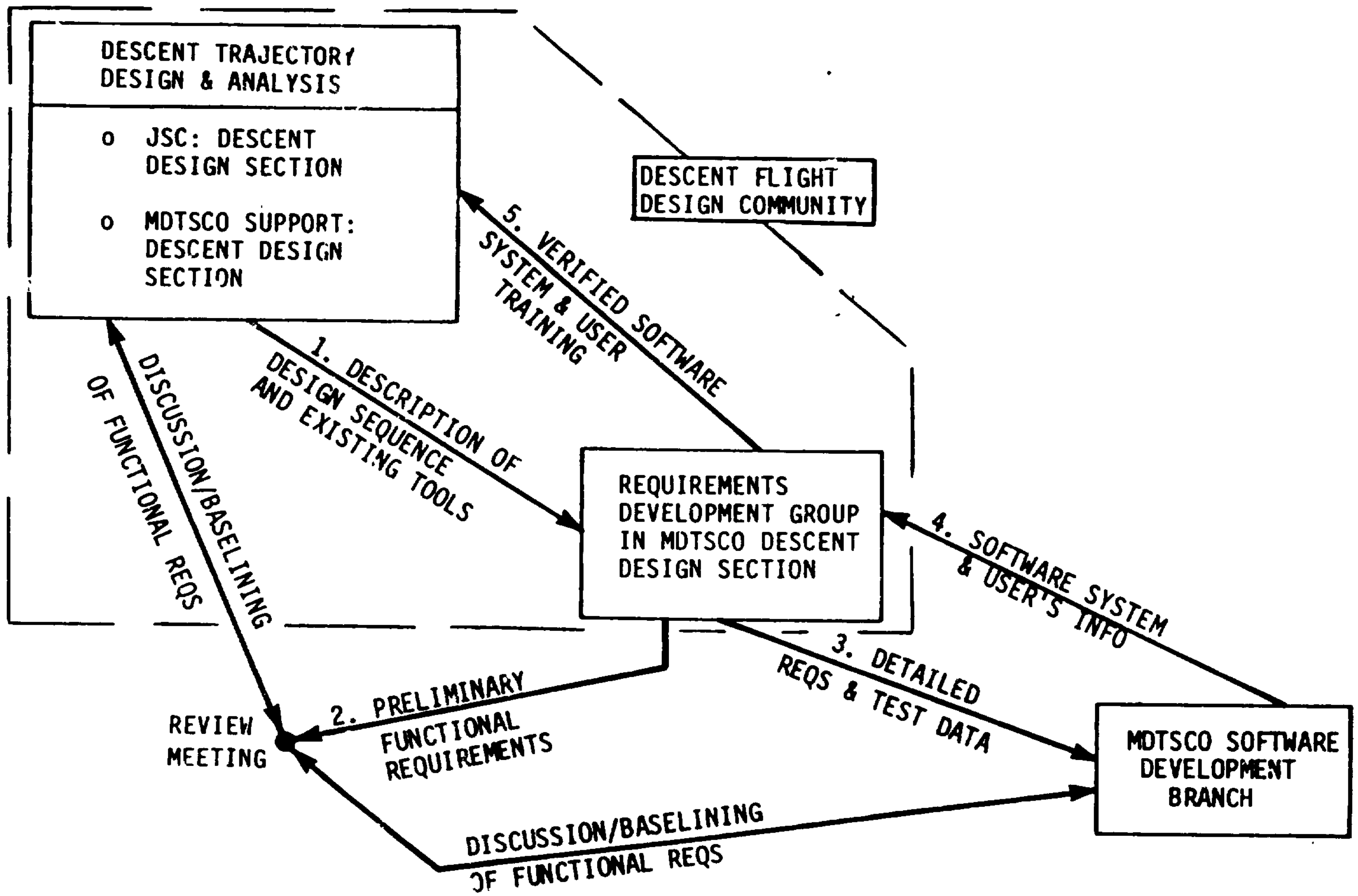
TOOL EVOLUTION: THIRD AND FOURTH GENERATIONS

Movement into the third and fourth generations of tools can be marked by two events: first of all, by the evolution of the descent design job from one of custom trajectory design to one of trajectory standardization and certification, and second, by the fact that DDS maintenance began to be done solely by members of the descent design community itself.

The transition of the descent design job to trajectory standardization and certification was accompanied by use of the DDS in the batch mode. Although originally engineered for interactive design applications, the DDS command structure proved to be well suited for constructing sequences of commands for generation of parametric-type data in the batch environment. Large quantities of data were generated to analyze trajectory energy management for many combinations of wind magnitude and direction, and for many different dispersed atmospheres. Initiatives were undertaken to streamline the handling of this data by establishing special data dumps to disk file for further processing by special purpose software. In many instances, special purpose iterators were developed within DDS to seek out solutions for different analyses. Most analyses for defining target lines and standardizing or certifying I-loads are now handled with this approach, i.e. with electronic data

FIGURE 3

ORGANIZATIONS & INTERFACES IN DDS DEVELOPMENT



transfers from DDS to disk file for further processing by another program. It is hard to conceive at this time how the standardization job and initial analysis of the Western Test Range environment could have been done any other way. A considerable number of routine products for flight-to-flight reconfiguration are also done using this approach.

Recently, initiatives were undertaken to introduce functions in the DDS capable of building a true performance data base. Kev performance parameters can now be stored along with the data describing the orbiter configuration, e.g., weight and center-of-gravity, and environment, e.g., atmosphere. The intent is to use the functions routinely on certain flight-to-flight reconfiguration products to build a historical data base. This data base will then be able to be processed to identify flights with a precedent and provide a means for more reliable quality assurance. Ultimately, automatic quality assurance checks are envisioned using this data base and other encoded reasonability checks. Currently, these reasonability checks are only able to be performed by a few highly skilled individuals. This data base activity, however, is still in the proof-of-concept stage (see Figure 2), similar to the stage that preceded development of the original DDS itself.

The fact that the descent design community developed and maintains the third and fourth generation tools has presented very few problems. Needless to say, the timeliness of new capabilities coming on-line, and the associated gains in productivity, have outweighed any problems. Mild controls were implemented for multi-user software. Included are a change request/discrepancy report system, publication of release notices and user information when versions are to be updated, and regression test procedures (although improvement is needed here in some areas). Engineers are free to develop experimental versions of DDS for their own applications, but are encouraged to document the software requirements via change requests or memo when their algorithms have matured; this allows their features to be available and current when subsystem models or other changes are brought on-line.

CONCLUSIONS

The experiences of the MDTSCO descent design support team point to a couple of major conclusions. First is that the tools must evolve with the job. Descent required integrated, interactive trajectory design tools during the flight test era. However, as the operational era approached, descent required the capability to process lots of data very quickly. The descent experience indicated these two capabilities were able to be performed by one system (DDS). Two factors seem to have contributed to this: (1) that sophisticated software systems expertise was brought to bear on the early system design; a flexible, easy-to-use, and growth-oriented structure resulted; and (2) that the engineering evaluation process was left with the engineer; no attempt was made to automate the start-to-finish design process. Trajectory design criteria were too soft and dynamic to allow "automatic" design; eliminating trivial operations via electronic interfaces and summary displays proved most useful to descent. Tool evolution, however, often meets resistance; there often is a tendency to succumb to the pressure of getting the job at hand done with available tools. But this must be overcome.

The second major conclusion is that tool improvements are best developed in an "open-shop" environment; engineers need to be free to experiment with new algorithms and develop them during initial application to real problems. Much overhead can be spared if algorithms are allowed to mature from infancy through adolescence before formally documenting their software requirements. Many of today's engineers are trained and quite adept at using the computer to eliminate their menial tasks. Encouraging them to do this can provide dramatic results and productivity gains. As well, many engineers gain considerable satisfaction from formulating algorithms for their applications. Software tools that come into use by more than one person, though, need to be subjected to some form of control. The descent experience indicates a very mild form of configuration control is adequate; excessive controls stifle creativity and productivity improvement.

Notes on the Authors

Tim Crull received a BS in Aerospace Engineering from Iowa State University in 1972. He has worked on the descent design support team at MDTSCO since June in 1974. Tim is currently the Section Chief of the team.

Ed Hite received a BS in Aerospace Engineering from the University of Kansas in 1978. He has worked on the descent design support team at MDTSCO since then. Ed currently leads the unit responsible for entry phase design.

COMPUTER-ASSISTED DESIGN AND ENGINEERING

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N86-15198

Productivity Increase Through Implementation of CAD/CAE Workstation

Linda K. Bromley
NASA/Johnson Space Center

ABSTRACT

On January 15, 1985, the Tracking and Communication Division Computer Aided Design/Computer Aided Engineering System became operational. This system, located in the Electronic Systems Test Laboratory in Building 44 at the Johnson Space Center, is presently being utilized in an effort to automate certain tasks that were previously performed manually. These tasks include detailed test configuration diagrams of systems under certification test in the ESTL, floorplan layouts of future planned laboratory reconfigurations, and other graphical documentation of division activities.

This paper will examine the significant time savings achieved with this CAD/CAE system in the following areas; 1) input of drawings and diagrams, 2) editing of initial drawings, 3) accessibility of the data, and 4) added versatility.

It will be shown that the Tracking and Communications Division's Applicon CAD/CAE system, with its ease of input and editing, the accessibility of data, and its added versatility, has made more efficient many of the necessary but often time-consuming tasks associated with engineering design and testing.

INTRODUCTION

The Research and Engineering Directorate of the Johnson Space Center is entering a challenging time. The directorate has the requirement to provide reduced, yet continuing quality support of the Space Shuttle as it moves into an operational stage, and at the same time, to begin the design and test of the even more complex Space Station, all in the light of ever tightening budgets. This challenge will require increased productivity in all areas of our work. One method of obtaining additional productivity is through the greater use of Computer Aided Design and Computer Aided Engineering (CAD/CAE) systems.

These systems will not only expedite many of the tasks that we presently perform manually, but will also enable us to perform additional engineering and managerial tasks that will ensure a better quality product, reducing the need for costly redesign.

The thrust of this paper is general in nature, discussing areas that can be made more efficient with most CAD systems. However, in order to present specific examples of uses and calculations of documented time savings, a specific CAD system and usage will be detailed. The system used is the Applicon CAD System located in the ESTL in building 44.

Current System Capabilities

The TCD Applicon CAD/CAE system was initially bought as a "bare-bones" system. As shown in Figure 1, the system consists of a single workstation ran from a stand-alone VAX 11/750 (packaged by Applicon). The workstation consists of a 19" color raster-scan CRT with specialized keyboard and function keys, a 11 x 17-in. digitizing tablet with electronic stylas, a thermal hard copy unit for quick screen copies, and an accompying VT100 terminal for system operation, editing, and other non-graphical functions.

Currently only the basic graphical software, the Applicon Editor, is running on the system. This software allows both two and three-dimensional drawings, eight colors, user-definable line weights and patterns, associative data base management system, user-definable symbol libraries and tablet menus, access to over 32,000 "layers" (logical partitioning of the graphic drawing), dimensioning features (extension lines, arrowheads, text, units, etc.), plus an assortment of other features that facilitate a users ability to create, edit and plot graphical information.

The input of the drawings is done in geometric form using any one or combination of methods available in most CAD systems. Powerful, convenient screen menus are usually used to present the operator with lists of executable commans, eliminating the need for mnemonic memorization. By successive menu picks users specify desired operations and command execution. In the Applicon CAD system, additional tools, such as on-line HELP documentation, enable users to minimize the number of menu picks and easily advance through the menu structure, making it especially easy to learn and use. Experienced Applicon users can adjust the level of prompting or frequency of menu display to suit their own degree of familiarity. These are two very important factors in the selection of a CAD system: 1) Ease of use so that non-programmers can operate the system in a productive manner with a minimal amount of training, and 2) versatility of the system to present increasing capabilities as the experience of the operators increase.

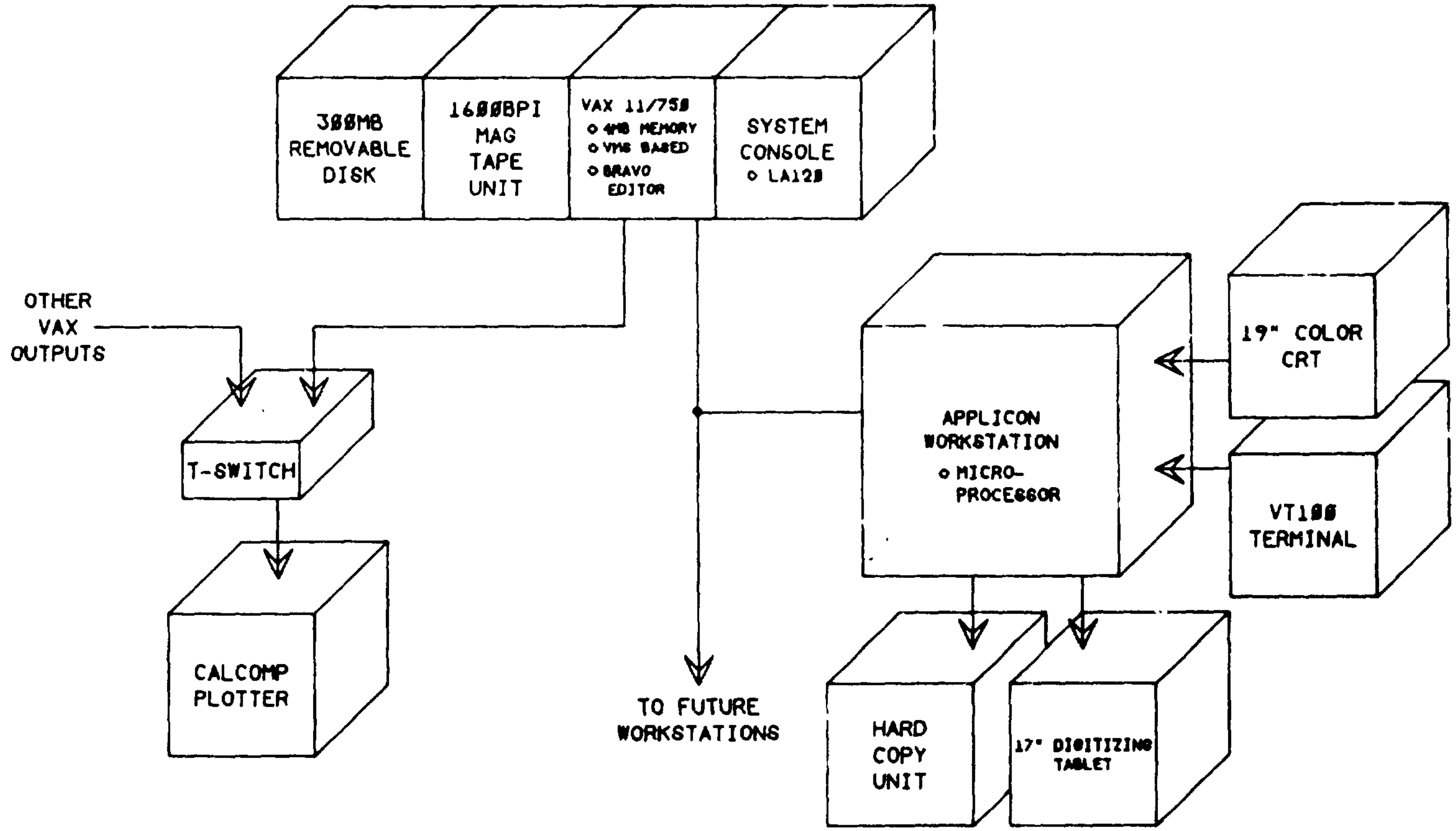


FIGURE 1 CURRENT CAPABILITIES

By supporting a variety of input devices at a workstation, CAD systems provide a considerable degree of flexibility in meeting the needs of individual operators. The Applicon CAD system, for example, has five different ways to input data and commands:

1) Special function key
2) Alphanumeric keyboard commands
3) On-screen menu selection using stylas
4) Tablet symbol
5) Digitizer tablet menu button

The 16 special function keys are used to - select the corresponding on-screen menu item. The alphanumeric keyboard, including its cursor control keys and numeric keypad, is used principally for entering textual data and as an alternate method of command entry. The most powerful method of data entry is through the pen and tablet combination. In addition to providing the ability to make screen menu picks, the tablet may be overlayed with a matrix of user-defined functions that can be easily invoked by touching the pen to a tablet region. Operators have full control over the location, physical size, and logical dimensions of the tablet menu as well as the function of each matrix element. Tablet menus may be saved and restored by name, and several nonoverlapping menus may be simultaneously accessed.

Applicon's tablet symbol recognition capability provides a powerful, convenient, and effective means for construction and manipulation of geometric data and general interaction between system and user. With this feature, operators may use hand-drawn symbols, which are interpreted as commands or a series of commands from which geomeric information may be extracted. For example, a sketched letter C might stand for the command to center the current view about a point corresponding to the center of the C symbol, a command normally requiring several menu picks.

Future Expansion

It is planned to augment this basic system with additional software application modules which fit neatly into the basic system software leaving the user interface I/O unchanged. A future module to be added will allow a user to rapidly input an electrical schematic, with any combination of analog or digital devices, in their component or gate form. Once the schematic has been created and edited as necessary, this software will take the schematic, create a printed circuit (PC) board layout, convert the gates into their IC form, automatically place the components optimumly on the board (although this can be totally or partially done manually), and perform automatic routing for up to an eight layer PC board.

Other modules exist for applications requiring solids modeling, finite element analysis, and facilities management should the need arise for these features in the future.

DRAWING INPUT

One of the first areas that can be made more efficient is when drawings are first converted from a rough sketch into a more formal form. When performed manually this may be performed by engineers, facility personnel, or trained draftsmen, depending on the quality of output desired. The creation of a drawing in CAD systems can also be performed by the same type of people. But, just as draftsmen and engineers are required to take the drafting courses as part of their studies, CAD personnel will also require new skills.

Training

These personnel will require training in order to use the CAD system efficiently. The amount of training required varies greatly with the CAD system selected and the depth of knowledge required. Even smaller PC-based CAD systems may require a significant amount of training before becoming truly productive. But, with proper attention paid to this aspect during the selection process, CAD systems can be found that require only minimal training. Larger CAD systems often have enough versatility that will allow new personnel to quickly become productive by learning to basic commands, yet still be able to grow in capability as the operator learns new, more "elegant" commands. In such large systems it is often best to have at least one person thoroughly trained. This may involve sending them to a formal 1 or 2 week class that is usually taught by the vendors from which the CAD system is purchased, followed by additional time with the system for further study. With most CAD systems, a month of intensive study should produce a well trained CAD specialist. This specialist can then train other CAD operators to whatever degree necessary.

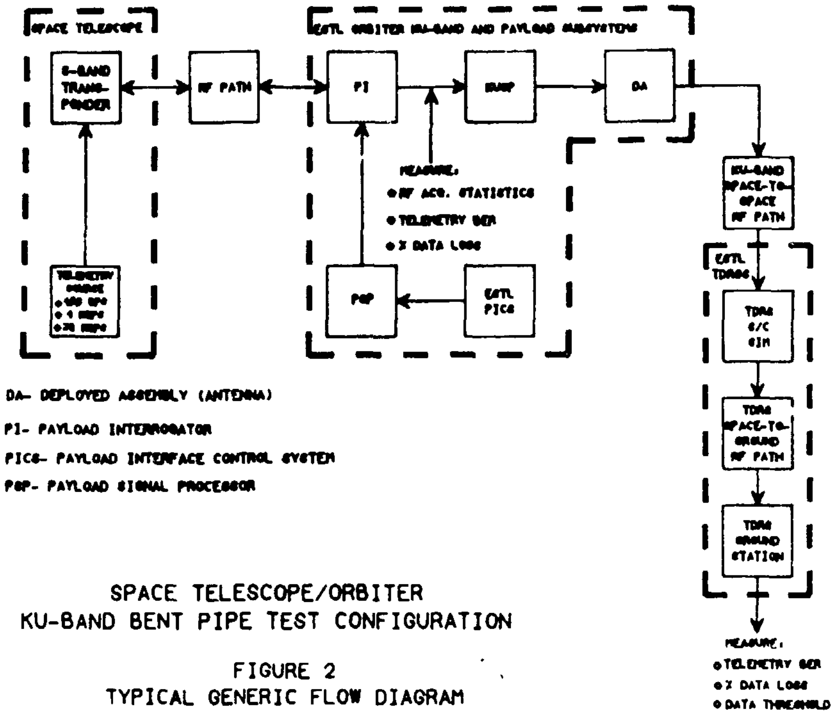
The larger, more versatile CAD systems can then be "customized" to fit the specific needs of the users. This can be done by setting up procedures, special menus, and libraries that can greatly simplify data input. Once this customizing is completed, new operators usually need only a few days training to begin to produce high quality drawings. As their familiarity with the system increases, so will their productivity as it begins to take less time to produce their drawings.

Input Example

As a major communications system test facility, the Electronic Systems Test Laboratory (ESTL) performs numerous highly detailed and complex testing involving numerous pieces of test evaluation, space environment simulation, and data recording equipment in addition to the systems under test. In order to document and control the entire configuration of the equipment involved in the testing of a system, detailed drawings are produced. These drawings are first created months prior to the start of a test as part of the pre-test documentation which includes Test Requirements and Status (TRAS) reports, Interface Control Document (ICD), Test Plan, and Test Procedures. In addition to supplying information to the Test Team as to how and what tests are to be performed, they are also used for scheduling and calibrated equipment cycle planning, ensuring no problems will occur from either conflicts from concurrent running tests, or due to a needed piece of test equipment having been sent to the calibration lab and thus unavailable.

These test configuration diagrams come in several forms. The first and more generic are simply signal flow diagrams using general blocks to depict systems involved. A typical diagram of this type is shown in Figure 2. These diagrams are used in the early stages to convey general concepts and systems that will be involved in a test. The next type of diagram is slightly more detailed. The generalized blocks of the generic diagram is replaced with a more detailed representation of each of the systems, as shown in Figure 3. A set of these drawings are produced for each type of test (e.g. Bit Error Rate, Percent Data Loss, Signal-to-Noise Ratio, etc.) as it is performed, depicting the exact configuration. In addition to the more detailed system information, the test equipment (such as oscilloscopes, data generators, spectrum analyzers, etc.) that was used to perform the tests is also shown. These drawings give a better insight to the scope and magnitude of the tests, and what specific equipment was used. Both the generic and detailed diagrams that are produced at this stage are drawn on 8.5 x 11 inch paper for inclusion in the pre-test documentation, management and test team briefings, and other presentations as necessary.

The final type of drawing that is used is an even more detailed version which includes specific information to the test team such as patching information for each signal (equipment rack number, patch panel jack number, pin number, etc.), type of signal to expect (NRZ-L, Bi-phase), data rates, frequencies and any other information to properly setup the configuration. Figure 4 shows an example of this type of drawing. These drawings are referred to as "bluelines" since the amount of detail require that these drawings be presented on size D paper and copies subsequently produced on blueprinting machines.



SPACE TELESCOPE/ORBITER
KU-BAND BENT PIPE TEST CONFIGURATION

FIGURE 2
TYPICAL GENERIC FLOW DIAGRAM

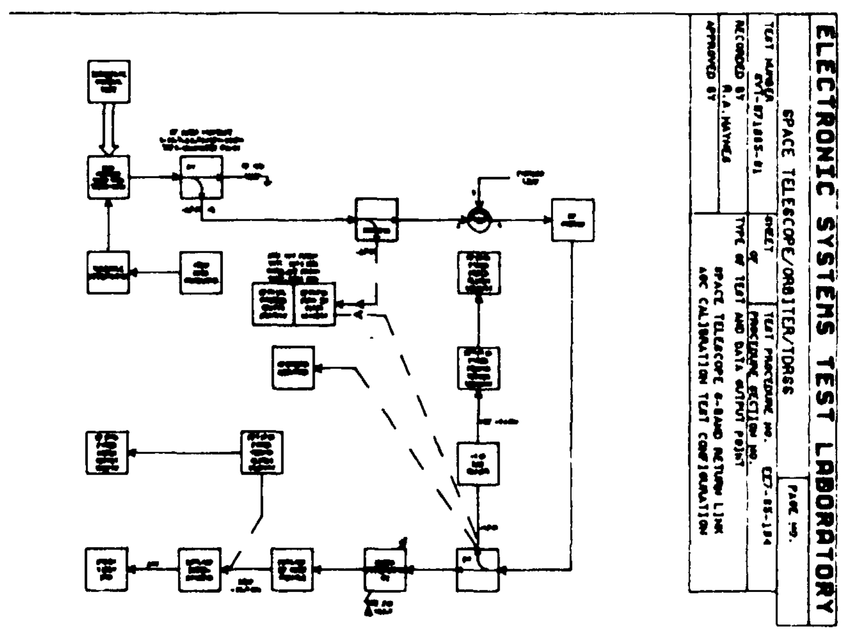
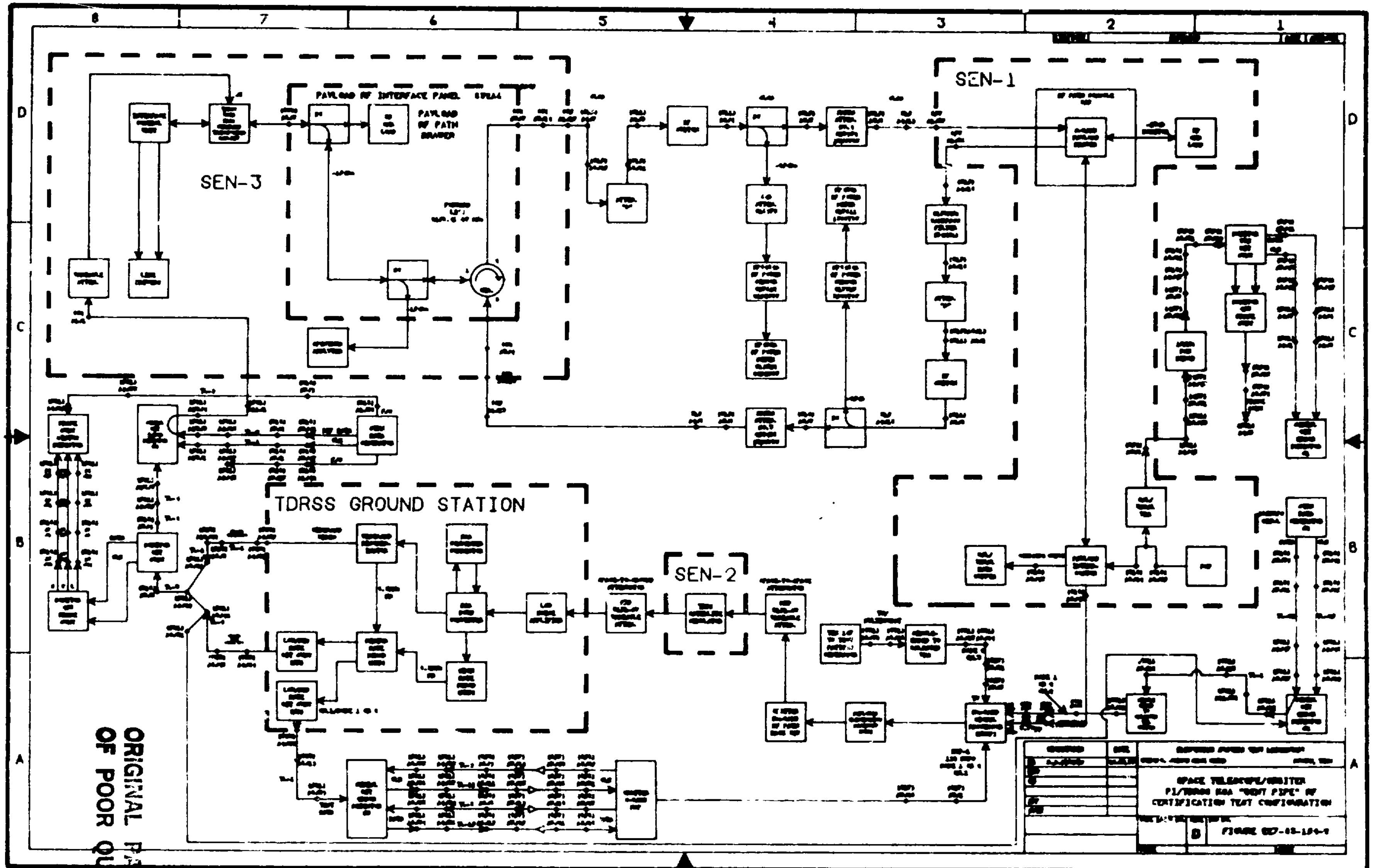


FIGURE 3 TYPICAL DETAILED DIAGRAM



ORIGINAL PAGE IS OF POOR QUALITY

FIGURE 4 - TYPICAL "BLUELINE"

Time Saving Example

In the past, all three types of drawings (generic, detailed, and bluelines) were manually drawn by laboratory personnel. This process involved first having the test project engineer draw up a preliminary sketch of the system to be tested, in both the generic and detailed forms. These sketches were given to the graphics personnel to be redrawn more rigorously and to be placed in a presentable form. All work was done using templates and curves with hand lettering. As information became available, the larger, more detailed "blueline" configurations were sketched and given to the graphics personnel for drawing. On the average, this initial drawing stage required approximately 2 hours for the generic, 3 hours for each of the detailed, and 7.5 hours for the bluelines. For a typical test phase, there is usually 5 generic drawings made, 12 detailed, and 3 bluelines. Therefore, the initial drawings for a given test represented 68.5 hours of manual drafting. Table I summarizes these results.

Using the CAD system, the basic process of acquiring the initial drawings from the test project engineer is still the same. However, now the sketches are input into the CAD system, with the results displayable onto the high resolution screen or plotted on a CALCOMP plotter that is time shared with the other Division computers. Using the same example as for the manual input method stated above, the time to input these drawings can be reduced to .5 hour for each of the 5 generic drawings, 1 hour for each of the 12 detailed drawings, and 3.5 hours for each of the 3 bluelines. Thus, the total time for each test phase can be reduced from 68.5 hours to 25.0 hours. In terms of hour savings, this represents a 174 percent increase in productivity.

EDITING

In many applications most of the time is not spent on the initial construction of the drawings, but in the editing of the drawing due to changes, errors, updates, etc., as it passes through various technical and managerial review cycles. When these drawings were being manually produced, these changes would require either the use of liberal quantities of Liquid Paper or a complete redrawing.

The drawings entered using the CAD system are more readily edited. The drawing to be changed is first recalled from disk storage and displayed on the screen. Most CAD systems provide a host of editing commands to conveniently change drawings. For example, one might be a MOVE command which will allow certain portions of the drawing to be selected and moved to another area to make way for new geometry to be added. Using a manual drawing system, this would require the draftsman to use Liquid Paper, the "cut-and-paste" method, or a complete redraw. With a CAD system like the Applicon, this move would take only one command string and be accomplished in seconds. Other types of editing, such as the deletion of geometry and test editing, have similar time-savings when performed on CAD systems.

TABLE I

TIME SAVINGS EXAMPLES FOR DATA INPUT

DRAWING TYPE	QUANTITY REQUIRED	MANUAL INPUT TIME/DRAWING (HOURS)	MANUAL INPUT TOTAL (HOURS)	CAD INPUT TIME/DRAWING (HOURS)	CAD INPUT TOTAL HOURS
Generic	5	2.0	10.0	.5	2.6
Detailed	12	3 0	36.0	1.0	12.0
Bluelines	3	7.5	21.6	3.5	10.5
		TOTAL MANUAL =	68.5	TOTAL CAD =	25.0

$$\text{PRODUCTIVITY INCREASE} = \frac{(68.5 - 25.0)}{25.0} \times 100 = 174 \text{ Percent}$$

TABLE 2

TIME SAVINGS EXAMPLES FOR EDITING

DRAWING TYPE	QUANTITY REQUIRED	NO. REVISIONS PER DRAWING	MANUAL EDITING TIME/DRAWING (HOURS)	MANUAL EDITING TOTAL (HOURS)	CAD EDITING TIME/DRAWING (HOURS)	CAD EDITING TOTAL (HOURS)
Generic	5	1	1.0	5.0	0.1	0.5
Detailed	12	2	1.0	24.0	0.2	4.8
Bluelines	3	4	4.5	54.0	1.5	18.0
			TOTAL MANUAL =	83.0	TOTAL CAD =	23.8

$$\text{PRODUCTIVITY INCREASE} = \frac{(83.0 - 23.8)}{23.8} \times 100 = 248 \text{ Percent}$$

Time Saving Example

In the ESTL test diagram application, these revisions occur on the average of once for each generic drawing, twice for each detailed drawing, and four times for each blueline. Unfortunately, the more complex blueline drawings receive more editing than the other simpler diagrams. The bluelines are produced before the tests are performed and at that stage represent more of a recommended patching configuration. Due to its complexity, the bluelines are usually edited twice prior to test start. As the tests are being setup, these bluelines are edited twice to reflect the patching that was actually used. Sometimes alternative routing has to be used, rather than the recommended route, due to test equipment failure or to allow for other tests being run simultaneously.

Using the manual method these revisions represent a total of 83.0 hours for a typical test. (Table 2 shows a detailed breakdown of this total). Using a CAD system, editing time can be reduced to 23.8 hours (see Table 2), representing an increase in productivity of 248 percent for the editing process.

Total Data Input and Editing Savings

Using the totals generated in Tables 1 and 2, the combined total time required in both the editing and data input process represents 151.5 hours for the manual method versus 48.8 hours for the CAD system. This represents a total productivity increase of 210 percent for these combined stages.

A true productivity calculation for the overall comparison of the manual versus CAD system would also have to include other areas such as training time for both methods, time involved in sending drawings from engineer through organizational chain to draftsmen or operator, etc. However, since documented time measurements of these items were not available, these additional factors will not be included.

DATA ACCESSIBILITY

An added feature of CAD-based graphics is the increased ability to readily retrieve and archive data. Graphical drawings or models that are most often referenced or used can be stored on the disk systems that are usually a part of a CAD system. Smaller PC-based CAD systems often have storage on removable floppy disks that can be stored for later use. Larger CAD systems will provide some combination of magnetic tape and high capacity disk storage. The disk storage of these larger systems will contain the operating system and most often referenced drawings, as well as the current drawings being created or edited. Drawings that are no longer required can be copied onto magnetic tapes and archived.

When properly setup, a CAD-based graphics system can eliminate or greatly reduce the overhead of manually maintaining a drawing library. Most facilities will want to keep a hardcopy file of all major drawings even in a CAD-based environment in the event that the system is down when a drawing needs to be referenced. However, by taking advantage of the databasing, cataloging, and security features provided by most large scale CAD systems, the maintenance of such a library can be reduced. One of the problems with maintaining a manual library is the need to either store several copies of a drawing or enforce strict controls over checking out drawings for reference or to make copies. Then when a single change is made to one of these library masters, new copies must be made/maintained and all those that have the old copy checked out must be informed of the changes and given new copies.

In CAD systems, however, the drawings are maintained in electronic form. A drawing is "checked out" by a user calling it up for display at his workstation. Since all updates are automatically maintained by the computer system, a user is assured that he is viewing the latest version. As with manual systems, a proper indexing system must also be used in CAD systems so that the exact file can be rapidly located when a given drawing is to be displayed or edited. Many CAD systems have system software that will aid the user in this cataloging, such as showing a summary of all files contained in a given account. But, the efficient retrieval of a given drawing depends upon the procedures developed by each facility as to where files are stored and how to develop unique names for the files.

ADDED VERSATILITY

One of the best features obtained from larger CAD-based systems, is the added versatility that can be gained. Not only do CAD systems create and edit manual drawings faster, but they can also perform additional functions. For example, once an item is constructed using solids modeling, one or two simple commands can produce the mass, volume, center of gravity, etc., of the model. The same type of commands that are used to create simple block diagrams can also be used to develop floorplans, electrical schematics, presentation slides, etc. Using features such as the ability to attach text to a geometic form can be used for inventory control. For example, starting with a 2 or 3 dimensional floorplan of the equipment contained within a laboratory, serial or model numbers can be "attached" to each piece of equipment. While the attached serial numbers can be invisible (not displayed to not to clutter the view), a single command could be sent so that the piece of equipment with serial number XXX would begin flashing for immediate location. Likewise, an accurate account of the number and location of desks, terminals or spectrum analyzers can be maintained. However, as with most computer databases, the accuracy of the data obtained is directly proportional to the accuracy of the data entered and the dedication of personnel to keep it updated.

An additional ability obtained from CAD-based modeling is the ability to make more accurate measurements for planning purposes. Once a floorplan of the facility has been made, some larger CAD systems like the Applicon can calculate the distance from any given set of points on the graph. This adds the ability to more accurately plan for the length of power or signal cables for equipment that is to be added to the laboratory in the future. The CAD system also enables the operator to find the optimum location for incoming equipment or furniture by editing the present floorplan to tryout different arrangements. This enables a facility to have a concise move plan and preventing the loss of production time by suddenly discovering after the equipment is in place that the power cable is too short.

CONCLUSION

This paper has discussed some of the advantages of employing CAD systems to accomplish significant savings in the time to produce drawings previously performed manually. In a documented example, it was shown that productivity increase of 210 percent can be accomplished in the drawing creation and editing process. It was also mentioned that additional productivity can be realized by taking advantage of other CAD features such as better accessibility of the data and added versatility.

The capabilities and applications of CAD systems described within this paper is but a small portion of that which is possible. It is often the case that once a CAD system is put in place, a myriad of unforseen applications will swiftly arise. Indeed, as CAD systems mature their capabilities will only be limited by our own imaginations.

AUTHOR BIOGRAPHY

Linda K. Bromley was born on May 28, 1951. She received her B.S. EE degree from the University of Oklahoma in 1973, and her M.S. in System Engineering from the University of Houston in 1978.

Ms. Bromley joined the National Aeronautics and Space Administration in 1973, and has been associated with the Electronic Systems Test Laboratory since that time. She has served in the capacity of Test Director, for performance and compatibility tests in the ESTL, in support of the Shuttle program. In addition to these duties, she serves as ESTL Software Manager and is responsible for all software relative to testing and data analysis. Ms. Bromley serves as the Tracking and Communications Division CAD Coordinator, and is a member of the Engineering Directorate CAD Panel.

N86-15199

R&D PRODUCTIVITY IMPROVEMENT AT HONEYWELL
A CASE STUDY

William E. Lyons - Honeywell Inc, Clearwater, Florida

ABSTRACT

This paper describes the problems encountered when computer-aided-design/documentation was applied to a large design program at Honeywell; how a study team was established to solve the problem; the techniques used by the team and the resulting solutions. The techniques used in this instance may be applied to other problem areas in the R&D process to improve productivity.

INTRODUCTION

Initial Computervision Computer Aided Design-Documentation (CAD-D) systems were installed at the Honeywell Clearwater facility as early as 1973, but not until the availability of the CADDS III software package in 1983 did the full potential for R&D productivity improvement become a possibility.

The program chosen for the initial implementation of the full scale CADDS III capability involved redesign of a large rocket engine digital control system. Although the system was typical of Honeywell's established display and control product technology, this particular controller design was more complicated than previous designs. The complexity and extensive documentation requirements made this program a logical candidate for testing productivity improvement potential of the CAD-D system.

The electronics design consisted of:

- Twenty digital boards averaging 10 layers in both printed wiring board (PWB) and wire wrap versions
- Eleven power supply boards averaging 3 layers in both PWB and wire wrap versions
- Forty multisheet schematic and assembly drawings
- Associated wire lists, drill tapes and artwork.

In the Spring of 1984 with the preliminary design complete, the electrical design group began releasing schematic data to the engineering graphics group responsible for CAD-D. Initially the documentation effort proceeded smoothly, and appeared to deliver the anticipated productivity improvement. Very quickly, however, routine schedule reviews revealed that the documentation, while moving within the system, was not being completed on schedule. Further, the status of a given document within the system could be determined only with great difficulty.

A technical study team was quickly established to determine what was happening and to recommend solutions for the problems uncovered. This paper describes the study team, its approach to the problem and the resulting solutions.

STUDY TEAM DESCRIPTION

Since an initial team goal was to solve the immediate problem impacting the ongoing program, a short intensive study schedule was established. A "full time" team was considered, but that approach was precluded by the simple fact that the best team members (those directly involved in the problem) were also those assigned to the ongoing program. Accordingly, a team was established with the following features:

- ***Small Membership.*** By using a small team with other participants on a consulting basis, key people were made available without adversely affecting the ongoing project.

- ***Team Ownership of Problem.*** By choosing those people closest to the problem, all involved functional areas were represented in an integrated approach.

- ***No Restrictions on Management Level.*** No arbitrary rules governed supervisory participation, so there were no artificial constraints to involving those closest to the problem.

- ***Working Meeting Format.*** The working meeting format provided "built-in" coordination and ongoing consensus since the team discussed and resolved all issues as they occurred.

- ***Flexible Meeting Frequency.*** By varying the frequency of the meetings, effective utilization of manpower was attained, again with minimum impact to program activity.

- ***Frequent Progress Reporting.*** Frequent progress reporting to management and reassurance that the team was "moving forward" resulted in minimal management intervention. Management did attend some meetings primarily to observe.

THE STUDY APPROACH

The team initially established the following approach: conduct interviews, review existing process descriptions, define basic problem and develop a "specification" for the solution. Reviews and interviews revealed three basic issues:

- Incomplete or inadequate CAD-D processes such as the software that transferred design data from the Computervision data base to a Honeywell mainframe computer
- Insufficient number of trained CAD-D personnel in the Engineering Graphics group
- Inadequate communication and poor coordination across functional interfaces, especially design engineering/engineering graphics.

Appropriate functional groups were already addressing some of the training and technical (process) problems such as the software interface mentioned above, and implementing some solutions. There were residual technical problems principally in software systems, but the study team decided that such problems should be resolved by those groups with primary functional responsibility without interference by the study team. The team's function regarding technical problems was to be one of identification only.

Those problems not technical- or process-related were found to be management type problems brought on by the new CAD-D technology. They were inadequate communication and coordination between functional groups, and lack of management control of the automated processes.

THE PROBLEM SOLUTION

The team decided to develop a "model" CAD-D process as a management tool in resolving communication/coordination problems and a "traveler" as a tool for implementing management control (a traveler is a routing form commonly used in production to move assemblies from one operation to another).

The Model Process Flow Chart

The first step in developing a model process flow chart was to create a requirement for the flow chart to define its purpose.

The key flow chart requirements for the model process were then established:

- Identify clearly the transition from computer-aided-design to computer-aided-documentation

- Identify and define key functional group interfaces

- Provide a process description (in summary form) for improved communication and training purposes

- Provide means for defining unique requirements of individual projects

- Serve as a framework for more detailed process descriptions when needed.

Using the available process descriptions from various sources as an information base, an integrated CAD-D summary flow chart was developed as shown in Figure 1. This chart is a condensation and integration of hundreds of individual steps within the total process. The ***key*** steps which are the numbered entries in each box are organized into stages (the boxes themselves). Note that the stages tend to identify the interfaces between design engineering and engineering graphics group. Other requirements for the flow chart were successfully met by this particular version.

The Traveler

The study team then prepared requirements for the traveler with the following key features:

- Identify the location and status of a task being performed on a document or group of documents

- Provide for management of tasks through the process by approval requirements at key stages

- Provide capability for cost/schedule tracking and visibility of iterations within the work flow.

With these requirements in mind, the study team evolved the CAD-D traveler in Figure 2. Note that continuity and compatibility between the model process flow chart and traveler are achieved by using the Stage number and Title from the model flow chart on the traveler. Additionally, the entire summary model flow chart is printed on the back of the traveler form for ready reference.

This single form, satisfying all the requirements established by the study team, was presented to management with the following recommendations:

- Revise the existing departmental procedures to provide for implementation of the traveler on a project-by-project basis and to specify which individual (by name) would have sign-off responsibility

- Implement an interim manual traveler tracking system; after completion of training, replace it with a simple computer-based system using existing terminals and computer programs.

All recommendations were accepted and the traveler has subsequently been used very successfully on two projects and has been specified for a number of future programs.

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FIGURE 1. CAD-D PROCESS FLOW CHART

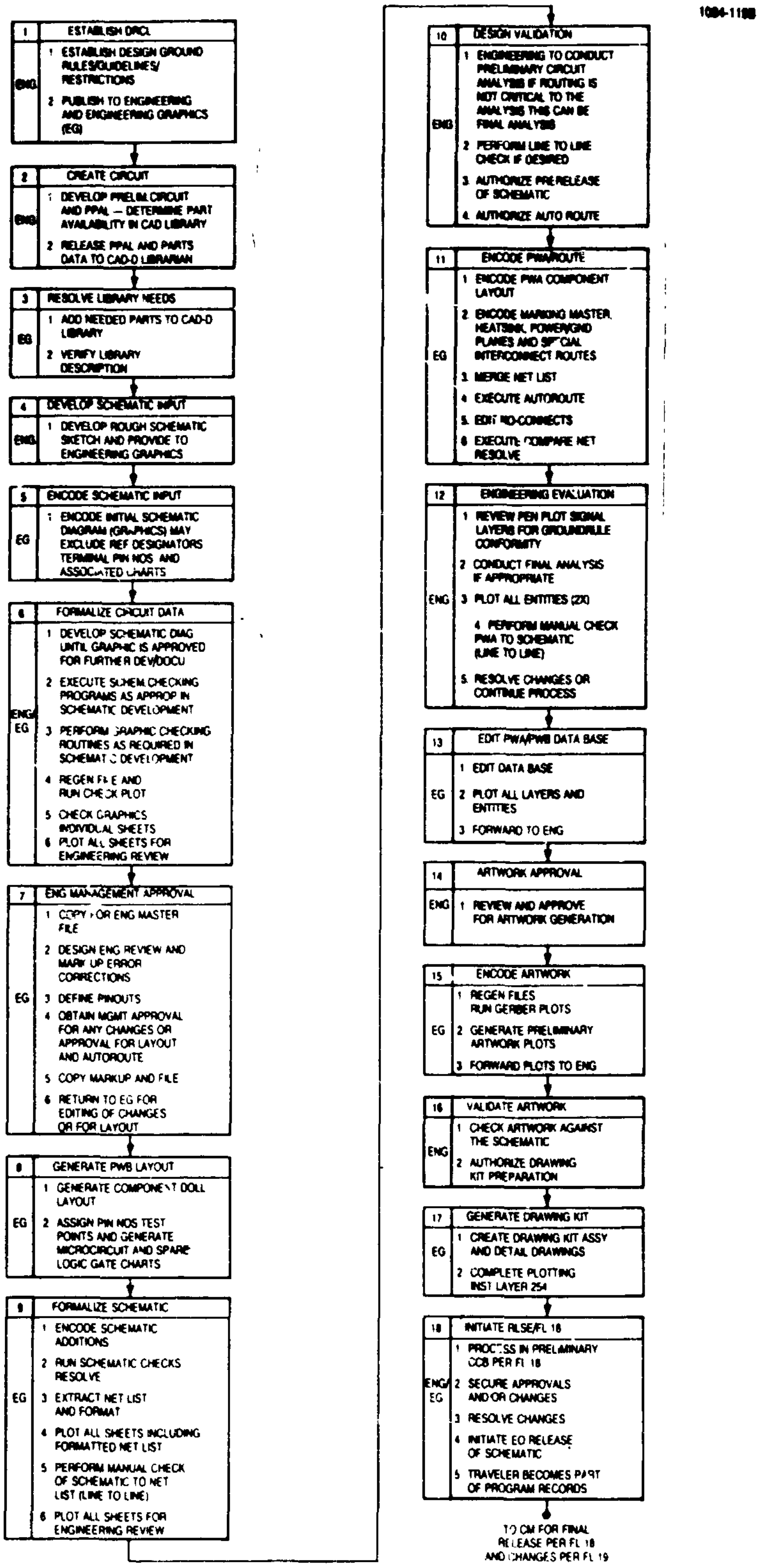


FIGURE 2. CAD-D TRAVELER

☐ Assembly Dwg#________

☐ PWA Detail Dwg#________

☐ Schematic Dwg#________

Board Name:________________

Board Designer:________________

Board Class:________________

Board Type:________________

Issue Date:________________

Program:________________

	Approval for New Cycle →													Cumulative Total Processing Cost %
Stage No.	Title	Cycle No. → 1	2	3	4	5	6	7	8	9	10	11	12	
1.	ESTABLISH DRCL													
2.	CREATE CIRCUIT													—
3	RESOLVE LIBRARY NEEDS													—
4.	DEVELOP SCHEMATIC INPUT													—
5.	ENCODE SCHEMATIC INPUT													5
6.	FORMALIZE CIRCUIT DATA													15
7.	ENG MGMT APPROVAL													20
8.	GENERATE PWB LAYOUT													30
9	FORMALIZE SCHEMATIC													35
10.	DESIGN VALIDATION													—
11.	ENCODE PWA/ROUTE													55
12.	ENGINEERING EVALUATION													60
13.	EDIT PWA/PWB DATA BASE													65
14.	ARTWORK APPROVAL													75
15.	ENCODE ARTWORK													85
16.	VALIDATE ARTWORK													90
17.	GENERATE DRAWING KIT													95
18.	INITIATE REL CCB/FL-18													100

Comments: See Other Side

Form Revision

SUMMARY

In analyzing what has been viewed at Honeywell as a small but very successful R&D productivity improvement, the following steps can be identified.

1. A team was established with emphasis on tailoring the team to the problem.

2. Team activity was structured to make maximum use of the limited time and personnel available to "work the study".

3. Problems were first defined and then a requirement "specification" for the solutions was developed.

4. Tools were then developed to meet the requirement specification.

5. Finally, the team followed up to assure implementation of the tools in the ongoing design process.

These steps are applicable to new studies of other portions of the design process and indeed have been successfully applied in part to the mechanical design process and also software development.

This study demonstrated that state-of-the-art technology often requires better or certainly different control systems than the old methods. New tools require new controls.

One final thought: Much progress has been made in developing techniques for productivity improvement of routine work and these techniques have been amply demonstrated both here and abroad. However, little progress has been made in productivity improvement of non-routine work and much of R&D is non-routine effort. R&D consists of a very long sequence of routine tasks connected not with a simple transfer between steps but with choices, decisions, assumptions and judgments; a study that focuses on the differences between routine/non-routine work and applies the above steps to the ***differences*** will shed new light on R&D productivity.

In conclusion, Honeywell appreciates the opportunity to participate in the NASA Conference R&D Productivity: New Challenges for the U.S. Space Program and is looking forward to sharing additional ideas and hopefully new successes with you in the future.

BIOGRAPHY

Mr. Lyons has thirty-five years' experience in engineering including design, support engineering, and management. The last twenty-five years he has been with Honeywell Inc. and he is currently a member of the systems engineering group of the program discussed in this paper. Mr. Lyons has BSME and BSEE degrees from the University of Alabama and a BSB degree from the University of Minnesota.

N86-15200

INCREASING PRODUCTIVITY OF THE MCAUTO CAD/CAE SYSTEM BY USER-SPECIFIC APPLICATIONS PROGRAMMING

Susan M. Piotrowski
Tom H. Vu
Lockheed-EMSCO

ABSTRACT

Significant improvements in the productivity of the McAuto Computer-Aided Design/Computer-Aided Engineering (CAD/CAE) system have been achieved by applications programming using the system's own Graphics Interactive Programming language (GRIP) and the interface capabilities with the main computer on which the system resides. GRIP programs for creating springs, bar charts, finite element model representations and aiding management planning are presented as examples.

INTRODUCTION

The extensive growth within the last twenty years of Computer-Aided Design (CAD), as well as the typically concomitant areas of Computer-Aided Engineering (CAE) and Computer-Aided Manufacturing (CAM), has largely been a result of the productivity gains realized through their use in mechanical, electronic, and architectural engineering. Most CAD systems feature interactive graphics software as well as sophisticated hardware to implement and automate design and drafting functions previously performed by pencils, erasers, and drawing boards. The addition of CAE capabilities simplifies the generation of engineering analyses being performed on geometry designed using CAD. CAM functions allow machining and manufacturing to proceed automatically from the design.

Although still early in the utilization history of CAD systems, glowing productivity improvement reports abound. Productivity factors are usually calculated as a ratio of estimated manual design labor hours over actual CAD labor hours, although other measures such as the output (e.g., the number of drawings) generated or total cost (labor and material) have also been used. In a 1983 survey entitled "CAD/CAM and Productivity" by Arthur D. Little, Inc., average productivity improvement factors were classified by application: design studies, 4.8; engineering analyses, 6.0. [2, p. 10] Engineering changes and revision typically receive a 20:1 improvement ratio. [1, p. 210]

In addition to these productivity gains realized from implementation of nearly any CAD system, further increases are attained and reported by CAD users who are able to write CAD applications software for their own use and to interface the CAD operations with existing third-party software. Many vendors provide one or both of these capabilities. For example, Applicon advertises a built-in graphics programming language which provides access to the BRAVO! system's tools. Auto-trol permits FORTRAN interface with its Series 5000. Graftek provides AGILE, a language to allow user customizing and interface with outside software. McAuto has GRIP, Graphics Interactive Programming language, and interface capabilities with the operating system through the User Function and File Management Executive modules.

The productivity gains from user-specific software using such capabilities should not be underestimated. In An Analysis of CAD/CAM Applications, Richard N. Stover presents several case studies of CAD users. McAuto users heralded their ability to tailor their CAD systems via GRIP as a key component of the productivity improvement. One of the studies profiled the Harris Corporation, Business Forms System Division, Dayton, Ohio, where nine worker-years have been invested in GRIP program development, with the following remarks:

> Compared with the conventional interactive operation of a Unigraphics system, the GRIP approach can provide very significant benefits. For example, using the Unigraphics keyboard and system command, an offset printing tower design program produces the necessary drawings in about 40 hours. Using GRIP programs tailored specifically for those design requirements, the same drawing can be generated in about 45 minutes. Such GRIP programs involve as many as 100 subroutines in about 30 source files. [2, p. 241]

The following section documents current GRIP software development at NASA/Johnson Space Center (JSC) Structures and Thermal Division.

CASE STUDY

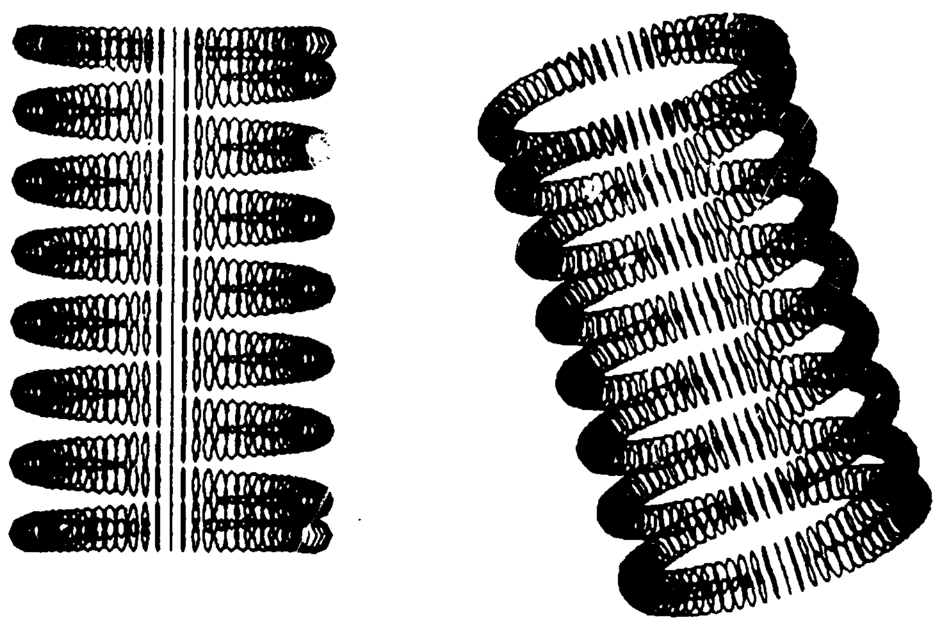
At NASA/JSC, a McAuto CAD/CAE system was installed for use by the Structures and Thermal Division in 1983. It currently resides on a Digital Equipment Corporation VAX 11/780 minicomputer and consists of the Unigraphics (UG) software, a number of graphics workstations, hardcopy units, and plotters. The UG software on the system has recently been upgraded from version I to version II and includes design/drafting, finite element modeling (GFEM), GRIP, File Management Executive (FMEXEC), and User Function modules.

GRIP, McAuto's Graphic Interactive Programming Language, allows operation of nearly all of the UG system capabilities through its FORTRAN-like commands. This includes graphics creation and editing, file management operations, and interactive input selection. FMEXEC is a system-independent, command-oriented file management program. Its most important capability (relative to the applications to be discussed) is the transfer of files between the operating system on which UG resides and UG itself. The User Function module, which has been significantly upgraded in UGII, permits interface with the operating system, including the ability to run FORTRAN programs and to use FORTRAN calls to perform UG system functions. To date, work with this particular capability for the Structures and Thermal Division has been somewhat limited, although it appears to be extremely powerful for many future applications.

The following are examples of user application programs written via GRIP to increase productivity in design, engineering, and management planning.

SPRINGS is a GRIP program that produces a three-dimensional graphic representation of either a compression, extension, or torsion springs at a user-specified location on an existing drawing. The user is prompted for input of the parameters defining that spring type as found in the Spring Handbook or a similar catalog. For example, an extension spring requires input of the outer diameter, wire diameter, and free length. The spring is produced by repeated transformations (i.e., rotation and translation) of a circle with a diameter equal to the wire diameter. This is an example of the automated creation of geometry possible through GRIP. Such a representation is prohibitively time-consuming for the user to create by existing system means, since seventy-two transformations are required to produce only one coil (revolution) of the spring. It is estimated that approximately thirty-five worker-hours were spent in developing this program and in upgrading it to UGII. A sample compression spring is given in figure 1.

Figure 1.



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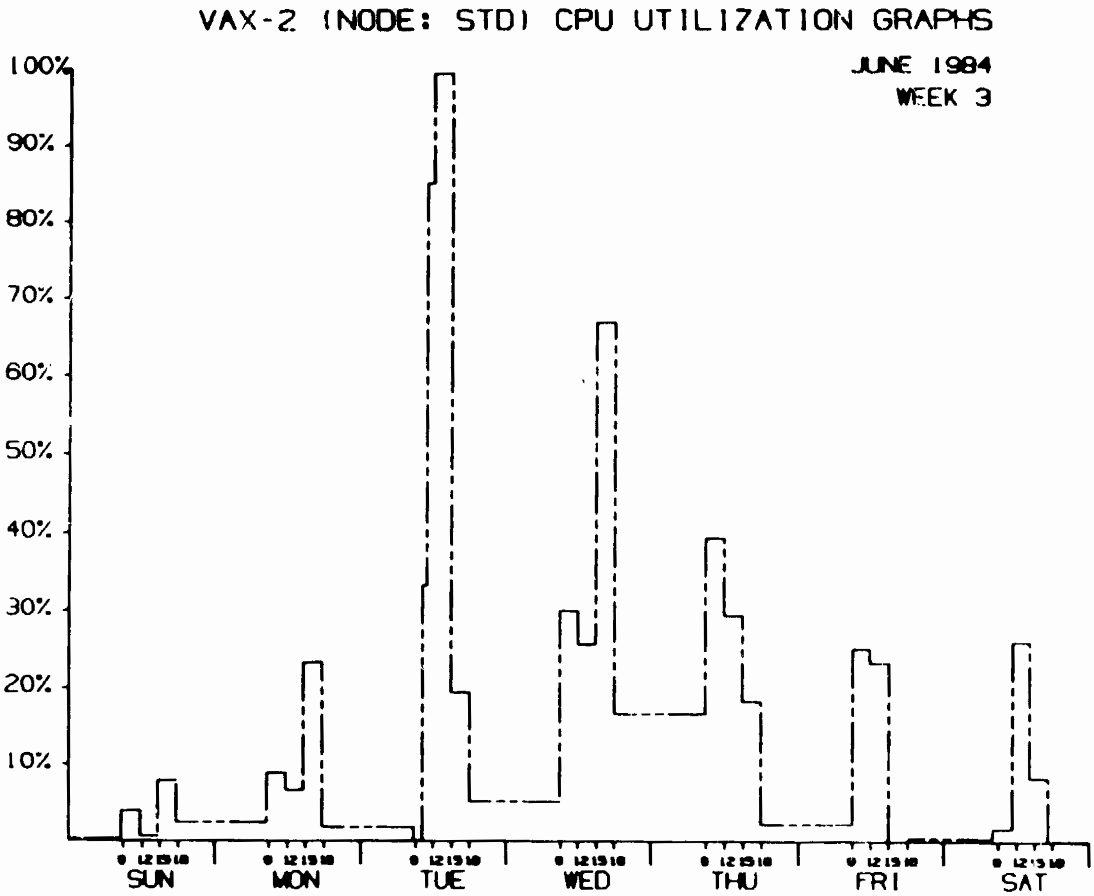
VAXCPU is a GRIP program which graphs VAX utilization data for a given month as bar charts on the CAD system and saves them for subsequent plotting and comparison. An important component is the ability to transfer the operating system data into the Unigraphics system using FMEXEC. Approximately 170 worker-hours were required to develop this capability. A sample chart is given in figure 2.

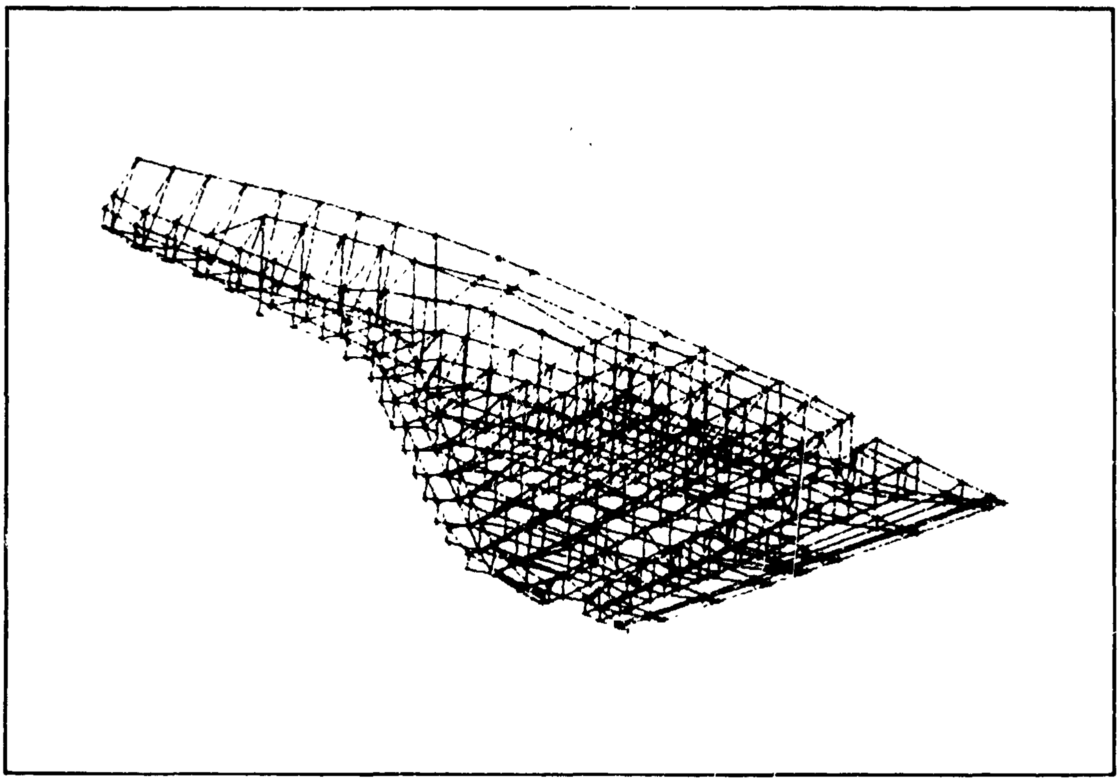
Figure 2.



Another capability which requires the transfer of data from the operating system into UG is the GRIP program NASTY, which automates creation of one of several types of representations of finite element model data on the CAD/CAE system. The original model in the form of a NASTRAN bulk data deck is processed by an existing FORTRAN program on an accessible VAX system to produce a number of files which define the graphic representation more efficiently. The relevant data files are transferred into the system using FMEXEC commands, and the user then runs the GRIP program NASTY. NASTY allows the user to choose one of the three options for representing the model: a three-dimensional line drawing (wire frame); a NASTRAN model using the GFEM capability of UG, which includes assigning appropriate node and element labels; or a two-dimensional hidden line drawing. Approximately 340 worker-hours have been devoted to developing NASTY, which includes its current set of seven sub-programs.

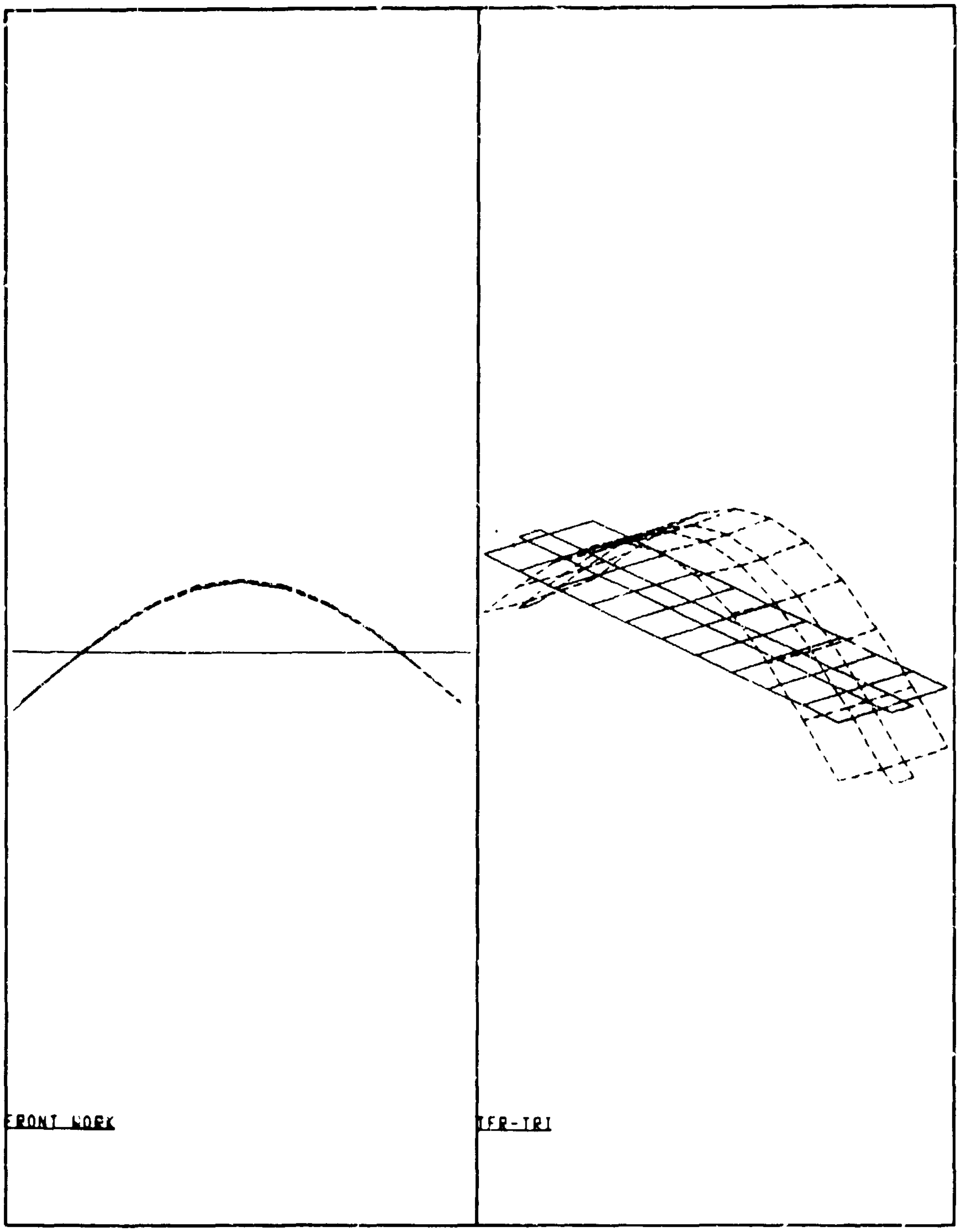
The first two options save the user from recreating a part on the CAD system for which sufficient information to automatically draw it exists; i.e., a NASTRAN model has already been made. As an example, figure 3 shows a line drawing of the shuttle wing which was transferred to the McAuto via NASTY. The GRIP program to produce this model ran twenty wall-clock minutes. It is estimated that to have created the same drawing interactively on the system would have required in excess of ten hours. Once on the system, the user can take advantage of the system plotters, the interactive editing options, and the various viewing options available.

Figure 3.



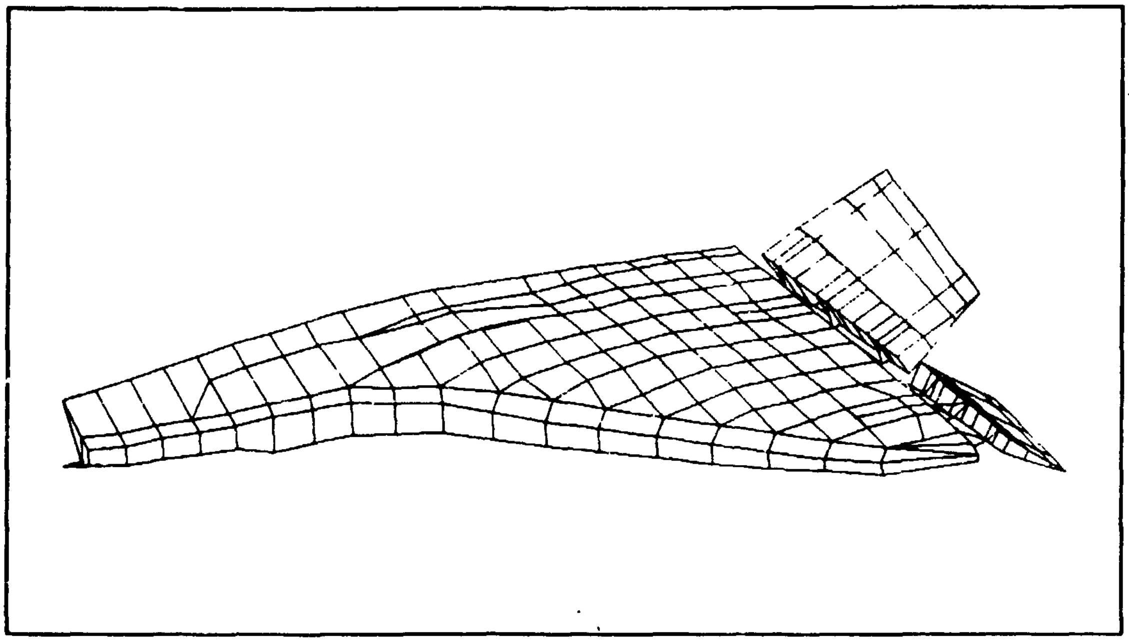
In addition, NASTY has provided two capabilities currently unavailable on the CAD system: showing post-processing NASTRAN information (the deflected shape) and a model with hidden lines removed. Showing the deflected shaped (in addition to the original) is an option available for both the line drawing and GFEM model representations. An example of a model with its displaced version is given in figure 4.

Figure 4.



Although the hidden line drawing is only two-dimensional and, thus, cannot be viewed at other angles, it has been a much-sought capability. Because of the extensive computation required for removing hidden lines, performing these calculations outside the UG system appears to be an appropriate strategy. A hidden line view of the wing is given in figure 5.

Figure 5.



The final example, the GRIP program MFR-RETRIEVAL, functions primarily as a management planning tool. For each shuttle mission on which the Manipulator Foot Restraint (MFR) is carried, it must be configured to fit on the Adaptive Payload Carrier (APC) relative to the other payloads. This means choosing locations among the thirteen bays, as well as specifying one of several positions on the APC in the chosen bay. The applications program developed uses existing CAD representations of the MFR, APC, and its accompanying hardware and places them in the configuration selected by the user. Thus, management personnel involved in planning, who are often unfamiliar with CAD usage, have a simple, easy-to-use method of checking the placement of the MFR under differing circumstances and need not be trained on the CAD system. This application is possible because GRIP includes all the system interactive selection capabilities and the part viewing options. By allowing the personnel involved in the decision making direct access to the system and its capabilities, no buffer person for creating configuration options on the CAD system is required. Approximately 170 worker-hours have been devoted to the development of this program.

In addition to these main progress, several general purpose subroutines have been created, which are used by a number of the above programs. They include subroutines to initialize parts, to allow the user to select a color and font, and to select any one of the canned system views. They are noteworthy as additional capabilities to the programs and as a demonstration of the modular design of software (i.e., separately compilable subroutines) possible in GRIP.

CONCLUSIONS

Development of applications software has been made possible in the McAuto CAD/CAE system by the existence of software to transfer data into and out of the system and by an interactive programming language which performs nearly all of the existing system's graphics creation/editing functions by command. Productivity has been increased by allowing transfer of mass quantities of data into and out of the system; by allowing transfer in of pre-processed data (especially important for CPU-intensive operations); by automating creation of complicated, repetitive, and otherwise time-consuming parts; and by simplifying CAD/CAE operation for users and "non-users". Thus, in addition to the productivity gains realized by nearly any use of CAD/CAE systems over previous means, applications programs with such systems allow tailoring of existing capabilities to make the most efficient use of the system.

From this, two recommendations are given for those involved in the procurement and management of CAD systems. Before purchase, be aware of the graphic programming and interface capabilities of any CAD systems under consideration, with emphasis on their ease of use and training required. Once purchased, provide for CAD programming support to undertake such projects. Effort devoted to such software development can greatly increase the productive and efficient use of a CAD system.

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[1] CAD/CAM Alert, Vol. III, No. 10, (February 1984), pp. 8-9.

[2] Stover, Richard N., An Analysis of CAD/CAM Applications, Prentice-Hall, Inc., 1984.

BIOGRAPHICAL STATEMENT

Susan M. Piotrowski is a computer programmer for Lockheed-EMSCO's Applied Mechanics Department and has been working on applications programming on the NASA/JSC's McAuto CAD/CAE system for approximately a year. She is responsible for the development of the GRIP programs SPRINGS and NASTY. She received a M.S. from Purdue University in 1983 and has a B.S. from the University of Dayton, Dayton, Ohio.

Tom H. Vu is also a programmer for Lockheed and has been involved in design, drafting, and programming on the McAuto for over a year. He developed the VAXCPU and MFR-RETRIEVAL programs and has a B.S. from the University of Houston.

Primary Contact and Presenter:

Susan M. Piotrowski
Lockheed-EMSCO
2400 NASA Road 1
Houston, TX 77258-8561

Phone: 333-6762 or 483-3013

INCREASING EMPLOYEE PARTICIPATION

N86-15201

D44-38

QUALITY CIRCLES
Organizational Adaptations, Improvements and Results

Ralph Tortorich, Martin Marietta Aerospace, Michoud Division

ABSTRACT

Quality Circles Work! Their effective application in industry and government has been demonstrated. The results achieved in quality and productivity improvements and cost savings are impressive. The circle process should be institutionalized within industry and government.

This paper addresses the stages of circle program growth, innovations that help achieve circle process institutionalization, and the result achieved at Martin Marietta's Michoud Division and within the National Aeronautics and Space Administration (NASA).

INTRODUCTION

Quality circle implementation efforts have three basic stages: the Pilot stage, the Expansion stage, and the Institutionalization stage. In the pilot stage, the objective is to prove that the quality circles process works. The quality circles process sponsor (usually one or more top level managers) is the judge of success.

If survival occurs, the implementation effort progresses to the expansion stage. In this stage, the objectives are: to add more circles, to expand the process into other areas of the organization, and to provide additional proof that the process works. The implementation challenge although still survival, now includes: logical, continued growth; increased training and facilitation support; and, increased technical and logistical support from the organization. Many quality circles programs get bogged down in this stage and some fail.

There are many reasons for failure at this point, a few major reasons are: lack of continued commitment and sponsorship by management and/or the union; inadequate or no training for the implementing group and/or circles; too great of a dependency on the consultant or inadequate consultant support; and, environmental instabilities. Reasons for program stagnation include: limited management support, isolation of the process in one part of the organization, limited/inadequate training and facilitation support, and satisfaction with limiting the program to this stage.

to quality and productivity. The committee initiated an agency-wide Productivity Improvement and Quality Enhancement (PIQE) Program, which focuses on seven goals. "Broadening employee participation in management decision making," was a key goal established. To help accomplish this goal, NASA developed an agency-wide plan to implement NASA Employee Teams-NETs (quality circles). In 1983, Martin Marietta's Michoud Division was selected to provide assistance in implementing the NETs process.

NASA has successfully progressed through the pilot stage and into the expansion stage. To date, nine hundred fifty-one NASA NET Coordinators, facilitators, team members, and members of NASA management have been trained in the NETs process. One hundred fifty-three NETs are operating within the agency.

Martin Marietta Aerospace, Michoud Division

In 1979, the Michoud Division, prompted by workforce performance concerns (e.g., 30% overall and 55% hourly workforce annual attrition rates) designed and sequentially implemented several Quality of Work Life programs. These programs have been successful in assisting the workforce to achieve 100% mission success on the External Tank (ET) Project. This was accomplished with all ETs delivered on or ahead of schedule, below estimated costs, and with high quality. Additionally, the present annual attrition rate for the workforce is 7% (below 7% for the hourly workers.)

The Systems Refinement Teams - SRTs (quality circles) process (one of the Mission Success Programs) began in June, 1979. Today, the division has one hundred two SRTs in eight major departments with an overall participation rate of twenty-three percent.

Both management and employees participate on teams. Twenty-six percent of all management (supervisor and above) and twenty-one percent of all non-management are directly involved in the process. Blue collar participation rate is currently thirty-four percent and white collar participation is fifteen percent. The eleven hundred SRT members belong to five basic teams: eighty-two Basic SRTs, five Task Teams, four Think Tank Teams, six Integrated Teams, and five management Teams.

Beginning in 1980 we began to track organizational measures that were readily available and of particular interest to division management at the outset of the SRT process. We compared performance of hourly employees on teams with performance of those not on teams and found better performance rates on all measures for team members. The rates for team members have continued to improve and the averages for four years (1981-1984), are as follows: 29% lower rate of safety accidents, 36% lower rate of hardware accidents, 29% lower rate of union grievances, 24% lower rate of hardware nonconformances, 40% lower rate of lost time, 51% lower rate of attrition.

Other benefits to the organization are more difficult to measure, but no less important. These include improved morale, job knowledge, problem solving skills, communication and cooperation, teamwork and management development.

The following are successful adaptations and are referred to as teams:

Management Teams - These are composed of the top management levels (staff) within a department and subdepartment. They normally work long-term goal setting, improvements to department systems, and employee development planning.

Integrated Teams - These are composed of members (usually middle level management) from various departments. These are individuals that normally work as a group, or separately, to resolve problems in major systems (e.g., nonconformance system) and major processes (e.g., welding process.) Membership frequently includes the customer (e.g., NASA) and the auditing agency (e.g., DCAS-Defense Contracts Administration Services). They monitor and work improvements to major systems and processes.

Task Teams - Task Teams are usually composed of all management (first and middle level management) or management and employees. They form, and sometimes reform, to work a specific task (e.g., improvements to a business system).

Think Tank Teams - Think Tank Teams normally draw membership from the technical ranks (e.g., engineering) of the organization. They form and reform as a team. These teams concentrate on research and development and new business.

Improvements to Circle Operation

The typical circle operation makes the circle dependent. The circle is dependent on the facilitator to provide access to management, access to technical support, access to logistical support, and other factors that limit its independent operation within the organization. Each dependency factor has to be identified and resolved to accomplish a significant degree of institutionalization. The following are in various stages of completion and implementation.

Circle development and operation - Orientation of organizational business and operating systems, long range goal planning, self-use circle project workbook and guide, expanded group process skills training, and group development and self-study guide.

Technical and logistical support - Establishment of technical and logistical networks.

RESULTS

NASA

In 1982, NASA formed an executive level productivity steering committee to develop an agency-wide approach to continued improvements

Managing the implementation effort becomes more of a challenge. Full time versus part-time facilitation and centralized versus decentralized operation are two decisions that have major impact on the control and expansion of the process. Additional issues require attention as the circles grow in number: providing management training, establishing a program measurement system, and insuring organization support for circle project implementation, to name a few.

The final stage, institutionalization, is the transitional stage that accomplishes transfer of the quality circles process to the organization. This stage is completed when the quality circles process persists as a normal, self-sustaining work process within the organization. In this stage, the major objectives necessary to initiate transfer of the process to the organization are: decentralization of the implementing activity, adaptations of the circle process, and improvements to the circle operation.

TRANSFERRING THE PROCESS

Decentralization

Decentralization of the implementing activity provides a transfer of responsibility of several major factors that affect institutionalization, from the central implementing group to each department within the organization. These factors are: sponsorship, commitment, sensing and recalibration, training, second level diffusion and intervention, formalizing mechanisms, goals, rewards, and consultant support. [1]

Decentralization should be well planned; implemented on a controlled, department by department basis; and, by a consultant/facilitator trained, and preferable experienced, in the decentralization process.

The initial steps are as follows: The facilitator - consultant is assigned by the central implementing group to a department and reports on a "dotted line" to the department director, while remaining on the payroll of the central implementing group. He conducts the necessary study and develops a training and implementation plan. With director concurrence, the plan is implemented through a department steering committee composed of the director's staff and the facilitator-consultant. The plan specifies top down training of all department management and employees, with resultant formation of circles throughout the department.

Adaptations of the Circle Process

Organizational adaptations of the typical circle are necessary, where application of the typical circle structure and/or process does not satisfy the particular organizational need. Providing the necessary adaptations satisfies this need and increases the number of organizational members participating in the circle process - allowing a higher degree of institutionalization of the process. [1]

The SRT process staff is composed of nine dedicated professionals with doctors (four) and masters (five) degrees in the behavioral sciences. They use a continuing research and development approach to the process and are credited with several major innovations to the quality circles process. The Michoud Division was awarded in 1985, the first International Association of Quality Circles' Excellence Award, for their contributions to the quality circles process.

REFERENCES

[1] Goodman, Paul S. and Dean, James W., 'Why Productivity Efforts Fail. Paper presented at the American Psychological Association, August 1981 and the Quality of Work Conference, Toronto, Canada, September 1981.

BIOGRAPHICAL INFORMATION

Ralph Tortorich is the Mission Success Manager of Human Resources Development for Martin Marietta Aerospace, Michoud Division in New Orleans. He is responsible for individual and organizational performance improvement programs at Michoud and their 80 major and critical suppliers. These programs include: Systems Refinement Teams, Manned Flight Awareness, Employee Suggestion System, Quality Enhancement Program, Socio-Technical Assessments, and Employee Recognition and Award. He has published several articles on the quality circles process.

Mr. Tortorich is the Martin Marietta Aerospace member of Space Shuttle Motivation Panel and has chaired several productivity panels for regional and national conferences - including the 1983 Industry - NASA - Air Force Space Division Mission Assurance Conference. He has 18 years experience in aerospace management.

N86-15202

PRODUCTIVITY ENHANCEMENT PLANNING USING PARTICIPATIVE MANAGEMENT CONCEPTS

Marvin E. White and James C. Kukla, Lockheed Engineering and Management Services Company, Inc., 2400 Nasa Road 1, Houston, Texas 77258

ABSTRACT

This paper describes a productivity enhancement project which used participative management for both planning and implementation.

It reports the process and results associated with using participative management to plan and implement a computer terminal upgrade project where the computer terminals are used by research and development (R&D) personnel. The upgrade improved the productivity of R&D personnel substantially, and their commitment to the implementation is high. Successful utilization of participative management for this project has laid a foundation for continued style shift toward participation within the organization.

INTRODUCTION

This paper describes a productivity enhancement project which used participative management for both planning and implementation. It provides comments on the concepts of productivity enhancement planning in R&D and participative management, as required, to establish the background and central ideas for the particular project being described. The paper is thus a report of the accomplishments, the procedures, and the observed results of this project. It does not lay a rigorous foundation justifying the concepts of participative management in a general sense. The particular situation dealt with in this productivity enhancement project was that of providing an efficient Johnson Space Center (JSC) computer mainframe interface for system and software engineers who work under contract to JSC* and are located off, but near, the JSC site.

*From the beginning of the project, NASA/JSC contract Technical Managers E. P. Odenwalder and R. D. Mercer were highly supportive of the enhancement objectives and the participative process. They encouraged management and the employee teams during the study and ultimately had the confidence to approve the funding. Their insights and understanding of the value of the planning and approach were essential to the results achieved.

PRODUCTIVITY IN R&D

Productivity in R&D activities is a composite of the productivity of both the team members who work in advanced technology and the members who provide support services and tools to those in advanced technology. A general approach to R&D productivity enhancement planning thus deals with (1) the effectiveness of the systems and tools supporting R&D, (2) the effectiveness of R&D personnel in applying the support systems and tools, and (3) the quality and quantity of R&D personnel's innovation.

All these are candidates for enhancement through participative management techniques. The first two can be dealt with by using R&D personnel as enhancement planners and implementers. The third can be dealt with by using the R&D personnel to help define and implement an organizational culture which will permit the natural curiosity and inner motivation of people to show up routinely in their actions.

APPLIED PARTICIPATIVE MANAGEMENT CONCEPTS

Experience and research have defined participative management as a strategy, and have shown its value in achieving organizational performance gains. Specifically, some of the quality programs which enlist the operative and concerned individuals in the organization to develop operation plans have produced very significant results. The basic principle in applying participative management to productivity enhancement planning is to let the "insiders," or concerned individuals, do the planning, since they have the most knowledge about the actual situation. This achieves a technically superior plan because of the special knowledge of the insiders and, just as importantly, a commitment to the solution by the insiders. Management and staff must provide all the encouragement and special technical expertise required by these insiders. In addition, management must provide for integration where two or more teams or individuals develop separate (and perhaps incompatible) plans.

Though the potential benefits of applying participative management are considerable, application of the concept has some characteristic difficulties for both management and the employee participators.

First, there is a learning process associated with participative management. Management's solicitation of and dependence on employees to provide an element of management planning is often a new concept for both managers and employees. Management sees this as lost control of a major element of the planning process, while the employee often is so awed by the increased planning responsibility that he retreats from it. Surrender to these early concerns drives the organization toward continuing the status quo and seriously impairs the development of a participative management process.

Secondly, participation is not always easy to establish. As it stands, managers have the ultimate responsibility and are at risk for planning. In a participative management environment employees can also participate in the planning and thus become responsible and at risk for the plan. However, they can also defer to management and avoid the risk. Consideration for safety will drive many to opt out of participation. A major responsibility of management in a participative management environment is to encourage and motivate participation.

Thirdly, using employee teams in participative management introduces an element of uncertainty into the planning process which can be of considerable concern to managers. One characteristic of a team, formed spontaneously to be an element of participative management and to address ill-defined situations, is the unpredictability of the form, content, or schedule of their output. The team may achieve a highly relevant and creative solution, have it in good form, and produce it on an acceptable schedule; or it may not do any of these well. To achieve all that is possible in getting at the genius of the organization through participative management, managers must accept this uncertainty and find a way to supplement the group's output or reshape it to fit the organization's structured planning needs.

TRADITIONAL VERSUS EMERGING STYLES FOR PRODUCTIVITY ENHANCEMENT PLANNING

Traditional approaches to productivity enhancement planning utilize an outside planning team (the planners in small organizations are the manager and supervisor, and in large organizations they are industrial engineers), which is composed of members who are not a part of the operative team actually engaged in the day-to-day work. They are generally highly skilled people who bring new methods to a local work situation. These approaches tend to be extremely effective where observation of the process can determine the most productive method and where human motivation and commitment are simpler to assess and accommodate. In R&D, however, the traditional concept of using the outside enhancement planning team has serious deficiencies in determining the effectiveness of various methods from outside observation, and in the commitment of the inside team to implementation of *someone else's* plan.

The emerging participative management approach enlists the actual team of insiders doing the work (and other experts as required) to produce an enhancement plan which they ultimately implement. Situation assessment becomes a matter of self-analysis, and commitment to the plan becomes a matter of supporting something which is self-owned. The most relevant issues are thus addressed in the plan by those who will implement the plan.

PARTICIPATIVE MANAGEMENT AT LOCKHEED VIA THE QUALITY PROGRAM

For several years Lockheed Corporation has had quality programs in the various divisions of the Company. Since these programs generally are designed by the employees at that location, the exact implementation of the program varies from division to division. At Lockheed Engineering and Management Services Company, the program is composed primarily of two major vehicles for employee participation. The two major parts of the program are Performance Development Teams (PDTs) and a written suggestion and information request system.

The PDTs are groups of concerned and operative individuals interested in assessing and changing some aspect of the work process. These teams can deal with ongoing operations or with a specific issue. They can be formed spontaneously by an employee group or as a management support team to answer a question of concern to management. They are assisted by a trained facilitator who helps the group get at their area of concern and acquire the management support/expertise they need to do their planning. They can make changes themselves if it involves only the way they interact. They can ask for management support if assets or changes outside their control are involved.

PDTs were used to effect the productivity enhancement planning project which is discussed in this paper.

PRODUCTIVITY ENHANCEMENT PROJECT BACKGROUND

The work situation which is the subject of the enhancement project involves several hundred system and software engineers located remotely from, but in the vicinity of, the JSC computer mainframes which they use to perform a wide range of engineering, data management, and software development tasks. The data bases and specific software used by these engineers are generally resident on the JSC mainframes. The engineers access the JSC mainframe via offsite or, as required, onsite terminals. They change the data bases and/or programs, set up the analyses to be accomplished, and establish the form of and view the program output via terminal interfaces. The effectiveness and appropriateness of this terminal interface impact the individual R&D engineer's productivity significantly. The interfacing terminals which were in place before the enhancement project were a number of (relatively) low capability terminals, which were over 5 years old, and a few personal computers. Terminals operated at low transfer rates and were capable of very little in the way of graphics. Low line speed, no local processing (for most terminals), and practically no graphics capability were the undesirable features which the engineers saw as limiting their productivity. Offsite operating limitations, some of which resulted from the above, were poor availability of word processing, local program development, and data base management capability. In addition, the low transfer rates caused terminal response time to be multiple seconds rather than the generally accepted standard of less than 1 second. Poor response and lack of graphics capability forced engineering personnel to go on the JSC site to access more appropriate terminals when work emphasizing these characteristics was performed. The unproductive time (1 to 3 hours) to travel to the JSC site and return was a major driver for enhancing offsite capability.

The goals of the enhancement project can be summarized as follows:

- Reduce onsite travel for terminal access to a minimum
- Increase line rate to improve terminal response time
- Provide adequate and cost-effective graphics
- Provide word processing, data base file space, and local program development capability in the engineer's work space
- Size and configure the hardware/software to provide enough capacity and access to perform the actual engineering task
- Develop operating processes for the terminals/systems, and optimize location of terminals, systems, and documentation

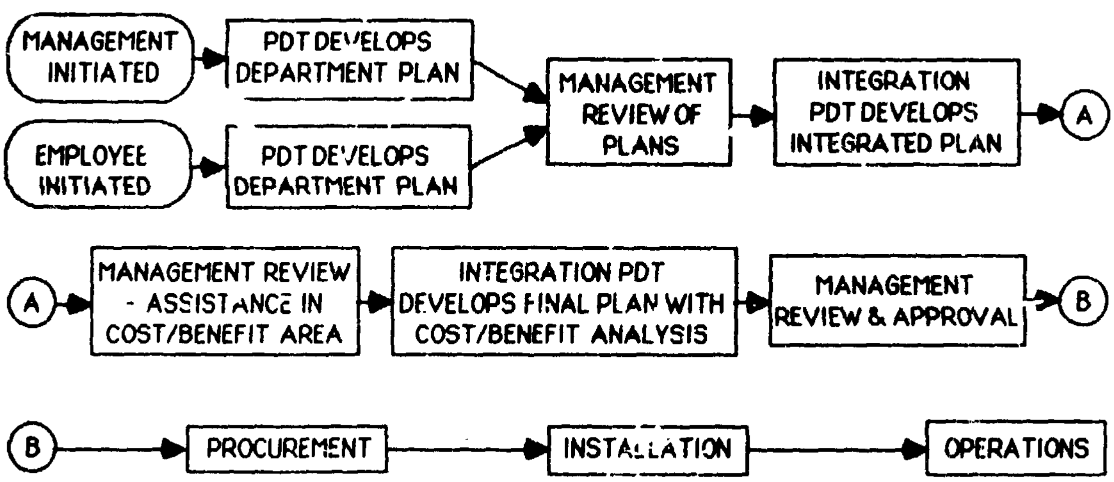
PROJECT PROCESS

Both personal and organizational concern for productivity motivated formation of PDTs to assess the terminal interfaces. One Lockheed department formed an employee-initiated PDT, while another department formed one by management initiative. Both assessed situations and developed plans per the concepts of the PDT process. Other offsite departments were candidates for similar team activities but were less motivated because of differences in their work. Figure 1, terminal upgrade planning process, illustrates the sequence and activities associated with the planning and implementation project. This sequence documents the way the process proceeded. It was not predetermined and was not a plan used to guide the process. Some of the uncertainties associated with PDT operations, along with a deliberate bias at Lockheed toward minimum management guidance for PDTs, often mean that only gross direction and plans are defined at project initiation. The process unfolds as management and employees interact to achieve commonly held objectives. The sequence and activities are varied and are recast as the process is carried out to address, among other things, the following:

- Level of PDT initiative (or lack thereof)
- Need for management or staff assistance to the PDT
- Need for integration of activities between more than one PDT or interest
- Approvals and review required to reach objectives

Scope expansion or compression, review, and rework are all common as the process evolves.

FIGURE 1 TERMINAL UPGRADE PLANNING PROCESS



On the terminal upgrade project, the team which was employee-initiated was formed from representatives from each section in the department; all were solicited by the initiators. A team was thus formed which included the initiators and representatives from across the department. The management-initiated team was formed in much the same manner, except that management solicited key people, who then solicited volunteers to serve on the team.

Both teams' initial meetings were with a trained facilitator. The facilitator introduced tools such as brainstorming, issue identification, and prioritization techniques to assist the group in the practical aspects of team analysis. These first meetings brought out common issues or problems around which the individual members could unite and design "team" action.

Initially under the direction of the facilitator, and later under elected group leaders, the two groups worked individually to identify issues and to evolve strategies to deal with the issues. A general sense of competitiveness between the two groups emerged and tended to keep the teams working independently. In addition, the employee-initiated team perceived themselves to have a lower level of management support than the management initiated team. This increased the strain on team relationships and motivated isolation. Little sharing of information was done, and some activities were duplicated. Management did not encourage integration at this point, preferring, rather, independent studies by the two groups.

Both groups devised strategies that included the use of survey and interview data to provide the base needed for determining current and projected usage of terminals. The teams solicited information from vendors and looked at state-of-the-art equipment to determine available approaches. During the course of the investigation, a number of working level changes in process were made by the team to increase their group's productivity and performance quality. These changes generally had to do with identification of available software developed by the group, rules on document use, software storage, and other such issues.

After a period of data gathering, surveys, and analysis, each of the two active teams produced its findings. The findings were their recommendation (and their justification) for acquisition of various kinds of terminals. The two sets of findings presented by the two departments were, of course, focused along the line of their needs. There were differences reflecting the variation in application and in the preference of the teams for certain solutions.

A study of the findings by management concluded that the output of the two teams should be integrated, reconciled, and supplemented with data from the remaining offsite departments. A team composed of several members of the original two teams was tasked to provide an integrated approach and to expand the study. This team, designated the Integration Performance Development Team (IPDT), was to produce a plan which addressed the needs of all offsite personnel using terminals/microcomputers to connect to JSC mainframes, and which also integrated the essentials of the plans produced by the two departmental PDTs.

Work on the previous PDT planning effort gave the team an experience basis. As a result, the team evolved their study plan and timetables in the first meeting. The team worked with management of the various offsite organizations to identify and define current and projected conditions, goals and operations drivers, need dates, and special operating situations. Most of this additional information was provided by a management-appointed representative from each department in response to a survey. All additional data were summarized and combined into an overall plan showing current and projected need.

A review by senior management was concluded with excellent comments. However, a cost/benefit analysis was required to make the final decision on funding. Neither of the PDTs had technical qualifications or experience in providing cost/benefit analysis. Senior management provided the expertise in this area and initiated a brainstorming session to identify "what ifs" pertaining to various plan implementation scenarios. Compilations of productivity losses and productivity gains associated with the status quo and with implementation of the plan were made. The kinds of data compiled were:

- Time lost in transit to terminals onsite at JSC because adequate facilities did not exist offsite
- New capabilities of the equipment and immediate as well as farther term productivity gains associated with the equipment
- Productivity improvement associated with a communication transmission rate upgrade and improved terminal response
- Evolution of the work toward more graphics, word processing, and local program development

The plan provided quantified cost/benefit data for two areas and additional performance justification, which was unquantified, in the general area of performance enhancement.

Quantified Benefits

- Eliminated 23,000 individual round trips per year to onsite terminals, for a yearly cost avoidance of $1.3 M.
- Improved response time at the terminal to less than 1 second for entry and edit functions, thus improving efficiency by 25 percent (based on entry and edit evaluation tests run at various line rates) and saving $575,000 per year.

Unquantified Benefits

- Improved graphics, more user-friendly equipment, and improved communications to the customer
- Improved and more available word processing
- More effective offsite data base development and manipulation
- More offsite program development on the microcomputers
- More terminal time available to JSC and other contractors on the JSC onsite terminals, as Lockheed engineers use offsite terminals.

By conservatively assigning real and best-judgment cost/savings values to some of the previously mentioned areas, the integrated plan cost/benefit analysis showed a 3-to-1 cost savings for the year. A phased plan was developed to prioritize requirements to correspond to various funding levels. The recommended implementation level was thus partitioned to recognize the possibility of inadequate near-term funding. The final review with senior management and with the JSC Contract Manager (since this is a cost reimbursable effort) resulted in approval for immediate implementation of 25 percent of the total plan with a commitment to continue to address the productivity improvement issues raised in the plan in phases over the next few years.

Procurement of the equipment was accomplished by the PDT with assistance from their management and the procurement staff. Those team members who had worked on the initial assessments and were very committed to the solution were still on the project. The team members were also used to install the equipment as received, establish new working guidelines as it came online, and develop performance measurement data collection methods. This group gradually diminished in size as the installation effort was completed. The chairperson of the group has remained and formed a new PDT for terminal utilization productivity and performance measurement.

MEASUREMENT OF RESULTS

In the plan's cost/benefit analysis section, projections were made concerning productivity increases and cost avoidance or savings. When the equipment was installed, a new scheme for measuring results was initiated. Recording procedures were enhanced and enlarged to include all users of offsite-to-onsite computer systems. Representatives from each department met to organize the data collection/design effort. Procedures were set up to measure mainframe/ local application, wall clock usage, number of trips made onsite to use the computer facility, data transmission rate, and device usage. In addition to these procedures, a monthly Offsite Terminal Report summarizing the performance information was initiated to keep both JSC and Lockheed management informed.

RESULTS OF OFFSITE COMPUTER EQUIPMENT ENHANCEMENTS

The figures referred to in this section are similar to the graphs included in the monthly report presented to JSC and Lockheed management. For the purposes of demonstration and discussion, the details of the monthly results have been reduced and simplified and are shown as "before" and "after." Data describing the conditions before the upgrade were assembled in August 1984, and the data describing conditions after the upgrade were assembled during the first quarter of 1985. The critical event determining the before and after is the installation of new devices into the work environment.

The data producing these results are supplied by the device users. Each time the user initiates and completes a terminal/microcomputer session, that person is responsible to make an entry in a log provided alongside the device. Each log entry then becomes a data point to be entered into a data set which is processed through a reduction program.

Figure 2 shows the change in offsite connect tim[illegible] onsite mainframes across the critical period. Prior to the equipment purchase, connect time was below 900 hours per month. After the purchase and installation of equipment, connect time increased over 150 percent, with the current monthly mainframe connect time running at 2400 hours.

Figure 3 displays the frequency of round trips per month made by the total user set to access onsite facilities. Plotted alongside the number of trips per month is the lost transition time due to the onsite trips (Note: Through interviews with frequent onsite travelers and observation, it was determined that lost time per onsite round trip averaged more than 2 hours). Reduction of both trips and lost hours is in excess of 83 percent.

The upgrade plan postulated that the reduction in onsite trips through the purchase of additional offsite equipment would dramatically and directly increase the offsite terminal to [illegible] mainframe connect time; figures 2 and 3 demonstrate that this has, in fact, occurred.

C... OF POOR QUALITY

FIGURE 2

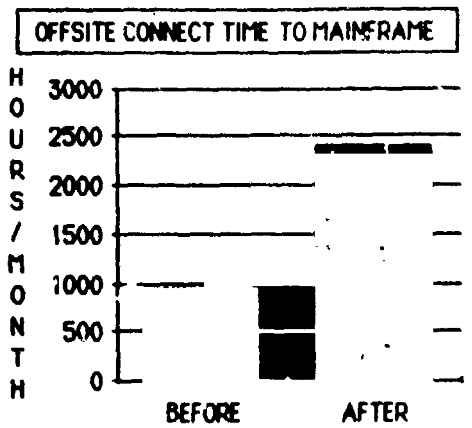


FIGURE 3

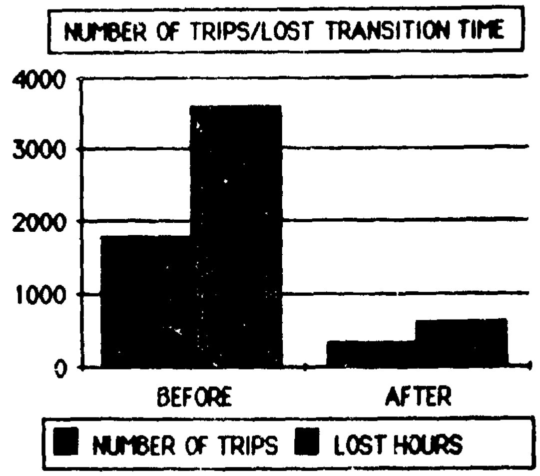


Figure 4 displays local microcomputer wall clock usage. In addition to the "before" and "after" data points, a "transition" data point has been added. The before and after change represents the increase observed in the first two months. Through data analysis, it was observed that this change was mainly attributed to the increased use of microcomputer word processing capabilities by experienced clerical personnel. The data taken through the first quarter of 1985 (transition step) show the increase in microcomputer usage by the new users (i.e., analysts not experienced with word processors and other microcomputer capabilities). These data illustrate both the near-term benefit of supplying improved equipment to already experienced users and the longer term benefit accrued as new users begin utilizing the new methods afforded by the equipment.

Figure 5 presents device usage rate. A total offsite usage rate is obtained by summing the hours of offsite mainframe and microcomputer connect time per period (figures 2 and 4). Dividing this sum by the total number of active terminals/microcomputers for the same time period determines a total device utilization rate. Prior to the plan implementation, the utilization rate observed was 60 hours per month. After the installment of the new equipment the rate increased by 10 percent to 66 hours per month. This figure demonstrates that a

FIGURE 4

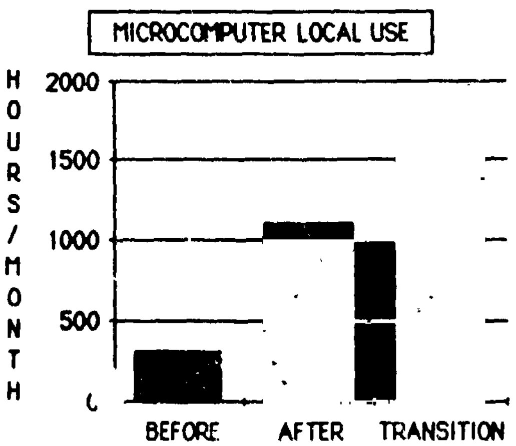
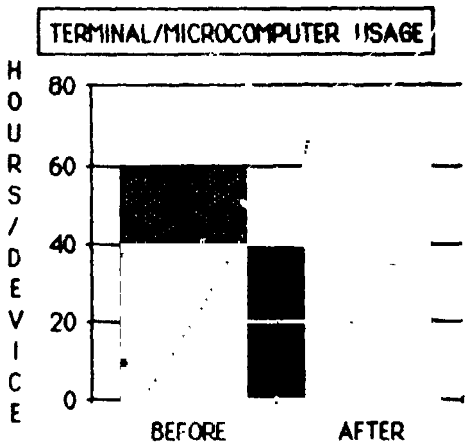


FIGURE 5



demand for additional terminals exists. Although 24 more devices were added, the device utilization rate actually increased.

SUMMARY

The final results of the project, when summarized, fall into the categories of productivity enhancement results and participative management observations. The paragraphs which follow summarize these two aspects of the results.

Productivity Enhancement Results

Through the investment of $150,000 in the terminal upgrade plan (one quarter of the plan) a cost avoidance of over $1.4 M has been established and easily verified, based on those areas most easily quantifiable. A number of other productive areas have been improved, though the cost avoidance associated with them is less easily established. Specific areas of cost avoidance and productivity increase are listed as follows:

- Cost savings of nearly $1.1 M per year were experienced as a result of reducing by 83 percent the number of onsite trips to use computer facilities.
- Connect time to JSC mainframes increased by over 150 percent.
- Local microcomputer use increased 500 percent.
- Individual terminal response time has improved by a factor of 2, thus establishing a work efficiency gain and resulting cost avoidance of $325 K per year.
- Though 24 new devices were brought into the work environment, the individual device usage rate has increased by 10 percent rather than decreasing.

Participative Management Observations

The participative management approach and its relationship to the project provided a teaching and learning forum for both participants and observers within the organization. The following observations were made for both management and employee/operative participants.

Observations about management behaviors were:

- Senior management was highly enthusiastic about the process.
- Initially uncommitted but willing, middle management finished the process committed and enthusiastic about future use of participative management.
- All managers learned a great deal about how a PDT must be supported motivationally and technically in order to achieve a useful end product.
- Prospects for future dependence on PDT effort are excellent.
- PDTs will compete if working in the same arena; competition is not necessarily negative and may actually inspire.
- Managers realize that a straightforward project plan which includes one or more PDTs is difficult to generate a priori.

Observations about employee/operative behaviors were:

- PDT members began the process feeling substantially at risk with colleagues and with the participative management concept but were motivated by personal interest in terminal upgrade.

- PDT members feel satisfied with the result and with their participation and are willing to be part of future planning processes.
- PDT members gained expertise and skill in PDT operations as the project unfolded.
- PDT members realize that it is not straightforward to get management attention.
- Individual PDT members gained valuable systems, business, and behavioral dynamics development through their experience.
- Cognizant employee groups are more receptive to the concept of participative management and are willing to participate.

CONCLUSION

The experience and results reported in this paper establish a successful case of using participative management for productivity enhancement planning and implementation. Both Lockheed managers and employees, cognizant of the project, generally agree with the good results and have a greater appreciation for employee participation. A major result of the project is the potential for style change toward participation within the organization because of having demonstrated the benefits thereof.

AUTHORS' BIOGRAPHICAL NOTES

Mr. Marvin E. White is Director of the Engineering Technology and Analysis Branch at Lockheed Engineering and Management Services Company, Inc., Houston Operations. Over the past 20 years Mr. White has managed in a variety of line and project management positions in the following technical areas: data systems, simulation, control, communications, and various mechanical/process technologies. Mr. White received a bachelors degree in mathematics and physics from Texas Christian University in 1958 and has pursued advanced work in engineering, business, and computer science at several universities since that time. He has extensively adopted participative management as his personal management style, and was the responsible senior manager for implementation of the productivity enhancement project described in the paper.

Mr. James C. Kukla received his bachelors degree in engineering from the University of Illinois in 1981. Since that time he has been employed with the Lockheed Engineering and Management Services Company, Inc., Houston Operations. While working at Lockheed, he obtained his masters degree in business administration through the University of Houston-Clear Lake. He works as a thermal engineer. He is a member of the Lockheed Computer Productivity Oversight Committee and actively supports and participates in the Lockheed Quality Program. Mr. Kukla was chairperson of one of the departmental PDTs and the Integration PDT for the productivity enhancement project described in this paper.

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RESULTS OF INNOVATIVE COMMUNICATION PROCESSES ON PRODUCTIVITY GAINS IN A HIGH TECHNOLOGY ENVIRONMENT

Brenda J. Kelly
Lockheed Engineering and Management Services Company, Inc.

ABSTRACT

The intention of this paper is to share the technology which has resulted in performance breakthroughs at Lockheed Engineering and Management Services Company, Inc. (Lockheed-EMSCO). As a result of the innovative approaches of communicating productivity concepts to the employees, specific outcomes can now be pinpointed at all levels of the organization in such areas as:

- Employee-headed programs
- Performance feedback processes
- An investigative approach to creating leadership

The Lockheed Corporation began the innovative trend in 1974 when they became the first company to introduce quality circles in America. Although some of Lockheed-EMSCO's processes may sound different from traditional improvement processes, the context out of which those to be presented evolved has sustained more than ten years of positive results through employee involvement activities.

THE CHALLENGE

Lockheed-EMSCO was established in 1980 and set its mission to be the recognized service industry performance leader. Although the company was already performing well, it recognized that its success depended on helping the customer be successful. What was needed was a way of looking at new possibilities which would produce sustained performance excellence. To fill this need Lockheed-EMSCO decided to develop a proactive culture - one which initiates rather than waits to be told which actions to perform.

The challenge became clear that to accomplish the mission, the focus must be on innovation and creation rather than simply problem solving.

QUALITY AND PRODUCTIVITY CONTEXT

In Lockheed-EMSCO's business, which is providing management and technical services, selected management teams go where the work is to be performed. Often the work is performed in government-provided facilities.

Therefore, the company's greatest resources are the men and women who work for Lockheed-ESMCO. Company investments are heavily focused on people-centered programs because Lockheed-EMSCO operates from the context that people make a difference.

THE PROCESS AND BREAKTHROUGH RESULTS OF THE INNOVATIVE ENHANCEMENT APPROACHES

Webster's Third New International Dictionary (unabridged) defines "breakthrough" as (1) a sudden marked increase in prices, values, etc. above previous levels, (2) a sensational advance in knowledge in which some baffling major problem is solved. Lockheed-EMSCO has observed a marked increase in creative ability to solve both major and minor problems.

This section discusses the processes used and the results of Lockheed-EMSCO's improvement efforts. Many lessons have been learned as a result of the actions that have been taken. Many breakdowns have been turned into breakthroughs as a result of these tools. The contention is that the company is now better prepared for future involvement of its employees in the decision-making process as a result of the lessons that have been learned.

Getting Started

The process began by sending out a questionnaire to all employees at all levels of the organization. The objectives of the questionnaire were to:

- Gather quick and useful data about the work force
- Pinpoint employee-perceived issues
- Avoid tackling the wrong issues
- Help employees focus their thoughts on what was needed to enhance their personal productivity
- Highlight points for future discussions

Feedback sessions were conducted with all employees after all the data had been analyzed. Many of these sessions evolved into ad hoc groups whose purpose was to look more specifically at which of the survey findings most often interfered with their ability to perform more creatively on the job. These group interactions, the survey stats, and the comments that employees wrote on the survey proved to be the most valuable indicators as to what was really stifling creativity in the organization.

Data Analysis

It was discovered that before task specific issues could be tackled, it was imperative that employees' concerns about the quality of their work life be addressed. Employees were interested in knowing more about marketing plans, company benefits, upward mobility, and reward and recognition practices.

The topics of interest and preliminary discussions with employees indicated a need for more coactive interactions between management and nonmanagement employees. The things to do next began to unfold once all the people were heard and the written data were analyzed.

The Actions Taken

At this point was begun what is called a "top-down/bottom-up" productivity enhancement approach. The first "top-down" efforts were aimed at preparing employees for the change that had begun to take place. To start the process, The Blanchard Training and Development consultants were invited to work with the management team. The Blanchard Situational Leadership training was to help managers and supervisors recognize the various developmental levels of the employee and to match each level with an appropriate leadership style. The management team needed to be prepared for whatever came up as employees discovered new ways of communicating their ideas. A major fallout of the Blanchard work with managers and supervisors was the design and implementation of a Performance Improvement Plan (PIP). The PIP is a set of formal discussions between a manager and an employee for the purpose of discovering how the employee is presently performing a job. It is an ongoing process consisting of three phases: performance planning, performance monitoring, and performance evaluation. Through this process, employees receive ongoing feedback -- which seems to be the number one motivator of people. Clarity of goals and accountability for performance are two by-products of this process.

Results of Situational Leadership

Blanchard Training and Development has had a significant impact on improving management effectiveness at Lockheed-EMSCO. Many managers are using Situational Leadership on a day-to-day coaching and counseling basis and in performance planning and review. Out of this work management saw a need to replace the Performance Appraisal Review system that was being used. The Performance Improvement Process (PIP) was designed to replace the old system which did not allow two-way interactions between management and employees. Management became more aware that employees need to know what is expected of them and must have regular, thorough, and honest feedback on their progress. This new process gives managers and employees the feedback both need.

This training and development process resulted in:

- A new performance appraisal system based on the concepts and language of Situational Leadership
- New performance appraisal forms
- Managers who can use the new performance appraisal process and train others to use it
- A core of in-house trainers who can assist others in learning and implementing the new performance appraisal process
- Improved communication between various levels of management
- Improved management skills on the part of managers and supervisors as related to performance appraisal (80% of the current management team has attended the Blanchard Situational Leadership training.)

Challenges to Overcome

Since the implementation of the process, many hours have been spent refining the system. The amount of time management would have to spend with each employee throughout each of the three phases of the PIP was not given enough consideration. Both management and the people being evaluated agreed that the procedures needed to be shortened. Both groups also agreed that although the procedures needed to be altered, the process was a marked improvement over the old format.

Another Action Item: Employee-Headed Programs Begin

The first "bottom-up" effort was a request that employees consider the possibility of devising or improving systems that would improve the quality of their work life. The first breakthrough was the creation of the Lockheed Information For Employees/Performance Enhancement Recommendation System (LIFE/PERS). The process was initiated by a nonmanagement employee who was excited about the opportunity to communicate an idea he had held on to for years. The LIFE/PERS was to provide a mechanism for communication among all levels of the company. The LIFE portion of the system focuses on questions and answers primarily about company policies and procedures. The PERS portion offers a mechanism whereby any employee may make suggestions that will, in his opinion, enhance operations and employee productivity. There is an optional provision for anonymity. The committee that is responsible for operating the LIFE/PERS consists of nonmanagement representatives from each of Lockheed-EMSCO's four branches. At least one of the members must be an hourly employee. The committee asks a fifth nonmanagement employee to serve as the chair.

Major by-products of the system are that employees are able to request information or make a suggestion in a timely way. Thus with less time needed resolving issues related to the quality of work life, employees can involve themselves more often with task specific innovations. Finally, although managers and supervisors do not serve directly on the committee, coactive participation is always needed to resolve issues or implement suggestions.

Results of the Lockheed Information For Employees/Performance Enhancement Recommendation System (LIFE/PERS)

The LIFE/PERS Committee was the first major demonstration of the work force's desire to share the accountability for improving company productivity. The original committee was comprised of highly technical individuals, which may account for some of the detail that the system exemplifies. For the first time in the history of Lockheed-EMSCO a group of nonmanagement employees devised a suggestion system, which included a scale to rate the impact of a suggestion on productivity. This totally volunteer committee began by writing a letter declaring their self-created functions and responsibilities. The committee passed the letter through the president's and the program manager's offices, for dual signatures, to be sent out to all employees as an expression of top management support. The committee was encouraged by senior management's obvious trust and committment to their success.

The committee's actions alone are one example of the enhanced creative abilities that can show up once innovative openings are created. Because of these employees' initiatives the company has experienced a marked increase in valuable suggestions over the past four years. Many have been implemented, some are being considered for implementation, and others cannot be justified based on cost effectiveness or other factors. Some valuable outcomes are:

- LIFE/PERS - has served as a valuable tool to help close any gaps of perception that may exist between employees at all levels. Because anonymity is maintained upon request (through the committee member of the requestor's choice) important, sensitive issues have been handled more effectively.

- Monetary rewards for suggestions - Committee members discovered in a random survey of employees that monetary rewards were desired over savings bonds or merchandise. Rewards are distributed at the end of each calendar year for suggestions scoring highest. The weighted factors used by the committee to rate the suggestions are quality of work life, cost saving/avoidance, productivity, employee morale, impact, cost to implement, applicability/scope, and health/safety.
- LIFE/PERS bulletin - Bimonthly distributions to all employees help to:
  - Clear up misinterpretations of company policies and procedures and communicate consistent information to all employees at the same time
  - Help other employees emulate the act of suggesting improvements
  - Point at what else needs to be addressed at all levels (benefits, management/employee development, facilities improvements, etc.).
- Special Purpose Teams - improve management/employee interactions as both groups align to investigate issues and suggest recommendations.
- In-house delicatessen - Growth in the Clear Lake area continues to affect the amount of time it takes to get to and from the joo in the mornings and afternoons, as well as during lunch. Employee awareness of the need to honor audit requirements led to the suggestion of an in-house deli. Workers can now leave home early, avoid the rush, and eat a hot breakfast in the deli without the anxiety of being late for work. Whether for the purpose of meeting a tight schedule, avoiding inclement weather, or simply avoiding the lunchtime traffic, employee morale has been improved as a result of this new addition.

These are just a few of over four hundred questions and suggestions the committee has received since it was first announced to all employees in 1982. It is important to note that this process is used more often to address issues outside the scope of ones work. The Performance Development Team is used to forward actions that are more task related.

The Difficulty of Reversing Roles

Initially managers were not accustomed to responding to requests from below, and nonmanagement employees were not always familiar with nor had access to information which helps them proceed efficiently. After four years of authentic top management support, training, and acceptance of the fact that everyone can contribute to each other, employees seem to be closer to realizing the value of working together at all levels. Some are still experiencing frustration adjusting to these new roles. Although unpopular responses sometimes evoke criticism from employees, participation is increasing. The committee has received more suggestions in the first six months of 1985 than it has in any previous full year.

The LIFE/PERS design was well thought out, and senior management was impressed with the employees' first attempt at suggesting methods of improving productivity at Lockheed. Success of this employee initiated/management supported process gave rise to other employee-headed efforts.

The Second Employee-Headed Effort

The Quality Program Committee (QPC) was established to facilitate the overall objectives of the bottom-up productivity enhancement efforts - to enhance the quality and productivity of the company's resources. The QPC is composed of five members who serve staggered one year terms. There is a maximum of one management representative on the committee, and at least one of the five members must be an hourly employee. A major activity of the QPC has been the formation of Performance Development Teams and Special Purpose Teams.

Results of the Quality Program Committee (QPC)

This group of volunteer employees decided that the company needed a standing committee responsible for keeping the organization abreast of ways and means of getting involved. To achieve their goal this committee did the following:

- Designed and published a "Quality Program Handbook" which described to all employees and new hires all entities of the employee involvement efforts
- Created "Quarterly Information Exchange Meetings" to provide a way that teams could report their success and gain more support, if needed.
- Began posting weekly productivity themes in selected areas to raise awareness of the need to improve productivity
- Assisted in the start-up of new teams throughout Lockheed-EMSCO
- Initiated the first "Skip-Level" meetings to be facilitated between management and nonmanagement employees at Lockheed-EMSCO (See explanation of "Skip-Level" in a later section of this paper.)

The biggest challenges this team has had to face are managing their own time and keeping themselves motivated. The team has realized that seeing what needs to happen is often easier than getting it done. They have begun to request more training in the area of facilitation as a means of being more effective in coaching other employees in problem-solving.

An Employee-Headed, Task-Specific Approach

A Performance Development Team (PDT) seeks solutions to issues at the task level. These teams are LEMSCO's version of the quality circle. The issues addressed by PDT's include improvements to situations which negatively affect work performance, actions that improve productivity and reduce costs, and activities which increase communications at all levels. The PDT usually has five to eight employees from the same department, section, or project area. Membership usually includes a supportive supervisor or project manager who has access to information that can be helpful to the team. The team leader is selected from nonsupervisory members.

Results of Performance Development Teams

These team members and their managers are convinced that coactive participation is a very effective means of improving their tasks. The greatest improvements have occurred in the high technology areas. Computer utilization PDT's have accomplished such tasks as:

- Optimized locations of microcomputers and terminals within a work area,
  - Established procedures and priorities for use of microcomputers
  - Improved mutual communications and sharing of computer resources
  - Actions collectively saved the company an estimated $96,000 in one year
- Compiled a reference library for microcomputer hardware and software

- Initiated joint meetings (to save and avoid cost) between the users and systems operators, which included NASA personnel
  - Resulted in computer/terminal usage problems being altered and better communication channels being established with the customer
- Gathered and published software from personal libraries for general use
  - Enhanced personal relationships, thus boosted morale
  - Identified a common interest group
- Conducted and published "Off-site to On-site Computer Communications Systems Upgrade Study" which addressed problem of lost productivity due to antiquated equipment and time spent traveling off-site to on-site by Lockheed-EMSCO personnel to access NASA equipment
  - Revealed a yearly cost avoidance in excess of $1 million if systems were to be upgraded
  - NASA invested $150,000 toward equipment upgrades in phase I
  - Phase II investments are to be determined based upon continued monitoring of effectiveness of phase I investments

These are just some of the accomplishments of the computer usage teams. Teams have also affected positive change in the areas of safety, health, and interpersonal relations.

What Helps Teams Survive

Team viability seems to be dependent on team leadership, confidence, and willingness to work hard, often with no initial support from middle management. On the other hand, lack of management support seems to be a motivator in certain environments. In some highly technical areas, in which management support does not initially exist, members have gained support through hard work and committment to resolving major technical issues. Early success also seems to motivate members to continue. On teams where tasks are not related in some way, members often experience major frustrations in deciding on common challenges. They soon become disinterested and decide to leave the team.

The Specialty Team

A Special Purpose Team (SPT) seeks solutions to a particular problem, usually with company-wide or program-wide scope. An SPT may be formed whenever a problem is outside the scope of a PDT or as a result of a question/suggestion submitted to the LIFE/PERS Committee. Employees from any level of the organization with relevant information, interest, or influence are recruited to form this team to work toward a feasible solution.

One example of a Special Purpose Team which evolved out of a LIFE/PERS suggestion is the Wellness Team. What began as a request for corporate discounts at local health facilities has culminated in the establishment of a comprehensive wellness program. This team was started to help facilitate the notion that total wellness depends upon thinking power, mental health, and physical condition.

Results of The Wellness Team

Getting people involved is the challenge of all successful productivity improvement efforts. This program has been most successful in getting people involved. Committment to a vision of healthy, happy, productive people is the driver behind their success.

Their first initiation was company sponsored exercise classes in the main conference room after hours. They went on to establish a program whereby employees could purchase discount vitamins from a reputable pharmaceutical company.

These were the small beginnings of what has developed in the past six months into the Lockheed Wellness Program. The Wellness Program consists of a wellness center conveniently located at the work place. Here employees can exercise on ten variable resistance machines, three treadmills, four exercise bikes or participate in any of nineteen aerobic exercise classes offered weekly. Through the center, educational activities are conducted on a continuing basis to create positive lifestyle changes regarding personal health. Such topics as nutrition, weight control, lower back care, high blood pressure control, and stress management are addressed. Voluntary health screening procedures and smoke cessation classes are also available. The American Heart Association's Heart At Work program has been implemented to help employees reduce the risk of developing cardiovascular disease.

Changes that have taken place in the last six months include:

- Coeducational fitness and educational programs
- Thirty-three percent increase in participation
- Participation from every level of the organization
- Nearly five hundred percent increase in number of aerobic classes
- Private fitness assessment testing and six-month interval retesting

Figures 1 and 2 are examples of the types of comparative data that are now available as a result of the fitness assessment testing and retesting. Figure 1 shows that the mean age of Lockheed-EMSCO employees committed to regular exercise is about thirty-eight; the occasional exerciser has a mean age of about twenty-eight; those who reported they never exercise are at a mean age of about forty-two. This type of information could (for example) indicate the need to get the older employees more involved in exercise if the risk of cardiovascular disease

Figure 1.- Comparative boxplots of age distribution of LEMSCO exercisers.

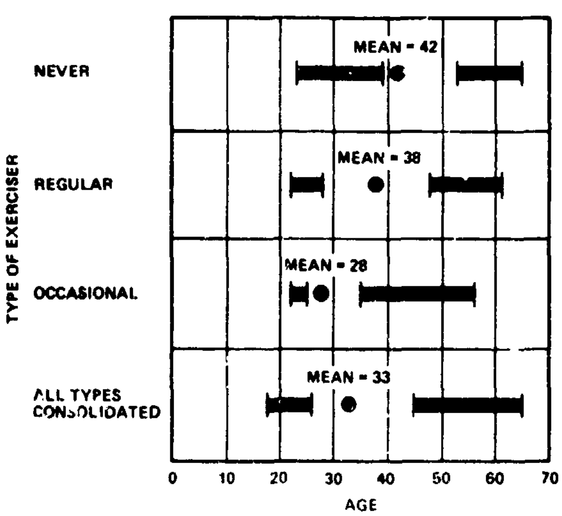
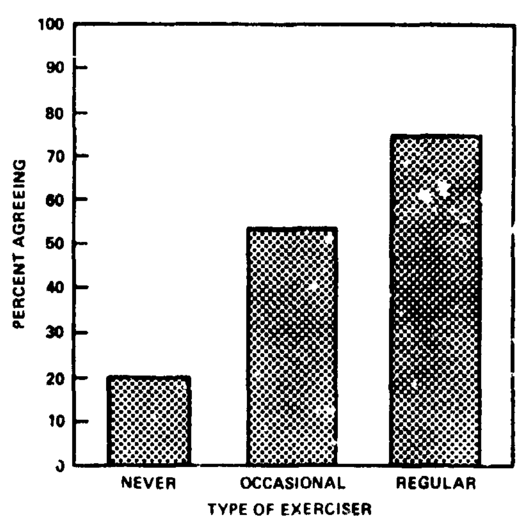


Figure 2.- Percent of exercisers who agree they perform their task better with regular exercise.



increases with age and decreases with exercise. Regarding performance, figure 2 shows that seventy-five percent of the regular exercisers perceive that they perform their task better when they exercise regularly; fifty-three percent of the occasionals agree. Only twenty percent of the employees who never exercise perceive that regular exercise positively affects their task performance.

The LIFE/PERS, the QPC, PDT's, and Special Purpose teams are all examples of "bottom-up" efforts. Blanchard Situational Leadership training has been the only "top-down" activity at this point. The next "top-down" endeavor was a communication feedback process called "Skip Level."

Skipping Levels Can Enhance Communications

The "Skip Level" process is designed to surface hidden problems and innovative ideas. It addresses two common communication deficiencies inherent in any organizational structure. In vertical communications, it corrects for the potential distortions and omissions that can occur at each level of message passing. In lateral communications, it corrects for the "limited field of vision" that makes it difficult to tell if a problem is minor and isolated or major and widespread.

"Skip Level" is a process in which a manager meets with employees at least two levels lower in the organization; this is the "skip." It can be a top manager who meets with all middle managers two levels below, or a middle manager who meets with selected employees from the same or different levels, or any number of other possible combinations.

"Skip Level" also includes a process for developing solutions and recommendations that places primary responsibility on those who identify the problem or suggest the idea. The purpose here is to counter the usual passive pattern of reporting a problem and then waiting for the solution. Of course, it is incumbent on higher management to be responsive in considering these recommendations and taking action on them.

Results of Skip-Levels

"Skip-Level" meetings were conducted between the Program Manager and the supervisory level. Initially supervisors were both skeptical and pleased that they had been chosen to participate in these meetings. A survey was conducted at the end of the process, and success was evaluated by a predetermined criteria.

Results of the survey suggested that participants were most satisfied with the opportunity to communicate with upper management, exchange information and discuss mutual problems, and meet new supervisors or get reacquainted with others. A negative comment was that the sessions were too long. The predetermined evaluation criteria stated that above average success was achieved if cost reductions and work process reconfiguration result in a savings of at least $4.00 saved for $1.00 spent and if the majority of participants felt the process had contributed. Above average success was achieved. The meetings cost $5,000, and cost reductions (that were tailied) amounted to $125,000.

Distinctions of Leadership

The creation of a totally new investigative approach by Lockheed-EMSCO's President and Chief Executive Officer is the most innovative undertaking to date. This course is called "Distinctions of Leadership." In light of increased organizational complexities, such as increased workloads, budget cuts, consolidation of efforts, etc., there seemed to be a need for training which expands ones ability to create possibilities that forward action. The course is comprised of classroom activities and individually selected projects designed to utilize classroom "theory" in resolving day-to-day issues. Collectively, the distinctions that are brought forth, discussed, and applied during the course provide the foundation for shifting from a creative work environment to an entrepreneurial environment in which action is continually forwarded toward desired results.

Results of Distinctions of Leadership

Employees at all levels of the organization have declared breakthrough improvements in how they accomplish their work. The following major accomplishments have been noted:

- Projects brought in early and under budget
- Employees working together in new ways to bring in new business
- Managers more willing to give up some control and accept creative suggestions
  - Example: new Lockheed-EMSCO twin facility
- People asking less often how to do the job and making more creative suggestions

SUMMARY

A flexible and innovative approach for enhancing productivity at Lockheed-EMSCO exists. It is employee centered and has adapted to changes required by time. It has taken four years to develop processes which "really make a difference." Most experts agree that five to eight years is a conservative estimate in which major productivity gains are noted. LEMSCO's efforts have evolved from a "quality of work life" approach to primarily a task-specific series of approaches to enhance quality and productivity. The company is now on the threshold of creating major performance breakthroughs.

BIOGRAPHICAL STATEMENT

Brenda J. Kelly is the Productivity Project Engineer for the Engineering and Science Program at Lockheed Engineering and Management Services Company, Inc. She is responsible for advising and consulting with all levels of the organization on matters pertaining to the design and implementation of an optimum organizational climate. Ms. Kelly received a B.A. in Psychology from Sam Houston State University and an M.A. in Behavioral Science from the University of Houston at Clear Lake City. Membership is held in Quality and Productivity Institute, American Productivity Center, and National Management Association.

BUILDING EMPLOYEE INVOLVEMENT

5110

WHITE COLLAR PRODUCTIVITY IMPROVEMENT: A SUCCESS STORY

E. L. Franzen
and
D. H. Hutchinson
McDonnell Douglas Astronautics Company
Huntington Beach, California

ABSTRACT

This paper discusses how white collar productivity improvement techniques and measures can be applied at the level of an operating department responsible for direct labor budgets of engineering and manufacturing organizations by program (contract). It focuses on the management issues of objective setting and productivity measurement in high-technology organizations.

The substance of the paper is a case study of a White Collar Productivity Improvement pilot action research project initiated on October 1, 1984, at the McDonnell Douglas Astronautics Company in Huntington Beach, California. Productivity improvement has long been a key part of the operating strategy at MDC under the leadership of Chairman and CEO Sandy McDonnell.

Three companies within the McDonnell Douglas Corporation have participated in six American Productivity Center White Collar Productivity Improvement pilot action research projects over a 2-year period. This project is one of the six. Twelve other corporations and NASA also sponsored pilot projects, all of which together formed a computer network to share experience and results.

This case study presents the experiences of an entire department as it proceeded through a six-phase process of organizational renewal. A team of nine selected as a cross section of the department guided the project through the process provided by the American Productivity Center. The purpose of the project was to improve effectiveness. For this goal to be achieved, the perceptions of the department membership, of the users of their products and services, and of their line management had to be obtained because many problems encountered in the pilot project involved these perceptions. The dynamics of their interactions are briefly outlined. Data needed to be gathered to properly deal with perceptions. Innovative techniques were developed as the process unfolded. The pilot project management team placed extensive emphasis on (1) surveys and interviews, (2) meetings of the whole department with its managers, (3) complete feedback of results of

surveys and interviews, and (4) participation of voluntary teams in working out plans for specific changes.

The success of this pilot has been positively received and plans are under way for initiating similar projects in other departments.

INTRODUCTION

The McDonnell Douglas Astronautics Company recently conducted a pilot project designed to improve organizational effectiveness in the 33-member Financial Controls-Direct Budgets department of the company's facility in Huntington Beach, California. The project began on 1 October 1984 and was scheduled to be completed in August 1985. It was one of six White Collar Productivity Improvement (WCPI) pilot projects participated in by McDonnell Douglas with the American Productivity Center. (See Figure 1.)

This report reflects this experience as evaluated by the authors and the pilot project management team, who were selected to represent the department. The resulting view of WCPI projects is that they are

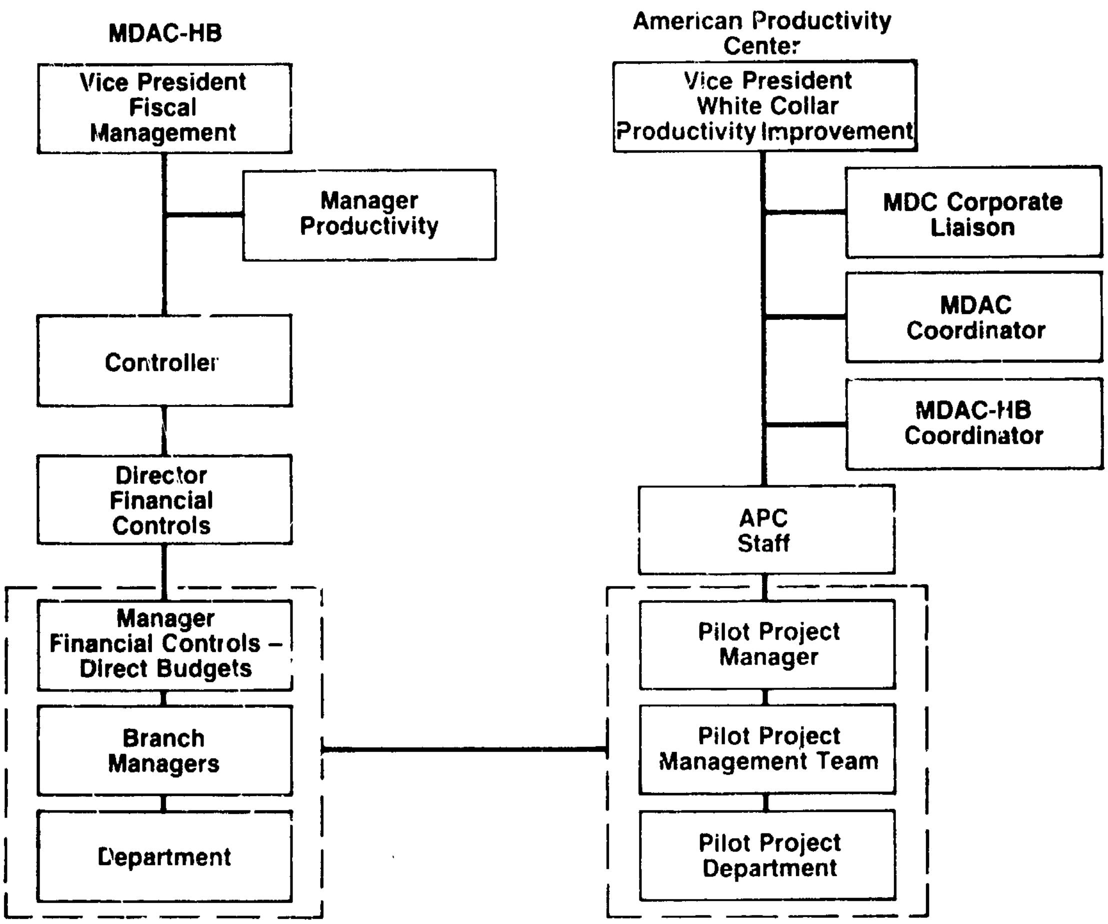


Figure 1. MDAC-HB Pilot Project Organization

key to improving organizational effectiveness in white collar environments. The six phases of the American Productivity Center methodology provide a framework for group problem solving in such an environment. The specific objectives were (1) to develop criteria for improving managerial and professional effectiveness and (2) to develop and refine methods of and approaches to improving white collar productivity.

This particular pilot project sought to go considerably deeper than many other white collar productivity improvement projects into gaining the personal involvement of three groups of people: the participants in the project, the users of the departmental products and services, and representatives of management. Meetings were held in which all 33 members of the department worked together and participated in making decisions about their "common purpose". The members responded to a 200-question survey that covered such areas as attitudes, leadership, communication, participation, goals, rewards and recognition, resources, etc., and each member received the results of the survey.

A survey was also developed and distributed to 150 users of the services of the department, including fiscal, programs, business, engineering, and operations users on seven different programs, and these people were interviewed as well. The involvement of this group provided a basis for redesigning the services of the department to meet strategic plans, building a team for organizational realignments, and applying technology to improve service to users.

The management group included the vice president of Fiscal Management, the directors of Financial Controls and of Productivity, and the company's controller. The involvement of this group resulted in personal briefings on the progress of the pilot project being given to the vice president and general manager of MDAC-HB, the president of MDAC, the vice president of Human Resources of MDC, and several groups of people in departments that may be candidates for future projects.

The schedule shown in Figure 2 provides a guide to the key activities of the project.

An initial task was to gain the commitment of those who invested the resources necessary to start the project. This task in performance improvement projects is probably the most critical and is often difficult, which was particularly true in this case. Corporate and company meetings were held on the subject as early as the winter of 1983 before it was decided to send a candidate coordinator to a 2-day orientation and training workshop conducted by the American Productivity Center in April 1984. From that time until the project was initiated in October, a commitment was being sought at McDonnell Douglas in Huntington Beach. One of the difficulties facing management in their considerations was that of introducing a research project in an environment already heavily involved in such other productivity improvement programs as Quality Circles and Juran Projects. Another difficulty in getting such a commitment is that because the WCPI process is one of learning while doing, it is difficult to share evidence that

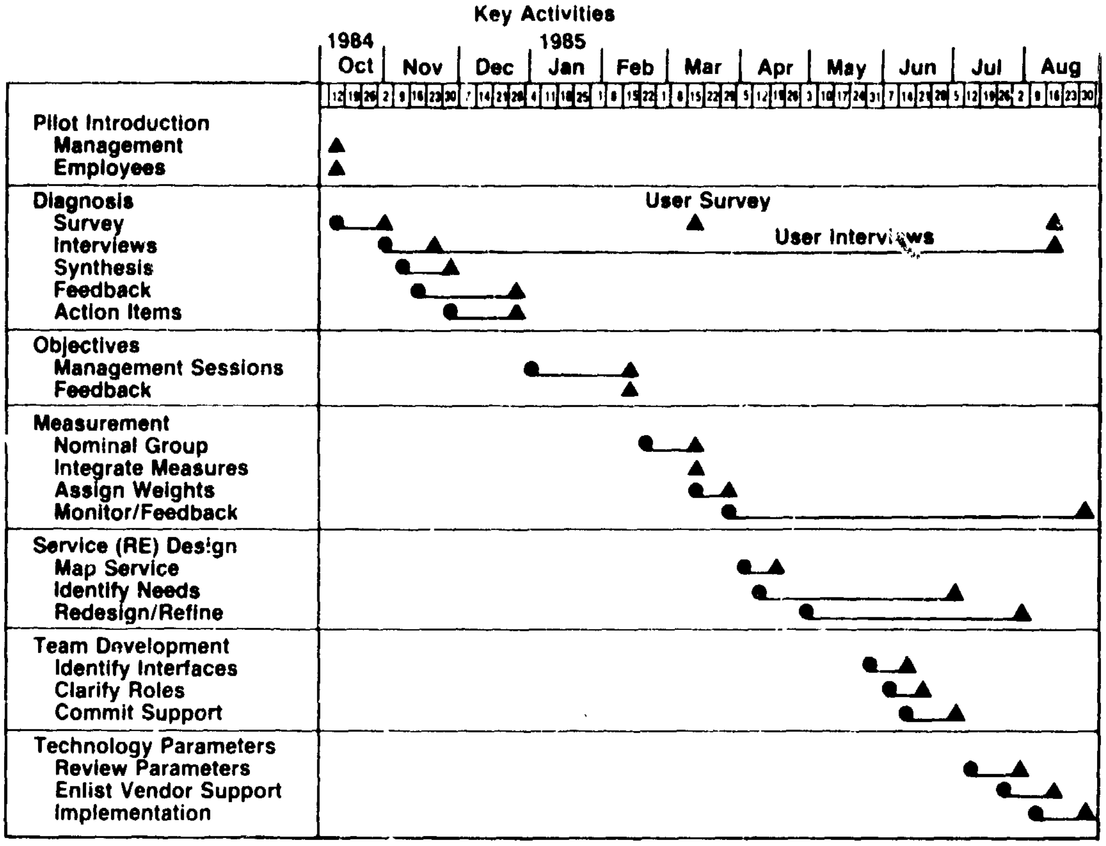


Figure 2. MDAC-HB Pilot Project Schedule

this kind of approach to improvement actually works. American Productivity Center methodology does not provide any exact formulas or rigid approaches to this first step; innovation is the key to success here.

At the beginning of the project, we began to share ideas with the American Productivity Center staff (and obtained corporate support coordinated through liaison between the Center's staff and corporate staff). To build the confidence of our local management and secure the appropriate level of commitment, pilot project coordinators from other corporate components, i.e., McDonnell Aircraft Company and McDonnell Douglas Astronautics in St. Louis, reported to the Huntington Beach management team their experience with similar St. Louis pilot projects begun some months earlier.

The project was pursued in the six phases--diagnosis, objectives, measurement, service redesign, team development, and technology parameters--discussed in the following paragraphs.

1. Diagnosis

The diagnostic phase began after management commitment had been obtained, methodology training had been completed, and a pilot project management team had been formed. Following the appointment of a branch manager from within the department as the pilot project manager, an additional seven members were selected by him, with the project coordinator filling in the pilot project management team complement of nine. The manager of the department was selected as a team member. The team represented a cross section of the department in terms of experience, age, gender, representation of users and clients (customers) of the department, and skills needed for the project. The nine members met for the first time on September 28, 1984. The coordinator provided training for the project team, and the American Productivity Center staff representative helped prepare for the survey and interviews. A 2-hour kickoff meeting to introduce the pilot project to the 33 members of the department was met with considerable skepticism. It was not until the survey was taken at the second meeting and the preliminary results were distributed the following week that enthusiasm for the project began to develop in the department.

A great deal of thought and effort went into promoting a comfortable atmosphere, ensuring the confidentiality of survey and interview results, and eliminating any possible connotation that the survey was a threat. The return rate was 100%. Informal discussions within the department indicated that most people felt comfortable taking the survey and pulled no punches in answering the open-ended questions and in making supplemental comments.

Each member of the department was interviewed (using an interview format recommended by the American Productivity Center), and the results of the survey and of the interviews were relayed back to all members of the department. Persons interviewed included members of management and a sampling of users of the departmental products, as well as the 33 members of the department.

All nine of the pilot project management team members independently analyzed the results of the survey and the interviews and documented general conclusions, opportunities for improvement, and recommendations. These data, together with American Productivity Center conclusions and recommendations, were combined by the project manager into a single 19-page document, which was used by the department manager to develop a set of action items designed to deal with the problems that had been identified.

These action items were reviewed by the other pilot project management team members and returned with comments and additions. A final set of action items was presented to the department in a 3-hour session January 8, 1985.

Completion of the diagnostic phase resulted in a sense of participation being established within the department itself and in the pilot project management team. They had developed a feeling of "ownership" in the resulting diagnosis of the situation.

In parallel with other project activities, the coordinator, the pilot project manager, the department manager, and two other team members attended conferences at the American Productivity Center in Houston, which provided tools and shared experiences and helped build a network of support at Huntington Beach, Houston, and St. Louis. This foundation proved to be important as the project progressed. A camaraderie developed along with a cooperative spirit. A coordinator of a St. Louis white-collar productivity improvement pilot project came to Huntington Beach to lend his talents when they were critically needed during the interview part of the diagnostic phase. The lessons learned in St. Louis had invaluable application, as did the discussions that were held, and helped us to avoid potential stumbling blocks at critical points in the process. All interviews were conducted by either the American Productivity Center staff representative, the MDAC-HB coordinator, or the coordinator from St. Louis. This preserved anonymity and continued candor.

2. Objectives

The diagnostic phase was oriented to the perceptions of work improvement and work environment of each person in the department, as well as those of a cross section of clients. As a result of the diagnostic phase, six internal volunteer task teams began to work on the improvements identified as desirable. Through this process, the 29 goals derived were synthesized and prioritized by vote and reduced to 12.

Each member of the department participated in this choice of goals oriented to areas including training, communications, performance measurement and career planning, department image, participative management, and reward and recognition systems, among others. This provided a keen sense of ownership within the department for "their" goals, which are conspicuously posted throughout the department and statused monthly. Annual goals or objectives may not always be effective whereas, in this case, the feeling of ownership with frequent review of progress leads to living with theirs in their daily work.

This objective phase shifted the attention to a management perspective that continued to enlist the participation of the pilot project management team and the members of the department. The manager of the department took on the leadership of an effort to prepare a statement of responsibilities and integrate worker and user perspectives to articulate the work of the department and develop a roadmap for the planned changes. The rationale for the phase was to develop an understanding of services and establish objectives for improving services and products that could ultimately be used for measuring departmental performance.

Services were defined as budget development, budget maintenance, internal and external financial reporting, program support, fiscal support, and functional (engineering and operations) support. Information developed from interviews with managers and users, brainstorming sessions of the pilot project management team, and refinements by the managers resulted in a statement of objectives for each of the services. The question asked was not what does the boss demand, but what does the job demand from the perspective of the producers, the users, and line management. The result provided a design for the future thrust of the department.

The results of management sessions and feedback processes between the three sources of perceptions were beginning to work. The objectives for each of the services provided an expanded awareness or sense of purpose within the department. Meanwhile, the progress of the internal task teams in the department provided immediate improvements that opened up communication channels and provided the initial awareness that participative management would become a part of the department's way of life. These improvement efforts were a source of providing more meaning and self-control [2] to the people who work in the department and opened discussions with users about specific improvements in services.

3. Measurement

The development of an approach to measuring improvement began in March of 1985 with a series of meetings of the pilot project management team. After consultation with the American Productivity Center staff representative, the team used the Nominal Group Technique [3] (structured brainstorming) to elicit potential measures of performance improvement in budget development and maintenance, financial reporting, program support, fiscal support, and support to engineering and operations. Indicators were listed and weighted for each of the previously determined services and objectives. These indicators were then evaluated by the project team and many potential measures were discussed. Where the emphasis of the project had been on effectiveness rather than on efficiency, there seemed to be considerable difficulty in determining effectiveness measures. However, those indicators of efficiency improvement seemed quite easy to obtain.

At this time an extensive review of the approaches taken and progress made in measurement (or indicator) development by other pilots within the American Productivity Center project was undertaken by the pilot project management team.

The review disclosed many similar findings among the other pilots and indicated that the problem could be partially resolved by extending the process of development of indicators through the period of the following phases. The redesign of services. the impact of redesign on the user interfaces, and the possible introduction of t[illegible]ogy changes in the delivery of a product or service are so int[illegible] they can scarcely be distinguished from each other. The [illegible]ss of the impending changes stemming from the survey of use[illegible] the pilot project management team to select effectiveness indica[illegible] as objective as possible for the time.

They are:

A. An annual survey of the department.

B. An annual survey of users.

C. Biannual evaluation of department performance collectively based on criteria developed by the department membership as a part of one of their goals for personal performance evaluation.

D. Monthly status of progress on all department goals.

A and B above reintroduce the exact surveys that were previously administered to provide comparative data necessary for effectiveness improvement analysis. Appropriate additional questions will be appended in each instance where indicated.

These are scheduled to recur on a continuing basis and are to be accompanied by interviews, when indicated, as part of the normal department future operating routine.

4. Service Redesign

The objective of redesign is to produce a new form of service in response to feedback about how a previous form failed to totally satisfy user needs. The pilot project management team found that the most important requirements for budget development and maintenance were timing and fitting the specific context of each user group. Changes implemented thus far have been met with considerable enthusiasm not only from the users but from the department personnel as well. The producers and the users of the products and services of the department continue to be engaged in the learning process of developing mutual objectives, collecting and analyzing facts, uncovering and testing concepts, determining needs, and stating problems.

5. Team Development

The team development phase was impacted by the announcement of an imminent reorganization of people, activities, and relationships at MDAC-HB, the planning for which was unknown to the department until midway through the project. The planned reorganization, when implemented, will transfer all but a very few of the department personnel to newly created business units. This could understandably have been looked upon as demoralizing, with the result of a rapid loss of interest in the pilot project in which these people now had such a feeling of ownership. However, the effect of the acquired sense of common purpose, their goals, and the gains made through the newly developed sensitivity to user needs held the common interest together. Furthermore, for department personnel it kindled a new interest in the potential of using their experience in this pilot project to introduce WCPI projects within the new business units of which they will soon become a part.

6. Technology Parameters

The technology redesign phase began with the composition of the pilot project management team through the inclusion of an information systems specialist. The interviews with users of the products and services of the department provided criteria for the next generation of system design improvements. The action research approach provided an opportunity to systematically collect research data about an ongoing system relative to objectives and user needs. Systems analysts can now take actions within the information system and through this established process better evaluate results. It is anticipated, however, that gains in this area will be limited by other management information system priorities, particularly with respect to timeliness.

CONCLUSION

Improvements accrue to each of the three groups when the members of those groups believe in the process. Credibility must be established as the first priority: the best presentation in the world will not achieve this credibility. Not one of the three groups was easy to convince. Even the pilot coordinator and manager had to go through the process. The key is complete honesty with total feedback. The first meeting with the entire department did not result in belief in the process because the "will" was not apparent. It took action to show that manager, user, and producer groups had the will to do something. Once the members of the department were given complete feedback and committed themselves to involvement in the diagnosis and objective setting processes, things turned around dramatically. Their commitment to the process came even in the midst of extremely heavy demands from the daily workload. Results of this project pointing to its success include:

A. Improvement in the quality of work attitudes, leadership, communication, participation, goal-setting, measurement and analysis, rewards and recognition, and resource utilization.

B. Improved user relationships with the department. This began with identifying the products and services with appropriate consideration of user perception. Effective interaction begins to occur when the department is viewed through the eyes of the user. Of 150 users surveyed, 115 responded. Seventy-eight of those responding provided supplemental comments expressing in their own words their specific perceptions of the effectiveness of the department and its personnel.

C. The creation of a belief in management. Management worked through the change with a representative team of nine people who knew the work intimately and were selected as a microcosm of the department. They provided a strong sense of mission and focus. They helped to ensure that the project got off to a good start, and then they let the people in the department (including the supervisors) carry it out. Through this demonstration of confidence in the people, management gained their trust.

It is appropriate to discuss certain of the lessons that were critical elements in the success of this pilot project.

A. The support of management, strong at the outset and enduring throughout, was at all times present, while never interfering with the process. When called upon for visible support, management personnel were available, while not pushing the project processes for demonstrations of "hard" cost savings. The involvement of the total department in the process either avoided or eradicated any feelings of distrust of management that might have otherwise been present.

B. The department survey and interviews most certainly established that there existed a general attitude of skepticism. The approach taken in involving all on a voluntary basis to participate in developing remedies to their perceived problems resulted in a feeling of ownership that will outlive the department as they know it today.

C. The user survey elicited many comments expressing enthusiasm for the opportunity to participate in restructuring the products and services upon which the respondents rely. Following up with each of the users to discuss, better understand, and form resolution action plans has opened communication in areas of interface that will endure through organizational transitions to the continuing benefit of all concerned.

D. Throughout the project, everyone's personal perceptions, valid or not, were considered to influence the way people interact with each other and contribute to, or detract from, one another's success. The attention paid to the importance of responsiveness to the perceptions of the department personnel and to those of the users has served to demonstrate the integrity of management's belief in the participative management process. Participative management must be a two-way process that allows all employees to share in shaping the future of their departments by encouraging them to express their opinions and by training managers to listen to those opinions and consider them carefully.

E. The concentration on effectiveness issues versus efficiency, with measures adopted to monitor effectiveness gains, will provide efficiency improvement opportunities downstream that will appropriately relate to the "right" tasks.

F. It is clear that there remains much to be learned in and of the process. We are therefore, continuing our participation with the American Productivity Center as they embark on IMPACT [1], a follow-on WCPI project.

This pilot project has shown that the key to productivity improvement is through the development of a recognition that it is a continuous process. That recognition is present in the management, the department, and in the user communities involved in this project and has resulted in mechanisms having been put in place to ensure that the process introduced in this pilot project and others that will follow will never be completed but will become continuous as a way of life in an organization having successfully experienced the process of self-renewal [4].

In closing, Figure 3 illustrates a very specific "hard" saving that, although not a part of an identified effectiveness indicator, is directly attributable to the "soft" gains made through this approach to increasing organizational effectiveness.

Fiscal Management
Financial Controls – Direct Budgets

	Population	Requirement
■ Doing more with fewer people		
• Started with 33 people in department	33	33
• Program activities reduced workload by equivalent of 4 people		(4)
• 5 people left department (terminations)	(5)	
• Overtime and new people increased department by equivalent of 2 people	2	
• Equivalent of 11 people assigned to new programs		11
■ Equivalent of 30 people doing job of 40	30	40

Effective Productivity Increase:

$$\frac{10}{30} = 33\%$$

Figure 3. Example: Productivity Increase

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BIOGRAPHY

E. L. Franzen is currently Branch Manager, Financial Controls-Direct Budgets, Missile Programs, at McDonnell Douglas Astronautics Company in Huntington Beach (MDAC-HB). In addition to his present assignment, he was appointed Manager-WCPI MDAC-HB Pilot Action Research Project in September 1984. He has been guiding that activity for the past year. In 28 years with the McDonnell Douglas organization, his time has been equally divided between managerial assignments in Engineering and Fiscal Management disciplines.

D. H. Hutchinson is currently a coordinator and internal consultant to leaders of management improvement projects at the McDonnell Douglas Company. He has been a facilitator and trainer on the initiation of Juran projects and the white collar productivity improvement pilot project as well as provided support to training and communications in the "Five Keys to Self-Renewal" since the inception of these initiatives at MDAC Huntington Beach. Hutchinson has gained extensive experience in Engineering, Program, Human Resources, and Operations departments during his 29 years at McDonnell Douglas. He received his BA and M.Ed degrees from UCLA and is currently in the doctoral program at Claremont Graduate School. His dissertation, entitled "Resymbolization of Work", deals with a theory of knowledge-work productivity and will be published in 1986.

WHITE COLLAR PRODUCTIVITY IMPROVEMENT IN A GOVERNMENT RESEARCH AND DEVELOPMENT ADMINISTRATIVE SUPPORT ORGANIZATION

Bradley J. Baker, NASA-Lewis Research Center

ABSTRACT

At NASA-Lewis Research Center, a governmental research and development (R&D) organization, a pilot productivity project was introduced into the Procurement Division, a professional administrative support group. The pilot group, the entire division of 108 persons, participated in the APC White Collar Productivity Improvement (WCPI) Project methodology to improve service effectiveness. The success of the project is attributed to three key factors: (1) the project emphasis on service improvements through participative methods (2) the commitment of the internal cross-sectional task force formed to head the effort and (3) the support of the Pilot Manager.

INTRODUCTION

In recent years much attention has been addressed toward productivity in the United States. This attention was highlighted by the increasing competition among domestic organizations caused in part by recession reduced demand and the challenge of new, high quality foreign suppliers. Many innovative management techniques have been introduced into U. S. organizations to increase productivity to meet the competition. One of the most commonly introduced type of change has to do with means to obtain workers input and cooperation in the work process. Although this type change has often been implemented in manufacturing and sales organizations, it is possibly of even greater significance in organizations comprised primarily of professionals where nonsupervisory personnel are less closely controlled and often have greater technical competence than their management. In environments such as these, it becomes critical for organizational management to obtain the input from the technical experts in order to accurately evaluate program status and new initiatives.

In governmental research and development (R&D) organizations, such as the NASA Lewis Research Center, in Cleveland, Ohio, similar productivity initiatives are being introduced in both the scientific and engineering professional groups and in the professional administrative support groups. Although the cause of government management concern for productivity is not the same as the competitive driver seen in the private sector, it is similar. In government R&D organizations there is recognition that in times of constricted budgets, more must be accomplished within the existing, reasonably static resources.

With nearly constant limits on personnel ceilings and little or no real budget growth in the non-defense portions of recent federal budgets, and with the public calling for increased research and development by the government to spur technological advancement, R&D organizations have been forced to explore means of increasing productivity and effectiveness. This pressure has been felt by both the scientific and engineering personnel and the supporting professional administrative personnel.

Into such a professional administrative support group, a pilot productivity project was introduced in May, 1984. Within the Procurement Division of the Lewis Research Center, an American Productivity Center (APC) pilot project was formed. The pilot group, the entire division of 108 persons, was volunteered by the Division Chief, to pursue the APC White Collar Productivity Improvement (WCPI) Project methodology to improve effectiviness of the organization. The WCPI design emphasized effectiviness and service improvements rather than efficiency and single numeric measurement gains often seen in similar initiatives. The methodology further stressed pilot leadership and commitment to divisional productivity enhancements.

Specifically, the WCPI methodology rejected the narrow framework seen in previous efforts in the Division which had examined ways to reduce leadtime. Perhaps because procurement lead-time has and likely will always remain a key issue to the service users, it had received substantial attention via several studies, internal and external to the Division, over the last several years. In contrast, the WCPI effort looked to service effectiveness, a much broader topic than simply lead-time reduction. The WCPI project focused the Division's energies upon the Division's purpose of providing "professional goals and services consistent with Center needs and legal requirements" and its six written objectives to achieve this primary goal. In addition, the methodology of the WCPI called for significant input from all levels of the organization, in sharp contrast to the earlier studies done by sources external to the organization and/or by middle and senior procurement management. The WCPI framework encouraged participation by all levels of the organization, working on a daily basis through a cross-sectional task force comprising of a supervisor and six representative non-supervisory personnel.

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* The careful reader should know that the assumptions and conclusions made in this paper are those of the writer, the first-line supervisor appointed to chair the cross-sectional task force. The problems of bias are recognized by the writer from his intimate involvement in the project, but so is the writer's unique vantage point to observe the actions of the Division Chief, the other supervisors in the organization, the task force itself, and the APC Research Consultant.

The service effectiveness model, with its multiple objectives and measures and with its participative structure was instrumental in overcoming the significant amount of skepticism which had built up from the many earlier efforts that by nature had all expressed dissatisfaction with the pilot organization's time to complete procurement actions. In the "Diagnostics" phase of the project, when the APC Research Consultant surveyed the entire organization and interviewed about 25% of the same, comments such as "little or nothing has come out of them (previous leadtime studies)" were voiced. Moreover, the internal organization was perceived as parochial and autocratic by many in the pilot as commments like "decisions get made in the chiefs' offices without input from lower levels," "everyone in the Division at times feels isolated, cut off, or by-passed," and "people follow the chain of command". The APC Research Consultant summarized these comments in the Diagnostics feedback session by stating that there was little sense of teamwork in procurement and that the Division sounded like several organizations, not one organization. Statistically, less than 17% of the respondents to the survey agreed that a sense of cooperation or teamwork existed in the Division. Yet the interviews also noted some willingness and desire for a better and more open organization which the APC Consultant and the Division Chief hoped could be channeled into positive changes.

THESIS

The progress of the APC project and the degree of success it has attained through the various project phases are deemed to be primarily attributable to three key factors: (1) the WCPI program emphasis on service improvement and effectiveness at a Divisional level through participative means, (2) the commitment and "buy-in" to the project by the established cross-sectional task force, and (3) the support of the Division Chief and his desire that this project succeed. Unfortunately, the final quantitative results of this project are still being gathered, but based on some preliminary results and the subjective judgments by many, the project has achieved significant results and will continue to do so as implementation of recommended changes is accomplished.

DISCUSSION

The WCPI emphasis on service effectiveness in a broad sense rather than a narrow focus on a specific variable in the procurement process has already been alluded to. Some of the pent-up skepticism and resistance to another new initiative was alleviated by the pilot personnel understanding that a variety of measures were to be formulated. Although uncertain what the measures would be, the opportunity for a more complete picture of the service to be measured offered some encouragement to many. Moreover, the openness and candor at the feedback session following the Diagnosis Phase, also was instrumental in building some credibility for the project. At that session employees heard some of their own comments, critical of the existing organization, voiced as legitimate concerns and deemed worthy of attention. In addition, the emphasis on Divisional measures rather than individual measures or even unit measures alleviated the fear of recourse and failure, especially at the individual working level. These small, but positive signs provided the opportunity to seriously begin the project in a positive manner.

In the Objectives Phase, when the entire supervisory staff worked on affirming/restating its existing overall purpose statement and in stating its priority objectives, the participative management thrust of WCPI was evident. To establish and prioritize group objectives, Nominal Group Techniques (NGT) were used. Underlying philosophic differences between first and second line supervisors and the Division Chief were exposed as the Division Chief's oft-stated priority of short lead time and low work-in-process, was challenged by other proposed less quantifiable objectives such as completing the requirements in sufficient time to support the user's need and increasing procurement's participation in advance planning and contract administration activities. This juncture in the process was significant as the Division Chief proved willing to share his management authority with his supervisory staff in this key policy area which was fundamental to following phases of the project. These decisions, attributable in part to the Division Chief's desire for the project to succeed, to his plan to be increasingly participative in his management style, and to the WCPI methodology of setting up a participative mode for these decisions, were significant in illustrating to the supervisory staff, that they would be involved in the project. Unfortunately the interaction of the project with the supervisory staff diminished after this phase as the cross-sectional task force was formed and was given the prime day-to-day responsibility of working through the project.

The task force of seven was composed of elected members of each branch and office in the Division, one elected clerical representative, and an appointed supervisor as chairman. This group began working closely with the APC Research Consultant at the September 1984 initiation of the Measures Phase, gradually becoming increasingly self-sufficient as it became knowledgeable of the methodology and confident in its own abilities. The progress of the project slowed appreciably at the beginning of the Measures Phase as the team learned the "jargon" of the WCPI and its NGT mode, became comfortable in its own internal workings, took time to understand the objectives which had been established by the supervisors, and relied on the once-a-month visit from the APC representative for direction. During the Measures Phase though, the team clearly began to assume ownership of the project and to be committed to its completion. Within a month after first being formed, the group agreed to establish a standard weekly meeting time to conduct WCPI business to reduce continuing conflict from other meetings and agreed to implement certain initiatives to try to keep the project visible and provide some measure of early success. The group's desire to select contributing, non-disruptive members to supporting subgroups, the group's own agreement to spend several meetings with bag lunch to gain more time to conduct APC business, and its own concern of the balance between schedule slippage and quality recommendations evidence this project commitment. Two implemented initiatives during this phase, the establishment of a "Recommendation Box" and a monthly "Brown-Bag Lunch" during which professional topics of interest to procurement personnel are discussed, required on-going maintenance which the task force assumed when no other party volunteered to maintain them. Finally in January 1985, the Measures for each of the six stated objectives were provided to the Division Chief. The Division Chief and his supervisory staff discussed these measures during February and early March.

Unfortunately, the supervisory staff had almost no input in the development of the proposed measures and had not been actively involved in the WCPI project since the prior summer. This period of lower visibility of the project to the supervisors seemed to combine with minor irritations some supervisors had experienced in providing their employees time to work on the project (some supervisors were requiring strict sign-in and sign-out for each project meeting), and possibly with status concerns. The result was that the initial discussions of the measures became heated with the Task Force Chairman, a supervisor, becoming very frustrated at the cool reception and seemingly petty comments made about the measures he was introducing. After the first meeting and the passing of several days, passions were calmed and in subsequent meetings, the Division Chief provided more visible support and some protection to the recommendations, while balancing this with an openness to rational, constructive comments. At this point, progress was rapidly achieved as constructive modifications to some recommendations were made and the measures approved. The Task Force was assigned the responsibility of implementation and maintenance of the measures.

The measures themselves have contributed toward service effectiveness and better communication within and without the organization. Specifically, the procurement personnel are implicitly being encouraged to communicate with their customers since we are measuring the accomplishment of a planned, mutually agreeable schedule to the actual schedule. Moreover, the Division is surveying the user community when procurement actions are completed to determine its effectiveness from their vantage point and affording them the opportunity to provide suggestions. Similarly, the Division is surveying its own contract specialists to receive their perceptions on their customer interface, especially in the contract administration area. Through these surveys, the Division has been informed of certain problem areas and has learned that the actual users of its services are generally satisfied with them, notwithstanding the common blame-the-delay on procurement syndrome frequently heard.

As the project moved into the most substantive phases of the project, Service Redesign, Teamwork, and Technology Parameters - the phases asking what changes should be made to the existing processes and procedures, how can the interrelationships and interfaces among personnel be improved, and what changes are needed from a technology and facility standpoint, the Task Force was assuming ownership of the project. By this time the Task Force's weekly meetings were often of more significance than the monthly meeting with the APC Research Consultant. At the beginning of these phases the Task Force agreed to meet for a longer period of time each week and then as the prime effort moved from the Task Force to its appointed subcommittees, the weekly Task Force meetings were shortened to provide the Task Force members more time in the subgroups they were leading.

The methodology suggested by the APC Research Consultant which was utilized for these phases was to divide the procurement process into specific parts from the initiation of a requirement by a user through final closeout of the contract after delivery and payment. (In addition to these phases a special issue of examining the clerical/para-professional role in the Division was separately included). After breaking the process into appropriate parts, each part was examined from a standpoint of comparing the current system to what an ideal system might be. In order to deal with such a large amount of data and the variety of procedures and processes, the Task Force selected knowledgeable, helpful nonsupervisory employees and supervisors to help them accomplish this effort. Two Task Force members headed each subgroup and reported back to the whole Task Force as to its progress and recommendations. From the subgroup's examination of the specific part of the procurement process it was assigned, which included consideration of teamwork concerns and technology potential, various recommendations were generated. With the approval of the Division Chief, the Task Force scheduled a one day retreat to review the final subcommittee recommendations and to integrate them into a coherent package for Division management review.

The initial plan for management review of the Service Redesign and Teamwork recommendations was that followed in the Measures Phase, with the Task Force Chairman presenting them to management. However, when the first three recommendations were discussed, again some comments were made which were perceived as being non-constructive. When the Task Force members heard of the somewhat rocky treatment the first recommendations had received from the management staff, they requested the Division Chief that they be permitted to formally present their recommendations to the supervisors in a retreat setting. Here one sees the Task Force, and the subgroup members who worked with them, taking full ownership of the project and their recommendations.

The participative approach of the methodology had borne fruit as nonsupervisory personnel on the Task Force and in its subgroups had recognized and defined problems, had designed and recommended solutions, and desired to take an assertive role in assuring the recommendations were fully understood and appropriately dispositioned. Here also one sees the vital support of the Division Chief as he supported the Task Force approach and approved a two-day retreat and a later one-day follow-up retreat to address in a timely and responsible manner, the multitude of recommendations made. As a result of these retreats, some 35 of a total of 40 recommendations were accepted in whole or in major part with 1 deferred for further study and only 4 not accepted. Finally, the Division Chief invited all the Task Force members and the subgroup members to a reception at the end of the retreat and recognized their valuable and time-consuming input publicly.

CONCLUSION

The potential improvement from the implementation of the accepted recommendations is great. The recommendations address means to enable the users to provide the Procurement Division better, more complete data for the processing of their requirements, to eliminate receipt of documents which the Division cannot process, to reduce the number of administrative reviews by consolidating input from various sources into a single review, to simplify the resolution of review comments, to make facilities and equipment more accessible, to increase thresholds for signatory authority, to provide specific training for defined needs, to improve procedures in working with the Division's support contractor, and to improve space utilization and technology. Interestingly, many of these recommendations will positively impact lead-time, the focus of many earlier studies, even though lead-time was not the specific focus of the project. In the words of a consultant (not APC) who reviewed the results of the project: "The work of the Task Force(s) and the management readiness (not without work) to accept them led to very many recommendation adaptations which should greatly improve productivity and morale, and which to date have already done so."[1]

The thesis of this paper has been that the reason this project achieved a large measure of success has been due to the WCPI emphasis on service effectiveness at a Divisional level with much worker participation, the commitment of a cross-sectional task team to the project, and the desire of the Division Chief, the pilot manager, for project success.

[1] Gannon, William H. "Consultant Evaluation of NASA APC Pilot Effort", Part I, Question 4, July, 1985.

Although recognizing eac' organization 'ias differing goals, values, skills, personnel, etc., it is predicted that similar projects can be successful in other organiz: ons if these three factors are present. "People will embrace innovc.ion and new technology if they are part of an open-ended, creative learning environment which they feel they had a hand in shaping".[2] The subject project reveal an organization of many workers who desired to participate in impro ing the excellence of the organization. These employees, many of t m youn, exhibited the necessary maturity and responsibility to generally make sound, balanced recommendations and to accept the organization's right to accept, reject, or modify the recommendations. The Task Force was the working tool of the project to acco lish its goals. Without a group committed to the possibility of improvement, there would appear little chance of success. The method of having the workers select their own representatives for the project again demonstrated the organization's belief in workers as mature and conscientious. The working level, perhaps sensing the potential significance of such a project and responding to management's trust, selected capable representatives they could trust. The representatives, in turn desiring to well represent their colleagues and to demonstrate the value of their effort and existence, soon began to see the success of the project as important to themselves and the Division, and became committed to it. Finally, the Pilot Manager's support of the project was crucial. "There is no realistic prospect for changing norms or standards if those leaders of the prevailing norm system absent themselves from the effort."[3] Clearly, the Procurement Division Chief, supported productivity intitiatives and likely without his support, the restrictions imposed by mid-level supervisors and their lukewarm support may have proved fatal to the project. The pilot manager's demonstrated support at open division-wide meetings and at meetings with his subordinate supervisors was necessary. His support of the project in providing concentrated time for the Task Force to coordinate the recommendations and for supervisors to review the proposals in a retreat-like atmosphere was firm evidence of his support. His frec ient project reviews with the Task Force Chairman and APC Research Consultant provided the necessary momentum for the project to continue during some of the dry spells when project completion seemed remote and distant. In the Kearney Study done in 1981," all the leading companies (with acknowledged successful productivity programs) believed they had firm top management support, but only 6 percent of the matched sample had it." [4] Firm management support may be the most significant variable to success of similar productivity initiatives in other organizations. With it, with a committed task force representing the entire pilot, and with a non-threatening methodology such as the WCPI, many organizations can similarly succeed.

[2] Pascarella, Perry, The New Achievers, The Free Press, New York, 1984 Page 132.
[3] Blake, Robert and Mouton, Jane, Productivity, The Human Side, AMACO New York, 1981, Page 76.
[4] Lehrer, Robert H., White Collar Productivity, McGraw-Hill, New York, 1983, Page 344.

In retrospect, perhaps the most important result of the WCPI project in this organization has been a shifting in attitude. As the management explained its disposition of the many recommendations to the Task Force and its subcommittee members, a sense of excitement grew. The "troops" became optimistic and eager to move to implementation and change. The barrier at that hour between supervisor and supervised blurred as there was a sense of unity in desiring to achieve excellence in the organization. "Just as people develop feelings about one another, so people develop feelings about the organization for which they work." [5] Although positive change of feelings and attitudes of employees towards an organization is at best difficult to achieve, it may be the most important effect of such a project this. Certainly this organization has only moved a small step toward a commonly held perception of organizational excellence, but even the taste of it experienced during the project provided a clearer vision of it with motivation to continue the path to reach it.

[5] Blake, Robert and Mouton, Jane, Ibid., Page 38.

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BIOGRAPHICAL STATEMENT

BRADLEY J. BAKER, NASA-Lewis Research Center

Mr. Baker is Head, Launch Vehicles Section of the Lewis Procurement Division and is responsible for all contractual actions supporting the expendible Atlas/Centaur launch vehicle and the Centaur G and G Prime upper stages used with the Shuttle Orbiter. He also is the Pilot Coordinator and Task Force Chairman for the APC White Collar Productivity Project within the Procurement Division.

QUALITY CIRCLES IN R&D ORGANIZATIONS: SOME LESSONS LEARNED AT NASA'S KENNEDY SPACE CENTER

Edward J. Hecker, Shuttle Management and Operations
National Aeronautics & Space Administration
Kennedy Space Center, FL 32899

ABSTRACT

This paper examines the results of a pilot quality circle program in an R&D engineering organization with special attention to principle lessons learned. Based on work with NASA's Kennedy Space Center shuttle launch team, issues of broader applicability are systematically surveyed: the relevance of quality circle process training, group dynamics and role skills, frequency and duration of circle meetings, the volunteerism premise, scope of membership and evaluation and measurement of results.

(The views expressed in this paper are those of the author and do not necessarily reflect those of the National Aeronautics and Space Administration.)

INTRODUCTION

At NASA's Kennedy Space Center, the Shuttle Management and Operations organization has instituted a pilot quality circle program to determine the strengths and weaknesses of this particular form of participative management in our high technology, white collar service environment. Six circles constitute the pilot program: an operations engineering circle, a support engineering circle, a program office circle, a logistics circle, a secretaries circle and a middle-management circle. These six were supplemented with two multiorganizational "integrated teams" with a broader membership base late in the pilot program. This paper will summarize principle "lessons learned" during the year and a half that this pilot program has been operating.

LESSON ONE: PROCESS TRAINING RELEVANCE

A great deal of the training material now available presumes either a physical product or a production environment for the generation of a set of services. This results in a preoccupation with the planning and execution of repeatable processes which is difficult for R&D oriented personnel to relate with their job perceptions. NASA personnel uniformly found it difficult to link the training provided with the necessary NASA focus on adapting to change, integration, coordination and short planning horizons for real time operations.

A second training concern was expressed by the technical participants. Engineers and scientists are by prior training very comfortable with both mathematics and cause and effect logic. The models offered in typical quality circle training were viewed as excessively simplistic and the training as a trivial review of fundamental basics. Clearly the absence of a reasonable measure of technically or intellectually challenging material constitutes a serious deficiency when using most available material to train mathematically sophisticated work groups.

A useful solution has been to assign the available training material as a resource for off-line review and to summarize it in a cursory manner in the training sessions. In continuing search for more appropriate materials, the disciplines of operations research appear to offer considerable promise.

LESSON TWO: GROUP DYNAMICS DEFICIENCIES

Significant weaknesses in interpersonal skills were found to be highly correlated with high technical competence. Technical personnel are very comfortable working independently but are much more unfamiliar with group roles, interpersonal dynamics and teamwork than less narrowly trained personnel.

This problem is compounded by a general lack of personal awareness of these deficiencies as weaknesses. The suggestion of possible training in behavioral skills (listening, conflict management and peacemaking, confrontation, negotiation) is not well received by individuals accustomed to more absolute values of rightness. More clever and convincing packaging may be required before participation in these "charm school" subjects will be viewed as a serious training opportunity.

LESSON THREE: MEETING FREQUENCY AND DURATION

The operational flows of four flight worthy orbiters and the completion of launch facilities on both coasts necessarily involves work on irregular shifts and frequent travel. The problem of choreographing a one-hour per week meeting with an assured quorum has been so difficult that three of our circles have changed their meeting frequency to once every two weeks and doubled their planned meeting duration to two hours.

This approach requires more comprehensive planning by the circle leader, but this limited experience suggests that sustaining the inertia of the meeting process frequently permits the circle to accomplish the same amount of meeting content in 90 minutes of continuous meeting as was formerly accomplished in two one hour meetings one week apart. More time will be required to confirm this perception of improved meeting efficiency.

LESSON FOUR: VOLUNTEERISM

Volunteer participation is a cornerstone of the current American interpretation of quality circles. Unfortunately experience suggests that younger employees have a markedly higher propensity toward quality circle participation (and other nontraditional management techniques) than do the more experienced personnel. A rigid adherence to the voluntary premise is limiting the knowledge base which may be as essential during the problem selection phase as it is during the problem analysis and resolution sequence.

The current approach focuses on the engagement of essential knowledge and skill resources by involving non-volunteers as technical support members. This brings the requisite background, knowledge, skills and abilities to the circle and makes it available as a team resource. But, because of the arms-length involvement of these technical support members, important perspectives which might emerge only after long incubation with the problem area and attendant issues are probably being missed. The question and answer sessions with the quality circle members and short exposure to perhaps only a limited part of the problem area constrains the quality of analysis and comprehensiveness of resultant solution proposals.

Several reinterpretations of "voluntary" need to be considered including: broad conscription through the problem selection phase, then voluntary; rotation of key skill positions; and the training of non-volunteers in the quality circle process as a resource for possible future assignment on special boards, panels task forces and teams.

If quality circles are irrevocably wed to an unyielding rigid interpretation of "volunteer", the reward for participation should be increased to attract fuller involvement. One readily available, but largely understated, reward could be sharing of real power. For example, a quality circle might be allocated some reasonable level of resources and delegated the managerial authority to develop and implement changes in some specified area of identified concern. No management presentation or similar review would be required. The circle would be fully empowered to implement such remedies as they deemed appropriate within the authorized resource limit and would be operating, in fact, as small project offices. Such an approach might attract seasoned professionals with a penchant for doing instead of just recommending and management might find it an efficient way to work some of their continuing problems that never make the 'top ten list' and receive necessary attention.

LESSON FIVE: SCOPE OF MEMBERSHIP

R&D personnel routinely have available to them numerous channels for initiating action. Local problems which can be resolved by the recommendation of a rational solution to management are usually handled through non-quality circle channels. Most of their continuing problems transcend their organizational boundary.

The early involvement of members of other organizations who have a stake in the outcome or a responsibility to contribute to the solution is rational and wholly consistent with the participative management principles upon which the quality circle premise is founded. Many organizations have recognized this need and have incorporated multi-department teams.

Where problems transcend major organizational boundaries (two or more contractors, government and one or more contractors), other issues arise. Most of the newly presented issues are process issues: Who is to chair the circle? Who is to facilitate the circle? Whose process and protocol is to be followed? Who is "management" for purposes of management presentation? How are organizational differences in how members are recognized and rewarded to be accomodated?

Limited experience suggests that reasonable answers can evolve clearly on a case-by-case basis. Since most "integrated teams" (multi-contractor and government-contractor quality circles) are organized around a recognized need, it is prudent to capitalize on the high interest a mutual goal naturally engenders. With cooperation at a maximum, some scheme of shared leadership through formal co-chairmen or deference to a dominant organization has been quickly reached. The same treatment has been applied to facilitators usually with the result that the dominant organization furnishes the primary facilitator support.

The issue of what procedures to follow for circle administration can be significant if the participating organizations have acquired their quality circle training from different sources. Various vendors have sought to differentiate their products from the competition by introducing different practices, methods, procedures and terminology. The potential for confusion and frustration are obvious.

Kennedy Space Center's approach to this issue has been from a preventative, rather than remedial, perspective. Two years ago, a cooperative effort to develop a single integrated quality circle leader training program was undertaken. The resulting commonality of language, sequence, procedures, et.al. has rendered the differing procedures issue moot.

"Management" for purposes of management presentation continues to be defined as the lowest level of the organization(s) with sufficient authority to approve and implement the recommended action. This frequently involves the concurrent presentation by the circle to representatives of more than one organization, but has introduced no special problems.

In sum, the expansion of the scope of membership to accommodate a multi-organizational base has not introduced any problem which reasonable professionals cannot resolve on a case-by-case basis. Our experience does not support any need for rigid uniformity among or between integrated teams.

LESSON SIX: EVALUATION AND MEASUREMENT

Much difficulty and frustration results from efforts to express quality circle progress in rigidly quantifiable terms. Technologists find a natural comfort in numerical measures. Management is similarly interested albeit usually for different reasons. Neither are satisfied with the products which have resulted to date.

Many service organizations have difficulty in defining tangible outputs for all of their component elements. Placing an unambiguous economic value on each is an overwhelming task particularly when the division of labor is complicated by (1) a matrix organization structure and (2) frequent changes in organizational responsibilities.

NASA's situation is further complicated by two distinguishing features. First, frequent involvement in one-of-a-kind studies preempts longitudinal measurement opportunities with attendant development of useful trend information. Second, the nature of NASA's mission requires many state-of-the-art specialists. The resulting organizations are not traditional groups of interchangeable personnel with common skills but, rather, confederations of specialists grouped into organizational subdivisions for administrative purposes.

This area of frustration is shared by those seeking to measure knowledge worker output for purposes of monitoring productivity. The national focus on the issue of productivity is resulting in a continuing wealth of literature addressing some candidate approaches to the problem (e.g., the Westinghouse composite index [5], several American Productivity Center alternatives [1] [4], W. A. Ruch's participative approach to white collar productivity measurement [3]).

It is likely that the Kennedy Space Center will continue to wrestle with a variety of techniques in what promises to be a long term pursuit of an elusive goal. The effort is likely to involve an evolutionary family of products developed at the grass roots. Adapting freely from Ruch [3] and Kinlaw [2], the use of carefully facilitated quality circles to generate and experimentally validate a family of (1) output measures, (2) input measures, and then (3) their combination into useful ratios may offer a mechanism by which credible numerical measures may evolve.

In the interim, reliance must continue to be placed on surveys, questionnaires, interviews and other 'soft data' as a transient compromise while the quest for quantitative results continues.

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BIOGRAPHY

Dr. Hecker is the Chief of Human Resources Management for Shuttle Management and Operation at NASA's John K. Kennedy Space Center. He received his B. Aeronautical Engineering from the University of Florida, his MS from Florida State University and his MPA and DPA from Nova University.

Dr. Hecker has over twenty seven years of industry and government R&D experience including twenty in management. He is an Adjunct Professor of Management Science in the Florida Institute of Technology graduate school and a Senior Consultant with the Edryn Corportation.

NEW TECHNOLOGY FOR INCREASED PRODUCTIVITY

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VLSI METHODOLOGY FOR SWITCHING SPACE STATION DATA CHANNELS

Robert E. Henrich, Ford Aerospace and Communications Corporation

ABSTRACT

This paper shows how the advanced technology of Very Large Scale Integrated (VLSI) circuits can be incorporated into the ground support equipment to support Space Station development and operations, such that productivity improvements in hardware design and large cost savings can be realized. A technology trade-off is made to support the usage of VLSI technology and a comparison is made between the existing switch card and a future VLSI switch card to illustrate the large cost savings associated with VLSI use. In addition, the methodology used to develop a VLSI switch card is described.

INTRODUCTION

The hardware design engineer of today has an unprecedented selection of technologies from which he may implement his design. The traditional technologies such as Small Scale Integrated (SSI), Medium Scale Integrated (MSI), and Large Scale Integrated (LSI) circuits are being augmented by the addition of semi-custom, VLSI circuits. The use of VLSI circuits, for applications requiring large quantities of repeat design hardware offer many system related economic advantages. They reduce the integrated circuit package count, which reduces the required number of printed circuit boards, card cages and cabinets. The reduction in the required quantities of these items, reduce the overall assembly, transportation, and associated facility costs, such as air conditioning, heating and available power. Systems that utilize VLSI technologies, typically provide higher reliability figures, lower power dissipation and lower mean time to repair figures.

The Mission Control Center at Johnson Space Center includes a large switching system that provides data channel switching and routing to support Space Shuttle Operations. The number of switched data channels to support the development phase of the Space Station could more than triple the present requirement. It is reasonable that the requirements for the support of mature Space Station Operations could easily approach seven times the present capability.

This magnitude of switched data channels, clearly shows the acute need to improve productivity in hardware design and to make use of the cost savings associated with the use of VLSI circuit technology.

TECHNOLOGY TRADEOFF

Today's systems and sub-systems are often difficult to design in a cost effective manner using traditional technologies. Functions previously designed on entire printed circuit boards are now being reduced to single silicon chips. However, as with any new technology, increased risks are associated with a semi-custom VLSI design project. These risks include:

- Poor schedule performance by vendors of software support packages,
- Poor schedule performance by the silicon foundry chosen to manufacture the device,
- The inability of the design engineer to modify the VLSI circuit during checkout, or
- Possible redesign to support changing system requirements.

To offset these risks, a very methodical design sequence is mandated which includes a hierarchical design structure along with in-depth software simulation before architectural layout. Total chip characterization during the checkout process ensures project success.

Traditional Design Method

The sequence of events for traditional design are as follows:

- System definition
- Requirements definition
- Sub-system definition
- Requirements apportionment
- Detail logic design
- Printed circuit board fabrication
- Checkout
- Sub-System integration
- System integration

The systems hardware designer defines the system and its requirements. From these requirements a system design emerges with a number of indicated sub-systems. The individual sub-systems are then defined and the system requirements are apportioned. From the sub-system design and the apportioned requirements the number and type of individual printed circuit boards are indicated.

The printed circuit board designer then develops a number of functional block diagrams and with the help of a standard parts catalog, implements the required design. After completion of design, board fabrication, and purchase of the required standard parts, the completed board enters checkout. If a part proves defective it is removed and replaced with a new standard part. If the circuit wiring is faulty or incorrect, rewiring or circuit modification is accomplished and checkout continues. This procedure can be repeated until the desired printed circuit board, design requirements are met. Following individual board checkout, it is integrated into the sub-system and checkout continues. If the sub-system checkout uncovers a fault, redesign and retest follows. As can be seen, the traditional design method allows many opportunities for redesign to fulfill the overall system requirements.

VLSI Design Method

In contrast, the semi-custom, VLSI design process allows only a few redesign opportunities. To reduce the risks associated with VLSI design, the design process must be highly structured and software simulation of the required VLSI device must be fully utilized. The system and sub-system functional design must be accomplished with the goal of reducing equipment quantities through the use of VLSI designs. In most instances, not all system, sub-system or even individual printed circuit board functions can be implemented within a single VLSI circuit design. Some functions, such as analog circuits, differential line drivers, and line receivers, or ultra stable clock oscillators are not readily available in standard VLSI circuit technologies. In addition, as most VLSI technologies utilize the HCMOS (High Speed, Complementary Metal Oxide) process, the designer may be unable to meet all required specifications. The required design might be less risky when implemented with a combination of standard and VLSI devices. The VLSI design process follows the same sequence of events through sub-system, requirements apportionment. The detail design sequence is much more exact, as an individual integrated circuit is being designed and is presented in a following section. As the designer has a limited ability to modify the VLSI design after architectural layout, the system definition phase must be more lengthy as well as the software simulation portion of the cycle.

In general, those functional designs which contain a number of identical circuits, or large combinational logic networks which might be implemented in standard SSI/MSI/LSI technology, would be a likely candidate for a semi-custom VLSI circuit design. The tradeoff between technologies must involve the estimated cost and scheduled delivery of the system implemented in either standard parts or in VLSI circuit technology.

Traditional design projects using standard off-the-shelf parts have only the non-recurring engineering (NRE) costs associated with the printed circuit board, card cage and cabinet design. The integrated circuits themselves are well characterized and their costs are minimized. The semi-custom, VLSI circuit design, includes all of the previously mentioned NRE costs plus the development cost of the VLSI device itself. Typical development costs for a gate array range from $5,000 to $75,000 while standard cell designs range from $25,000 to $200,000. From the previous statement, it becomes obvious that the NRE cost associated with a VLSI circuit can only be justified by the reduction in quantity of equipment required. As a VLSI circuit design is a proprietary device, the design tradeoff must also compare the difference in procurement schedules. Traditional integrated circuits may often be purchased from local stock. VLSI devices must first be designed, checked out and then released to production. In some instances, the project schedule may not allow this luxury.

Conclusion

The design tradeoff must be made initially at the system or sub-system design phase and reevaluated throughout the design sequence. Semi-custom VLSI circuit design, when mixed with traditional design, offers the advantages of reduced costs and often, increased performance, while maintaining a manageable risk.

VLSI IMPLEMENTATION EXAMPLE

The Mission Control Center's ground support equipment for supporting Space Shuttle Operations, includes a large switching system that provides data channel switching and routing for 294 input channels and 294 output channels. The number of switched data channels required to support the Space Station environment could easily approach 2,000 input and 2,000 output channels. This magnitude increase requires the use of VLSI technology to improve productivity in hardware design.

Present Switching Environment

The present data channel switching equipment is based on a two level, 7 X 7, digital switch card implemented in traditional, SSI/MSI/LSI- technology. The 7 X 7 switch card is the basic building block for a 294 X 294 digital switch. To provide the ability to switch the 86, 436 crosspoints required by a 294 X 294 switch, a three stage, segmented switch approach was chosen. In choosing the segmented switch approach, a significant reduction in quantity of equipment was achieved. This approach was first observed in 1952 by Charles Clos of Bell Laboratories. It was observed that a general purpose switching array with 'N' inputs and 'N' outputs may be configured with less than 'N X N' crosspoints. A crosspoint is defined as a physical connection between an input and an output. In a three stage array, three crosspoints, one in each stage must be closed to complete a path from an input to the output side of the switch array. The equation for finding the number of crosspoints needed to implement a three-stage array is:

# of crosspoints = 6(N exp (3/2)) - 3N

By using the three stage switch array, it can be seen that fewer than one-half the 86,436 crosspoints were needed. The present three stage switch requires 35 card cages housed in eight switch cabinets. Each card cage contains an average of 18 switch cards and two interface cards. The advantages of this design approach are depicted in Table 1.

PARAMETER	DESIGN APPROACH	
	SINGLE STAGE	3-STAGE
COST	3	1
MAINTAINABILITY	2	1
RELIABILITY	2	1
SCHEDULE	*	*
GROWTH POTENTIAL	*	*
TESTABILITY	*	*
RISK	1	1
FAIL-SAFE	*	*
CURRENT TECHNOLOGY	*	*
CONFIGURATION TIME	*	*

1-BEST, 2-NEXT BEST, 3-LAST, *-MEETS REQUIREMENTS

TABLE 1

In addition to the large reduction in the number of switch crosspoints, the three stage switch approach was selected because its architecture provided alternate paths. This path redundancy is provided by alternte wiring inside the switch architecture. The concept behind path redundancy is shown in Figure 1.

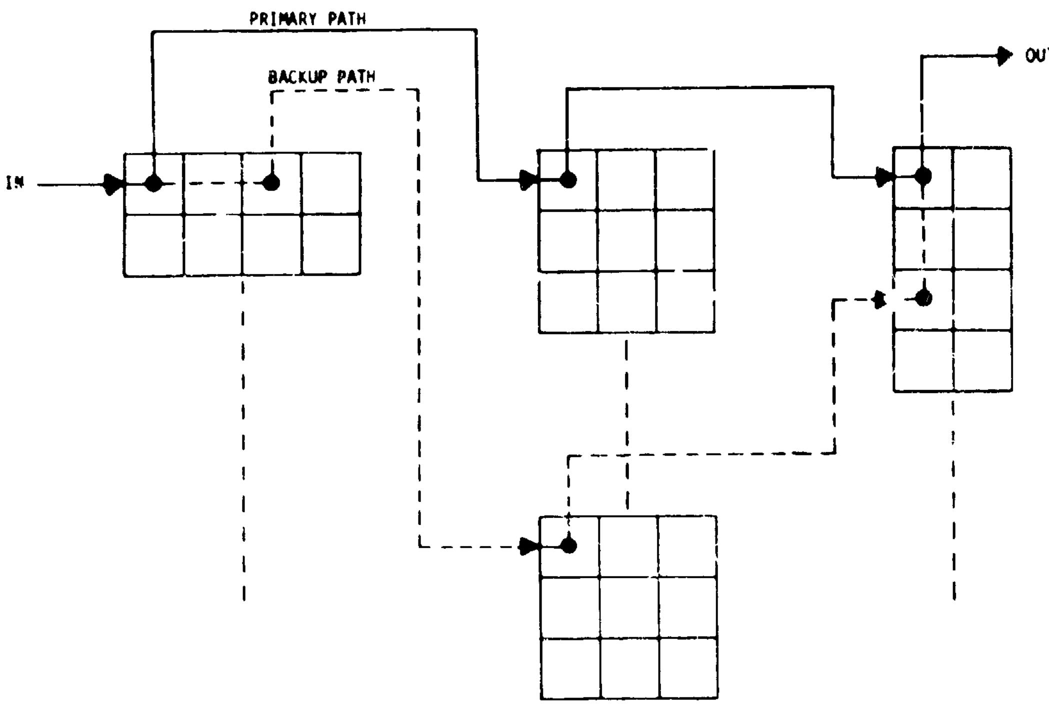


FIGURE 1

Future Switching Environment

To support the Space Station development phase, the number of switched data channels is projected to be approaching 1,000 inputs and 1,000 outputs. As the system matures and requirements become finalized a switching matrix that supports 2,000 inputs and 2,000 outputs is not unreasonable. This magnitude of switched data channels may require hardware that can provide up to 4,000,000 combinations of input to output connections. With the additional requirement of not permitting an input to output blocking condition and maintaining high reliability figures, a three stage, VLSI based digital switch is clearly indicated.

A study was conducted based on the existing 7 X 7 two level, switch card, to determine if cost savings could be realized by increasing the crosspoints contained on a single switch card. By expanding the size of the switch card through the use of VLSI technology, a very large savings in required switch cards and associated costs can be realized. Table 2 indicates the savings associated with a 20 X 20 switch card versus the existing 7 X 7 card, for a 1,000 X 1,000 two level, three stage digital switch.

	7 X 7 SWITCH CARD	20 X 20 SWITCH CARD
NUMBER OF CARDS	3,786	560

TABLE 2

Figure 2 and Figure 3 describe the architecture for a three stage switch using the 7 X 7 switch card and the 20 X 20, VLSI switch card.

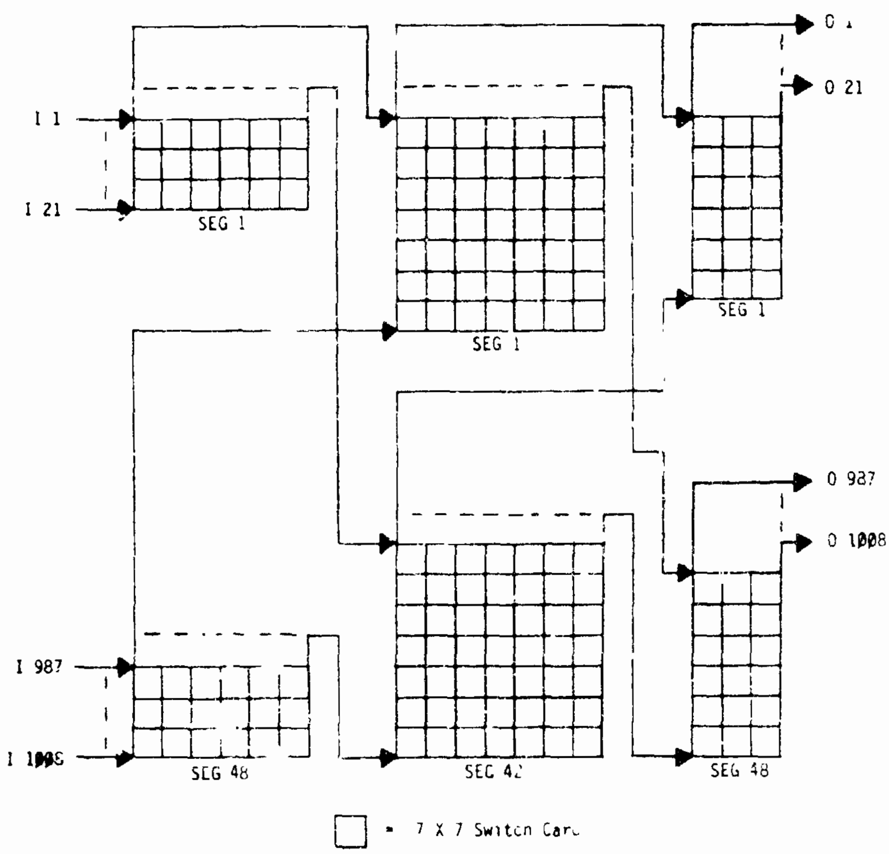


FIGURE 2

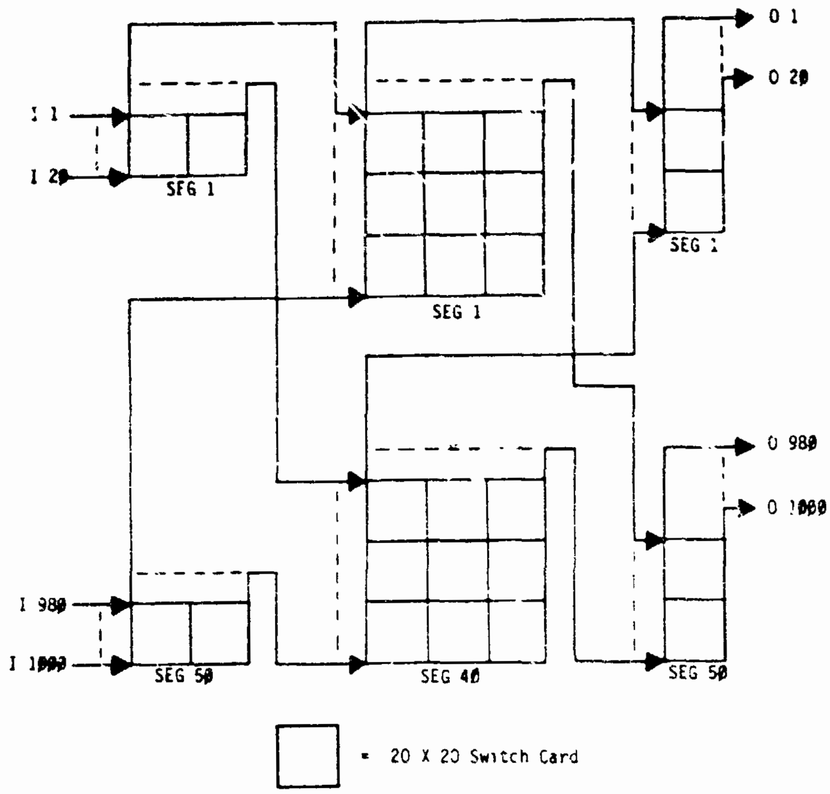


FIGURE 3

Conclusion

As clearly indicated by the quantity difference between the two examples, the most cost effective alternative would be the 20 X 20 VLSI switch card implementation.

When coupled with a higher card cage, packaging density, the difference in cabinet count (49 cabinets versus 10 cabinets) leaves little doubt that a VLSI design would be more than justifiable. The reduction in assembly costs, power supply requirements and facility related costs more than offset the cost of VLSI development.

VLSI DESIGN METHODOLOGY

General Design Methodology

The design sequence for a semi-custom, VLSI circuit begins in much the same way as that of a traditional design project. The analysis of system requirements, functional partitioning and the development of a sub-system design must also be accomplished. The VLSI designer must be even more meticulous with these tasks as his design efforts extend down to the gate level within the device itself. During the checkout phase, the VLSI designer does not have the ability to modify the design itself without resorting to an additional architectural layout and subsequent prototype fabrication. The tasks, peculiar to the VLSI design process are depicted in Figure 4.

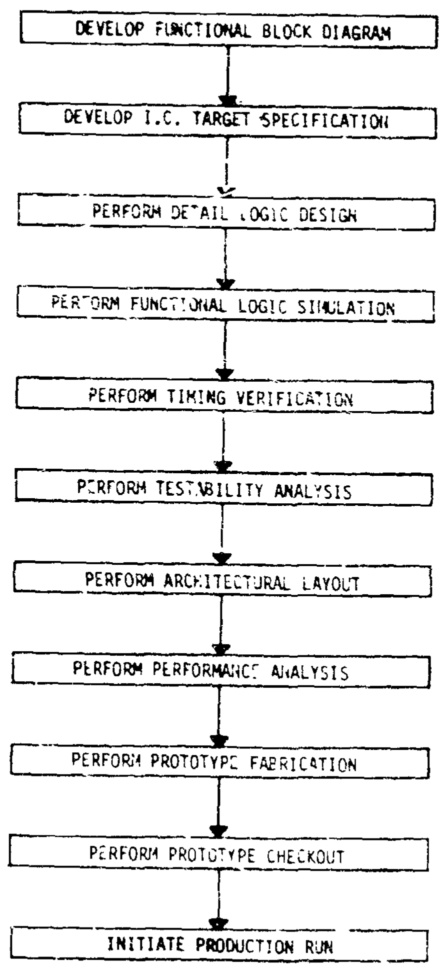


FIGURE 4

Functional Block Diagram Development

The development of functional block diagrams is especially critical to a VLSI designer. The hierarchical design process associated with VLSI design enforces the structured, top down design method. Functional block diagrams are developed for the printed circuit board and help to associate requirements with their respective logic blocks. As the design progresses, additional sub-blocks are developed which enable the designer to further define the requirements associated with the VLSI device. When complete, the resulting block level diagrams are useful in specifications, design reviews, software simulations, and prototype checkout.

Integrated Circuit Target Specification

The I.C. Target Specification resembles the detailed data sheets published by traditional I.C. vendors. The Target Specification includes the following:

- Functional description
- Block diagram
- Packaging information
- Pin assignments
- Maximum ratings
- Recommended operating conditions
- D.C. characteristics
- A.C. characteristics
- Application information

The Target Specification is initiated at the beginning of the project and is updated periodically to ensure all design specifications are ultimately satisfied. The designer uses the Target Specification to choose the technology family from which the design will be implemented, the type package used, and most important, as a verification document during prototype checkout.

Detail Logic Design (Schematic Capture)

The detail logic design closely follows that of traditional logic design. As the VLSI design cannot be easily modified during the prototype stage, it is of great importance that the designer adopt a design method that increases the chance for a correct first time design. The hierarchical design methodology allows the designer to proceed in a top down approach, and coupled with design rule checking, offers an excellent chance for a correct first time design.

The design is initially entered into the data base in block diagram form. As the design progresses, each block or sub-block is reduced to a detailed logic design. The data base connectivity and electrical descriptions are checked on a circuit by circuit basis to ensure a correct design. When all functions have been implemented, functional, software simulations are executed ensure all functional requirements are met.

Functional Logic Simulation

The functional simulation phase of VLSI development serves two purposes. The obvious purpose of functional verification takes place along with the development of test vector stimulus files. These files not only enable the functional simulation of the VLSI circuit, but also serve as the basis for test program, stimulus files used by Automatic Test Equipment. Functional simulation is ultimately done at the highest block level, used to describe the VLSI device. If anomalies are detected, resimulation at the lower gate level is performed, redesign occurs and simulations repeated until all functional requirements are met. All semi-custom, VLSI circuit vendors require complete and accurate, functional simulation test vector files. These are used, along with the timing verification test vectors, to analyze the fault coverage merit of the combined stimulus files. If a high percentage of fault coverage is not guaranteed (usually 90% to 98%), then additional test vectors are requested. This attention to detail ensures the high, first pass success rate (usually 90%) associated with semi-custom VLSI design.

Timing Verification

As previously stated, simulation is extremely important to the success of a VLSI project. If all functional requirements have been met, the VLSI designer progress to timing verification.

Timing verification require test vector files that not only encompass functional descriptions, but timing limits, temperature, voltage and process specifications. The intent of these simulations is to ensure no race conditions or timing specification violations occur. In addition, the ability of the part to correctly function under adverse conditions is stresses. The VLSI Target Specification must detail all allowable limits under which the device must function. Combined with the functional simulation test vectors, these stimulus files serve as a basis for Automatic Test Equipment program generation, and provides an increased probability of first pass success. When timing verification is complete, all pertinent files are transferred to the selected VLSI vendor for analysis and architectural layout.

Testability Analysis

After all simulations are successfully completed, the input stimulus files, and output verification files are transferred to the VLSI vendor. To ensure a high probability of first run success, an analysis is performed to determine if a high test vector, fault coverage has been achieved. This usually takes the form of testing for stuck at one or stuck at zero internal, malfunctions and determining the possible percentage of detection. If the fault coverage percentage does not approach 95%, additional test vectors or a modified design is requested from the logic designer.

Architectural Layout

After completion of the testability analysis, architectural layout is accomplished. If a small number of critical timing paths have been designated by the logic designer, the VLSI vendor may choose to auto place the required silicon gates and auto route the interconnects. This method of layout is less costly than hand layout and is used successfully on many projects. If an exceptionally high number of critical paths are required or close timing specifications must be adhered to, hand layout is justified. In all cases, the VLSI logic designer is involved from a consultating standpoint to ensure all required specifications are met. The completion of architectural layout makes possible the next design step, of performance analysis.

Performance Analysis

Performance Analysis includes resimulation of the device on the VLSI vendors mainframe computer. The primary enhancement to these simulations is the addition of the actual interconnection length between silicon gates. As the architectural model now specifies all parameters, parasitic capacitance can now be calculated for each internal node. These values are integrated into the simulation model and very precise simulations are accomplished. In most instances, this simulation only serves to substantiate the validity of the design. If redesign is required to ensure complete specification adherence, a very stable starting point is now provided and the redesign time period is considerably shortened. If the design is validated, prototype fabrication takes place.

Prototype Fabrication

Prototype Fabrication takes place at a silicon foundry chosen by the VLSI vendor. The VLSI vendor transfers a mask tape that defines the required VLSI circuit both architecturally and electrically. The silicon foundry processes a number of wafers, which contain a number of individual die. Upon completion, the wafers are shipped back to the VLSI vendor for further testing and packaging.

The test vector, stimulus files are reused by the VLSI vendor to ensure each die meets specifications. After testing, the individual dies are placed into the prescribed package.

After packaging, a final test is run to ensure package bonding was successful. Finally the completed VLSI circuit parts are shipped to the VLSI logic designer for checkout.

Prototype Checkout

After integration of the new VLSI device into its target printed circuit board, a total system checkout takes place. After all Target I.C. Specifications are tested, production runs are initiated at the silicon foundry. At this point the VLSI device can be utilized in the same manner as a traditional design, standard parts.

Conclusion

As can be surmised from the previous discussion, the methodology concerning a VLSI design is not a particularly fast nor inexpensive one. However, the risk in utilizing VLSI technology is quite manageable, as the preceding sequence demonstrates. When the cost of VLSI development is weighed against the cost savings associated with equipment reductions, a design using VLSI technologies is clearly the victor.

CONCLUSION

As the Mission Control Center begins to phase up for support of the Space Station, the ground support equipment must also be upgraded to increase the data channel switching capacity. The present 294 X 294 switching and routing equipment does not have the required capacity and cannot be cost effectively upgraded to accommodate even the development phase of Space Station. When mature, the switching and routing function could require a capacity of 2000 X 2000. The critical need to improve productivity in hardware development and to reduce system costs clearly indicate the need for a VLSI based, switch card. This switch card will utilize a 10 X 10, two level, VLSI switch element, connected in a quad configuration to provide a 20 X 20, two level switch card. This basic building block, along with RS-422 differential inputs and outputs enables the design of large digital switches. When coupled with the three stage, switching architecture and an increased card cage packaging density, large scale, cost competitive digital switches approaching 2000 X 2000 can be implemented

VLSI technology could be used to improve productivity in hardware design and to control rising costs to adequately meet the future needs of the Space Station.

AUTHOR'S BIOGRAPHY

Robert E. Henrich is a Senior Specialist Engineer at Ford Aerospace and Communications Corporation, Space Inform[illegible]n Systems Division. He completed a B.S.E.T. from the University of [illegible]ston in 1973. His recent experience includes microprocessor based digital design, design and development of switching systems, and a VLSI switch element design. He is currently assigned to Design Assessment, and is working on a VLSI based implementation as described in this paper.

MODULAR SYSTEM DESIGN FOR SPACE STATION DATA HANDLING REQUIREMENTS

Mitchell T. Stowe, Ford Aerospace

ABSTRACT

NASA and DoD spend enormous sums of money on the development and maintenance of specialized (custom) data handling and processing equipment. The development cost of these custom systems often outweighs manufacturing cost when a small number of systems are required. To provide a cost effective and efficient implementation of special data handling and processing requirements for programs such as Space Station, a highly structured, modular approach to building custom systems is needed. Design should reduce recurring development, maintenance, and operation cost over the life of the equipment. A standard set of intelligent "building blocks" that support a wide range of high performance real-time processing architectures is needed. It must include "buy-it-by-the-yard" capability to accommodate any size application, and provide easy expansion, modification, or even redesign of existing systems to accommodate new and changing requirements while retaining virtually all of the hardware and software that has already been developed.

This paper describes an adaptable multiprocessing architecture utilizing a modular system approach to development of high performance data handling and processing equipment. A working model developed under an IRD program is presently being demonstrated.

FUTURE REQUIREMENTS/NEEDS

Current trends in telemetry processing indicate that data rates will increase at a rapid pace. This data must be processed and stored in real-time. Investigations into the ground Space Station Data System (SSDS) show that peak data rates may be as high as 600 Mbps and could average over one-fourth that rate. One possible architecture of the SSDS is shown in figure 1. In this example architecture, the data is systematically broken down into smaller and smaller pieces while the processing on each piece becomes more and more complex. Massively parallel processing is used at the front end, and specialized architectures for the intermediate processing. More conventional architectures handle the processing at the end user's site. All these architectures should meet several basic requirements:

FLEXIBILITY - allows the system to meet changing needs in a timely and cost effective manner.

TECHNOLOGY INSERTION - As technology changes, upgrades should be possible without requiring a major redesign.

GROWTH - As functions become mature they usually increase their resource requirements. A good design can allow for growth without excessive expense or initial over specification.

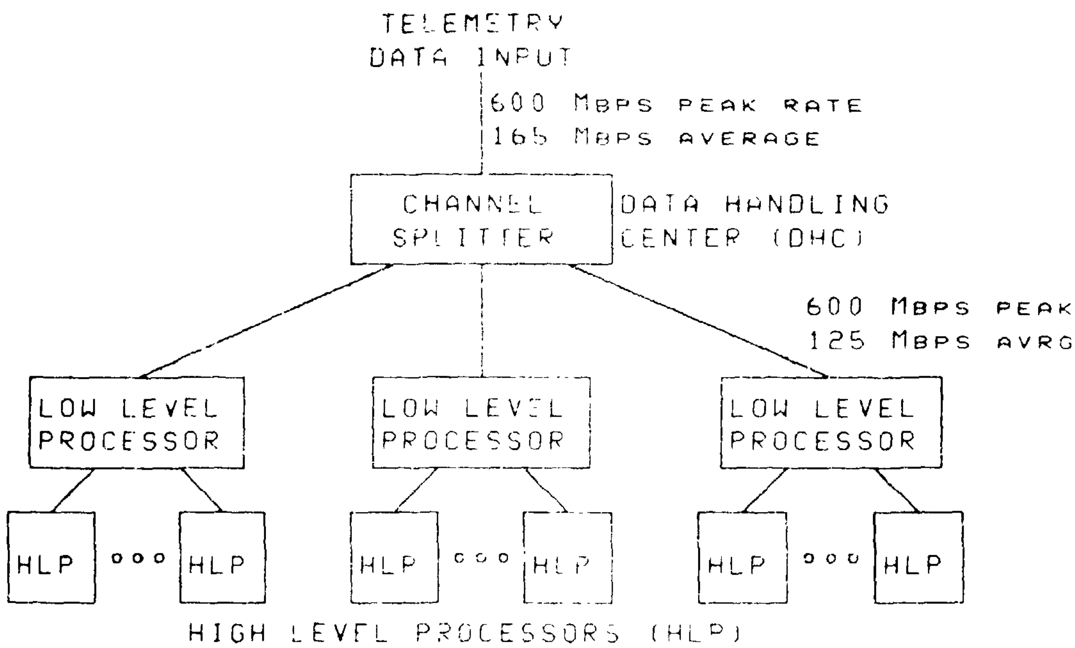
LIFE CYCLE COST - The cost of a system reaches far beyond the purchase price. The operating costs must be considered in order to provide a cost effective solution.

AUTOMATION - The system should utilize technologies that allow equipment to perform an increasing number of tasks in order to improve productivity and reduce staffing.

REUSABILITY - The design should utilize hardware and software developed through other projects when possible.

FIGURE 1

SIMPLIFIED TELEMETRY DATA FLOW FOR SSDS TIMEFRAME



ADVANTAGES OF COTS AND CUSTOM SYSTEMS

There have been two basic choices in designing systems for a customer. They can be composed of commercial-off-the-shelf (COTS) components or built from the ground up using custom designs. The advantages and disadvantages of each approach are grouped into the several categories below:

Manufacture/Purchase cost - This is the cost to make or buy the equipment. It does not include any one time costs (engineering, documentation, etc.) or maintenance costs. There are two factors involved here - volume efficiencies (COTS) and the "custom fit" efficiencies. When implementing a function using COTS equipment, usually there will be "extra" areas of functionality that are not needed, but they must be paid for. The importance of these two factors depends on the particular application.

Engineering and Documentation cost/unit - This is the one time development cost associated with any product. It is also where COTS equipment seems to have the greatest advantage over custom designs. In most cases, these one-time costs are a very large percentage of the total cost to implement a custom system. COTS equipment, however, can amortize these costs over large numbers of systems, making their impact much smaller on the total selling price.

Maintenance and support costs - Again, because COTS vendors have a large volume, it becomes economical to have trained personnel dedicated to maintaining a particular system. Custom systems, on the other hand, are so few that personnel must be trained on several different systems to be cost effective. The technician responsible for the custom system does not have the benefit of experience with several installations, nor the resources that can be justified by large volume maintenance. This means custom system maintenance will be more costly and time consuming.

Availability risk factor - The availability of a product several years in the future is a major concern to maintenance operations. A COTS vendor may go out of business or stop supporting his older products. This is especially valid in a rapidly advancing technology, such as computers and electronics. A custom vendor may be headed for the same fate. However, a custom design comes with more complete documentation and training. This makes it much easier for another vendor to take over maintenance and upgrades to that system.

Time to deliver system - Once a need is established, the time it takes to fill that need reflects lost performance. As the name implies, COTS equipment can be brought in to fill that need almost immediately. Custom equipment, though, must go through a long design/manufacture/test cycle that many times takes over a year. This requires advanced planning that may not be available or may be inaccurate, leading to unnecessary expenditures.

Design risk factor - Both COTS and custom systems have a risk factor. The risk factor associated with custom systems involves whether or not what is on paper will actually work. The answer to this question arrives late in the design cycle. If it does not meet specifications, it will have to be redesigned, which means increased cost and time. However, the case for COTS is not much better. If the COTS system does not meet specifications, a new system must be found. There is no way to enhance or redesign a COTS system, without incurring heavy additional costs. At least with a custom system, the expertise in house makes it easy to modify.

Custom interface support - Here, the in house knowledge gained by building a custom system makes it easy to interface custom equipment to it. Custom interfaces will always be necessary in equipment, due to unique customer needs. COTS equipment will be more difficult to interface to custom equipment because there is no in house expertise.

Performance efficiency - Custom logic has the advantage here, because it is specifically designed for the task. Special hardware and software can be optimized for the task. COTS equipment must be general to appeal to a large market. This means that for a given application, COTS will be larger and more difficult to apply.

Modification/upgrade potential - Here, again, custom designed equipment has the advantage. In-house expertise makes it much easier to modify or upgrade a custom system. Vendor support for a COTS system determines how easily a system of this type can be upgraded. This support may be non-existent if the customer represents only a small fraction of his business.

TABLE 1

	Custom	COTS
Manufacture/purchase cost	?	?
Engineering and documentation cost	poor	good
Maintenance and support cost	fair	good
Availability risk factor	good	fair
Time to deliver system	poor	good
Design risk factor	poor	fair
Custom interface support	good	poor
Performance efficiency	good	fair
Modification/upgrade potential	fair	poor

COMBINING ADVANTAGES

COTS systems, in general, have a cost advantage over custom systems. Custom systems, however, have a performance advantage as well as better long-term support. A system specifically designed to utilize both the advantages of COTS and custom would be a better alternative than either of them. The features necessary in such a system are discussed below:

Flexible architecture - This is the key to adaptability. This allows the system to be optimized to the requirements. It must be designed into both hardware and software in a transparent way, i.e., the same hardware and software must work with any architecture.

Minimum number of modules - To accomplish the high volume necessary to lower costs, a small number of different hardware modules must be designed to handle all tasks well. This gives the overall system a COTS appearance.

Easily upgradable/modifiable - Changes to the architecture should be painless. Hardware must be designed with common interfaces using uncomplicated interconnect techniques. Software must be auto configurable and independent of the architecture of the system.

Fixed user interface/industry standard - To maintain compatibility between systems and utilize existing applications, the user interface

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should be fixed and an industry standard. This applies to both hardware and software.

Biased toward customer requirements - The system design should reflect the requirements of the main customer. This increases the performance/cost ratio for that customer.

State-of-the-art technology - By using advanced technology, the overall design will be lower cost, more efficient, and longer-lasting. New modules that are upward compatible should be designed when significant technology improvements are made. These should be integrated into existing equipment with no loss of previous investment.

DESIGN EXAMPLE

One design of a system that meets these requirements consists of four basic modules. The first is a processor, or P module, which handles all high level programs and the bulk of data processing. A memory, or M module, is needed for program and data storage. This module also contains a processor optimized for low complexity high speed data manipulations. The third module is a disk controller, or D module. It is used for a high performance interface to secondary storage, again with its own processor to handle all low level disk operations. The last module is an industry standard bus interface, or I module. All other peripherals will be connected to the system through this interface. It is designed to get maximum performance out of the industry standard bus.

Modules

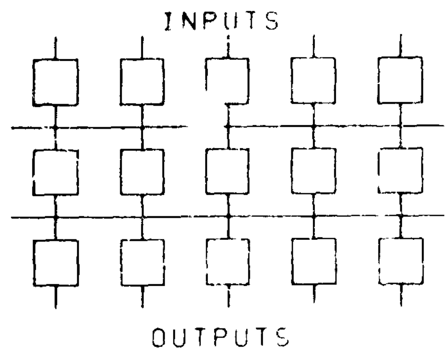
A key feature of all the modules is the bus structure. Most existing systems are limited to a fixed number of modules and a fixed upper limit to bandwidth. This is due to their bus architecture, which allows for only a limited increase in the number of boards and busses. However, the P, M, D, and I modules have a two-dimensional bus structure. This allows the system architecture to expand indefinitely in number of modules and total bandwidth. This two-dimensional structure is very simply accomplished in hardware by using two identical bus interfaces per board. Figure 2 has some examples. These examples are totally arbitrary architectures, but they show the unlimited expansion capability of the architecture. Determining the best architecture depends on the application, which leads to more efficient use of the modules.

The processor module is based on the Motorola 68000 series processors. Current technology uses the 68010, a sixteen bit external, thirty-two bit internal processor. In the near future, the 68010 can be replaced by the 68020 for a 3x processing improvement and existing code compatibility. Support circuits on the P module include cache memory, high speed local memory, timers, interrupt vector logic, and memory map/virtual memory logic. The support for the processor makes the module a very high performance self-contained unit. This module will run the operation system software and all applications software.

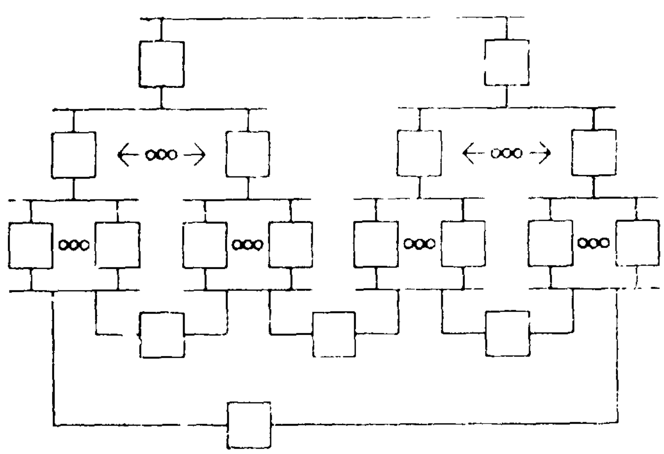
FIGURE 2

VARIOUS ARCHITECTURES USING MODULAR SYSTEM

PIPELINE ARCHITECTURE



TIERED PARALLEL ARCHITECTURE



COMPLEX HYBRID ARCHITECTURE

The memory module is actually two functions in one package. Included is one to eight megabytes of error-corrected memory along with a 29116 microcontroller operating at 8 MIPS. The memory is available to both bus interfaces and the 29116 through a three-port arbitrator circuit. The 29116 can do very fast data moves and bit manipulations, and is available as a resource to the P module for DMA, data searches, and semaphore management. The 29116 can also manage virtual connections between busses, which allows data to be moved from one location to another independent of the system architecture. This is a very important feature to make the architecture transparent to the operating system and to make the user interface independent of the architecture.

The D module is a high speed SMD interface disk controller. The SMD interface is an industry standard and makes available disk drives in the range from 80 to 500 megabytes, with the capability to interface to optical drives as they become more practical. This storage is used to support the operating system file structure and data capture/logging. Internally, the D module uses a 29116 microcontroller and 512 kilobytes of error-corrected memory. The task of the 29116 is to manage the file structure at a low level, leaving only high level requests for service to the operating system. This improves the throughput of the disk as well as the speed of the operating system. The D module's 29116 is also available for data searches and verification of the disk contents.

The interface module connects the system to an industry standard bus. This allows for COTS peripherals to be directly plugged into the system. Local area network (LAN) boards, terminal and printer interfaces, floppy disk drives, and other peripherals would be some examples. The I module is designed to be "transparent" to both the system bus and the standard bus, which improves throughput and response time between busses.

One addition to these basic boards, because NASA is the customer, could be a frame synchronizer/correlator module. This is particularly useful in telemetry data processing. It would be an intelligent board that is used as a system resource, not dedicated to any particular data stream. This means fewer modules are needed than if each was dedicated to one input stream. The function of the board is to synchronize and split up telemetry data. These functions would be more than ten times faster than if done on the P or M modules. The heart of this module would be a 29116 and several correlator circuits.

The operating system (the application's interface to the hardware) must be an industry standard. Unix was chosen because of its wide acceptance and previous use for a number of applications already done. The user interface to Unix is standard, with the peculiarities of the hardware hidden from the application. In addition, Unix on this system is modified to run in a multiprocessor as well as multitasking environment. What this means to the application is that an almost linear increase in performance is achieved with the addition of P modules. The operating system manages these resources transparent to the application. The architecture is also managed transparently, to make the application and operating system portable between different architectures. The features of the modular design can be summarized as follows:

- Standard hardware modules support various high performance real-time processing architectures
- Expansion of existing systems accommodates new requirements
- "Buy-it-by-the-yard" accommodates any size application
- Operating system provides a standard software interface transparent to the system architecture
- Uses existing applications without source code modifications
- Industry standard bus for interfacing to other commercially available equipment
- Easier to implement unique interfaces than COTS
- Very compact form factor
- Lower risk than commercial or custom implementations

APPLICATIONS

NASA's most demanding application - telemetry data processing - is both compute and I/O intensive. This is one of the best applications for the modular system. Various components of a complete telemetry processing system include high-speed front end data gathering, logging, and routing; network communications, gateways, and bridges; and data decommutation, calibration, and display. Below are some examples of the various pieces of such a system implemented with this modular architecture.

Using the four basic modules, several specific applications can be shown. The first application is a front end telemetry processor for low data rates (those that exist now). Serial data comes in, is buffered, validated, and packetized. These packets are then routed to workstations that calibrate and display the data. Its functionality can be increased later by adding a large mass-storage pool and/or increasing data throughput by adding more modules. This is done with no loss of original investment and no software re-design (see figures 3 and 4).

FIGURE 3

FRONT END TELEMETRY PROCESSOR

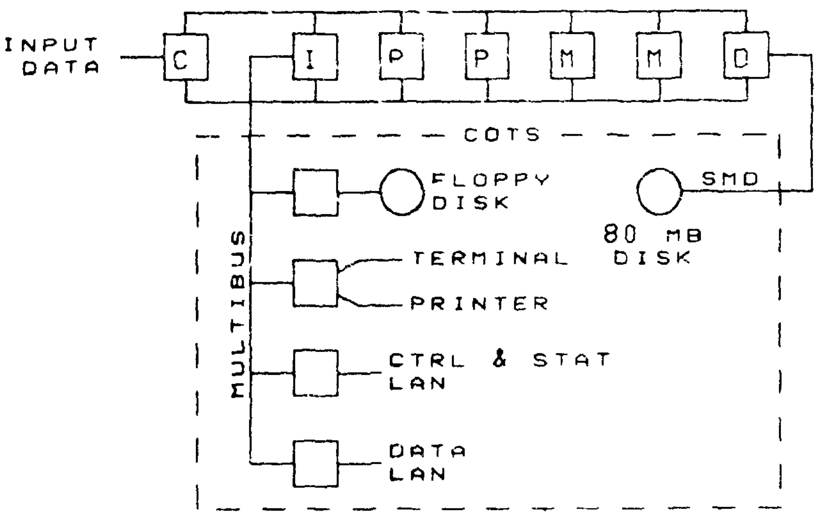
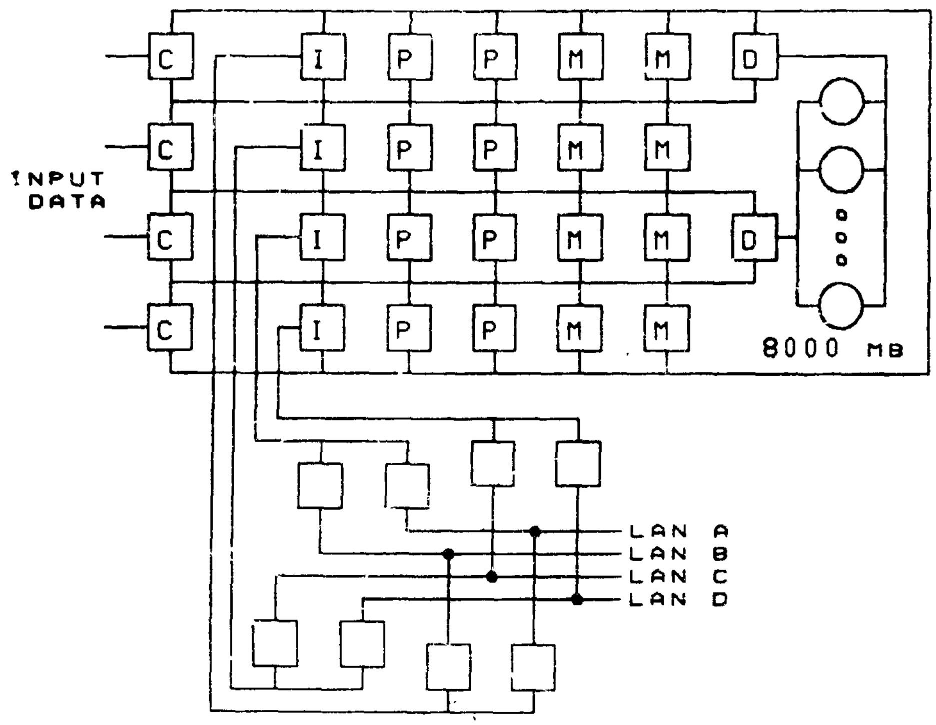


FIGURE 4

EXPANDED, FAULT TOLERANT TELEMETRY PROCESSOR



Another application for this modular system would be a network bridge or gateway. Its function would be to route data from one network to another, depending on the destination specified. Implementing routing algorithms would allow the data to take the most efficient path through the network. Transaction monitoring and logging would provide valuable debugging and fault isolation/recovery information. This could be implemented in the system shown in figure 5. The system could be expanded into a network "hub", connecting more than two networks and/or becoming a processing and data storage resource (figure 6).

FIGURE 5

LOW COST LAN BRIDGE OR GATEWAY

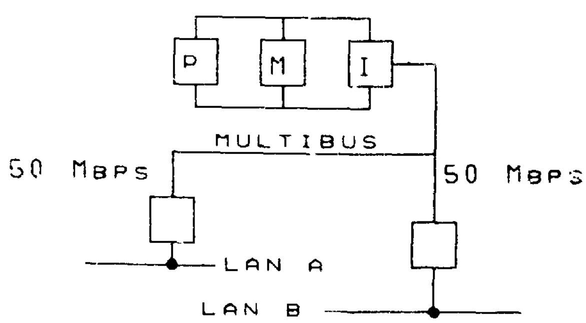
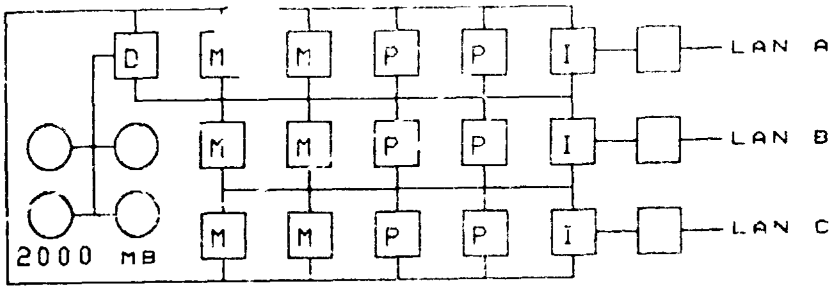


FIGURE 6

NETWORK PROCESSING/STORAGE RESOURCE



A more sophisticated architecture combines all the requirements of flexibility, growth, low cost, reusability, and technology upgrades, into a highly parallel, redundant, and fault tolerant processing system. Input data rates are sufficiently high to serve as the Data Handling Center or the low level rocessing function in the SSDS configuration (see figure 1). In fact, this system can be built up in stages as the data rates increase. This shows the flexibility of the modular system. The highly symmetric architecture in this example gives it fault tolerance and gradual performance degradation as modules or busses fail, which is highly desirable. The complete system as shown in figure 7 could easily fit in three standard racks of equipment!

CONCLUSION

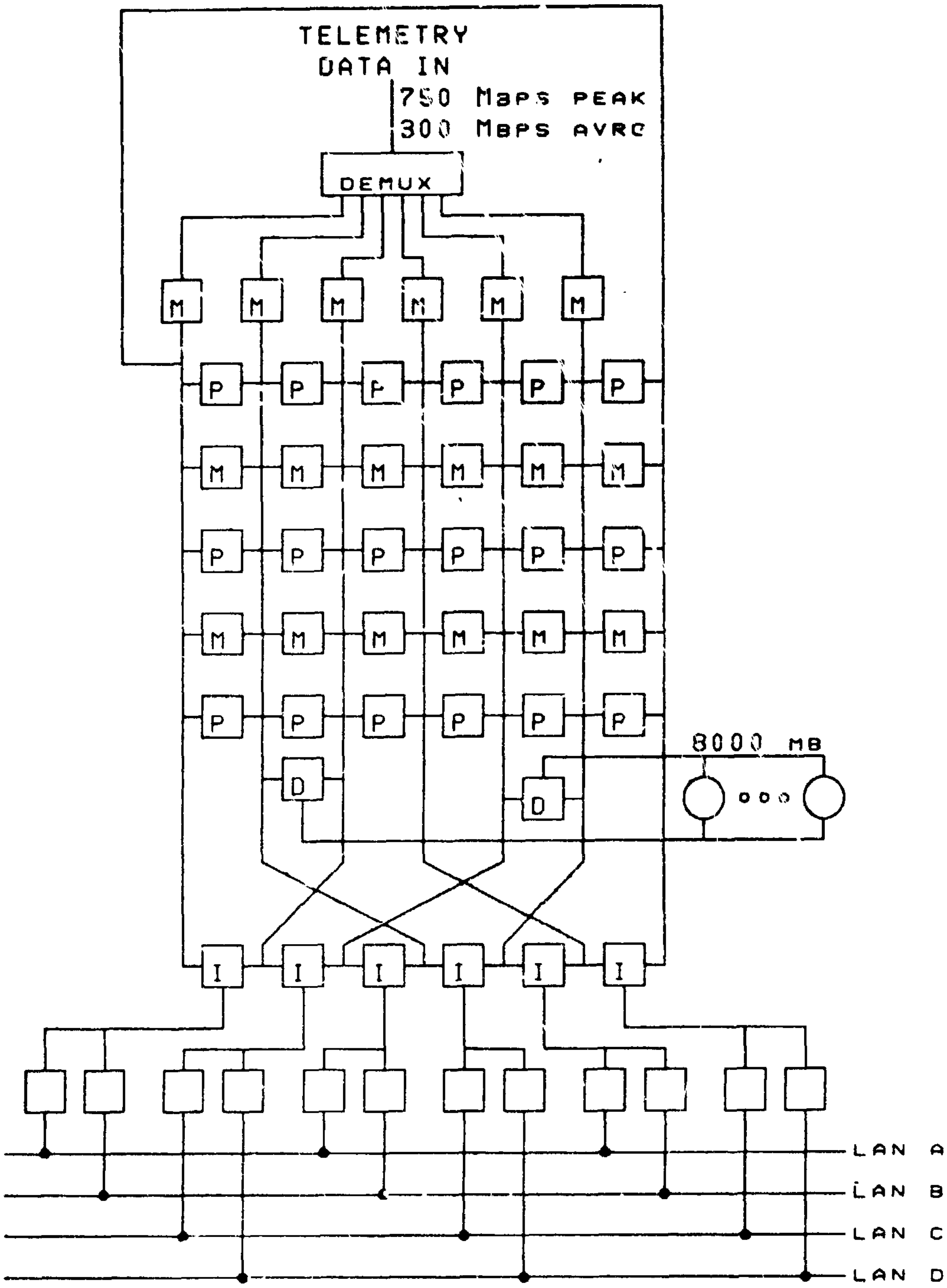
By using a highly flexible modular approach to system design, most of the benefits of custom and COTS implementations can be combined. This reduces the cost and increases the performance of the system. These modules can be used for many different applications, reducing logistics problems and improving maintenance of the overall system. New modules reflecting advances in technology can be easily incorporated into existing systems, increasing the life of that system and fighting obsolescence. Systems can grow and change without lost investment, making the cost of respecification low. Overall, this modular system approach is well suited to applications such as Space Station, where requirements are not completely defined before implementation begins and where growth and change are expected.

AUTHOR'S BIBLIOGRAPHY

Mitchell Stowe is a research and development engineer at Ford Aerospace, Space Information Systems Division. He has a BSEE from the University of Houston in 1982. His experience at Ford Aerospace includes state-of-the-art microprocessor based digital design and high speed Fiber Optic link design. He is presently working on an implementation of the modular system described in this paper.

FIGURE 7

HIGH PERFORMANCE TELEMETRY DATA PROCESSOR



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White Collar Productivity Improvement

American Productivity Center 123 North Post Oak Lane Houston, TX 77024 (713) 681-4020

Executive Summary and Findings

o Research scientists cut "average study" time by more than three months.

o Engineers made time and cost estimates one of their first responses to a request for services. Unnecessary paperwork and overall time to process the requests dropped significantly.

o A personnel unit gave other departments direct computer access to employee files. The departments now update their own workers' files. Personnel employees maintain the integrity of the system and the confidentiality of privileged data, but former file-keepers have been reassigned to more fruitful endeavors.

o An operational auditing group reexamined its mission and took a radical change in direction. The group shifted its focus from exceptions to business procedures to opportunities to guide and advise those making the exceptions. Members turned to roles as counselors rather than policemen.

Across the nation, in similar departments or functional areas of 13 corporations, white collar employees are proving that their productivity can not only be measured, but also improved. These accountants, engineers, scientists, human resource specialists, information management experts, and other professionals and their staffs -- nearly 4,000 altogether -- are pioneers of an approach developed by the American Productivity Center to boost white collar worker effectiveness. They are the heart of the the Center's two-year sponsored action research project, White Collar Productivity Improvement, completed in August, 1985.

Dispelling suspicions

The Center developed a six-phase methodology for white collar productivity improvement in response to a growing need among its more than 250 corporate, labor, government and academic supporters to address productivity in their fast-growing managerial, professional, and clerical ranks. At the same time, the project was designed to dispel suspicions that white collar work was too varied, too dependent on subjective judgement or "creativity" to hold opportunities for the types of productivity gains generally associated with manufacturing operations. The project followed a 1983 survey by the Center and Steelcase, Inc., that found both knowledge and practice of white collar productivity improvement severely lacking.

Traditional attempts aimed at cutting costs or staffing levels, often alienating workers at the outset. They typically focused on increased efficiencies in individual activities or specific procedures, such as paperwork processing. In the worst instances, a specific technique -- usually available only by hiring an outside expert -- became viewed as an all-purpose solution in search of applications. Improvements were isolated and short lived. Employees affected were left with no greater capability to do their jobs well, and with much greater suspicion of the next "productivity program."

In contrast, the Center's new approach to white collar productivity focuses on the effectiveness of actual outputs, typically professional services. These typically consist of both tangible products, such as a financial report or research study, and intangibles, such as the expertise, advice or guidance that accompany the product. Effectiveness is assessed primarily as the degree to which these services meet both internal objectives, those of the work unit, and external, or "customer," needs and expectations.

This service orientation and focus on effectiveness avoids many of the pitfalls of the traditional approaches.

It aims at innovations in the delivery of products or services to adapt to changing business conditions. It stresses improvement in the quality and timeliness of white collar activities and ensures they stay in line with overall organizational strategies. The Center's approach also focuses on individual capabilities and their contribution to the functional unit. It gives employees tools, such as productivity measures and team-building techniques, they can adapt to their own unique circumstances. Most important, the employees and their managers take responsibility for every step of the productivity improvement process so they can take it over and carry it on.

Involvement

The White Collar Productivity Improvement project was carefully crafted from the outset to ensure a high degree of managerial and employee involvement.

Each of the project's 13 sponsoring companies assigned liaisons to serve on a steering committee that set the course for the ensuing research. Corporate coordinators were assigned to assist each firm's several pilots, groups of 25 to 200 workers responsible for recognizable services of a functional unit or department. At each of the 56 pilots, a pilot manager was assigned to work directly with one of seven Center research associates.

The pilots represent nine functional areas: accounting and finance, customer service, engineering, facilities management, marketing and sales, operations, information systems management, human resources, and research and development.

Frequent steering committee meetings, training sessions for coordinators and pilot managers, and project conferences at the American Productivity Center in Houston brought sponsoring firm participants together to share ideas and experiences with the methodology. In addition, the project employed computer conferencing for on-line surveys and report preparation, tutorials, ongoing discussions, and messaging. These computer networks proved invaluable to both pilot progress and overall project management.

Progress

Progress and success with the methodology varied considerably from firm to firm and pilot to pilot with pilot members' level of participation in and commitment to the project, management's dedication, and the use of the methodology.

The 56 pilots were initiated into the project at various points during the past 24 months, and proceeded at their own paces. At the formal close of the research in August, 1985, all but two had completed or were continuing to work through the methodology. (One dropped out due to drastic management change; the other, due to its divestiture from the sponsoring corporation.)

More than three fourths of the 56 pilots had progressed through the measurement phase -- perhaps the most difficult of the six steps -- in which employees themselves selected indicators of their present and future effectiveness. Most of these also had completed redesigns or new designs of their services aimed at boosting their productivity and organizational effectiveness.

Phase-by-phase results can be generalized as follows:

1. Diagnosis phase

   o Clarification of and agreement on the work unit's outputs and services.

   o Definition of users' needs and expectations.

   o Identification of leverage points for productivity gains.

2. Objectives phase

   o Clarification of the unit's mission and purpose.

   o Creation of a vision for achieving the mission and purpose.

   o Objectives tied to the development and delivery of services.

3. Measurement phase

   o Measures emphasizing service effectiveness and critical points.

   o Means to track and feed back data for problem solving.

   o Data useful for ongoing improvements.

4. Service (Re)Design

- o Clear, agreed upon approaches to service development and delivery.
- o Services that are consistent with objectives and measures.
- o Improved capability to identify opportunities for improvements and to execute changes.
- o A framework for effective implementation of new office technology.

5. Team Development

- o Smoothed working relationship among coworkers and with other units or functional groups.
- o Agreement on back-up personnel and procedures.
- o Improved morale, enhanced cooperation, active participation.

6. Technology Parameters

- o Parameters for technology directly in support of services.
- o More efficient performance of routine tasks.
- o Enhanced communication ability.

Overall, the progress of the research pilot groups falls in these categories:

- o Business discipline resulting from a service orientation.
- o Improved operational capability and better control of resources.
- o Improved morale and motivation.
- o Internal ability for continued productivity improvements.

Findings

In addition to spurring productivity at the pilot group level, the project also contributed significantly to general knowledge of white collar productivity and improvement practices.

Center research associates documented project developments in written case studies of various pilot groups. They wrote bri fings on assessing opportunities for improvement, measurement in white collar environments, the role of management in the improvement effort, environmental design as related to white collar productivity, and a consulting perspective on the improvement process. The Center's six-phase methodology also was refined thoughout the project to reflect lessons learned at the various steps of each phase. These additional research products are available from the American Productivity Center.

The two-year test of its methodology supported many initial assumptions by the Center about white collar productivity and improvement efforts. These findings fall under eight general observations:

1. White collar productivity improvement is founded on basic issues of vision, orientation, and management practices.

2. Attention to "operational" issues will enable productivity improvement to take place.

3. White collar professionals require additional training in order to deliver their services effectively.

4. Administrative systems within an organization offer a major opportunity for productivity improvement.

5. Measurement of white collar work is both possible and desirable.

6. Technology, such as computer mediated systems or new office environmental designs, is best justified when linked to critical junctures or features of white collar services.

7. Self-reliance is a key to ongoing productivity improvements.

8. White collar productivity improvement is dependent on seven critical success factors. These are:

   o A climate supportive of change, innovation, and risk-taking.

   o A vision for the future of the function that is shared among all employees

   o Emphasis on service issues and opportunities.

   o A flexible methodology, one the function can adapt to its own circumstances and business.

   o Leadership by the function's managers, not by a consultant or lower-level employee.

   o Technology directly linked to productivity leverage points.

   o Involvement and "buy-in" by most employees at all levels of the function.

Work continues

Pilot groups, managers, and coordinators involved in the White collar Productivity Improvement project continue their efforts to become more effective, productive professionals even as the first phase of the research effort draws to a close. In the more aggressive of the sponsoring companies, the methodology and new management skills are spreading to other locations and functional areas.

From its headquarters in Houston, the American Productivity Center also continues its work to seed continued white collar productivity improvement and to expand understanding of this vital issue.

The Center has undertaken a second phase of sponsored action research, White Collar Productivity Improvement: Innovative Methods and Plans in Action (IMPACT), based on findings from its first research study. IMPACT will pursue continuing improvements in operations within pilot groups, in the working interfaces between pilot groups, and in firm-level administrative systems.

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White Collar
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STEVEN A. LETH

Steve Leth is Senior Vice President at the American Productivity Center where the major share of his efforts are directed toward white collar and knowledge worker issues. He is responsible for the development of White Collar Productivity Improvement, a Research and Advisory Services strategy of the Center, and manages the present multisponsor action research project.

Mr. Leth is experienced in productivity consulting and behavioral science research. He is a frequent speaker before professional groups concerned with white collar productivity. With the Center, he has conducted several diagnostic and change efforts within plant and corporate staffs. Recently he managed a national level survey of white collar productivity projects and the development of case histories.

Prior to joining the American Productivity Center, he worked as an internal consultant at the Phillips Petroleum Company. Earlier he was a professor and Director of Graduate Studies in the School of Communication at the University of Houston. He holds a Ph.D. in interpersonal and organizational communication from Purdue University.

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American Productivity Center [illegible] Oak Lane Houston [illegible] 77024 (713) 68[illegible]

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