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Space Administration

SPACE STATION
OPERATIONS TASK FORCE

PANEL 4 REPORT

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MANAGEMENT INTEGRATION

DECEMBER, 1987

FORWARD

This report of the Management Integration Panel of the Space Station Operations Task Force forms the basis for some of the recommendations summarized in the SSOTF Summary Report dated October 1987. Where recommendations here differ from those in the Summary Report, the Summary Recommendations take precedence. (Recommendations of all panels were reviewed and debated by the Task Force and in some instances were changed).

The official Space Station Operations Concept Lexicon is provided as an Appendix to the Summary Report. Should the definition of a term in this Panel Report be interpreted by the reader to conflict with the corresponding definition in the Summary Report, the definition in the Summary Report will take precedence.

Some of the papers prepared in the spring of 1987 address topics which have undergone significant change in the Space Station Program since that time. These sections have not been updated except in the following respects:

-use of current terminology to lessen confusion (e.g. Level I and II rather than Level A and A')

-reorganization of material within and across sections to increase clarity

-use of a relatively common format throughout the report

-minor technical corrections/clarifications

-occasional addition of an editor's note where it seemed appropriate

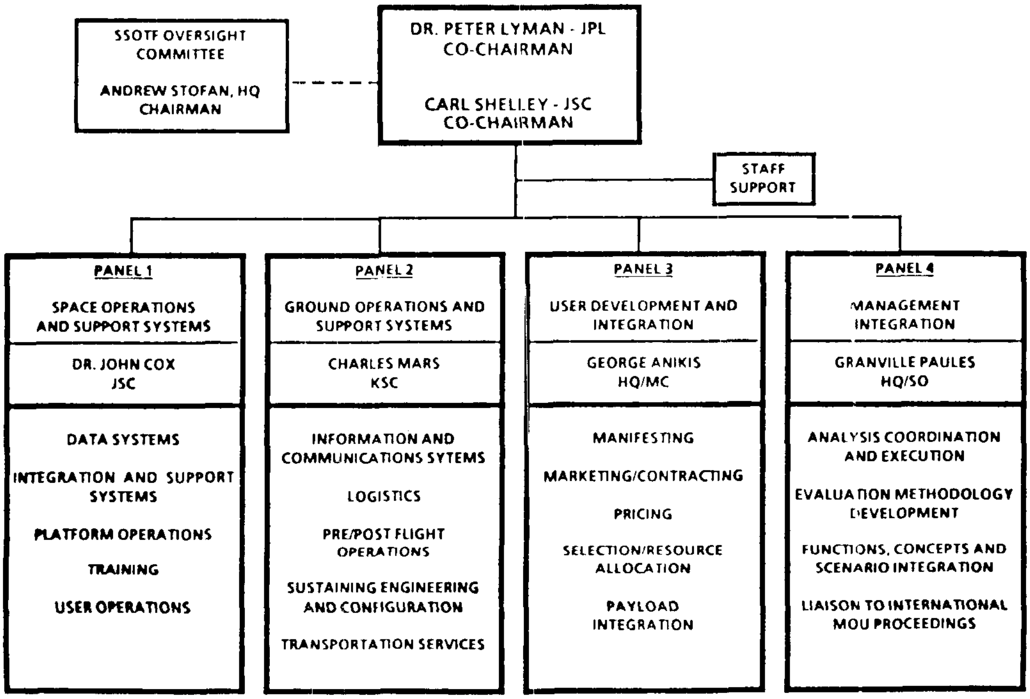
Any questions or clarifications needed concerning details or recommendations contained in this report should be addressed to the Panel Chairman, Mr. Granville Paules, Code SO, NASA Headquarters, Washington, D.C. 20546, (202)-453-1163.

Granville E. Paules III 7-13-88

Granville E. Paules, III Date

SPACE STATION OPERATIONS TASK FORCE PARTICIPANTS

The following is a listing of all participants in the Space Station Operations Task Force (SSOTF). It has been extracted from the SSOTF Summary Report.



PANEL MEMBERSHIP

PANEL 1 Space Operations and Support Systems		PANEL 2 Ground Operations and Support Systems		PANEL 3 User Development and Integration		PANEL 4 Management Integration	
*John T. Cox	JSC	*Charles Mars	KSC	*George Anikis	HQ/MC	*Granville Paules	HQ/SO
Anne L. Accola	JSC	Judy Anderson	KSC/VAFB	Laura Crary	JPL	Kevin P. Barquinero	HQ/S
Lawrence S. Bourgeois	JSC	Barbara Arnold	DoD/OASD	William Gray	JPL	Daniel A. Bland	JSC
Robert L. Bowman	LeRC	Dick Bohlmann	KSC	Carolyn Kimball	HQ/S	Karen Brender	LaRC
Walter Bradley	GSFC	Charles Bunnell	MSFC	Deborah Langan	JSC	Johanna A. Gunderson	JSC
Robert S. Clark	JSC	Bonnie P. Dalton	ARC	Lisa Mann	ARC	Joseph Joyce	LeRC
Romo Cortez	HQ-T	John Ewashinka	LeRC	Larry Milov	ARC	Douglass Lee	DOT
Anthony W. England	JSC	James Kelley	KSC	John Mitchell	JSC	Richard O'Toole	JPL
Carolyn S. Griner	MSFC	Kam Kersey	KSC	Dave Porter	JPL	William Pegram	HQ/SU
Mike Hawes	JSC	John McBrearty	KSC	William Roberts	MSFC	Robert Shishko	JPL
Frank E. Hughes	JSC	Roland (Mack) McCartney	KSC	Jeff L. Smith	JPL	Gregory Williams	HQ/SO
Richard Koos	JSC	Robert J. Manly	LeRC	Olav (Ole) Smistad	JSC		
Richard Laeser	JPL	Jim Mizell	KSC	Nicholas Talluto	KSC		
Charles M. Lewis	MSFC	James W. Moore	MSFC	Richard Tyson	OAST/LaRC		
James S. Logan	JSC	Danny F. Nail	KSC	Don West	GSFC		
Edward Lowe	GSFC	Eugene Nelson	KSC				
Axel Roth	MSFC	Rick Nelson	DoD/USAF				
William C. Webb	GSFC	Raymond L. Norman, Jr.	KSC				
R. B. (Pete) Williams	JSC	Christian Poulsen	KSC				
		Kal S. Purushotham	MSFC				
		Haley Rushing	KSC				
		David H. Suddeth	GSFC				
		Libby Wells	KSC				
		Lynn Wolard	DoD/USAF				

* Leader

PANEL MEMBERSHIP
(Continued)
ASSOCIATE MEMBERS

PANEL 1 Space Operations and Support Systems		PANEL 2 Ground Operations and Support Systems		PANEL 3 User Development and Integration		PANEL 4 Management Integration	
Kathleen Abotteen	JSC	Steve Alexander	LeRC	Harry Atkins	MSFC	Katherine R. Daues	JSC
Bob Brotherton	GSFC	Richard Baldwin	GSFC	Susan (Stacy) Edgington	HQ/I	Donald Eide	HQ/SO
Jack Bullman	MSFC	Charles Baugher	MSFC	Walt Feitshans	KSC	Paul Heartquist	DoD/USAF
Rick Chappell	MSFC	Stanley Blackmer	JSC	F. Michael Goeser	HQ/MC	Harold Miller	HQ/SO
Tony Comberiate	GSFC	Lloyd Chamberlin	KSC	Ben Higbie	DoD/USAF	James Robinson	HQ/SO
Denis Dahms	JSC	Robert R. Corban	LeRC	Bryant J. Keith	HQ-M	Robert J. Soltess	HQ-S
Charles Elachi	JPL	William Galoway	MSFC	Richard Ott	HQ-M	Mike Stevens	HQ/T
Jerome B. Hammack	JSC	Guy Gardner	JSC	Thomas Overton	KSC	Guilio Varsi	HQ/S
Adrian Hooke	JPL	Charles E. Howard	JSC	Lowell Primm	HQ/MC		
Bill Kilpatrick	MSFC	Gary Johnson	MSFC	Donna A. Shortz	HQ/S		
Kristan Lattu	JPL	Gerald P. Kenney	JSC	John R. Yadvish	HQ/I		
Roy C. Lester	MSFC	Harold A. Loden	JSC				
Daryl Rasmussen	ARC	Joe L. Lusk	MSFC				
Jack Schwartz	JPL	James F. McGuire	HQ/S				
Taylor Wang	JPL	Herman Mobley	JSC				
Jerry Weiler	MSFC	Gregory A. Opresko	KSC				
Bob Williams	JSC	William H. Oyler	KSC				
Michael Wortham	DoD/USAF	Glenn R. Parker	KSC				
		David Tipton	KSC				
		Dennis Vander Tuig	GSFC				
		Emeterio Zarraonandia	KSC				

PANEL MEMBERSHIP
(Continued)
MEMBERS AT LARGE

James F. Buchli	JSC
Philip Cressy	GSFC
Michael Devirian	HQ-E
Kenneth Frost	GSFC
Ronald H. Gerlach	JSC
Adam Gruen	HQ-LBH
David C. Leestma	JSC
Michael C. McEwen	JSC
Remer Prince	HQ-SU
Erwin Schmerling	HQ-E
Ray Sizemore	LeRC
Marsha Torr	MSFC

SPACE STATION OPERATIONS TASK FORCE SPECIAL CONSULTANTS

NAME	ORGANIZATION	PANEL NO.
Joe Allen	Space Industries Inc.	3
Herbert Bartlett	Aeroflex	2
William E. Brooks	Booz, Allen and Hamilton	4
Randy Davis	U of Colorado	1
John Egan	The Egan Group	3
Robert T. Everline	Consultant	3
Dennis Fielder	TADCORPS	4
Owen Garriot	Consultant	1
David Greulich	Cabot Corp	3
John Hunsucker	University of Houston	4
James T. Kaidy	Booz, Allen and Hamilton	4
Bill Lenoir	Booz, Allen and Hamilton	4
Bryon Lichtenberg	PSI	1
James Moore	Consultant	2
Henry J. Pierce	Booz, Allen and Hamilton	4
Chris Podsiadly	3M Company	3
Mark Oderman	CSP Associates, Inc.	4
George Schmidt	Booz, Allen and Hamilton	4
Rebecca Simmons	CSP Associates, Inc.	4
Ed Sofinowski	Consultant	1
Marc Vaucher	CSP Associates, Inc.	4
Charles Walker	McDonnell Douglas Astronautics Co	3
Charles Williams	Earth Observation Satellite Co.	3
Michael Wiskerchen, Jr.	Stanford University	3
Donald York	University of Chicago	3

SOME OTHER CONTACTS

- Center Directors
- Other Associate Administrators
- Past Program Directors
  - Charles Mathews
  - William Schneider
  - Leland Belew
- Projects/Programs
  - SR 71
  - Trident Submarine
  - British Navy Submarine Operations

BACKGROUND BRIEFINGS COMPLETED

● SSOTF Special Directions	A. Stofan
● What is a Space Station	T. Finn
● Background and Status of Agreements with Internationals	G. Rice/M. J. Smith
● Space Station Baseline Configuration	T. Bonner
● Space Station Evolution Configuration	D. Black
● Development Program Management	J. Aaron
● Space Station Budget Perspectives	J. Sheahan/D. Bates
● Columbia Lakes Operations Symposium Review	C. Mathews
● Integration Assembly and Checkout	H. Benson
● Characteristics of R&D vs. Operations Organization	J. Hunsucker
● Pricing Policy Overview	J. Smith
● Space Station Information Systems (SSIS)	D. Hall
● Technical and Management Information Systems (TMIS)	C. Harlan
● KSC Operations Lessons Learned	J. Ragusa
● Congressional Perspectives	M. D. Kerwin
● SS Work Breakdown Structure	W. Whittington
● Commercial Operations	Coopers-Lybrand/J. Egan
● Space Policy	CSP/M. Vaucher
● Soviet Space Station	DoD and B. J. Bluth
● Program Logic	W. Whittington
● Automation and Robotics	G. Varsi
● Astrophysics	F. Martin
● Lessons Learned From Other Programs	Skylab, Spacelab, et al.

OPERATIONS TASK FORCE INDUSTRY EXCHANGE LIST

ABEX CORPORATION
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ALCOA TECHNICAL CENTER
ALLIS CHALMERS CORPORATION
AMERICAN CYANAMID
ARMCO, INC.
ASARCO, INC.
ASHLAND CHEMICAL COMPANY
ATLANTIC RICHFIELD CO. - ARCO
AT&T BELL LABORATORIES
BALL AEROSPACE SYSTEMS DIVISION
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LIFE SYSTEMS, INC.

STARK & STROBEL ASSOCIATES
STAR TECHNOLOGY AND SCIENCE
SUNDSTRAND MISSILE & SPACE POWERS SYSTEMS
TELEDYNE BROWN ENGINEERING
TELEPHONICS CORPORATION
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XEROX CORPORATION

Bold means Briefed Task Force

PREFACE

The work of the panel was performed by its members, associate members, and special consultants. The organizational affiliation shown below is that which existed during winter and spring 1986-1987, the primary periods of panel activity.

Members

Granville Paules (Chairman)	Operations Division Office of Space Station NASA Headquarters
Kevin Barquinero	Strategic Plans and Programs Division Office of Space Station NASA Headquarters
Daniel Bland	Data Management and Operations Office Space Station Level B Program Office Johnson Space Center
Karen Brender	Evolutionary Definition Office Space Station Office Langley Research Center
Johanna Gunderson	Program Analysis Office Space Station Level B Program Office Johnson Space Center
Joseph Joyce	Operations and Special Projects Div. Space Station Systems Directorate Lewis Research Center
Douglass Lee	Transportation Systems Center Department of Transportation
Richard O'Toole	Systems Analysis Division Jet Propulsion Laboratory
William Pegram	Utilization Division* Office of Space Station NASA Headquarters
Robert Shishko	Systems Analysis Division Jet Propulsion Laboratory
Gregory Williams	Operations Division Office of Space Station NASA Headquarters

* Detailee from the Jet Propulsion Laboratory

Associate Members

Katherine R. Daues	Customer Integration Office Space Station Level B Program Office Johnson Space Center
Donald Eide	Operations Division* Office of Space Station NASA Headquarters
Paul Heartquist	Space Station Military Liaison Office of Space Station NASA Headquarters
Harold Miller	Operations Division Office of Space Station NASA Headquarters
James Robinson	Operations Division Office of Space Station NASA Headquarters
Robert J. Soltess	Resources and Administration Division Office of Space Station NASA Headquarters
Mike Stevens	Office of Space Operations NASA Headquarters
Giulio Varsi	Strategic Plans and Programs Division** Office of Space Station NASA Headquarters

* Detailee from the Langley Research Center

** Detailee from the Jet Propulsion Laboratory

Special Consultants

William Brooks	Booz, Allen, & Hamilton
Dennis Fielder	TADCORPS
John Hunsucker	University of Houston
James Kaidy	Booz, Allen, and Hamilton
Bill Lenoir	Booz, Allen, and Hamilton
Mark Oderman	CSP Associates, Inc.
Henry Pierce	Booz, Allen, and Hamilton
George Schmidt	Booz, Allen, and Hamilton
Rebecca Simmons	CSP Associates, Inc.
Marc Vaucher	CSP Associates, INc.

Authorship of each section is noted in the text. Because of the function of this panel to integrate the work of the other panels, a number of panel members and consultants made significant contributions to the Summary Report and other Task Force products. To avoid duplication, these contributions do not appear in this panel report, but are listed here:

SSOTF Summary Report	Dan Bland Marc Vaucher
Operations Functions (Summary Report, App. B)	Bill Brooks James Kaidy Henry Pierce
User Integration Scenario (Summary Report, III.D)	Rebecca Simmons
Operations Scenarios/ Test Cases	Dan Bland Marc Vaucher
SSOTF Comments on RFPs	Joe Joyce (coordinator)
SSOTF Comments on MOUs	Greg Williams (coordinator)

This report is an account of ideas developed during the Task Force. The Task Force provided both the opportunity to develop these ideas and for critique, generally of oral presentations of these ideas, both by members of one's own Panel and the other panels. Panel members converted these ideas into papers at the end of the Task Force. From these raw contributions, Doug Lee and Gran Paules developed an outline for this report and Doug Lee converted these contributions into a first draft. Doug Lee, Bill Pegram, and Gran Paules reviewed this draft and the original contributions to produce a draft copy of this report which was circulated to all Panel members for review and comment. Bill Pegram and Gran Paules dispositioned these comments and Bill Pegram edited and prepared the final panel report.

All of these reviews deferred substantially to the original author as the panel member selected for his/her expertise in the designated area. Ultimately, therefore the sections represent the viewpoint of the contributors and not the Panel was a whole.

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5.0 PROGRAM MANAGEMENT EMPHASIS AREAS

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1.0 EXECUTIVE SUMMARY

by Bill Pegram

1.1 PANEL OVERVIEW

Efforts of the Space Station Operations Task Force (SSOTF) were organized into four Panels:

- Panel 1--Space Operations and Support Systems
- Panel 2--Ground Operations and Support Systems
- Panel 3--User Development and Integration
- Panel 4--Management Integration

Panel Four was chartered to provide a structure and ground rules for integrating the efforts of the other three panels, and to address a number of cross-cutting issues that affected all areas of space station operations.

Work of the panel consisted of (1) development of conceptual tools to assist other panels, and (2) examination of a number of cross-cutting special topics.

1.2 REPORT OVERVIEW

Chapter 2, Operations Concept Implementation

Underlying much of the Task Force effort was a realization that operations activities could usefully be analyzed as falling into one of three types of program management levels: strategic, tactical, and execution. Another major tenet was that a focus on users and their needs was essential to fully realize the potential of the Space Station. Section 2.1 discusses the SSOTF focus on the user in terms of its strategic, tactical, and execution level implications.

Central to the Task Force analysis of operations activities was to develop a comprehensive listing of operations-utilization functions at the strategic, tactical, and execution levels. Functions were defined not so much by their titles or a traditional definition, but by defining the explicit flows of information and products among the functions. This functions structure is separate from and independent of the NASA organizations that implement the various functions. The Management Integration Panel developed this listing of function which is presented in Appendix B of the SSOTF Summary Report. Table 2-2 in this Panel Report provides a listing of Level I and II responsibilities consistent with this functional description.

The focus of the Task Force effort was on mature operations. However, the Task Force did address the functions and organizational responsibilities during the development phase, assembly, and evolution phase. This issue is discussed on p. 67-79 of the Summary Report. Section 2.2.3 of this Panel report discusses the application of the mature operations concept to the assembly phase.

The Task Force was aware that success of the Space Station Program was critically dependent on other programs within NASA. Section 2.3.1 discusses the formation of intercode Steering Committees to facilitate this cooperation.

The Management Integration Panel believed that program plans and requirements would be instrumental in managing the program. Proposed contents for a number of program plans are discussed in Section 2.3.4. Fashioning of process requirements in areas such as logistics, including supportability, was seen as a way to counteract common biases in development programs. Section 2.3.5 proposes requirements for inclusion in the Program Requirements Document (PRD, the Level I-imposed requirements) and the Program Definition and Requirements Document (PDRD, the Level II-imposed requirements).

Chapter 3, Alternatives Development and Integration Process

Much of the Task Force work was to develop a preferred alternative and then develop this alternative in considerable detail so that it addressed most, if not all, of the questions that those presented with the alternative might raise. Other, inferior alternatives are not described in much detail in the documentation of the Task Force, partly because if time is limited, dwelling on inferior alternatives may have appeared to be less productive than developing the preferred alternative. Evaluation of alternatives was done in a subjective, qualitatative manner.

Chapter 3 presents the case for an alternative approach in which a structured, "objective" process is used to develop and evaluate alternatives. This process has a number of components, almost all of which have utility used either in isolation or in conjunction with other parts of the process. As is noted there, this process and its various components were used in varying degrees by the Task Force. An example of application of some of the components is found in Section 5 of the Panel 1 report. Some members of the Panel believed strongly that greater use of this process, or some parts or variants of it, by the Task Force would have been desirable. However, even if one agrees that the proposed process is useful, it is of course inappropriate to judge the Task Force product in terms of the degree of adherence to this, or any other approach. What matters is the quality of the product, not the process for getting there.

Section 3.4 describes six scenarios and six text cases developed by the Panel to serve as a catalyst for discussion by the SSOTF. These scenarios and test cases were designed to illustrate the way the recommended operations concept would work and to test the ability of the concept to handle extreme situations. Use of the test cases and scenarios by the Panels was limited, partly due to lack of time. The test cases and scenarios hopefully will be useful to the Program in the future--they are described in much greater detail in a two volume report submitted to the Task Force.[1] The scenarios were operations planning, user integration, Station manifest, sustaining engineering, flight crew integration, and operations transition. The test cases were assembly operations, mature operations, co-orbiting platform operations, polar platform operations, evolutionary operations, and operations impact of a major program contingency. The user integration scenario is described in detail on p. 79-88 of the Summary Report and was the scenario/test case most used by the other panels.

Section 3.5 describes a number of operations options areas that were developed to aid the other panels in developing operations alternatives.

Chapter 4, Strategic Policy Issues and Options

Section 4, Strategic Policy Issues and Options, describes a number of strategic issues which received varying degrees of attention by the Task Force.

Section 4.1, International Cooperation in Space, deals with issues also discussed in Section 5.11.1 of this report, Space Station Partnership Options.

Section 4.2, Transportation, addresses issues that while viewed by the SSOTF as very important, were judged to be outside of the SSOTF purview and therefore best left for other groups, and hence did not receive SSOTF attention commensurate with the perceived importance of the issue to NASA. However, discussion of transportation issues is also found in Section 5.1.5, 5.1.6, and 8.6 of the Panel 1 report and Section 5 of the Panel 2 report.

Section 4.3, Civilian Control, discusses the role of the DOD in the Space Station program. Consideration elsewhere in the Task Force was more related to whether the possible presence of the DOD altered the recommended concept.

Section 4.4, Manned Spaceflight Program Directions, discusses possible mixes of manned and unmanned programs to achieve objectives.

Section 4.5, Resource Allocation and Subsidy Policy, was the subject of two different subpanels within Panel 3. The efforts of these subpanels constitute Section 2 and 4 of the Panel 3 report.

Section 4.6, Initial User Mix, was dealt with somewhat by the Marketing subpanel of Panel 3, and is described in Section 3.4 of the Panel 3 report.

Section 4.7, Commercialization of Space Services, and Section 4.8, Commercial Markets and Spinoffs, discuss possible options in these areas.

Chapter 5, Program Management Emphasis Areas

Much of the work of the panel was devoted to a number of special emphasis areas and this effort is described in Chapter 5. Each of the sections are described briefly below. Some applicable recommendations from the Summary Report are noted.

Section 5.1, Operations Management Structure, describes a number of major strategic issues relating to the nature of the organization that would operate the Station, to STS/Station or Center consolidation, and to strategic management and control. The issue of Station/STS Operations Synergy is also addressed on p. 98-100 of the Summary Report.

Section 5.2, Performance Assessment Process, provides background relating to the recommendation in the Summary Report (p. 126) that NASA "Establish an operations performance assessment system available to each level of Program management which identifies symptoms of non-optimal performance as well as decision path alternatives which, if implemented, could improve ground and onboard operations effectiveness."

Section 5.3, Operations Cost Management, and Section 5.4, Modeling Space Station Costs, describe the elements of a major Panel recommendation that NASA adopt life cycle cost as the relevant cost parameter in decision making. The work of the Panel in this area led to the following Summary Report recommendation:

> "6. To facilitate Program operations life cycle cost projections:
>
> A. Conduct an operations costs estimation study with each participating operations organization using the center assignments, facility requirements and overall operations framework described in the Summary Report.
>
> B. Develop a process for estimating annual operations costs which accounts for all elements of the operational framework as described within this Summary Report." (p. 126)

Section 5.5, Risk Management/Safety, discusses possible approaches to risk management, and applications to safety, cost, and performance risk. Although most of the Safety section of the Summary Report (p. 100-103) was derived from the work of Panel 1, the SSOTF conclusion "that there is a need to develop quantitative methodology for performance of safety risk assessments. Such methodology would help to reduce the dependence on conservative assumptions which could unnecessarily reduce operations flexibility ..." was based on work performed by this panel and discussed in Section 5.5.

Section 5.6, Financial Management, recommends changes in the functional and organizational structure and in the management tools for financial management. It discusses alternative planning and contracting mechanisms.

Section 5.7, Information Management, lists a number of recommendations that emerged from developing two sections of the Summary Report: Space Station Information System (p. 113-120) and Space Station Management Information Systems (p. 120-124). SSOTF Summary Report recommendations 7, 8, 16, 23, 24, 25, and 26 are also directly relevant (p. 126-127).

Section 5.8, Hardware and Software Design Issues, documents the SSOTF's work on the Phase C/D RFPs. Panel 4 integrated comments from the four panels into a presentation to the Space Station Associate Administrator and comments to the five Source Evaluation Boards developing the RFPs. In addition to this effort, the SSOTF continued to address design issues, and this work is described in the second part of this section. This discussion amplifies a number of recommendations in the Summary Report (p. 125-128).

Section 5.9, Automation and Robotics, and Section 5.10, Evolution, describe the SSOTF and Panel work in these areas.

Section 5.11, Integration of International Partners in Operations and Utilization consists of three parts. The first is a high level discussion of Space Station partnership options, the second a detailed discussion of international management issues, and the third a discussion of sharing operations costs among the partners. The latter relates to the Summary Report recommendation that the Program "Develop an equitable policy regarding sharing of operations costs among the partners. This policy must be straightforward and easily implemented and should consider individual partner resource allocations, sustaining engineering responsibilities, and overall contributions to routine Station operations." (p. 126)

Appendix A, is a description of the Model for Estimating Space Station Operations Costs (MESSOC), an operations cost model used within the Space Station Program and by the Task Force. Appendix B describes the application by the Panel of this model to the repair-on-orbit issue.

ENDNOTES

1. Technical and Analytical Services in Support of a Space Station Operations Scenarios and Test Case Development Strategy, The Center for Space Policy, Inc., January 29 and February 18, 1987, 2 volumes.

2.0 OPERATIONS CONCEPT IMPLEMENTATION

by Granville Paules

This chapter begins with SSOTF recommendations reflecting Program focus on the user, then discusses program management mechanisms and concludes with a description of the implementation plan for the recommended operations concept.

2.1 PROGRAM FOCUS ON THE USER

This section of the report is an attempt to summarize the SSOTF recommendations as they specifically impact and respond to user needs. Details can be found in the SSOTF Summary Report and in the appropriate panel reports. The User Integration Scenario described in Section III.D. of the Summary Report is especially useful to assist in understanding the step-by-step user involvement. Also an excellent background document is the report, Technical and Analytical Services in Support of Space Station Operations--Scenario and Test Case Development Strategy (in two parts).

The following is a summary of the key points resulting from the Task Force efforts with respect to user concerns.

From its inception the Space Station Operations Task Force was to focus on the users and their needs. The predecessor guidance document, the Level I Operations Management Concept, which evolved through considerable review within the NASA institutions and with the international partners, was strongly influenced by user needs in the Space Station era.

As conceived the Station program is to provide a permanently manned orbital laboratory and unmanned platforms for user research instruments. The facilities should provide an environment which enables "discovery" in its truest sense. In a relative sense NASA has taken only the smallest steps toward providing such capabilities during the past decade. The Station Program was envisioned to provide a cost-effective environment which supports not only the fundamental seminal research but the facility for moving the research into a pilot production phase if appropriate. This evolutionary process would proceed through a prototypical learning phase to the point of having proved the concept for a space-based production facility. The concept is necessary for special research areas such as materials processing. It requires no stretch of the imagination to visualize the production facility migrating from the permanently manned base to a nearby man-tended platform. Given the variety of such scenarios the SSOTF took special efforts to involve the user community in its day-to-day activities and thus to arrive at designs and operations techniques offering the potential to maximize the return to all users.

From the outset a major SSOTF recommendation was that users would be represented, would personally participate, or would actually have the full decision-making responsibility for the planning, management and execution of user experiments. The baselined operations concept highlights this user involvement.

For the design and development phases the Program has made major commitments to the systematic consideration of long-term utilization and operations. That is, the Program will consider the life-cycle costs of development decisions as part of its design-to-cost process. A specific approach referred to as Logistics Support Analysis (LSA) is strongly recommended by the SSOTF for use during the Program's system engineering efforts. A potential example where these evaluative processes will provide insight is for implementation options which consider the automation of certain operations functions and support systems. Additionally, the operations concept has been structured to respond to productive opportunities based on experience obtained during the early years of Space Station operations. The SSOTF recommends that the Program routinely assess the performance of the operations and utilization support functions and provide guidance where technological or procedural enhancements could improve overall cost-effectiveness.

A number of specific decision-support processes and management mechanisms are incorporated in the SSOTF operations concept. They are summarized here, grouped under the three primary Program management levels referred to as Strategic, Tactical, and Execution where each of the levels is related to the scope and magnitude of Program and user related decisions more than to time horizons. Following the three-level summary are recommendations which relate the operations concept to the manned base assembly phase and to organizational plans for long-term operations.

Strategic Implications

As conceived by the SSOTF the allocation of U.S. Space Station resources and the initial commitment of these resources to specific uses or discipline groups would be accomplished by a NASA chaired Space Station Users Board (SSUB). The United States SSUB would be made up of user organization representatives and would implement the agency established resource allocation policies. Similar approaches may be used by the international partners. The SSUB would also submit the selected payloads for technical feasibility assessment and ultimate manifesting. User-oriented Program organizations would shepherd the payloads throughout the remainder of the planning and flight activities. In summary, the users always are in control of the resources allocated for use at the Station; the Program provides technical assurances that it can deliver the services.

The SSOTF concept of resource envelopes is recommended as the approach for making commitments to individual users and groups of users. On-orbit resources such as power and the crew-time would be allocated to specific users in specific timeframes perhaps years in the future. Blocks of resources would go to the international partners for further allocation to their user community. Additional blocks could be set aside as user reserves for the "quick response" payloads that might come along opportunistically close to launch. The package of resources would carry with it the necessary launch capacity and network services. Commitment to specific launch vehicles and rack space in specific on-orbit laboratories could be deferred until the last reasonable time to provide flexibility for both the user and the Program to better guarantee a launch window, adequate time on board, and a scheduled return to Earth.

The SSOTF recommends that a NASA-wide pricing and resource valuation process be established as soon as practical. The approach is essential if there is to be a rational, implementable policy for administering the scarce Space Station and other NASA resources. It will be essential for establishing consistent approaches to bartering of resources for use among the U.S. users and between the partners. It will also provide a consistent mechanism for communicating to the users and operators what incentives they should consider in payload design, operation, maintenance, and servicing.

The SSOTF recommends an integrated end-to-end approach to manifesting for both user payloads and laboratory "housekeeping" support. The end-to-end approach includes the commitment of all essential resources as noted earlier. It includes all services such as transportation to space, communications and tracking needs, some data processing services, all Space Station related support services, and all logistics support services. This includes both the trip to space and back. Thus, the user will be provided one well identified support path through the integrated process.

The international partners will be part of this integrated process. Such an approach is critical since nearly half the United States sponsored users will likely be assigned to an international laboratory.

The SSOTF recommends that each manifested user be assigned a Payload Accommodations Manager (PAM) who will follow and nurture the payload from the point of Space Station commitment until the time that all "contracted" payload support is complete. This includes payload return to Earth or a similarly recognized completion event. As currently proposed the PAM will work for the Space Station Program and will be extremely knowledgeable about the Station's capabilities as well as the needs of the user discipline which she/he is most likely to represent.

Tactical Implications

The SSOTF recommends the concept of Science and Technology Centers where experts in specific user disciplines provide critical design and technical integration support during the payload development and verification phase. The Centers would be Program certified and primarily responsible for payload rack integration or the equivalent services required for attached payloads. The Centers would be instituted and supported by the user organizations and would provide a variety of discipline-oriented services such as data archiving and engineering support analyses.

Much of the strategic level manifest commitment and detailed follow-on user integration support will be handed off to the Tactical level organization at the appropriate point in the payload life-cycle. Again the PAM remains with the payload to assure proper integration support and the key access back in to the formal remanifesting process were this may be required.

As at the Strategic planning level it is still presumed that users and groups of users are planning and working within their allotted resource envelopes. To the degree practical all data and information necessary for planning and managing operations and utilization will be automatically stored and retrieved. Paper documentation will be minimized.

Activities at the Station are organized in increments of time delineated by manned launch vehicle arrivals. Major crew involvement and relatively time-critical events characterize the activities typically associated with the Shuttle arrival. This includes the Station crew changeout and the new load of experiments to be transferred to the Station. Completed experiments must also be off-loaded to the Shuttle during its short stay or loaded in a returnable Expendable Launch Vehicle canister.

The Increment Change Manager (ICM) becomes the most important decision-maker of interest to the user at this time. The ICM controls all the programmatic resources necessary to assure that the experiments in his increment receive the proper prelaunch (or pre-postlanding) attention to meet the launch and return schedules. The ICM is also responsible for assuring that any experiment logistics needs will be satisfied during the increment for which he is accountable. The ICM will be strongly influential in seeing that users receive the proper support to stay on schedule prior to and during increments for which he is responsible.

Several ICMs might be involved with a single experiment if it is to be active onboard the Station over several increments. But note that only one will be involved with launch issues and one with return issues. Others over intervening increments will have little if any involvement in such a case.

Thus, as complex as the user integration process might appear when viewed end-to-end, the SSOTF concept provides the user with two key advocates: the PAM who protects the individual user's interest and the ICM who protects the "corporate" interest of the group of users associated with his increment.

Execution Implications

The SSOTF recommends the use of a centralized Payload Operations Integration Center (POIC) to coordinate and plan for user requirements during the real-time execution phase. User Working Groups will work through the POIC to reconcile any conflicts over resources (for instance, where a particular user must exceed his peak power requirement to complete an experiment).

Discipline Operations Centers (DOC) are conceived to perform a similar function within a particular discipline. The DOC will bring to bear the knowledge of specialists to prepare plans for a group of users during specific periods of time. Real-time resource demands and scheduling problems which cannot be reconciled at the DOC will be negotiated through the POIC support team. The POIC will integrate the individual requirements of each DOC or individually sponsored user to assure proper support system configuration and support team manpower scheduling.

A major recommendation by the SSOTF is that users, as much as possible, be able to execute the specifics of their experiment from their normal work sites, not from a "control center" prescribed by the Program.

This recommendation is based on historical experience with space programs in general. Laboratory science is best conducted in a laboratory environment. This includes the environment envisioned for Space-based research where the Earth-based Principal Investigator may be working a project that has Earth-based parallel efforts associated with that underway on-orbit. Direct voice contact with the cooperating Station crewperson and direct control of up and downlink data from the Earth-based laboratory is essential.

This recommendation is consistent with the resource planning and management concept embodied in the POIC and DOCs described above, i.e. decentralize to all degrees feasible the user activity to his normal work site. Note that the DOC can be identified as a normal work site but this should be a decision negotiated between the user and his sponsor--not one dictated by the Program.

Consistent with the above discussion a major recommendation of the SSOTF is that the current Zone of Exclusion (ZOE) be closed. This is a ground-coverage gap between the currently planned TDRSS satellite locations. The routine accommodation of this gap for every orbit of the Earth for thirty years carries with it an unacceptable opportunity cost.

This becomes especially apparent when one considers the user-based concept of telescience. This concept provides for the transparent end-to-end ability to "command, control, and communicate" with the experimenter's payload or, for instance, the system operator's robotic maintenance efforts. Modern ground communication technology and that projected to be available on-orbit in the Space Station era should support the telescience concept.

The SSOTF stresses that closing the ZOE must be studied from a life-cycle cost perspective and the most cost-effective approach found for closure.

Concept for Mature Operations Consistent with Assembly Phase

The SSOTF first developed an operations concept for the mature phase to be in place following Station assembly and on-orbit verification. It then reviewed the concept for feasibility during the assembly phase. The consensus was that the mature phase concept was completely rational for the Station assembly and that concept implementation should begin as soon as possible. The major benefit is that the mature phase support systems and ground-based facilities provide a highly rational approach to manifesting, remanifesting, payload integration and launch site processing. In general, the concept appeared to also provide the best process for managing the assembly phase activities. A highly beneficial outcome will be that the Program and the user community can, in parallel with the mostly centralized Apollo-like assembly operations, develop and understand various approaches to the much more decentralized user operations.

The SSOTF recommends that during the Assembly Phase the Utilization-Operations organization be tightly integrated with the Space Station development program to better assure the long-term consideration of user and operations concerns during the hardware development phase. See "Controlling" in Section 2.2.1 below for further discussion.

Long-Term Utilization/Operations Organizational Planning

The SSOTF envisions that during the mature operations era that the Utilization/Operations organization will, in effect, become the dominant organization. Development activities will likely continue for a significant period after the Phase I (and II) manned program has been completed. However, since actual utilization and operations activities will have been underway for a few years, the major operations sustaining engineering requirements and the utilization "market" analyses should dominate the Space Station Program engineering and development activities. The Summary Report (p. 68-75) includes a recommended organizational approach for the mature era.

Thus, the SSOTF strongly recommends that as the Station moves into its mature operations phase, about a year after assembly, a much more accountable organization be put in place. Individual managers at each organizational level must be assigned the authority and responsibility for the acquisition and use of all operations and utilization resources. They must be accountable for the performance, cost and risk management associated with their areas of functional responsibility. Positive use-oriented incentives must encourage them toward the most cost-effective use of their resources. Implementing this recommendation will clearly prescribe, at least in part, several "new ways of doing business" for NASA institutions.

2.2 PROGRAM MANAGEMENT MECHANISMS

The SSOTF made several recommendations relative to program management with respect to operations and utilization. Several of the following recommendations elaborate on the recommendations summarized in the previous section.

2.2.1 Establish Program-level Decision-Support Processes

Program-level decision-support processes fall into two major functional grouping: planning and controlling. Both are summarized below.

Planning

Planning processes are designed to establish measurable, time-based performance criteria and objectives for the specific plans or other products of the functional area covered by each process. Strategic and tactical operations planning, market research, and budget planning are examples. Several SSOTF recommendations resulted from efforts to define the processes. They are included in the Summary Report as part of the Operations Framework. Others which are described below provide expanded detail about implementing the processes.

Recommendation:

As the Program moves to implement the operations concept it must clarify the various Program phases through which operations must transition. This is especially important since the funding mechanisms are quite different and the transition of major operations and utilization roles and responsibilities might be significant from phase-to-phase. The Program should clarify Program Phase Definitions for:

-Development--including Operations Capability Development. Specifically clarify those activities or developments funded under operations capability development but which require a major continuing investment as part of the actual conduct of operations such as sustaining engineering.

-Assembly--including the transition through the full Assembly-Verification phase

-Mature Operations--all operations after Assembly phase

-Evolution Operations Capability Development--this effort is of key importance since technology evolution is the area having the most promise for increasing operational productivity both on the ground and on-orbit.

Recommendation:

The Program should formally adopt a number of specific utilization-operations goals:

-Incorporate the goals stated in the SSOTF Summary Report (p. 11-13)

-Operate the Manned Base as an integrated complex

-Provide for cost-effective synergy between the Manned Base and Platforms

-Make the most cost-effective use of all NASA operations resources

-Allow for the use of Commercial Services to support operations which: meet operations safety and performance criteria, have acceptable management risk where an equivalent capability does not reside within NASA, and, otherwise, are cost-effective from a life-cycle perspective.

Recommendation:

Utilization/Operations Functions. The Program should refine the functional areas summarized in the SSOTF recommended operations framework. The SSOTF, through the Panel Four efforts, developed a comprehensive set of operations-utilization functions. These were used: to stimulate SSOTF thinking about the whole of operations, to provide a framework for organizing the operations concept, and to provide end-to-end validation checks of the various panel efforts in order to reconcile functional overlaps and gaps. The complete set of functions and their descriptions is included as Appendix B to the SSOTF Summary Report. The Program should take the following steps to complete and formally adopt the functions approach for use in implementing the operations concept:

-Complete the definition and development of Space Station operations functions, functional interfaces and product flows among functional areas using a methodology similar to that initiated by the SSOTF. This must: cover all aspects of operations, define end-to-end responsibility and accountability, identify all activities and products, and provide a basis for measuring management effectiveness.

-The functions, functional interfaces and product flows, and the assignment of roles and responsibilities should be formally defined and placed under a TBD form of configuration control.

Recommendation:

The Program should provide a number of policies and capabilities which respond to the concerns of utilization and operations interest:

-Level I Operations Management Concept (OMC). This document was developed by the Program as a early effort to define the highest level concepts and to establish Program-wide agreement with its stated principles. The review included the international partners. The concept was used a point of departure for the SSOTF to begin its deliberations. The OMC should be updated to reflect the SSOTF recommendations and be approved as a program applicable document.

-Joint Manifesting Process. The Program shall develop and implement manifesting procedures that:

* provide a "one-stop" concept for users and systems operators including support for: transportation services; communication, tracking, and data services; Space Station Manned Base services

* provides the most flexibility in assignment-reassignment to launch

vehicles, and

* provides the most flexibility in assignment-reassignment to earth-return vehicles.

-Operations Planning Procedures. The Program shall incorporate planning procedures which:

* assume when permanently manned, the Manned Base will be supported by a minimum of five Shuttle visits per year

* assume for manifesting purposes, an EQUIVALENT of five Shuttle arrivals per year

* allow for an annual mix of Shuttle and ELVs (specifics to be identified) and that ELVs may be used for any upload or download activity exclusive of routine crew delivery or transfer

* assume an EQUIVALENT of two TDRSS channels for the Manned Base and one for all platform operations.

Recommendation:

Operations Concept Review and Enhancement. The SSOTF completed a significant effort to describe an operations concept. Many steps are required to implement such a concept. The Program should undertake a comprehensive operations concept review and enhancement process as outlined below:

-Define concept alternatives for each major functional area. The following options as defined in Section 3.5 of this Panel Report should include utilization themes, organizational control, implementation approaches, and engineering design emphasis areas which includes the two subareas of use-oriented initiatives and system performance-oriented initiatives.

-Synthesize operations concepts including definition of support systems, facilities, materials, and manpower required to carry out the functional area. This effort should include a clear indication of what inputs are required from other functional areas, the products or outputs produced by the functional area, and a summary of the processes required to conduct the functions.

-Develop scenarios and test cases to validate the concept by using Program baselined scenarios such as those developed by the SSOTF.[1] Two steps are involved. First, the scenarios should be developed, then configuration controlled for program use and should include at a minimum the following. For both mature and transition ops, the reference cases should include end-to-end user integration and integrated operations planning. In the mature ops area, there should be a special focus on flight crew integration including 2 year rotation, station manifesting, sustaining engineering, and integrated logistics support. For transition ops, the special focus should be on assembly-verification and man-tended operations.

Second, the Program should develop and use operations test cases such as those developed by the SSOTF and described in the reference cited above. These ultimately should be configuration controlled since they provide a standard against which future concept proposals may be evaluated.

-Select integrated concept evaluation criteria. Consider especially: user friendliness, feasibility-flexibility, resource allocation-utilization equity and management, utilization/operations procedural efficiency, operations cost management (short and long term), international cooperation (accommodation of functional allocation concepts, resource allocation, operations cost sharing), and risk management. The criteria should incorporate measures of effectiveness, equity, and efficiency. Suggested performance measures (stratified by user community and partner) include: utilization/unit of resource availability, utilization-unit of resource consumed, housekeeping/ utilization resource consumption, cost/unit of productivity, risk exposure vs. productive benefit, and overall goal satisfaction/unit resource consumption.

-Evaluate concept alternatives for the full integrated set of functional areas using the steps outlined in Table 2-1.

Recommendation:

Top-down Program Management Process. The Program should create an Operations organization which has clear lines of responsibility and authority from the Strategic to the Tactical and down to the Execution level of the organization. The SSOTF studied a wide range of alternatives for organizing operations and utilization and selected one combination which it recommends as the concept of operations for program implementation. It is outlined in the SSOTF Summary Report.

Controlling

Controlling provides program assessment and redirecting functions including specific measurement of performance versus costs to carryout utilization and operations functions. Program budget versus costs tradeoffs are normally reconciled as part of a control process. Use of life-cycle cost methods during design is another example. Recommendations of importance in utilization and operations are outlined below.

Recommendation:

Level I Operations Management Concept. The Program should update the Level I Operations Management Concept to incorporate the SSOTF strategic level recommendations, have the document widely reviewed and subsequently adopted as a Level I applicable document. See earlier discussion under Planning.

Recommendation:

Operations Program Documentation. The Program should develop an Operations Program documentation process that is consistent with the Development Program. There should be a set of documents for Operations Capability Development and another for actually conducting operations. Documents include the following at a minimum: interface control documents, international integration, user integration and support, resource allocation and tracking, planning processes, operational procedures, operational plans, mission rules, operations lexicon.

It should develop new, or revise existing, program documentation to reflect requirements both for operations capability development and for the actual conduct of operations. The documentation tree should reflect all interfaces with external institutions and programs which have formal space station support roles as defined by the baseline. These applicable documents include:

-An updated Program Approval Document (PAD) which including broadly defined criteria with respect to the Station Configuration, top level roles-responsibilities NMIs, top Level CoF requirements, a program organization chart which establishes high-level roles-responsibilities and provides for major milestones schedule control.

-Level I Operations Management Concept

-Top Level Operations Functions Definition

-Level II-III Documentation Tree

-InterCode Agreements--roles-responsibilities

-Program Budget documents including

TABLE 2-1
EVALUATION OF CONCEPT ALTERNATIVES

- Select scenarios requiring evaluation according to major Space Station Program Phases and which consider major risk management decisions including a range of reasonable evolutionary paths for Station uses.

- Provide an end-to-end test of functional continuity using the reference and selected scenarios and test cases.

- Verify resource availability, that is, confirm that the proposed Space Station elements support the scenario.

- Evaluate alternatives which pass screening
  - Describe degree of responsiveness to various initiatives
  - Test for management effectiveness including:
    - Clearly identified resource control responsibilities at each decision level
    - Responsive (effective and efficient) but minimal interactions within each major functional grouping and between decision levels
    - Accountability vs. responsibility within and between functional groupings
    - Well defined information management and control mechanisms
  - Confirm international participation (if required)
  - Perform cost analysis and develop cost management plan
  - Prepare multiyear financial plan
  - Conduct overall risk assessment

- Identify impacts using the previously established criteria and summarize aspects of risk.

- Rank alternatives within Functional Area.

- Prepare evaluation summary in two parts:
  - For each functional grouping, include the following:
    - Title of Functional Area (e.g. Logistics Integration)
    - Brief description of Functions covered
    - Baseline Concept Definition and optional approaches
    - Functions Groupings
      - Integrated Functions Groupings chart
      - Definition of Interfaces
        - Inputs Required (from what other functions)
        - Outputs Required (to what other functions)
        - Outline of required documents: ICD, MOU, Schedules, etc.
      - Requirements for System-oriented concepts
      - Description of required components which provide operations capabilities
        - Support Systems
        - Facilities including outfitting
        - Manpower (NASA, Civil Service, contractor, other)
        - Materials
  - For the integrated set of functional areas, report:
    - Comparison of optional approaches
      - Responsiveness to Use-oriented concepts
    - Implementation Proposal (including rationale)
      - Proposed Organization charts reflecting NASA Center and international roles
        - Organization Transition Plans
          - Development Phase
          - Assembly-Verification
          - Mature Operations
        - Rationale for option selection including
          - International considerations
          - Other non-NASA arrangements
          - Proposals on long-term operations cost management
        - NASA NMIs for Operations Organization
      - Site recommendations
      - Common Cost functions-groupings
      - Annual cost profiles
      - Outline of Operations plans for each major functional area
      - Development to mature operations transition considerations
      - Open Issues

the Levels II-III and other closely related NASA Codes' Budgets

Recommendation:

Key Databases. The Program should identify key databases needed for Program operations management and execution.

Recommendation:

Operations Cost Management Process. The process (see details in Section 5.3 of this Panel Report) shall require that life-cycle costs (LCC) be considered for ALL engineering decisions. The process will:

-Minimize LCC consistent with crew safety, system performance criteria, and program budget,

-Establish economic lives for use in LCC decisions including: Data Management System; Communications and tracking; SSIS major components; ECLSS; Power; and other considerations such as, the flight and ground crew professional development cycle for specific classes of crew-types; operational ground-support systems, e.g. SSCC and POIC; and others as identified by the Program,

-Incorporate LCC envelopes or benchmarks which will be: developed and allocated to engineering managers for all onorbit and ground systems, set at Level II SE&I, set at WP WBS level of accounting,

-Use expected values for LCC-based decisions with the range of uncertainty presented for performance and cost, and

-Incorporate the use of management incentives which promote LCC savings.

Recommendation:

Management Assessment. The Program should implement program control mechanisms based on consistent, top-down processes. These mechanisms include:

-Operations Performance Process. Establish an operations performance assessment system which provides key facts to all levels of management.

-Develop hierarchically consistent operations performance indicators at all organizational levels. Using such indicators a diagnosis is intended to determine the nature and extent of less-than-optimal conditions through a careful analysis of symptoms. The idea is to provide a logical framework that will allow an operations manager to explore systematically the full range of actions that might be taken, and to select those that are most suitable for the particular circumstances.

-Use as a driver of evolution considerations where operational efficiency or effectiveness can be improved.

-Develop incentives programs tied to performance-cost management. Establish performance-cost objectives for key managers.

-Resource Allocation Process. Establish a formal process for allocating the Space Station resources to appropriate organizations responsible for planning and developing Station uses. The NASA-wide process would be supported but not necessarily managed by the Office of Space Station.

2.2.2 Establish Utilization/Operations Organizational Approach

Integrated management of utilization/operations will be accomplished through establishing the Level I/II/III program organization, the NASA institutional, and the international partner roles and responsibilities.

Establish Integrated Management of Utilization/Operations.

Recommendation:

The Program should establish a top-down (project-oriented) organization control process for the strategic and tactical level operations functions. Specifically the Program should provide a totally integrated program management structure including the following considerations:

-Establish top-down organization control from strategic planning (project approach) to the execution level (matrix approach-if required)

-Centralize the strategic-level policy making body and control the top level management functions at Level I

-Integrate resource utilization planning with crew activity planning

-Distribute on-orbit systems support and user operations

-Tightly integrate the Level II Ops-Util organization with the Systems Development organization to assure appropriate attention to acquisition logistics, that is, supportability considerations.

-Integrate international partners at all levels of planning and control.

Establish Level I/II Roles and Responsibilities.

Level I organizational responsibilities are outlined in Table 2-2 to give a sense of the functions envisioned to be strategic in nature. The essential implementing mechanisms are then listed and followed by a summary of the programmatic focus areas which are consistent with the Level II tactical organizational structure.

Establish Institutional Roles/Responsibilities.

Recommendation:

The Program should implement the SSOTF proposed roles and responsibilities, verify these assignments as part of the SSOTF review cycle, and identify any agreements required for implementation.

This clarification includes the need to study and resolve international partner roles and responsibilities and to agree on each partner's specific authority on operations boards and panels. Specifically, the Program must establish the formal mechanisms by which the international partners, the DoD, other Federal Agencies, and the commercial sector will be integrated into the utilization-operations planning processes. As part of the effort it should be determined what operations roles may be accepted as exchange for U.S. (or other partner) provided services.

Concomitantly, within NASA the roles and responsibilities of other NASA codes, the NASA Field Centers, and other actual or potential program participants must be established as soon as possible.

The processes should be established by clear, written lines of authority and responsibility for all operations decision-making levels. Also, as the agreements are developed all participants should be appraised of the process by which operations and utilization support costs will be determined and allocated.

2.2.3 Emphasizes Use of the Concept During the Development/Assembly Phase

Transition Organization

The SSOTF studied the issues of transition from the initial development through assembly to mature operations. The following outlines the SSOTF proposal for such a transition.

TABLE 2-2
Recommended Responsibilities for Level I and II

Level I specific responsibilities:

Develop operations incentives-policies leading to "user-friendly" operations support

Create policies that minimize barriers to commercial opportunities-involvement in long-term space station operations

Develop and provide for implementation of overall operations management concepts and required organizational policies leading to:

- integrated space station resource planning and management support systems
- integrated manifesting support systems
- integrated logistics support systems
- integrated data and information management systems
- integrated operations cost-financial management approaches

Develop operations-required service acquisition policies for:

- transportation to-from orbit
- communications and tracking support
- data and information system support
- other

Assure that operations concepts and concerns are incorporated in Space Station Element DDT&E planning and programmatics including appropriate life-cycle cost considerations

Contribute to development of policies required for operating as an international partnership. The complex of NASA internal operations agreements and international partner agreements should be established through this level of the organization.

Establish programs and policies which identify opportunities and provide incentives for operations-related advanced technology development and exploitation throughout all stages of Space Station Program evolution

Integrate and reconcile all components of the annual operations-related budget including:

- Space Station Program DDT&E
- Construction of Facilities
- R&PM for Operations
- Other reimbursable and non-reimbursable annual operations costs, direct and indirect for all services
- Advanced development

Other functions as described in the Strategic level operations functions appendix to the SSOTF Summary Report.

Level II specific responsibilities:

Develop the following capabilities:

- Space Systems Operations Capability Development
- User Operations Support Capability Development
- Prelaunch-Postlanding Operations Capability Development
- Integrated Logistics Support Capability Development
- User Payload Operations Requirements Integration
- Space Station Element Design Input for the manned base and platforms

Support of Level I Operations-Utilization activities which include:

- making the initial commitment of Space Station resources
  - allocation to on-orbit systems operations
  - allocation to users
    - assume that users will allocate and manage their dedicated resources
- developing the support agreements required with appropriate NASA Offices
  - cover all non-program controlled resources required by the Program to conduct operations
    - transportation
    - Communications, tracking, and data services
    - user interface support, e.g. Discipline Operations Centers
- developing and managing the integrated Station Pricing-reimbursement policies
- planning, negotiating, and managing the international operations support
  - Development of Operations Management Plan
  - Preparation and maintenance of the Consolidated Operations-Utilization Plan
    - System Operations Panel
    - Utilization Operations Panel
  - Operations cost sharing estimates and management
- assessing the long-term operations-utilization performance-cost-risks which affect:
  - other NASA offices
  - international partner activities
  - other external agreements
  - new program development or operations budget requirements
- conducting market research.

Conduct tactical planning and integration functions and execution management functions as described in the SSOTF Summary Report.

Recommendation:

The Operations Organization should manage the complex assembly and verification process for the Development Organization and allows for a special Program emphasis in areas where operations advocacy at a visible organizational level is important during development.

The strategic functions for the transition operations organization should include those outlined for the mature operations organization program policy divisions, specifically: utilization and operations development, strategic policy, program management, and evolutionary planning. The existing division of operations and utilization functions should be retained since both functions at the strategic level face significantly different policy drivers and constituent interfaces. Assignment of the above functions at the policy and strategic planning level of the program retains the existing, essential synergy required between the hardware development and the early operations responsibilities. This complex of NASA internal operations agreements and international partner agreements should be established through the strategic level of the transition organization.

Recommendation:

Even during the development phase the operations organization will require the support and direct the resources of many NASA institutions. Typically, the institutional operations support organizations are quite different from the institutional development organizations. As envisioned in the recommended concept, most already have ongoing operations responsibilities. The institutional commitments to support operations will be no less significant than those required to support the hardware development work packages and will evolve for a much longer time (20-30 years and more).

Thus, as a major responsibility, the operations organization should develop, as soon as possible, key operations agreements with each NASA institution, that is, with each Associate Administrator and, as appropriate, each Center Director. As with the Space Station hardware development program, these agreements will be essential since the Program has no current authority over any of these critical institutional assets. Agreements should cover the significant institutional manpower and the development or enhancement of critical support centers, facilities, and systems. Others should cover the major commitments by NASA's transportation system providers and communications-data services organizations. In order to support the Space Station Program many of these institutions must make organizational realignments and budgetary commitments to provide facility support.

Recommendation:

Over the long-term, major NASA funding commitments will be made to support the Station Program operations. Many will be outside the Program's direct control. Thus, after considering the previously described evaluation criteria, the SSOTF strongly recommends that the organization under the Director, Utilization and Operations be a parallel structure with the Station DDT&E Organization during the Development Phase. Both would continue to work for the AA for Space Station but major policy and budgetary tradeoffs would be elevated to the AA level for reconciliation. Consistent with this approach the SSOTF recommends that operations agreements should be separate from development agreements since different institutions or parts of the institutions often provide the operations support to a project after it has been developed.

This IS NOT a recommendation that the operations capability development nor the management of assembly operations and initial user support operations be located outside the AA for Space Station's control. Quite the contrary, since the operability and maintainability aspects of the Station systems and facilities must be designed in concert with the capability to operate and use them. It IS a recommendation that development of the capability to operate, support, and use the Station be given equal weight and visibility during the development phase, especially since the Program must establish commitments of key NASA operational resources and clear lines of authority and responsibility throughout the NASA institutions early in the development phase of the Program. In summary, the SSOTF organization proposal facilitates a gradual "organizational transition" to a structure independent of the development organization.

Operations Management Responsibilities During Assembly Phase

The Operations Concept should be implemented as soon as practical. Early implementation will allow for appropriate synergy to develop between the Shuttle operations processes and those which will evolve with the Space Station. It is also essential that the proposed planning and manifest management procedures be developed and validated for use in planning and executing the Space Station Assembly phase.

Recommendation:

Establish the Space Station operations organization as having primary responsibility for integrated assembly and checkout.

One approach is to base a management mechanism such as the Engineering Master Schedule around the Assembly-Verification operations activities since the opportunity costs associated with hardware delivery schedule uncertainty will be greatly magnified when considering the thousands of activities involved with assembly payload manifesting-remanifesting, with payload ground transportation scheduling, with final preflight checkout, and with cargo processing at the launch site.

Were this approach taken the proposed integrated operations control process would be appropriate for accomplishing the assembly planning and execution.

Once this management process were established the Program could conduct formal risk assessment studies for all major milestones and assist in the establishment of cost-effective contingency procedures.

Operational events and activities during the Assembly-Verification Phase operations will become the primary drivers for when and what Space Station hardware should be delivered to the launch site and subsequent delivery to orbit. The operations management process should allow for greatest program control flexibility given the variety of launch phase uncertainties. It should permit the greatest schedule flexibility to remain with the Shuttle. Every effort should be made to simplify the launch vehicle interfaces. The Program should be prepared for significant remanifesting as a result of potential or unexpected operations contingencies.

Recommendation:

The Program should provide second copies of critical elements as determined by vulnerability studies.

Recommendation:

Establish the Operations Capability Development and the Operations budgets as line items separate from the Space Station flight hardware development budget. Exchange of funds between the three budget lines should be permitted only with formal, Level I Control Board approval by the AA for Space Station.

2.3 OPERATIONS CONCEPT IMPLEMENTATION PLAN

> *Note: The following material was developed in outline form during the SSOTF effort and was expanded in the summer of 1987 to provide a more complete and relatively current portrayal of the approach intended by the SSOTF.*

Once the AA for Space Station has reviewed the Space Station Operations Task Force proposal and has accepted its intent, the objective should be to incorporate the programmatic implications of the proposed concept, and those recommendations which are fully accepted, into the Space Station Program plans by the time of the Program Requirements Review in the spring of 1988. This section summarizes the recommended approach for proceeding and involving the essential NASA organizations and international partners in this review and implementation process.

It is important to establish program intent to adopt the concept and recommendations and to formally incorporate them in the program documentation as soon as possible. Top level requirements documents such as the Program Requirements Document (PRD) and the various configuration control documents should be updated. As expected, formal control board actions are implied for many of the decisions. Others require the development of policy and procedural understandings or formal agreements with NASA institutions and field centers as well as with the international partners.

In summary, there are a number of activities requiring joint decisions. Examples include: agreement on specific roles and responsibilities in the planning, management, and execution of operations and utilization for NASA's various organizations and international partner organizations; concomitantly, the identification of long-term institutional and field center resource commitments resulting from Space Station operations and utilization requirements; specification of major operations and utilization capability development requirements requiring joint development effort; identification of manned base and platform hardware and software development requirements implying multiorganizational commitments; and identification-clarification of transportation system and communication, tracking, and data services requirements.

There are many options and approaches which can be taken to completing the details of implementation. For instance, the recently completed Space Station Science Operations Management Concept is generally quite consistent with the SSOTF proposal. It refines, enhances, and in some cases, provides counter proposals to specifics of the SSOTF approach. Clearly, many of the recommendations and aspects of the overall framework itself require commitments by other NASA institutions, their field centers, and the international partners. Clarifying and reconciling the implied internal NASA and international partner roles and responsibilities is the next step in implementation.

Operations participation and planning are occurring earlier and more intensively in the Space Station Program than in any other manned spaceflight program. It is vital that the foundation and momentum built by the SSOTF be carried forward. The next steps outlined do just that.

2.3.1 Establish Strategic Level Steering Committees

It is proposed that the Program should form two Level I steering committees to initiate and expedite the review and implementation process. One, composed of Codes S, M, and T and the other, of Codes S, R, E, and C. Through these committees representatives from each Code can meet to establish the best approach for coming to closure on the items of mutual interest and to identify or establish formal implementation mechanisms. And, though formal interface panels such as the International Operations Concepts Working Group already exist, the international partners may participate as appropriate in any of these new steering committee efforts to improve their own understanding of NASA's approach to implementing the operations concept.

The intention is that most of the review, and then implementation, activities will be handled by existing line organizations, short-life task efforts, and by mutually accepted-established focused working groups. Thus, the two high-level Steering Committees will act as initial clearinghouses for a number of operations concept implementation activities. The committees will meet as required to assure that issues of common interest are being promptly dealt with and that information on overall progress toward implementation is synthesized for top management in the participant organizations. The steering committee's major contribution will be that of integrating and expediting the implementation effort. These tasks should be completed by the Space Station PRR.

The proposed Steering Committee objective is to implement the Operations Task Force concept and recommendations. The committee approach would provide a structured review of SSOTF Framework and recommendations, would identify and clarify issues, would assign to existing program or institutional organizations for action and closure, would recommend program or institutional mechanisms for implementation and execution and would dissolve by PRR.

Its products would specifically focus on preparing agreements (Memoranda of Understanding?) among Codes to clarify implementing roles and responsibilities such as

-Clarify specific implementation and execution roles and responsibilities

-Commission policy studies

-Identify Space Station requirements affecting other Codes and/or their respective Field Centers

Facilities
Procedures
Manpower

-Identify management mechanisms for implementation

Control Boards
Integration panels
Documentation

-Prepare status reports to AA's on implementation progress

Its interfaces with other organizations would be accomplished through working groups, which will interface as required to come to closure on issues of common interest. Only major policy items and unreconcilable issues will be brought back to the Committee for taking to higher management.

The Steering Committees initiated products would be scheduled to meet the PRR deadline for identifying and committing to a concept for operations.

Recommendation:

Two primary steering committees are proposed.

Code S/M/T

To provide top-level, NASA-wide focus and closure on operations concept implementation requirements. This Committee will focus on requirements necessary to provide the complete package of resources to operate and utilize the Station manned base and platforms. The resources include the Station facilities; the transportation to and from space; the communications, tracking, and data services; and the crew. The Committee will include international partners in this process of clarifying operations roles and responsibilities and of defining integrating operations-utilization management mechanisms.

The following working groups are suggested.

-Overall Planning Process Integration
    -Integrated Manifesting
    -Prelaunch-Postlanding Support
    -Space Systems housekeeping

    - resource management
    - -Integrated space transportation services requirements
- -User Integration Support
- -Communication, Tracking, and data services support
- -Systems operations procedures integration
- -Integrated training requirements
- -Assembly-verification operations management
- -Operations performance-cost assessment
- -Platform operations planning and integration

Code S/E/R/C

To provide top-level, NASA-wide focus and closure on operations concept implementation requirements. This Committee will focus on requirements necessary to assure end-to-end integration and support for users of the Space Station manned base and platforms. All aspects of utilization will be covered from the perspective of the NASA institutional organizations, the U.S. commercial interests, and the international partners. The Committee will assure that the Science Operations Management Concept and the Space Station Operations Task Force Concept are integrated and that any differences are reconciled.

The following working groups are suggested:

- -User Planning Process integration
    - -Integrated manifesting
    - -Comm,Track and Data Services
    - -Manned Base resource management
- -User operations procedures integration
- -User facility support (e.g. DOC's)
- -Payload training rqmts

Committee Review Process

The two committees should establish the following review responsibilities:

First choice--existing line orgs
Second--short-life task efforts
Third--focused working groups

The review should be coordinated and reviewed at appropriate organizational levels and if acceptable to involved parties, implementation may proceed without further Steering Committee review. The effort should bring only unreconcilable differences to next level of management. Finally, any actions requiring AA attention may be communicated through the Steering Committees or normal organizational channels.

Code S Level I/II will regularly brief the Steering Committee on the progress of concept implementation, to include:

-Review all points implying resource commitment and schedule by non-Code S parties,

-Identify issues and requirements for Steering Committee assignment to WGs et al, and

-Code S will presume acceptance of all requirements which affect and direct Code S-only resources.

2.3.2 Conduct Review of SSOTF Concept

The Program should resolve remaining OTF functional relationships including:

-POIC relationship to SSSC which requires a more rigorous cost-effectiveness study

-Centralized vs. distributed Sustaining engineering which requires developing a case-by-case transition plan

-SS crew selection vs STS crew selection process which requires international involvement and should consider arguments presented by Dr. J.L. Hunsucker to the Task Force.[2]

-Centralized vs. distributed training concepts especially those related to multi-year ops costs and "user-friendliness" considerations

2.3.3 Consider SSOTF Proposal in Context of a NASA-wide Operations Concept

In any NASA-wide effort to organize for long-term operations the Agency should not attempt to identify the key organizational roles before completing an end-to-end functional analysis of operations, especially operations as they relate to utilization of scarce NASA resources...STS, manned base, Communications-Tracking, data and information resource management.

The effort should pay particular attention to the long-range goals established for the Agency as an R&D organization, that is, what NASA is all about

- -conducting space research
- -providing access to space
- -providing facilities to use space
- -all related to the understanding and uses of space.

Any NASA-wide effort to establish such a long-term approach to operations should:

- -Begin a more deliberate NASA-wide functional review of operations--all operations, manned and unmanned
- -(Potentially) Establish a separate organization in Code M, S, or T to conduct the functional study. The organization should have:
  - -permanent positions
  - -support contractor
  - -Advisory panel experienced with long-term operations
  - -formal interfaces with joint Steering Committees described below which are supporting Space Station efforts in the interim
- -Use SSOTF approach as a model for the process. Use the SSOTF evaluation criteria (use, performance, and cost criteria) for selecting an ultimately recommended approach to all operations, i.e. focus on the uses of the NASA capabilities and on the long-term user support provided by operations.
- -Examine all significant operations policies as part of the effort. Suggest consistent approaches to NASA-wide issues such as "pricing", and operations cost "recovery"
- -Endorse the SSOTF proposal as a starting point for Code M-S-T and the Code E-R-C use-oriented implementation during the interim and, at least, until Shuttle recovery.

2.3.4 Develop Program Plans

Two levels of program planning are recommended. At the Strategic Level (I), Operations-Utilization Program Plans should include, at a minimum:

- -Periodic Level I review of Program Operations Requirements. This requires developing PRD update criteria and triggering mechanisms.
- -Level I review of Program's Annual Operations Budget including the Ops Capability Devel and Ops lines.
- -Prepare Operations Automation and Robotics Advocacy Plan
- -Prepare Assembly Planning and Execution Oversight Plan
- -Prepare Operations Performance-Cost-Risk Appraisal Plan
  - Track key cost drivers
  - Develop performance indicators
  - Develop program-wide risk assessment process
  - Conduct studies

-Prepare Integrated Logistics Advocacy Plan

-Prepare Information Resource Management Plan
  - C&T Requirements
  - Identify Key operations databases
    - Establish Program-level guidance for responsibility, use, and maintenance

-Prepare Operations Cost Management Plan

-Develop approach for Strategic International Operations Planning
  - Implement SSOTF recommendations
  - Draft System Operations Panel Charter

-Prepare Annual Construction of Facilities Plan

-Support for any OMB-Congressional special interest items

At the Tactical Level (II), the Utilization/Operations Program Plans should include, at a minimum:

-Annual Operations Plan reflecting:

* major on-orbit payload activity

* a summary manifest by launch vehicle for:

  - System operations support
  - User operations support

* a summary of resources required to conduct operations:

  - by the Program
  - from each non-program controlled NASA institution

* a summary of key performance-cost-risk indicators

  - to support decisions on future development priorities
  - to guide and justify non-program-controlled operations support
  - to support program position on future payload selection and operations support guidance

* is submitted to Level I for CONCURRENCE

-Annual Operations Capability Enhancements Plan to include:

  - proposed enhancements to all on-orbit and ground support systems
  - those which will change the relationship among currently projected performance, operations costs, and risks
  - those which have a special focus on automation and robotics
    - for Phase I systems development
    - for Phase II systems development
    - shall be performance and LCC-based
    - shall include onorbit systems and ground-based support systems
  - a special focus on integrated logistics management
  - is submitted to Level I for CONCURRENCE in a format compatible for inclusion in the Consolidated O-U Plan

-Operations Cost Management Plan. The Plan will be prepared as part of the annual budget cycle and will provide:

a description of the program's integrated approach for operations cost management,

a summary of planned and achieved operations cost benchmarks including an estimate of the annual operations costs expected for the next five (ten?) years and will provide details as follows: is presented by major operations functional area; identifies common costs to be shared with the international partners; provides estimates of cost reimbursements expected from users; provides estimates of costs borne by other NASA offices based on projected operations; presents estimated values during the development phase, presents estimated vs actual values during the operations phase, and

a summary of major LCC cost decisions that occurred in the past year and a summary of operations-utilization support enhancements to be included in the next budget cycle.

-Information Resources Management Plan which includes:

identification of key program information sources,

accountability and responsibility for the program controlled information and databases that are essential for operations and that indicate the assignment with end-to-end functional flows and management control points,

provision of a process and schedule for transferring or adapting program-developed engineering databases to the organizations responsible for operations support,

identification of all non-program-controlled databases, that is, those requiring program level agreements for access and long-term support, and

plans for the "knowledge-capture" essential to development of expert systems.

is submitted to Level I not later than Program Requirements Review and shall be updated annually as required.

-Annual Program Budget. This will include:

clear statement of the Development budget that

identifies all WBS items required for Operations Capability Development

identifies the Operations budget

includes all WBS items (to WBS level-___) required to actually prepare for and conduct operations

provides estimates of non-program controlled resources implied by the annual operations plan

defines procedures and decision authority for moving funds between the Development and Operations Budget lines

specifies all Construction of Facility requirements

is submitted to Level I for APPROVAL

2.3.5 Prepare PRD/PDRD Requirements

Through the Program Requirements Document (PRD) the Program shall formalize the method for assuring that ops-util requirements are considered in systems development. This especially includes strengthening the logistics-supportability considerations and requires strengthening the ops-util data systems function including incorporating a systematic effort to educate all program participants and potential users about the SSIS-TMIS-DMS-SSE requirements dictated by the program.

Recommendation:

The Program shall design and develop on-orbit and ground operations systems that include the following characteristics:

-Provide an end-to-end concept of data and information management systems, the operation of which is, to the degree feasible, transparent to the users and system operators; which provides for continuous contact with ground-based users; and which permits the use of commercially available telecommunications services,

-Allow for the maximum cost-effective use of on-board and ground support resources by Station users,

-Clearly identify costs to be borne by users as a result of program decisions, and,

-Clearly identify "scars" and potential development plans for incorporating advanced technologies.

Recommendation:

Throughout the development phase the Program shall assure proper consideration of acquisition logistics which includes supportability.

Supportability has the following characteristics:

-is Acquisition related, that is, it affects module and primary subsystem hardware-software design from the outset and lays requirements on the DMS-SSIS-TMIS interfaces and capabilities.

-is a systems engineering assignment since it relates module and subsystems independent design efforts to one another, and it includes hardware and software design and logistics support planning for criteria related to reliability, maintainability, serviceability, and operability, including the consumption of ground-based resources.

-is the primary system engineering effort which drives the design of operations support systems for space system operations, user support operations, prelaunch-postlanding operations, and integrated logistics support.

-has a life-cycle cost basis, i.e. is concerned with cost-effective operations over the long term. Specifically, supportability criteria and measures of success should be traded against life-cycle costs. Criteria include resource consumption and operations cost for non-user related activities and services, operational costs for support services provided to the user, and operational costs for optional services which the user must buy or provide for himself.

The Supportability goals include:

-establishing performance/cost measures which will be considered by the SSCB for design decisions

-granting few waivers from the general requirement for commonality for like systems

-implementing supportability concepts in the flight hardware system engineering and the operations capability development organizations. Formal life-cycle based Logistics Support Analyses should be conducted for all hardware components and ground support systems. Hardware and procedural commonality should be a design criteria waived only through a formal control board action. As part of the effort designers should consider commonality vs proprietary (or independent) capability development (applies to internationals and U.S. WPs) and study impact on U.S. users

Design phase products as a result of concern for supportability include:

-Subsystem and space station module engineering configuration-management databases which transition to the Operations phase

-Engineering test beds should be developed considering that they may be used in the operations phase

-Assembly, verification, and long-term sustaining engineering support systems which include:

subsystem diagnostics software

common test equipment

common EVA and IVA tools and workbenches

common approaches to diagnostics

common approaches to crisis management procedures

common approaches to crew training for preventative maintenance

integrated CAD-CAM-CAI support software and database management systems

-A standardized, integrated parts inventory cataloging and management process

-Common interfaces and support equipment to assure "user friendliness"

-Cost-effective, Space Station-provided interface "black-boxes", including:

Generic hardware

Generic software

Communication, tracking and other data interface support systems

User "training and education" support systems

-Long lead spares--major subsystem components and unique ORUs

Recommendation:

During the operations phases the operations organization will be responsible for integrated logistics. Integrated Logistics Support has the following characteristics:

-Is operations phase related, that is, it is the operations analog to Supportability during the design phase and it affects and potentially interfaces with all operational support procedures and systems.

-Requires a system engineering effort during the operations phase.

-Is the basis for long-term life-cycle support of system and subsystem operation. As such, it

provides for and controls key databases related to system configuration and support including the engineering drawings for modules, systems, subsystems, and components, specifically for hardware and for software including system embedded software and that required for operations support, such as ground systems and orbital and other airborne systems and complete parts and suppliers lists

provides for overall requirements analysis, coordination, database-related support and conduct (but does not actually do work) of sustaining engineering for the entire station infrastructure as a resource consumer.

-As an integrating function those responsible for logistics support will identify areas for coordinated improvements. Each partner will actually conduct his own work related to systems engineering. The integrated logistics effort provides for coordinated depot maintenance capabilities.

coordinates (but does not do) all ground and orbital crew training requirements and capabilities. The integrated effort provides criteria and support systems for servicing and maintenance training, as well as coordinating and assuring maintenance of all training support databases and test beds, such as databases, documentation, and training aids and facilities.

integrates all manifesting and logistics support requirements as part of the integrated manifesting process including, US and Partner's station "housekeeping" requirements and users.

coordinates and executes the tactical and execution related manifesting processes

obtains all station-related support services especially

transportation services to and from space via the NSTS and ELVs

point-to-point ground transportation not related to very localized operations support

communications and tracking services for all partners

data and information handling and management for systems support and to key data system entry points for users.

maintains the centralized parts inventory and supply support system and reorders spare parts through an integrated procurement activity.

Recommendation:

The Program should assure that the common content section of the Phase C-D contracts is technically and logically consistent for the Program Support Contract, the C-D Hardware procurements, and the Non-prime support systems development contracts.

Recommendation:

The Program should provide contract and programmatic incentive concepts that are: vertically integrated within each system development effort, horizontally integrated across subsystems, modules, partners, operational procedures, and so on; a major driver in evolutionary thinking; and are a catalyst for automation and robotics evolutionary concepts.

Recommendation:

Since system design synergy may exist between the Manned base and platform where common payloads are possible, the Program should examine the benefits of ORU commonality between the Co-orbiting platform and the Manned base.

Recommendation:

Since there may be opportunities for utilization and operational synergy among payload delivery systems and among the payload developers, the Program should strive for standard interfaces, common utility connections, packaging, and handling procedures among the systems and should establish a formal systems design interface with the transportation development organizations, e.g. STS, ELVs, OMV, etc.

Recommendation:

The Program should require the Work Package contractors to submit a plan under which the Program could negotiate the purchase of a second copy of any element, subsystem, or long-lead component. The original RFPs made no provision for consideration of buying second or more copies of major components. The major concern is with the potential loss of key station components at certain points during the assembly phase. Such a loss could jeopardize completion of the manned base resulting in total loss of the station and termination of the entire program. Such a loss at that point would involve a major national investment having far greater financial cost than any program NASA will have had to date. Additionally, the continued planning for growth and evolution may indicate a need for additional elements and/or subsystems at a point while the prime contracts are still involved.

Thus, the program should require that the Phase C-D contractors propose contract language and negotiating strategies which will allow NASA to order second or more copies of major elements, subsystems, and long-lead components with an objective being to establish the optimal points during the contract for ordering the components given certain program risk and planning assumptions. The language should reflect key milestones that, if exceeded, the negotiated cost might significantly increase.

Recommendation:

Users will typically require a variety of general support equipment on-orbit. Included is test equipment, maintenance tools, work benches, and similar paraphernalia. The Space Station program must identify these requirements and establish which are of general use and should be provided as commonly available to any user. It must also establish whether the Program provides such equipment as a service or the user sponsors provides it as an optional service to its own community.

2.3.6 Prepare Implementation Schedule and Program Resource Requirements

Implementation activities should consider the following schedule in order to have the desired impact as the Program accelerates its efforts to implement the Operations Concept.

Recommendation:

Assign key utilization-operations functional area responsibilities--not later than PRR. At a minimum:

-Update Level I Operations Management Concept--late Nov 87

-Agree on functional area definitions--mid December 87

- Agree on Code and Partner roles and responsibilities--PRR

- Establish management interfaces and configuration control mechanisms--PRR

Recommendation:

Identify major operations and utilization capability development requirements including:

-Primary CoF facility def--PRR
-Support systems--PRR
-Operations procedures def--TBD

Recommendation:

Identify-clarify Space Station manned base and platform hardware requirements driven by utilization/operations requirements.

-Update PRD

-Update PDRD, develop CRs to impact by PRR

-Establish SS control board membership

Recommendation:

Identify-clarify space transportation and communications/tracking/data systems hardware development requirements

- Develop and coordinate joint CRs by PRR
- Establish SS control board membership requirements
- Specifics of requirements must meet key CoF deadlines
- Prepare and transmit requirements to appropriate NASA offices

Recommendation:

Identify long-term NASA institutional and international resource requirements as soon as practical being certain to specify those requiring formal joint or multilateral agreements to commit the non-Program controlled resources.

ENDNOTES

1. See Technical and Analytical Services in Support of a Space Station Operations Scenarios and Test Case Development Strategy, The Center for Space Policy, Inc., Presented to Space Station Operations Task Force, January 29 and February 18, 1987 (2 volumes).

2. "Side by Side Comparison: R&D to Ops.", Presentation by J.L. Hunsucker to SSOTF, October 17, 1986.

3.0 ALTERNATIVES DEVELOPMENT AND INTEGRATION PROCESS

One of the primary areas of Panel activity was the development of a process for generating and evaluating alternatives that could be used by the other Panels. As noted in Chapter 1, this process was used in varying degrees by the panels, but no panel, including this panel, adopted it throughout. This was partly due to timing--this process was not fully developed early enough for complete use by the other Panels. Also, this approach is somewhat foreign to NASA; thus it required extra effort to introduce and adopt it. The major goal of this chapter is therefore to bridge this "culture gap"--to explain why an alternatives evaluation approach is useful and to put forth the elements of such an approach.

3.1 PURPOSES IN EVALUATING ALTERNATIVES by Doug Lee

In determining a course of action, whether it results in tangible assets such as a space station, or in a policy for making best use of that station, it is necessary to consider and evaluate alternatives. Decisions, or choices, can be grouped into topical categories referred to as option areas. The decisions can also be sorted as to the level in the program organization at which the decisions should be made, and those reported here are primarily for the strategic level, i.e. the level concerned primarily with establishing and coordinating policy and objectives.

Several reasons can be offered as to why it is important to develop a range of alternatives in each option area, and evaluate them systematically.

Documentation of Recommendations

Even if the correct solution is well known and generally agreed upon, describing the alternatives and providing the rationale for choosing the preferred alternative has many benefits. Reasons can be subsequently reviewed and revised if conditions have changed, and justification is strengthened for the course of action recommended.

Responsiveness to Constraints

Resources are never adequate to accomplish all that would be desired, and fallback options must be considered even though it may be distasteful to shrink program expectations. Maintaining a range of options can also facilitate the expansion of scope when such opportunities occur.

The topics addressed in this report concern issues that do not have a unique resolution at this point in time. As discussion continues between NASA and Congress about the requirements and constraints that the Program will work under, it is desirable to have anticipated as many contingencies as possible and to be able to offer focused and timely responses.

Improve Odds on Making the Best Choices

An explicit process for identifying areas where choices need to be made, and generating alternatives in each area, enhances the likelihood of making good decisions. Ideas are stimulated, and the basis for choice is forced out in the open so that objective bases can be separated from preconceived preferences.

3.2 OPTION AREAS by Doug Lee

The Task Force (SSOTF) considered over twenty different subject areas where choices regarding Station operations needed to be made. The Management Integration Panel cast its net somewhat more broadly than the Task Force as a whole, including any issue whose resolution might have a significant impact on Station operating procedures, costs, or performance. Attention is directed especially at continuing management and policy issues, as most of the operations issues have been covered in the SSOTF Summary Report and the other panel reports.

Strategic versus Tactical

The option areas can be described with respect to several characteristics. The exact line between tactical and strategic is hard to define precisely, and most important issues have components of both. Nonetheless, it is useful to consider the best level in the Program organization at which decisions should be handled. Options that warrant attention at the strategic level are those that affect many operations functions at the strategic and tactical levels.

Internal versus External

Another characteristic of each option area is the extent to which it is an internal matter to the Program, or to NASA, or a matter involving external decisions by Congress and the Administration. This dimension parallels the tactical-strategic dimension, operations decisions being the most internal, management questions in the middle, and policy issues the most dependent upon factors external to the agency.

The option areas discussed in this report are listed in summary form in the next column. They can be grouped into three areas: one, concerned with how the Station will be operated (Section 3.5); two, regarding public policy issues that impact on the Program (Chapter 4); and three, directed at strategic management questions (Chapter 5); . Each of these option areas is covered in greater depth in the remainder of this report.

Within each of the option areas, a range of alternatives can be designed that serve approximately the same ends, meaning that the alternatives are mutually exclusive. Once one is selected, the others are dropped. All of the option areas are described below, whether or not an explicit choice has already been made. In essentially every option area, major choices remain for review and evaluation.

OPTION AREAS

Major Operations Alternatives (Section 3.5):

User Autonomy
Station Autonomy
Risk Acceptance
Payload Verification
Operations Automation
Functional Allocation
Evolution
Supportability
Transportation
International Partnership
Program Operations
Station Utilization Themes

Strategic Policy Issues (Chapter 4):

International Cooperation in Space Transportation
Civilian Control
Manned Spaceflight Program Directions
Resource Allocation and Subsidy Policy
Initial User Mix
Commercialization of Space Services
Commercial Markets and Spinoffs

Strategic Management Questions (Chapter 5):

Operations Management Structure
Performance Assessment Process
Operations Cost Management
Modelling Space Station Costs
Risk Management/Safety
Financial Management
Information Management
Hardware & Software Systems Design Issues
Automation and Robotics
Evolution
International Operations and Cost Sharing

3.3 SPACE STATION GOALS AND OBJECTIVES by Doug Lee[1]

Because the space station is a public sector initiative, it is necessary to be explicit about the goals and objectives the station is expected to serve. Goals may be political, as expressed by Congress, the President, or others, or goals may be derived from objective standards of reference. All that is expressed by a goal statement is that something is desirable; there is no inference that all goals will be served, or served equally, or that some goals are more important than others.

Clearly there are tradeoffs among goals in their accomplishment, especially when some of the goals concern the reduction or control of costs. Most goals overlap to some degree, in that they are part of the same overall goal (space research and development). The goals listed below, however, are also partly independent, in that each goal requires some additional effort -- holding the achievement of all other goals constant -- in order to obtain more progress toward that particular goal.

The following is an attempt to first define a set of groupings for Space Station goals, and then to classify Space Station Program into these groups. The groups are as follows:

- -leadership in space
- -permanent manned element
- -international cooperation
- -national research and development
- -access to space
- -return on investment
- -facilitate commercial applications
- -strong management structure

Each of these groups contain many subgoals as shown in Table 3-1.

In addition to these goals, Table 3-2 presents a set of goals that embody a particular programmatic implementation.

3.4 EVALUATION OF ALTERNATIVES

by Richard O'Toole

Before getting into the details of an evaluation process, it is worth discussing those attributes of the Space Station which make operations considerations so important to the program and to NASA as an organization.

(1) The space station is the largest NASA program in the foreseeable future and will provide benefits and incur significant costs over a long duration.

(2) The station's success will be judged on the efficiency and effectiveness of the services it provides.

(3) The operations environment will include multiple partners, varied user classes and multiple services.

(4) The station will be in an almost constant state of evolution and growth over its lifetime.

(5) There is a considerable amount of uncertainty concerning both user and system demands for services.

(6) The cost of operating the space station over its lifetime, including transportation and communications, will be at least as large as the development costs.

Given the above considerations, it is difficult to design an efficient and effective operations system at this stage of the Program. As a generic strategy, the most promising approach is to recognize the inherent uncertainties, iteratively improve upon the baseline concept as additional information is obtained, and make the system flexible enough to permit changes at relatively low cost.

The evaluation process outlined in this section is consistent with this generic approach in that it is designed to incorporate the concepts of recognition of uncertainty, improvement over time with new information, and flexibility. Evaluation consists of choosing among alternatives according to a valuation of their impacts. Impacts are always described relative to something (e.g., a base alternative), so evaluation is necessarily relative, requiring at least two alternatives for comparison.

As the Space Station Program examines new operations issues during the development period, it will need to evaluate operations options on a continuous basis. New option

TABLE 3-1
SPACE STATION GOALS

Leadership in Space

Support Free World leadership in space science with demonstrated accomplishments, and stimulate advanced technology across a broad spectrum.

-Meet scientific, technological, and commercial objectives set by partners.

-Contribute to US pride and prestige.

-Catch up with the USSR.

-Strengthen National security.

-Establish US leadership in space in 1990s and beyond.

-Maximize scientific accomplishments.

-Construct a viable station without crowding out other scientific activities such as unmanned space exploration.

-Promote automation and robotics technologies (e.g., Flight Telerobotic System)

-Stimulate interest in science and engineering education.

-Extend human presence and enterprise beyond earth into the solar system.

-Advance scientific knowledge of the planet Earth, the solar system, and the universe beyond.

Permanent Manned Element

Establish a permanently manned space element, by 1994.

-Incorporate a man-tended concept in the baseline program.

-Blend manned and unmanned systems and capabilities.

-Include all of the following elements:

Manned base.
Co-orbiting platforms.
Polar orbiting platforms.
Orbiting maneuvering vehicle
Telerobotic servicer.
Attached external payloads.

-Provide a base for future growth and development.

Plan and design for evolution.

Continue exploring, prospecting, and settling the solar system.

International Cooperation

Promote international cooperation in space research and technology.

-Create effective international partnership.

Give US/NASA authority and responsibility for managing the station.

-Provide benefits to partners commensurate with their share of costs, and share costs equitably among partners.

-Allow sufficient independence among partners that they can develop their own space resources and capabilities.

Canada: Mobile Servicing Center (MSC).

Japan: Japanese Experiment Module (JEM).

ESA: Four "Columbus" elements (laboratory module, resource node, co-orbiting platform, polar platform); permit ESA to conduct work in microgravity, telecommunications, and meteorology.

-Involve partners at all management levels.

-Minimize cash transfers among partners.

National Research and Development

Promote domestic cooperation and development in peaceful uses of space.

-Incorporate participation by several US space centers.

-Utilize the shuttle (STS) for transportation.

-Optimize productivity of public-private partnerships, including the NASA-industry partnership.

-Establish international (e.g., metric) standards for compatibility.

-Establish relationships with the DoD that minimize impacts on other potential space station users.

-Maintain a (primarily or purely) civilian space program.

-Control transfer of technology so as to benefit favored nations and restrict transfer to unfavored nations.

-Strengthen aeronautics R&D technology.

Access to Space

Make routine utilization of the space environment, provide low-cost access to space, and support evolving user activities in user-friendly fashion.

-Establish stable evolutionary operations in space.

-Design and operate space station to serve users.

-Exploit unique capabilities of the station and the space environment.

-Devise an optimum man-machine mix.
-Enhance (capabilities for) space science and applications.

-Serve all or some of the following purposes:

Permanent observatory/laboratory in space.

Manufacturing facility.

Servicing facility.

Transportation node.

Assembly facility/staging base/storage depot.

-Reduce/constrain costs of space operation.

-Provide low-cost access to the space frontier, by minimizing the sum of user plus station costs, and by offering useful services at reasonable price to user.

-Develop more than one source of transportation for getting payloads and logistics support to and from the Station.

-Reduce the complexity of space operation.

-Anticipate and minimize safety hazards.

-Incorporate human engineering factors in system design.

-Design for long run (life cycle) costs, by considering initial engineering and construction, operation, and costs imposed on interdependent systems, and by building in maintainability and supportability.

-Create commonality and modularity to facilitate ease of repair and replacement.

-Maximize use of computers for information handling (documentation, paperwork) rather than manual records.

-Assign responsibilities for full cost accountability.

-Ensure that users perceive the costs of the resources they utilize, and respond accordingly to economize on them.

-Eliminate excess or reducible costs in decision processes and engineering design processes, as well as in production and operations phases.

-Provide a user-friendly work-research environment.

-Permit flexible arrangements between space station and users.

-Provide a single point of contact for every user.

-Minimize special knowledge required to use the station.

-Maximize information exchange about users and payloads, while operating and on the ground.

-Permit remote control operation (telescience) from ground.

-Maximize user flexibility within a defined envelope.

-Allocate resources through incentives rather than command and control processes.

-Coordinate logistics to minimize cost and disruption.

-Provide data and communications systems to facilitate user control and information access.

-Permit both proprietary (secure) and scientific usage.

-Permit or stimulate a mix of uses:

Space Manufacturing

Weather observation

Earth observation.

Space Research

Materials science

Life science

Chemical processes in microgravity environment

National defense

Astronomy

Physics

-Incorporate a balanced range of users:

Government
University
Commercial
Non-profit
Military

Return on Investment

Maximize return on investment, and recover some share of costs from beneficiaries, and minimize cost of risk.

-Require that usage whose benefits are internal to the user pay its full costs.

-Distribute subsidies to users, sectors, disciplines, etc., so that National goals in science, technology, and commerce are enhanced.

-Evaluate government agencies (e.g., DOD) in the same way as other users.

-Obtain the best return on public investment in the Station.

Table 3-1 (cont.)

-Derive the best return on private investment in user facilities and equipment.

-Provide for safety (especially crew safety) through criticality assessment, redundancy, reliability, and quality assurance.

-Maintain the security and integrity of the station through redundancy, spares, interchangeability, etc.

-Plan resource allocation with margins for reserve.

Facilitate Commercial Applications

Create profit incentives for commercial use of space, and facilitate the transition from research to commercial application.

-Stimulate space enterprises.

-Encourage private sector investment and participation in space.

-Construct negotiated agreements between NASA and users.

-Promote privatization/commercialization of space.

Expendable boosters (US DOT).

Weather and remote sensing (Dept of Commerce).

-Stimulate development of expendable rockets (ELVs).

-Stimulate private industry spinoffs from space efforts.

Strong Management Structure

Put in place a strong management concept and organization that will ensure that resources are put to their most productive use, that duplication and waste are minimized, and that responsible parties are held accountable for performance.

-Establish with confidence the space station cost, schedule, and performance.

-Produce and operate the station at the least cost that will provide for the intended performance.

-Evaluate program progress and alternative directions so as to achieve the best performance for the resources expended.

-Control program costs and ensure cost accountability.

-Establish an organizational structure with clear lines of authority and functions across and between all management levels.

-Create a science-oriented management structure.

-Establish "normal" mode of operations from which "exceptions" can be focused upon.

-Control information flows and databases for consistency and elimination of duplication.

-Shift control of space station from engineering R&D organization to operations management at the earliest possible opportunity.

-Delegate responsibility to the lowest levels consistent with maintaining management control and accountability.

-Provide clear direction and leadership.

TABLE 3-2
SPACE STATION GOALS THAT EMBODY A PROGRAMMATIC IMPLEMENTATION

-Accommodate user requirements from a broad range of users including science, applications, technology development and commercial payloads.

-Support international participation by accommodating international partners into the space station program as both providers and users of services.

-Enhance U.S. aerospace productivity by developing new technology, which will have applications in non-space industries.

-Support commercial development of space by encouraging commercial experimentation in new technologies and actively seeking opportunities for privatization of selected space station program services.

-Support automation and robotics technology development by searching for applications of these technologies which reduce cost, increase performance, or increase safety.

-Provide for evolution, by designing the station and its operations concept to efficiently adapt to changes in the user community, the quantity of services offered, and productivity enhancing investments.

-Provide for commonality and maintainability by designing the station and the operations concept to take advantage of these desirable properties for low cost operations.

-Optimize human productivity by automating those flight and ground functions that increase performance or reduce the life cycle costs of the program.

-Design to Life-Cycle-Cost by considering all program costs (DDT&E, system operations, and government users) in making trade-offs in services provided, investment costs and operations costs.

areas will be discovered, previous alternatives will get refined, and better information will become available. Thus, emphasis must be placed on developing a consistent and accurate evaluation process for program tradeoff analysis, rather than attempting to make all important choices at the beginning and lock them in for the duration of the Program.

The evaluation process provides a mechanism for guiding the program towards the selection of preferred options for performing operations functions. In the case of the Space Station, however, the desirability of the operations system is inherently tied to the Station design and to user satisfaction, and hence must be concerned with more than just operating responsibilities. The process outlined below was used in the development of the SSOTF operations concept, and is presented in that context, but the general approach to evaluation is recommended for wider application to decisions at all levels in the Space Station Program.

Methods for evaluation approach it from many perspectives, providing both confirming redundancy and deeper understanding. In order for these qualities to emerge, the various components of evaluation must be consistent with each other and mutually supportive. The approaches described below range from the enumeration of goals without prejudging conflicts among them, to narrowly-focused rules that do not explicitly acknowledge goals. In between are criteria, which provide a balance between breadth and practical application.

The evaluation process is illustrated in Figure 3-1, and the key components of this evaluation process are described below in summary form.

Considerations in Developing Alternatives

In constructing a range of alternatives for consideration, several key characteristics can be used to ensure that the range covers the relevant dimensions of variation. Some of these are generic--such as cost and capital investment -- and pertain to all option areas. Some can be derived from the goals of the Space Station Program, such as user friendliness and automation. Yet others are specific to the functions, hardware, and systems pertaining to each particular option area.

Because of the multifaceted nature of Station resources and services offered to users, and the complex interrelationships among them, a strategy for the design of alternatives can be based on tradeoffs between competing objectives. Some of the many dimensions of variations among alternatives are contained in the following list:

Development Cost
Maintenance Labor
Replacement Feasibility and Cost
Power Requirements
Consumables Requirements
Capability for Remote Operation
Crew Skill and Time Requirements
Level of Automation
Isolation/Contamination Requirements
External Communications Support
Level of Management Involvement
Institutional Incentives Generated
Political Acceptability

No single option area is likely to span more than a portion of these dimensions of tradeoffs, but this list or an expanded one can serve as a check on relevant possible alternatives.

Among the option areas and alternatives evaluated, several patterns can be described. In the operations areas, user friendliness, operations control, organizational responsibilities, partner operating procedures, and cost seem to dominate. In the management areas, communications and organizational control receive the focus of attention. In the policy arena, removal of ambiguity and conflicting constraints (especially those forcing costs upward) were objectives in the design of many of the alternatives.

The panels in the OTF were asked to consider a range of options for performing the operations functions assigned to their panel. A consistent set of alternatives was given to each panel to stimulate their

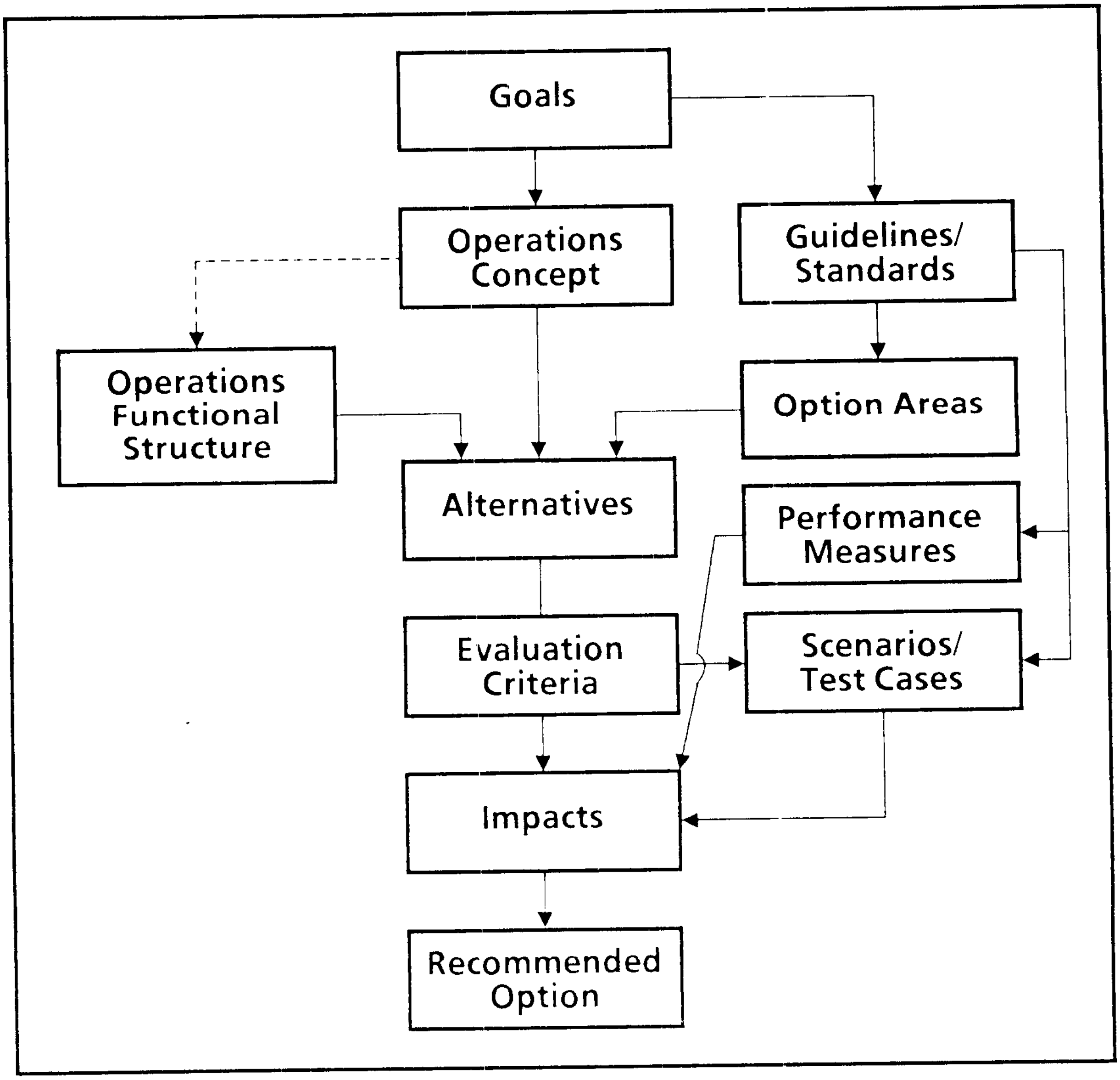

Figure 3-1. Process for Evaluating Alternatives

thinking on developing operations concepts. They in turn were not constrained to limit themselves to these alternatives or to pursue each one unless it looked like a promising approach. The 12 option areas presented by Panel 4 to the other panels are described in Section 3.5.

Functional Analysis

In order to ensure the completeness of the operations concept two types of functional analysis were conducted: (1) top-down functional descriptions and (2) end-to-end functional flow analysis. First, functional descriptions were developed which include all the operations functions in the strategic, tactical and execution levels. The panels then developed their options for performing each function. The alternatives in the previous section were considered where appropriate. As options were developed for each function or group of functions within a panel they were evaluated using the evaluation criteria discussed below. Options were refined in the evaluation process given their interactions with other options within that panel. When the panel recommendations were essentially complete, an end-to-end functional flow analysis was conducted to verify that the functional flows and product flows between all parts of the operations concept were identified. Thus, an operations concept consists of: descriptions of functions, functional relationships, product flows, and roles and responsibilities.

Components of the Evaluation Process[2]

Evaluation results in a description of why the preferred alternative is better. Quantitative measures of impact and evaluation are preferable, but verbal assessments and ranking or scoring methods may serve a supporting or intermediate purpose. An example of the latter approach is to ask two questions:

-What objectives must be fulfilled?

-What properties or conditions will a good solution satisfy?

There are a number of components of the evaluation process, which are described below. The components are listed in the approximate order in which they should be carried out so as to provide the basis for the subsequent step, but all steps can be initiated independently and reconciled and refined subsequently.

(1) Goals. The goals of a program comprise all things that are good and may be affected in a positive or negative way by the program. In a general sense, goals are the dimensions along which the output of the program can be evaluated.

Goals may be ordered, or prioritized, according to importance. They may also be structured into a hierarchy, so that some goals are parts of larger goals. It does not matter much if statements of goals overlap, although the least amount of redundancy is desirable. It is more important that goals be enumerated exhaustively, so that all possible beneficial impacts are covered by at least one goal.

The most significant characteristics absent from goal statements is any assessment of tradeoffs and choices. More output and lower cost are both desirable, for example, but goals provide no information for determining the point at which additional output is not worth the cost.

(2) Objectives. As goals become more specific, and thus necessarily more partial, statements of subgoals can be called objectives. There is no absolute or relative standard for defining where this break occurs, and it does not matter whether there are goals, or objectives, or both. If there are both, objectives refer to the group at the specific end of the scale.

Greater specificity of goals and objectives should suggest measures and indicators that reflect actual versus planned performance, recognizing, however, that measurement does not necessarily improve the evaluation. It can, but other characteristics must be present as well.

(3) Functions and Subfunctions. These are a description of what has to be done to do the task. The description can include activities, products, and connections. This information defines the units and terms for describing alternatives. Analysis of an issue involves determining where the issue fits in the functions structure.

(4) Alternatives. Alternatives are a description of possible ways of performing a function. The number of alternatives should be only as many as are needed to span a plausible range of options. The alternatives should be real choices, meaning that each alternative has some likelihood or could be reasonably recommended; none are extreme or artificial cases. The generation of alternatives leads to two questions:

-Why is the issue unresolved?

-What makes it difficult?

(5) Organization and Location. Description of where things will be located and where or how they will be housed organizationally. This information may be minor or may constitute the content of the alternative. Two aspects of this are:

-What is the process by which decisions will be made?

-What organizational units, teams, etc., are involved?

(6) Performance Measures. Quantitative measures or other indicators of final output, intermediate output (used to produce final output, e.g., housekeeping), and inputs, should be developed for the purpose of observing and assessing performance. Good measures of performance help to locate both strengths and weaknesses.

Measures may be tabulated in absolute units, for comparison over time, or as rates and ratios (e.g., unit costs of output). Some measures may be called "effectiveness" measures. Some examples:

-Actual vs. Scheduled accomplishments

-Resource utilization rates

-Services consumption rates

-Actual versus Planned expenditures

-Productivity and other input-output rates

-Cost per unit of output indicators

For interpretation, performance measures should be both exhaustive and mutually exclusive (non-overlapping), as well as balanced in relative importance at each level of detail.

(7) Impacts. Impacts are a description of what difference it makes whether something is done one way versus another. IMpacts include output, cost, where things are done, who does them, and who bears the cost or other burden. Impacts lead to a focus on three questions:

-What is at stake?

-Why is it important?

-What kind and level of effort should be brought to bear?

(8) Criteria. A criterion is a condition which, when applied to a suitably comprehensive set of performance measures, indicates when a group of tradeoffs is optimum.

The broadest criterion is efficiency, which says that output should be expanded until marginal benefits just equals marginal cost. The resulting output level will maximize net benefits, or total benefits minus total costs, for that type of output. The practical approach for evaluating efficiency is the comparison of incremental costs and benefits.

Another primary criterion is equity, which is applicable to the sharing of costs among partners. There is no algorithm for determining when equity is optimum, but it is possible to reformulate various desirable characteristics of an equitable allocation as constraints, which can be imposed until an acceptable solution is narrowly bounded.

(9) Guidelines. Procedures or methods for achieving good performance or approximating optimal tradeoffs can be described in terms of guidelines. The application of the principles to the specific case is likely to leave considerable room for professional judgment, but the process should tend toward more robust and complete evaluations.

Statements in guideline form imply that at least some tradeoffs have been considered, and some conclusions reached (and have, therefore, progressed beyond the level of goals and objectives), or that the process for doing so can be described in moderately specific terms.

(10) Standards. Guidelines that take the form of specific quantitative constraints are often called standards. The constraint may be exact (e.g., nuts and bolts, docking port) or a threshold (minimum volume per person, maximum weight).

The virtue of a standard is that it does not require a complete reevaluation (data collection and analysis) of optimality for each small and repetitive decision. It is also a mechanism for achieving commonality, i.e., standardization, without requiring that all participants debate and agree upon a common design element. The disadvantage of imposing standards is that possible superior solutions are ruled out in some cases.

(11) Ground Rules. This is an informal term referring to common assumptions, guidelines, objectives, or other suggestions for pursuing the evaluation of alternatives. The purpose of ground rules is to orient a group of individuals to begin efforts in a consistent direction and with a common understanding.

Space Station Evaluation Criteria

The evaluation criteria suggested by the OTF cover the major areas of performance and cost associated with the Space Station Program. They are not shown in priority order since all these criteria are important to a desireable operations concept.

(1) Feasibility/Flexibility: An option is considered "feasible" if it is likely to work as planned in routine types of operations. Thus, to some degree it is a measure of confidence in the understanding of the concept. "Flexibility" refers to the capability of the concept to accommodate a wide variety of operating conditions.

This first criteria is intended as a screening device to determine if the operations concept is workable in the judgement of the evaluators. A high ranking for "feasibility" implies there a high degree of confidence that the concept can perform the needed functions in routine operating conditions. Similarly, "flexibility" of each concept is important because the station will have to respond to a wide range of conditions, and thus, concepts cannot be judged solely on how well they respond to baseline conditions. Given the time pressures of the OTF schedule this criteria was subjectively used to rank the alternatives, but in the longer run more rigorous methods could be adopted.

(2) Cost Effectiveness: An option or concept is cost effective if it produces a given set of benefits or performance at minimum life-cycle-cost (including DDT&E and operations cost).

The cost effectiveness of an operations concept must be judged in the larger context of total program costs which includes any DDT&E or deployment costs, any transportation cost supporting operations, and station systems operations costs. Ultimately, all of these costs are supported by the U.S. taxpayer and thus operations should be done in a manner which minimizes the total life-cycle costs consistent with a given level of performance.

The concept of cost effectiveness is more narrow than the concept of economic efficiency. In cost-effectiveness evaluations, the performance (and thus benefits to the user) is a given; in economic efficiency evaluations, the level of performance sought is that level where total benefits minus minimum cost to achieve that level of benefits is maximized. The cost-effectiveness criterion was more relevant to most of the SSOTF deliberations since the station size and performance levels were taken as given in deciding most issues.

(3) Operations Performance: The term "performance" is used here in the broad sense pertaining to the overall service level of the station. Thus, any concept which increases on-orbit user resource levels or throughput of the ground support system at a given or reduced life-cycle-cost is an improvement in the operations concept.

It is desirable to encourage designs, policies, and practices which consume as little housekeeping resources as is possible, consistent with other goals. Some of these performance improvements may cost more, but the tradeoff is not clear on whether they are beneficial or not without further analysis. Ideally, as the tools become available for detailed analytical evaluation these tradeoffs will be easier to make. In this example the life-cycle-costs of investments in greater housekeeping efficiency must be compared with the incremental cost of increasing the gross size of that resource. The tools necessary to perform this analysis were not available to the OTF necessitating a subjective assessment of performance impacts.

(4) User Accommodation: A concept is considered superior in terms of user accommodation if it provides mechanisms to give the user a combination of greater control over his payload with relative ease of accommodation, integration, and access to information. This criteria is intended to reflect the importance placed on making the user a driving force in designing a space station operations system. Some of the specific measures used in applying this criteria were: number of interface points for users, simplified documentation, ease of accommodation, ease of integration, ease of access to information, and greater user autonomy. In particular, an attempt must be made to have the system be responsive to user needs.

(5) Safety: An option is considered safe if there is a high probability that its associated ground and/or onboard operations functions can be executed without physical impairment or loss of life to equipment, operators or to personnel in proximity to the equipment or operation.

Spaceflight operations and operations support safety assurance must involve both objective and subjective measures. Objectively, hardware (or software) must be built to specific materials, reliability, redundancy and operability standards which are technically specific, measurable, predetermined, and standardized. On the other hand, any system is vulnerable to both inadvertent or covert operator error. Decisions regarding alternative methods of operations should seek out those operational paths or techniques which tend to minimize system vulnerability to such errors. These decisions may often be somewhat subjective and based on empirical experience or statistical data. Additionally, any operation should be able to be conducted within an overall environment that is both physically compatible with the operating systems as well as one that assures competency and friendliness with respect to system operators. Some specific measures in using this criteria are: empirical system and component reliability data, statistical performance data, level of operational redundancy, level of operator exposure, level of operator task familiarity, level of operator motivation, and level of physical systems.

(6) Management Effectiveness: A management structure and process is

"effective" if it facilitates decision making at the lowest practical levels which promotes cost effectiveness, increased performance, safety and leads to greater user satisfaction.

Management effectiveness is one indirect means to achieve the other goals of the program. It is kept as a distinct criteria in the evaluation process because it is not possible to anticipate all the uncertainties and consequent decisions which will have to be made to make this program fully successful over its lifetime. A well designed process for management of operations will be able to deal with whatever problems arise in the future. Key ingredients to effective management are availability of necessary information and incentives for all participants to be making decisions consistent with the program goals. Some of the specific measures which are useful in this evaluation are: decision making pushed to the appropriate levels, commensurate responsibility and accountability, elimination of unnecessary decision steps or interface requirements, built in incentives for decision makers at all levels of management to behave consistently with program goals, a well designed management information system, clear lines of authority, an effective cost management system, and an efficient resource allocation and utilization system.

Scenarios and Test Cases

Although the time pressures on the OTF precluded fully implementing this phase of the evaluation process it is worth documenting for further operations concept analysis.[3] A set of scenario guidelines and test cases for the operations concept were developed to both illustrate the way the recommended concept would work under routine conditions and also a number of test cases to examine the ability of the concept to handle extreme situations. To this end, six general end-to-end scenario descriptions were defined to emphasize user accommodation, political, international and DOD related components, as well as other traditional operations issues.

The scenario subjects recommended by the OTF are shown below with a brief description of the issue to be examined:

-Operations Planning Scenario: Describes the process of formulating a general operations plan for the mature operations phase of Station activities, covering strategic, tactical and execute levels of the management process.

-User Integration Scenario: Traces the end-to-end operational interfaces between a specific user and the Program beginning with the user's preliminary involvement in the Program, and continuing through the stages of requirements acquisition, manifesting of his payload, integration of his requirements, inflight execution of his payload operations, and any required post flight support.

-Station Manifest Assessment Scenario: Describes the end-to-end operations assessment process that would be required prior to committing a specific complement of user payloads to a specific operation interval onboard the Station.

-Sustaining Engineering Scenario: Describes the end-to-end process required to be in place as the Station and platform elements/systems become operational to assure that their operations support performance is maintained at the highest level.

-Flight Crew Integration Scenario: Describes the process for integrating a specific flight crew into the end-to-end mission preparation process.

-Operations Transition Scenario: Applies the various mature Station and platforms operations concepts to the precursory assembly and operations verification program phases for the purpose of performing a relevancy check.

In addition, six operations concept test case situations were developed, each emphasizing different key attributes of Station operations and designed to evaluate specific operations situations. These test cases include:

-Assembly Operations: An off-nominal operations situation which occurs during or in support of one of the manned base assembly flights; one which has the potential for significant impact to operations plans and schedules at the strategic, tactical and execute levels.

-Mature Operations: Using a given complement of Technology Development and Commercial payloads, describe how the various SSP operations support functions respond to real-time or execute level perturbations to strategic and tactical level planning processes.

-Co-Orbiting Platform Operations: Using a given set of requirements for platform maintenance and servicing at the Station as well as a sequence of off-nominal events, describe how the ground and onboard operations associated with platform support are performed.

-Polar Platform Operations: Using a given set of requirements for platform maintenance and servicing by the NSTS as well as a sequence of off-nominal events, describe how the ground and onboard operations associated with platform support are performed.

-Evolutionary Operations: Given a set of potential growth options and program goals as well as a hypothetical set of "lessons learned" from early Station operations, prioritize and schedule their implementation in a manner that allows for safe, reliable and cost-effective evolution of operations capabilities.

-Operations Impact of a Major Program Contingency: Given an operational Station and an unanticipated SSP program contingency which significantly impacts strategic and tactical planning for at least one year, describe the ground and onboard operations likely to be most affected and determine a workaround strategy which preserves as much operational capability as possible.

These scenarios and test cases would have been very useful in conducting the feasibility and flexibility evaluations if time and resources had permitted such an analysis. Between now and the time operations begin, however, there will be numerous opportunities for operations studies where these scenarios and test cases will prove useful.

The evaluation process described above was not applied in its entirety by the SSOTF because of time and resource constraints. It is included in this document as a way to preserve any ideas which might prove useful in the future. The essence of the methodology is that a wide range of alternatives must be evaluated in a consistent fashion.

3.5 SUMMARY OF MAJOR OPERATIONS ALTERNATIVES by Doug Lee, Rich O'Toole, Gran Paules, and Bill Pegram[4]

In January of 1987, the Management Integration Panel presented 12 option areas, listed below, to the other panels of the SSOTF to provide a catalyst for their work:

-User Autonomy
-Station Autonomy
-Risk Acceptance
-Payload Verification
-Operations Automation
-Functional Allocation
-Evolution
-Supportability
-Transportation
-International Partnership
-Program Operations
-Station Utilization Themes

This section describes why the Panel selected each of these option areas for presentation to the other panels and what it saw as the continuum of alternatives in each area. The discussion below represents the first steps of an evaluation such as would be produced by application of the methodology described in Section 3.4. Option areas are selected, the importance of each option area is analyzed, and alternatives are generated. However, subsequent steps are not described--selection of evaluation criteria, description of impacts of alternatives, recommendations, unresolved issues and recommendations for next steps, and so forth.

In addition to the descriptions below, user accommodation, cost reduction, and safety enhancement were major drivers in generation of alternatives. In user accommodation, a range of alternatives were considered to give the user greater control of payload operations, including: delegated resource allocation, distributed payload operations, single point servicing, user responsibility in payload verification, and user autonomy. Cost reduction alternatives included standard versus integrated processing, commonality, consolidated support operations, supportability, and operations automation. Safety enhancement included centralized versus distributed system management, integrated versus element crew concepts, and U.S. control of safety integration.

User Autonomy

User autonomy represents the ability of users to conduct work with minimum interference, with maximum user discretion, and without special training in space station operations. The option area was chosen for a number of reasons:

- -User autonomy is apparently highly valued by users,
- -Some members of the SSOTF felt that past NASA programs had been deficient in providing user autonomy, and
- -The degree of user autonomy could have a major effect on station operations

Two polar alternatives envisioned were as follows:

- -Provide each user with a minimum envelope and permit decentralized autonomy in operation. Users may exchange resources among each other.
- -Constrain users to predetermined timelines and schedules for all activities, with centralized control of user commands. Users operate from or through NASA control centers.

Station Autonomy

Station autonomy represents the relationship of station crew and users to ground control, and the allocation of authority and responsibility. The area is important for a number of reasons:

Effect on Station Cost and Performance. Because of the continuous nature of Space Station operations, extensive ground supervision of all on-orbit activities may be very expensive. Additionally, the continuous nature of operations may make on-orbit resources less expensive than in past manned flights. For example, on Shuttle flights, the cost of a shuttle launch generally provides 5-7 days of crew time. For the Station, the same shuttle launch provides considerably more crew time (e.g. 45 days on the Station based on a 90 day crew stay time, with changeout of one-half the crew every 45 days). This reduced cost of on-orbit resources decreases the optimal amount of pre-planning.

Effect on Safety. Greater Station autonomy is viewed as less safe than ground, especially station operator, control.

Effect on Astronaut Morale and Performance. Station crew will generally prefer more station autonomy.

The preferred degree of station autonomy may also depend on crew rotation and shift operations. Present crew rotation plans imply 2 shifts on board: a "fresh" shift and an "experienced" shift. Present plans for daily shifts are for 2 shifts and that these will be the same as the crew rotation shifts because of the importance of working with the crew one has trained with. The resulting degrees of experience and fatigue/capability deterioration in the shift running the station may imply the need for changing degree of station autonomy each day or during the course of an increment.

Alternatives envisioned by the Panel were as follows:

-Ground monitoring and supervision of all on-orbit activities to ensure compatibility and resource adequacy.

-Crew discretion to adapt to contingencies and opportunities.

Control by users was included as part of the latter option. However, since these users are on the ground, user control could also be classed with the first alternative as another form of ground control of the station.

Risk Acceptance

Risk acceptance refers to the measure and control of failure or other contingency so as to meet reliability and safety standards at minimum cost. The importance of this to the Panel derived from the following assumptions:

-The Challenger accident and recent Expendable Launch Vehicle failures have heightened the awareness within NASA and the SSOTF of the possibility of accidents.

-The long-term, continuous nature of Station operations increases the possibility of mission failure or risks to safety and suggests the need for a framework to evaluate these against cost impacts.

Alternatives listed by the Panel included the following:

-Anticipate all contingencies and failures and provide alternative procedures or backup,

-Build in substitutability and adaptability to minimize adverse impacts of contingencies, and

-Determine allowable risk categories and accept the cost of possible failures in those categories

Section 5.5 presents an expanded discussion and results of the limited analysis that the Panel was able to conduct in this area.

Payload Verification

The issue concerns the extent to which users are responsible for verifying that their payloads are safe and working. The importance of the issue derives from the effect on cost burdens of NASA and the user, the cost to society of verification, and the probability of mission success.

Cost Burden. The ultimate cost burden on NASA and the user is a function of the initial allocation of costs and how this initial allocation is affected by pricing policy. User responsibility for verification was represented in January to the other Panels as involving high user cost and low NASA cost whereas NASA responsibility was depicted as implying low user cost and high NASA cost. If this were the end of the story, one might wonder why users might want responsibility for verification. One possibility of course is that, as mentioned before, pricing policy reallocates costs and thus some costs that NASA incurs for verification are ultimately borne by the user through prices. Another possibility is that the options may imply different efficiency in verification or different objectives regarding the probability of mission success.

Cost to Society of Verification. An important goal in this option area is to place the burden of verification on the party who can do it in the most cost-effective manner. Proponents of NASA verification could argue that NASA has a number of advantages: learning economies from having done it many times before, interaction economies through superior knowledge of the Station, Shuttle, and other payloads, and scale economies by performing verification for a number of payloads at the same time. Proponents of user verification could argue that the user's superior knowledge of his own payloads outweighs NASA advantages, and that the user is in a better position to implicitly choose that level of verification that meets his performance and cost objectives.

Probability of Mission Success. The extent of payload verification affects the probability of mission success. A number of members of the SSOTF argued that the user should be able to choose this level, as long as the payload met safety standards. NASA's view has been that it must have some control over mission success because, rightly or wrongly, the public will hold NASA responsible for payload failures. However, the extent of this externality of perception could probably be changed by a deliberate policy.

Options identified by the Panel included:

-Ship and shoot policy, in which users take full responsibility for ensuring proper functioning of their payloads, within NASA-defined standards and constraints.

-Mix of containerization, modularization, and customizing of payloads to match user requirements.

-Thorough testing and verification of all payloads by NASA organizations before manifesting.

Operations Automation

Operations automation reflects the degree to which operational decisions are reached through machines. This automation can occur on the ground or on-orbit. The importance of this option derived from the value of on-orbit crew time, and the value for safety and performance.

Value of On-Orbit Crew Time. There was a general consensus within the SSOTF that on-orbit crew time would probably be a very scarce and valuable resource. This argues for maximizing operations automation.

Value for Safety and Performance. Minimizing crew intervention reduces the chance of safety risks and saves crew energy for tasks which benefit the most from human involvement.

Options identified by the Panel included the following:

-Use of automation, either on-orbit or on the ground, for routine monitoring and operation of the station

-Monitoring and operations by ground personnel or on-orbit crew

Section 5.9 presents further discussion of this topic.

Functional Allocation

Functional allocation represents the degree to which similar types of on-orbit operations are clustered to maximize output and minimize contamination or other adverse interactions. The importance of this issue resulted from its effect on station cost, international cooperation and dependency, and international competitive advantage.

Station Cost. Functional allocation was generally regarded as being cheaper to build. The effect on operations cost was unclear.

International Cooperation and Dependency. Functional allocation results in the international partners being more dependent on each other.

International Competitive Advantage.

The most important factor is the possible effect on international competitive advantage. The advantage could accrue in two ways:

(1) Supplying a particular capability (e.g. building a lab for microgravity research) may result in technological knowhow apart from that gained from using the lab. Under functional allocation, use is open to all, but only one partner will supply the lab.

(2) Supplying a particular capability may give particular advantage to that partner's users. This could result if partners faced different costs of integration into that facility (e.g. taking payload to that country for integration, or necessity to adapt to that partner's conventions on a host of matters-e.g. electrical, computer, etc.).

The alternatives identified by the Panel were as follows:

-Provide specialized labs, modules, platforms, etc. where use of each is shared by all those desiring to utilize that special capability, and

-Provide generalized labs, modules, platforms, etc. in which a partner has complete and exclusive use.

One can also envision a range of possibilities for operation:

(1) National Enclave. Each partner has full use of facilities provided by that partner, including ground and onboard.

(2) Integrated Onboard Operations, Ground Operations by Enclave. Onboard resources and facilities are jointly utilized, while ground control and communications centers are by separate partners.

(3) Integrated Onboard Operations, Distributed Ground Element Operations. Onboard resources jointly utilized, with ground control centers spatially distributed to convenient locations according to discipline or type of usage.

(4) Integrated Onboard and Ground Operations, Centralized Safety-Critical Operations.

(5) Integrated Onboard and Ground Operations, Centralized Safety and Routine Operations Control.

(6) Integrated and Centralized Onboard and Ground Operations.

(7) Internationals Supply Hardware to US Space Station.

The issue of functional allocation has been a central issue in the international negotiations which are discussed in more detail in Section 5.11.

Evolution

Evolution represents the provision of scarring for possible growth alternatives. The area was selected by the Panel because of the obvious importance of the area for long-term performance and cost of the Station.

Options presented by the Panel included the following:

-Build in hardware components that permit future growth in a wide range of possible directions. Preserve future options by scarring, to the extent that allowing for uncertain alternatives is less costly than making future modifications.

-Consider possible growth configurations, but accommodate only those that appear very likely or will be precluded by specific designs.

-Adapt the station to growth as it occurs.

Section 5.10 presents an expanded discussion of this area.

Supportability

Supportability represents the design of elements and equipment to be easily maintained and supported at reasonable cost. This option area was chosen because it represents a new challenge for NASA: previous spacecraft have either been built for no repair (unmanned satellites although now communications satellites could be built to facilitate repair by Shuttle crews) or for repair upon return to earth (the Shuttle).

Options presented by the Panel were different mechanisms to achieve supportability:

- -Design modular components with common interfaces to facilitate isolation of problems and ease of replacement. Maintain stock of spares in resource nodes.

- -Build in robustness and redundancy so as to minimize requirements for maintenance.

- -Reduce on-orbit complexity so that problems can be diagnosed and repaired as failures occur

Transportation

The transportation option area focuses on the extent of usage of Expendable Launch Vehicles (ELVs) for carrying station and user payloads to and from the Station. The issue was selected because of its impact on operations complexity and flexibility.

Operations Complexity. Use of ELVs may add a degree of complexity to Space Station operations. Prelaunch/postlanding operations and user integration are affected, as well as rendezvous operations. In other respects, use of ELVs may reduce complexity--use of an ELV for some purposes may be far simpler than use of the STS.

Operations Flexibility. Availability of alternatives to the Shuttle adds an important measure of flexibility in Space Station operations. A more robust transportation system means that other parts of the Station need not be as robust.

The three alternatives presented to the Panels were as follows:

- -STS is sole transportation vehicle.

- -The Station will broker commercial ELVs for users.

- -Users may provide their own transportation.

This option area is discussed further in Section 4.2.

International Partnership Groundrules

International partnership groundrules are the constraints on resource allocation and service availability imposed by international agreements. This area was selected by the Panel because of its importance to resource allocation.

The options presented by the Panel were:

- -Pooled resources with joint allocation.

- -Off-the-top partition of resources with separate allocation.

This option area is further discussed in Section 4.1, International Cooperation in Space.

Program Operations Control

Program operations control refers to the ways in which control over space station activities and users is distributed and structured into a hierarchy of responsibilities.

Options presented by the Panel were the following:

- -Direct NASA management

- -Separate National enclaves

- -US private industry

-Quasi-government organization

-Science/user institute

Further discussion of these alternatives is contained in Section 5.1.

Station Utilization Themes

Station utilization themes refers to the primary focus of the Station. The primary options are:

-All things to all users

-Focus on one or more, but not all, objectives.

The possible objectives presented by the Panel were:

-National lab in space

-Permanent astronomical observatory

-In-space servicing facility

-Space transportation node

-Assembly facility for space structures

Further limited discussion of these alternatives is contained in Section 4.4 below, on manned spaceflight program directions.

ENDNOTES

1. Doug Lee developed this list of goals from a variety of sources obtained by the SSOTF. Rich O'Toole developed the list of goals at the end of this section which embody a particular programmatic implementation.

2. This section was developed by Doug Lee.

3. These are described in more detail in Technical and Analytical Services in Support of a Space Station Operations Scenarios and Test Case Development Strategy, CSP Associates, January 29 and February 18, 1987, (in two volumes).

4. The options areas were developed by several members of the panel including Doug Lee, Gran Paules, and Rich O'Toole. Bill Pegram supplied material concerning the importance of each area and completed the final writing.

4.0 STRATEGIC POLICY ISSUES AND OPTIONS

by Doug Lee[1]

The nature of strategic issues is that they affect many levels of the Space Station Program, and they cannot (or should not) be resolved without active concurrence from a broad range of interests. By their nature, strategic policy decisions are made jointly by the Program, NASA management, and Congress, with the scientific community and numerous other participants. Hence it is necessary that choices be offered for meeting various objectives, and information be provided on the impacts of the alternatives under consideration.

Purposes in Addressing Strategic Issues

Some of these issues are unresolved because there are alternatives whose consequences have not been fully studied, and hence the right answer can not yet be determined. For the majority, however, the areas of uncertainty involve decision factors that are external to space station operations. They have to do with such things as the emphasis to be placed on competing objectives for the station, as well as alternative means for achieving them.

(1) Outside the SSP. One purpose in addressing strategic issues is to explain to NASA management and policymakers how the decisions they make in specific areas will affect space station operations, and offer a range of alternatives (e.g., transportation vehicles, reimbursement policies) where that is a suitable response to the issue.

(2) Inside the SSP. Another purpose is to communicate to the space station organization as a whole that changes are expected to occur in the way decisions are made within the organization (e.g., cost management, centralization of strategic control).

For each of the issues outlined below, an attempt has been made to summarize the alternatives and to describe the cost and other impacts of selecting one alternative versus another. In describing the differences among alternatives, some clearly appear to be desirable or undesirable, while others have unclear value. In all cases there are important tradeoffs, but the magnitudes of the tradeoffs are not currently known, and hence there may be no basis as yet for preferring one alternative over others.

Also, choices made in regard to one strategic issue affect the benefits and costs of alternatives for other issues. If priorities change in one area, evaluation of alternatives on other issues changes (e.g., which "market" is emphasized alters the optimal configuration).

General Conclusions

While it is difficult to reduce the strategic policy issues to a few simple recommendations, the following list gives at least a suggestion of the initiatives that might taken in order to succeed in the key policy areas. The audience for this section is threefold: Congress (the political realm), NASA management, and NASA centers.

(1) The long term importance of manned spaceflight in National priorities needs to be considered explicitly, because the answer will have a major impact on Program direction, efficiency, and cost.

(2) There are several issues -- notably transportation, subsidy policy, and

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[1] Section 4.7 was provided by Kevin Barquinero.

commercial application of space research -- that need to be studied further, and soon.

(3) Effective and productive international participation will depend upon the right procedures and groundrules for cooperation and cost sharing.

(4) Decisions concerning space station construction will have major impacts on station operations.

(5) Some critical kinds of information (especially operations and supportability cost) need to be collected to address policy and management issues, and that information is not normally obtained under present procedures.

(6) In order to achieve a consensus on objectives and funding for the station, it will be necessary to offer alternatives to Congress, the Administration, the scientific and technical communities, and commercial interests.

(7) Good cost management and life cycle cost design are essential to success of the Station.

(8) Some center autonomy must be given up for the greater good of the space station.

(9) Adoption of some kinds of standard business practices and business thinking that are not normally considered by NASA are necessary.

Although a number of recent commissions have reviewed NASA's mission in general and the space station in particular (National Commission on Space, the Space Sciences Board of the National Research Council, the Ride Committee, and the American Institute of Aeronautics and Astronautics), the Space Station Program is not well understood outside NASA. Better communication may involve something more of a dialogue or conversation than has been characteristic of previous patterns of information flow.

4.1 INTERNATIONAL COOPERATION IN SPACE

The US has expressed a goal of having other nations participate in the space station program as partners, for purposes of international cooperation. As partners, Japan, Canada, and ESA will contribute elements of the station, funds for operation, and will receive some share of station resources. Benefits to non-US partners are, in addition to use of the station, the knowledge and experience gained for undertaking their own space programs.

Several interrelated obstacles may hinder these international partnerships. Partners are concerned that NASA's construction and operating costs that will be billed to them will be inflated by including non-essential or overhead program costs. Each group also demands control over its own activities and whatever facilities it brings to the station. One result is the "National Enclave" arrangement, in which each partner carries out a diverse range of activities within its "own" module. By providing the module, the partner gets back the in-kind benefits of its use. This is only one possible in-kind exchange, but purely barter transactions place severe practical limitations on the range of alternatives that can be negotiated.

The objective in resolving this issue is the negotiation of contractual agreements that will protect the interests of all parties concerned. Clearly this requires an equitable balance, because advantage to one party comes at the expense of another. Inefficient restrictions, however, can easily reduce the total benefits of the station below their full potential. Thus there is a mutual self-interest in making the station as productive as possible, so long as all partners gain.

Each partner's interests have three aspects: (1) what it produces, (2) what it consumes, and (3) what it pays. Although it is the net result of all three that ultimately determines partner satisfaction, the three can be separated in principle and perhaps in practice.

There are several options for cooperation:

(1) No International Participation. If the coordination and decision costs of including international partners outweigh, on balance, the benefits from multiple participants, then each country should go its separate way. Transactions costs in decision making, and operating costs or underutilization resulting from artificial restrictions, are real costs and should be considered in judging the long term political benefits of international partnerships.

(2) Partners as Users/Contractors. One approach to station management is to view the US as the prime contractor, and the partners as suppliers and users. The US could purchase modules and equipment from the partners at agreed prices to meet jointly-determined specifications. Both US and foreign agencies could enter this competition. Separately, partners could negotiate for use of the station and its various resources. Whether a partner preferred to "buy back" the same facilities it constructed would depend upon the relative benefits and prices to the partner.

To protect against padded bills, the cost estimates for a package of station services could be firm in advance, or constrained to narrow ranges that still create incentives for cost control among all parties. Although the net effect for each non-U.S. partner is likely to be a bill (rather than a credit), the bill could be modest in size.

(3) Joint Venture. For complex endeavors that contain a substantial amount of risk, management of such an enterprise can be in the form of a joint venture among major partners. Emphasis is then directed at developing decision processes and organizational structures that will deal with problems as they arise, rather than specifying all contingencies in advance. In contrast to the explicit business deals of the partners-as-buyers/suppliers mode of negotiation, partners would share in strategic planning as well as long term risk.

The outcome of such a process is not readily predicted, and could include the national enclave arrangements that have been proposed. A properly structured joint venture could also, however, adapt to other arrangements if they offered net gains to all partners. Current negotiations are attempting to allocate resources by developing rules and policies that do not explicitly recognize prices, i.e., in approximately a barter mode. This method can be blended with dollar-denominated agreements as desired by the partners.

Something between an explicit price/cost system and an informal balancing process needs to be developed for achieving a rational allocation of resources and responsibilities. This mechanism should recognize the market-like nature of the exchanges of goods and services that must occur, and design the contractual agreements that will enforce the results of the negotiations.

NASA and the partners are capable of carrying out these negotiations in an effective manner, but political ambiguities have complicated NASA's position. One problem is the question of whether NASA can walk away from the table if there are no satisfactory offers, or whether the national goal of international participation creates a hard constraint. At some point in the future, joint efforts with additional countries -- including a Mars exploration with the USSR -- may become mutually desirable, and an effective organizational mechanism for facilitating such undertakings will most likely need to evolve in incremental steps.

Editor's note: See Section 5.11.1, Space Station "Partnership" Options, for an expanded discussion of several of the international options.

4.2 TRANSPORTATION

At present, NASA has no heavy lift capability other than the Shuttle, and conditions since the Challenger accident have left the agency with several years in which there will be few scientific or commercial launches even on the Shuttle. The ability to plan for construction and operation of the station and to retain effective management and control over it depends in part on the station's ability to obtain the services of a fleet of transportation vehicles.

Acquisition of a Mixed Fleet

Several previous civilian and military launch vehicle programs have been reinvigorated, and expendable launch vehicles (ELVs) of a variety of sizes and shapes could be put into operation within the same general time frame needed to restore the shuttle to normal schedule. Proliferation of vehicles has advantages and disadvantages, and there is a wide range of possibilities for who should be responsible for different vehicles and how they should be financed. Some of the possible alternatives are shown in Table 4-1.

There are a variety of alternative paths regarding transportation:

(1) Shuttle Initially, Perhaps ELVs Later. This continuation of what is, effectively, the current situation, leaves the station with constrained transportation to construct the station, modest ability to service it, and use of only the highest cost (manned) mode. The assembly schedule will be vulnerable to any significant events which affect the Shuttle schedule, including urgent priority payloads. Mixed fleet options could still be developed for long term support, even if it is infeasible to obtain ELVs for early assembly missions.

(2) Hired Heavy Boosters. Several contractors have been given permission to market their medium-lift ELVs competitively. The space station could be provided with a transportation budget with which to purchase transportation meeting station requirements, especially a heavy lift launch vehicle. Other agencies and firms might also be interested in this program, but NASA could be the lead organization.

A mix of launch vehicles could be made available in this manner, with lighter and less complex vehicles more likely to be provided by private suppliers. The problem of incompatibility and interchangeability would be the most difficult with multiple privately-provided launch services. Foreign vehicles, both manned and unmanned, are possible candidates as well. All combinations (including an evolved shuttle, shuttle-derived vehicles, and the Titan) should be studied, and station designs and operating procedures influenced by the results.

(3) Joint Development of New Vehicle. NASA, could undertake to create the catalyst for designing and constructing a Heavy Lift Launch Vehicle (HLLV) or other vehicle that will serve several purposes and require time and effort to realize. The intent would be to stimulate interest, channel design funds and preside over design decisions, and possibly transfer responsibility to another agency or a private firm when the vehicle or vehicles became operational. A logical participant in this project might be the Department of Defense Air Force, in that both organizations appear to have similar requirements.

While it is hard to imagine a private firm undertaking the research and development task, it is also true that public agencies normally attempt such programs with many, often conflicting objectives, and thus have not been outstandingly effective at controlling costs. Contracting the engineering and construction to aerospace firms does not necessarily make things better or worse. The problem is one of establishing clear objectives and constraints acceptable to all parties at the outset. The management challenge is significant if significant R&D is required prior to delivering an operational system.

Many scientific and commercial activities in space can utilize expendable vehicles just as effectively and at lower cost than the Shuttle. A number of studies are examining whether

Table 4-1.

SPACE TRANSPORTATION VEHICLES

Vehicle Type	Space Station Purpose	Date of Availability
Space Shuttle	Cargo Up and Return Construction EVA Manned Servicing Logistics	1988
Extended Duration	TBD	TBD
Shuttle with Advanced Solid Rocket Motors	Same with more capacity	TBD
Shuttle Derived Vehicles	TBD	TBD
Heavy Lift Launch Vehicle (HLLV)	Large Cargo Up	TBD
Titan, Jarvis	Logistics Cargo Up	1988
Other Expendables (Delta, Atlas)	Small cargo up	1987
Foreign (Ariane, H-1)	Small cargo up	1988
Orbital Maneuvering Vehicle (OMV)	Spacecraft servicing	TBD
Rescue and Cargo Return	Crew Rescue Small cargo down	TBD
Space Tugboat	Rendezvous Assembly	TBD

the space station could use HLLVs for assembly and logistics purposes in order to save the Shuttle for manned transportation and servicing. Clearly, the US space program warrants a mixed fleet of vehicles, and the choice is how to get the right mix at the lowest cost in delay and resources.

Editor's note:

The NASA Authorization Act for FY 1988 (P.L. 100-147, October 30, 1987) contained the following language:

"Sec. 109. (a) It is the sense of the Congress that the launching and servicing of the space station should be accomplished by the most cost-effective use of space transportation systems, including the space shuttle and expendable launch vehicles.

(b) Not later than January 15, 1988, the Administrator shall submit a preliminary report on the cost-effective use of space transportation systems for the launch of space station elements during the development and operation of the space station. The Administrator shall consider--

> *(1) the potential use of future advanced or heavy lift expendable launch vehicles for purposes of the assembly and operation of the space station;*
>
> *(2) the use of existing expendable launch vehicles of the National Aeronautics and Space Administration, the Department of Defense, and the Private Sector;*
>
> *(3) the requirement for space shuttle launches; and*
>
> *(4) the risk of capital losses from the use of expendable launch vehicles and the space shuttle.*

"Sec. 116.

(a) It is the sense of the Congress that the space shuttle is a critical national resource that should be preserved; that it should be used primarily for those missions which require its unique capabilities; and that a diversified family of expendable launch vehicles should be incorporated by use into the Nation's civilian space flight program.

(b) The Administrator shall establish a program for launching payloads by means of expendable launch vehicles and, if available, by commercial launch services.

(c) The Administrator shall take such action as may be necessary to ensure that expendable launch vehicles or, if available, commercial launch services are obtained for the launch of the following payloads:

> *(1) Roentgen Satellite (ROSAT), for launch in 1990.*
>
> *(2) Tracking and Data Relay Satellite (TDRS)-F, or a planetary mission.*
>
> *(3) Extreme Ultraviolet Explorer (EUVE), for launch in 1991.*
>
> *(4) Mars Observer, for launch in 1992.*

(d) The Administrator shall report to the Congress not later than January 15, 1988 on the Administrator's compliance with this section, and shall submit such report to the Committee on Commerce, Science, and Transportation of the Senate and the Committee on Science, Space, and Technology of the House of Representatives."

4.3 CIVILIAN CONTROL

As a consequence of the Challenger accident, annual lift capacity has been significantly reduced below what had been planned prior to the accident. Even though all categories of users will suffer, priority for that limited capacity is likely to be heavily influenced by the Department of Defense (DoD) requirements, leaving NASA-supported scientific payloads several years or more behind schedule and commercial payloads encouraged to use other launch vehicles.

Existing plans call for the space station to be constructed and serviced using only the Shuttle. Any unanticipated claims by other users on the Shuttle, under these conditions, will severely affect the station. Even if alternative launch capacity is introduced, uncertainty and schedule disruptions from preemption by higher priority payloads will directly impact the station.

Need for Groundrules

Recently, the DoD requested that international agreements not be undertaken that would preclude possible future use of the station by the military, but the DoD has not stated what the characteristics of those uses might be. It is difficult to plan efficiently for the station with this level of uncertainty, and a set of groundrules for the DoD needs to be worked out that will provide suitable assurances to both agencies, as well as to any international partners. NASA and the Congress have recently taken steps to define what the groundrules will be.

Editor's note: Section 255 of the Defense Authorization Act for FY 88/89 required the DoD to "report on the activities planned by the Department of Defense to be conducted on or in conjunction with the permanently manned space station." The DoD report is Potential Department of Defense Use of the Permanently Manned Space Station, U.S. Department of Defense, March 1, 1988.

The space station is nominally a civilian program, and it should be strengthened as such, but it is still possible for the space station to accept the DoD as a user without compromising the civilian orientation of the program. Accomplishing this will require a willingness on the part of the military to state the types of uses it wishes to preserve as options, and a political agreement that provides guidance on the share of station resources the military can plan to use.

There are several options to define and limit the DOD role:

(1) Purchase-of-Services Agreement. Several areas can be imagined where the military might have an interest. One is man-in-space experiments, for which the crew might be military personnel and the R&D experiments classified. Another area might be earth or space observation, for research purposes or for long term monitoring, perhaps requiring secure data transmissions. Another area might be experiments in high-energy physics.

A services agreement would need to include a statement of the types of uses contemplated, an expected level of use, and guarantees to provide relevant information and abide by safety and other standards for adverse impacts on the station and its other users. Based on its resource requirements, the DoD would cover, as would any other agency, the base costs plus any incremental development and operating costs associated with its unique specifications.

(2) No Weapons Testing or Development. If a clearly defined boundary for acceptable military space station research can be developed, then the possibility for civilian and military payloads to share the station is improved.

Editor's Note:

The NASA Authorization Act for FY 1988 (P.L. 100-147, October 30, 1987) states:

"Sec. 105. No civil space station authorized under section 101(a)(1) of this title may be used to carry or place in orbit any nuclear weapon or any other weapon of mass destruction, to install any such weapon on any celestial body, or to station any such weapon in space in any other manner. This civil space station may be used only for peaceful purposes.

(3) Cap on DOD Share of Resources. In addition to restrictions on weapons testing, an allocation of station resources that would allow the DoD to use up to some modest share (e.g., 10-30%) would assure that the program remains a civilian one and, yet, still

serve many Defense purposes. Such a program would likely enjoy greater political support and have more syntergistic beneficial impacts on the US economy.

Some defined agreement needs to be put in place which spells out the conditions under which both civilian and military users of the station will be selected and allowed to operate. In order to do this, the DoD must be willing to state its needs with sufficient specificity to provide for proper planning and to meet the conditions of any nationally-established international agreements with Space Station partners.

4.4 MANNED SPACEFLIGHT PROGRAM DIRECTIONS

A fundamental consideration in the size and shape of what will ultimately be the space station is the direction of manned space research and exploration. For a manned expedition to Mars, a space station may be necessary to conduct the required life science research. The size and shape of this station could well be different that a station designed as a operational staging base for a Mars mission. If a lunar base is on the agenda, then a somewhat different station (either for life science research or as a staging base) may be called for. At the other end of the spectrum, an absence of interest in manned space research may suggest a station operated primarily by remote command and perhaps visited occasionally by the shuttle. In between are many synergistic combinations that could serve a mix of purposes, some better than others.

While it may be desirable to combine related research activities with those of the core station, rational evaluation of alternatives urges that goals be considered separately, along with the means for achieving them. One reason is to allow for changes in scope, with recognition of the attendant consequences. Another reason is to consider the impacts of these alternatives on operating procedures and costs.

If a subset of market segments is selected, rather than the entire spectrum, the station can be designed to optimize performance to those users and also reduce costs. The major dimension to this range of alternatives is the role of manned space activity. Providing safety and life support for humans makes man-rated vehicles extremely expensive, and these costs can be avoided if the manned presence is not essential to National goals. A great deal of concern has been expressed about the possibility that manned space activities will crowd unmanned science out of the NASA budget.

At the most basic level, the purpose uniquely served by the space station is man-supported space research. To varying degrees, other kinds of activities have alternative means for serving them, some better on the space station and some no better. The range of alternatives, then, reflects the size of the manned program, and the number of optional (i.e., that could be unmanned) activities that are combined with the manned program. Table 4-2 provides some additional examples.

The principal alternatives are the following:

(1) Multipurpose Facility. The current initial operational configuration (IOC, Block I) incorporates a heterogeneous mix of modules, structures, equipment, and services. This approach offers a good deal of flexibility for both immediate use and future evolution, but it does so at some cost in complexity, construction effort, and overhead. If manned spaceflight is the major goal that current expressions indicate, then it should be possible to acquire the necessary funding without sacrificing unmanned space research in the process.

(2) Separate Platform Program. Although there are beneficial interactions between platforms and the manned base, the two may be independent enough that they could be separate programs. Payloads and activities that operate within pressurized volumes or must be attached externally to the station should be examined as one interrelated group of activities, and polar and co-orbiting payloads and support activities as another. Total life-cycle costs might be similar or different, depending upon

Table 4-2
MANNED SPACE ALTERNATIVES

Strategy	Major Elements Needed
Deep Space Exploration (Moon or Mars)	Large permanently manned base Shuttle Heavy lift launch vehicle (HLLV)
Space Station (IOC)	Permanently manned base Attached structures Shuttle HLLV
"Skylab" Station (MIR)	Permanently manned base Shuttle HLLV
Man-Tended with Life Support	Intermittently manned base Shuttle
Man-Tended without Life Support	Unmanned base Shuttle
Extended Duration Orbiter with Spacelab	Shuttle Spacelab
Shuttle and Spacelab	Shuttle Spacelab

numerous choices to be made, but the costs and expected outputs of each program could be assessed as separate activities rather than being inextricably lumped together.

(3) Station Design Based on Different Transportation Capability. From the perspective of establishing a permanently manned capability as a primary objective, a pre-assembled large volume (similar to Skylab or the USSR MIR) placed in orbit by a heavy lift vehicle (HLLV) is one means under study for providing manned and man-tended services. Attached payloads could be added on, or placed in the platform program, according to how the synergies worked. Modules provided by international partners could also be attached.

Advantages of this arrangement would be reduced assembly time and effort, reduced EVA in servicing and maintenance, fewer STS flights for assembly and crew rotation, and possibly simpler coordination among supplier centers, reduced overhead in planning, and processing of user payloads. Establishing a permanent base on the moon has also been urged as a motivating goal for the US space program, to build on the Space Station program and serve as an intermediate objective in a long-term Mars effort. These advanced exploration commitments do not need to be made right away, but future intentions should shape current efforts. A major disadvantage to this option is the present lack of an HLLV and that its development and demonstration would be done at the same time as the Space Station. Thus any schedule or performance slippage in the HLLV program could impact the Space Station Program directly, and cost overruns in the HLLV program could impact the Space Station budget if overall NASA funding is constrained.

(4) Extended Duration Orbiter. The shuttle could remain as the basis for an extended manned or man-tended program, with most other activities distributed to polar or other suitable platforms. These could be large long-term facilities in space, such as the Hubble Space Telescope, or smaller single-purpose satellites.

Although many of the activities now planned for the Station might be accommodated iusing an EDO, this approach could affect the pace at which the Nation moves into areas of new discovery. An EDO option could delay needed decisions to provide heavy lift capability and could delay opportunities to gain experience with long duration manned spaceflight.

4.5 RESOURCE ALLOCATION AND SUBSIDY POLICY

Resource allocation includes reimbursement (pricing) policy, and the distribution of Space Station services to users. A subsidy policy allows the question of how much each user pays out of its own pocket to be separated from the question of how the services should be priced. The objective is to accomplish the allocation of resources and subsidies in a way that most closely approximates the result of an efficient market, without introducing the uncertainties uncontrolled markets might create.

Resource Allocation

"Resources" are the power, manned tending, consumables, and other goods and services demanded by users. The output of the station is the amount of these resources that is available to users. "Allocation" refers to the distribution of the services to users, whether accomplished by a political process, a centralized command system, a peer group review process, or a market process. Resources consumed for housekeeping are not included in output, and are therefore part of the cost of production. Although resource allocation and user selection are highly interrelated, the issue of resource allocation as represented here assumes users are selected through an associated but separate process.

The station produces an enormous range of services, as shown in Table 4-3, that may be of potential interest to users. Whether a small number of these (e.g., power and crew time) will dominate all others from a scarcity standpoint, or whether most services will be consumed independently of each other (ceteris paribus), every service has its own optimal design and level of output, depending upon both demand and cost. Thus it is necessary to know the incremental costs of each type of service, along with the amounts that each user intends to consume at various prices to the user.

Basis for User Fee Rates

In an ideal market equilibrium, prices are determined by both supply and demand. In the absence of any revealed demand information, prices must be initially based on cost. For the purposes at hand, there is no unique cost concept that is the correct one to use in setting prices. Some guidelines, however, can help to narrow the range of discretion:

(1) No price should be below the short run incremental cost of providing the good or service.

(2) No price should be above fully allocated cost, until such time as revealed demand warrants a higher price.

(3) No price should be below fully allocated cost if there is a reasonable possibility that an unsubsidized private firm may be willing to supply the service.

Interpretation of these guidelines depends upon the specific meaning of the terms used, so the terms are discussed below.

As services are provided and consumed, information is obtained about demand for

Table 4-3
SERVICES POTENTIALLY AVAILABLE TO STATION USERS

Service	Description and Inputs
Window	Bounded fixed-time periods to be on the station.
Trajectory	Required path through space or in orbit.
Volume and Weight	Accommodate particular size and shape, including transportation up and down, attachment points, rack space.
On-Orbit Program	Required sequence of on-board activities.
Consumables	Usage of depletable resources such as propellant.
Orientation	Attitude and pointing requirements.
Altitude	Specified height above earth.
Priority	Accommodation or service in the place of another user.
Power	Directly consumed or indirectly used through other services.
Crew Time (IVA, EVA)	Direct services, indirect through requested services, and indirect through station maintenance.
Free Flyer Service	Transportation, launch, adjustment, repair, communication.
Attached Payload	Tending through EVA or remote manipulator servicing.
OMV	Communication, remote control, rendezvous.
MRMS/RMS	Remote manipulation, normally an intermediate service which is derived from requested services.
Tracking	Monitoring location from the ground.
Ephemeris Data	Data from star tracking.
Status	Real-time analysis of health and progress, etc.
Contamination	Gas, vibration, movement, dust, light, and heat in payload environment.

Table 4-3 (cont'd).

Service	**Description and Inputs**
Microgravity	Level and stability of low-gravity environment.
Movement	Physical placement, removal, positioning by fixed or mobile manipulator system.
Extravehicular	Human servicing outside modules (not remote).
Suit	Depreciation of EVA suit through use is variable resource cost; rate depends upon technology of suit.
Rendezvous	Physical interception of vehicle from high-energy orbit, coincident orbit, or polar orbit.
Data Collection	Density (rate), volume, and type of user data collection, processing, and analysis.
Data Transmission	Storage versus communication to ground stations, with extent of real-time monitoring and reporting.
Pressurized	Normal atmospheric environment in pressurized module.
Cooling	Thermal rejection of excess heat that must be radiated to maintain temperature tolerance.
Heating	Additional heat to maintain temperature tolerance.
Voice Link	Ability to communicate directly with on-board crew.
Command Link	Ability to control on-board activities from the ground.
Flexibility	Adaptation of services to suit unexpected user needs.
Responsiveness	Lead time needed to adjust to change in user requirements.
Proprietary Data	Security for sensitive information.
Trash	Disposal of waste materials generated on-orbit.
Contingency	Need for action in real time in response to user payload breakdown, malfunction, or unexpected event.
Emergency	Response to system or user equipment failures that affect other equipment; planning for risk.
Reliability	Probability of resource shortage, due either to system malfunction or overconsumption.

each service. Those with excess supply can be scaled back or reduced in price; those in demand can be expanded or the price increased. Prices or non-price surrogates serve to ration scarce capacity in the short run, during which capacity is fixed. "Auctions" are one approach to generating a market-like process. Capacity should respond to demand in the long run if the evidence of benefits justifies the costs.

Short Run. The meaning of the expression "short run" is that something is fixed, and hence there are some costs which cannot be avoided. The shorter the time frame, the more that is fixed and the fewer the costs that are included in the price basis. Short run incremental cost is the operational application of the concept of marginal cost.

For example, once the space station is in operation, it will have some pressurized volume attached to it. The short run then excludes all construction, launch, and assembly costs for producing the station, and includes costs of payload and crew launch, operating cost on orbit, and return costs. Operating costs would include heat, light, air, and power, all of which could presumably be avoided if the payload did not go up. Once the payload is up, the avoidable costs become fewer, involving only those that could be recovered from shutting the payload down.

This suggests that the shortest practical time frame for pricing is a "space available" situation: room is available -- on both the launch vehicle and the station-- which would otherwise go to waste, and sufficient time remains to integrate the payload. Such circumstances should be rare, however, making the relevant costs on which to base pricing more inclusive (and therefore higher).

One method for differentiation among users might be priority, with level one (top) priority getting guaranteed space and resources, and level two getting deferrable claims on resources but with a lower price. Priority would be differentiated by service, so users could acquire high priority on some services and middle or low on others. Under a pricing allocation system, users purchase the priorities they desire, while under an administrative system the priorities are awarded.

Opportunity Cost. A more realistic intermediate between space-available discount prices and fully allocated prices can be based on opportunity cost. Here, the value of the fixed resource (e.g., volume) depends upon how much the "displaced" user with the highest willingness-to-pay places on the resource. In other words, if someone is displaced in order to make room for another payload, how much would it be worth to the displaced user to get back on?

Again, this points up the need to separate pricing from subsidies. Once users know how much subsidy they will receive, their willingness to expend funds from their budget (even if it can only be used to buy Space Station services) is a valid reflection of how much they value the services. Such a process begins to generate the missing demand information.

Fully Allocated Cost. In the long run, a viable enterprise should recover all its costs, including a return on the initial investment. Prices based on fully allocated costs would accomplish this, subject to two reservations:

> (1) If some users pay less than fully allocated cost, other users must pay more, in order to recover the full costs.
>
> (2) Fixed or common costs can be allocated in any number of ways, and, while some methods seem fairer or more accurate than others, usually there are several allocators that are defensible.

Prices based on fully allocated costs provide a valuable starting point for gauging the kinds of users and usages that will be cost-beneficial, and future prices can be adjusted in various ways as experience in operations is gained.

Services That Are Priced

Costs can be traced from inputs through to the services provided to users, but prices should be charged as close to the output end as possible, namely, the specific things the user desires. For example, if a user wants an attached experiment tended once every twenty-four hours, the hourly EVA rate for a crew scientist is insufficient information until the user knows how much time must be devoted to the task. Once NASA finds out from the user exactly what is required, an "estimate" can be prepared.

The cost of every service that is provided by the Station should be known to NASA, and price information should be conveyed to the user or potential user. Whether each and every service has a separate price depends upon how closely tied the consumption of various services are to each other. If one service (say, volume) implies a fixed rate of consumption for other services (say, transfer and installation), then pricing one to include the others makes things simpler. If the input relationships are not fixed (e.g., ten minutes of installation per cubic foot of volume), and the cost of the resources is significant, then the services should be priced separately.

On orbit, the net quantities of services and resources that will be available to users at any given time will not be entirely predictable. A method for dealing with this beforehand (rather than when a shortage occurs) is to assign priorities to users beforehand. Users could be given the option to purchase both quantity and priority, such that low consumption with high priority would cost as much as higher quantity and lower priority. Such a system would permit users to place a value on reliability of service, within a given time period, and allow the station operator to resolve real-time conflicts in ways that reflect user preferences.

Subsidy Policy

At the time the space station becomes operational, it is unlikely that there will be many users willing to pay even their full incremental costs, let alone a share of development costs. Even in the long term, the bulk of the users of NASA's space station are likely to be partially subsidized, or fully taxpayer-sponsored activities, because if a sector emerged that could pay "full price" and was large enough to occupy the bulk of the Space Station, several things would likely occur. First, entrepreneurs would develop proprosals for private space stations or platforms. Assuming no change in commercial space policy, the U.S. government would react to this new supply and demand situation by offloading much of the "full price" customers to the private stations, leaving the NASA space station available for more preliminary R&D. Distribution of subsidies to user categories, then, is a reflection of the values of these activities (e.g., science, technology, commercial development) to the Nation as a whole.

What the User Actually Pays. The price of the service should not depend on who the user is, only on what the user is doing. Users, not services, should be subsidized. A user may be 100% sponsored by NASA, but that simply means the user buys Station services with NASA money, not that the services are free to the user. Once a budget is granted to a user, the user should choose what to buy on the basis of the prices for each service. Even though the budget is designed around a particular user and usage, charges against that budget should be based on full prices. Whether the user brings all, none, or some portion of the funding required to accomplish the task, the prices faced are the same

Where the revenues go may also create incentives that influence efficiency. Sending all external revenues to the Treasury, so as to have no effect on NASA's budget, relieves pressures to market aggressively and extract maximum revenue (or favor external customers). Which set of institutional incentives are preferred is a matter of choice.

Distribution of Subsidies. To the extent that the resource allocation process does not function like a market, the choices are made through a political balancing process. Whatever the organizational structure for selecting users and allocating resources, pricing (or bartering) approaches can substitute for political bargaining.

Subsidies allow users who would not otherwise be able to purchase spaceflight services to make claims on usage of the station. It is not necessary -- and, indeed, undesirable -- to create subsidies by altering prices. The purpose of prices is to get users to internalize the tradeoffs between consumption of resources, e.g., between crew time (tending) and payload refinement (automation, reliability). Even if entirely subsidized, allowing a user to make purchases based on real prices leads to rational choices.

A science user, for example, might receive a grant through NASA (Code E, C, or R) analogous to a "gift certificate". The user could purchase services, based on such characteristics as weight, size, consumption patterns, and special requirements. If, in comparing intended usage with prices, the user found a way to trade one resource for another and have enough left over to enhance or expand the experiment, then the user would have responded to station costs, to the advantage of both parties.

Pricing versus In-kind Allocation

Two fundamentally different methods exist for allocating resources among users. One approach relies on determining prices that balance supply and demand (separate from subsidies, as discussed above), leaving the actual allocation to be an output of the process. The outcome will depend upon the value each user places on each resource, relative to other users and other resources. Another approach allocates services and resources directly (whether packaged or separately), without explicitly recognizing the value of the resource (either its cost or its benefit to the user) in dollars.

(1) Pricing. In the ideally functioning competitive market, supply and demand equilibrium is achieved through the price system. Users reveal their benefits by their willingness to pay for the services, relative to other opportunities for consumption; suppliers of different outputs bid for scarce inputs on the basis of the revenues that can be earned from each output. In equilibrium, the marginal value of each input is the same for all activities, and equal to its price. The value of the output is measured by the willingness to pay of the marginal consumer.

The Space Station will be produced by a public enterprise, and the degree to which either the supply side or the demand side are guided by a price system is a matter of political choice. Whether all or none or something in between, however, the problem to be solved remains the same: consume inputs and allocate outputs so as to maximize the net benefits to society. To the extent that competitive price and cost incentives are not desirable or not feasible, some surrogate must be used to make the same consumption and production decisions.

(2) Allocation by Resource. In-kind allocation of resources (e.g., amounts of power, volume, servicing time) can produce efficient use patterns under some conditions. One condition is that consumption of services by users is not influenced by price, i.e., demand-price elasticity is zero. By and large, this is not true; payloads can be redesigned -- at some cost -- in response to constraints and opportunities in resources. Another condition is that users are allowed to trade and sell their resources freely. If enough trades occur, the "prices" of the resources can be stated in some common unit, even if not dollars.

The effectiveness of in-kind resource allocation depends in part upon whether or not a few resources (power, crew time, data transmission) tend to drive all the rest. If a few resources dominate, a user with an envelope of the critical resources could obtain any others that were desired without having to compete with other users. These non-critical resources are either included in the basic package or can be purchased at incremental cost, without having to be concerned about whether there is sufficient capacity. Similar to price elasticity, this condition implies that users cannot readily substitute one resource for another in achieving the same ends.

Editor's note:

For additional discussion of Space Station pricing policy issues, see Chapter 2 of the Panel 3 report and p. 103-104 of the Summary Report.

Also, as additional background, note that the NASA Authorization Act for FY 1988 (P.L. 100-147, October 30, 1987) states that:

"Sec. 106(a) The Administrator is directed to undertake the construction of a permanently manned space station (hereinafter referred to as the "space station") to become operational in 1995. The space station will be used for the following purposes --

> *(1) the conduct of scientific experiments, applications experiments, and engineering experiments;*
>
> *(2) the servicing, rehabilitation, and construction of satellites and space vehicles;*
>
> *(3) the development and demonstration of commercial products and processes; and*
>
> *(4) the establishment of a space base for other civilian and commercial space activities."*

(b) The space station shall be developed and operated in a manner that supports other science and space activities.

(c) In order to reduce the cost of operations of the space station and its ground support system, the Administrator shall undertake the development of such advanced technologies as may be appropriate within the level of funding authorized in this Act.

(d) The Administrator shall seek to have portions of the space station constructed and operated by the private sector.

(e) The Administrator shall promote international cooperation in the space station program by undertaking the development, construction, and operation of the space station in conjunction with (but not limited to) the Governments of Europe, Japan, and Canada.

(f) The space station shall be designed, developed, and operated in a manner that enable evolutionary development.

Sec. 110 (a) The Administrator shall set and collect reasonable user fees for the use and maintenance of the space station.

(b) The Administrator shall set user fees so as to --

> *(1) promote the use of the space station consistent with the policy set forth in section 106;*
>
> *(2) recover the costs of the use of the space station, including reasonable charges for any enhancement needed for such use; and*
>
> *(3) conserve and efficiently allocate the resources of the space station.*

(c) The Administrator may, on a case-by-case basis, waive or modify such user fees when in the Administrator's judgment such waiver or modification will further the goals and purposes of the National Aeronautics and Space Act of 1958, including--

> *(1) the advancement of scientific or engineering knowledge;*
>
> *(2) international cooperation; and*
>
> *(3) the commercial use of space.*

"Sec. 111. No later than September 30, 1988, the Administrator shall submit a detailed plan for collecting reimbursements for the

utilization of the space station under section 110, including the services to be offered, the methodology and bases by which prices will be charged, and the estimated revenues."

4.6 INITIAL USER MIX

Which user categories -- or, more accurately, usages -- to emphasize in the design of the space station is analogous to the selection of a "market strategy." The market here is construed broadly, to include scientific and manned space objectives that will not be expected to support themselves financially from user revenues, as well as activities that may eventually become commercially viable. How much these activities are able to claim in space station resources depends upon the amounts Congress chooses to appropriate, and distribution of those amounts to user categories.

Primary Usage Categories

A major choice is between two broad sectors of "demand":

(1) Public Goals. Manned space exploration, manned spaceflight, life science research, astrophysics, and military purposes are inherently dependent upon public funds, whatever the magnitudes of benefits from these activities.

(2) Commercial Goals. Materials processing, space technology, manufacturing, earth observation, micro gravity research, and spacecraft servicing are activities which have market potential. The benefits may be immediate or distant, but most of the activities are likely to need subsidy, at least initially.

No economic market currently exists for valuing the relative worth of each of these activities (with minor exceptions), and some can only be valued through the willingness of elected representatives to spend public revenues. Nor is there currently much information on the costs of serving these activities, separately or together. Thus the Nation needs to be explicit about how much it is willing to invest in each of these activities, and what can be provided in the way of expectations.

Market Segmentation Alternatives

A normal response to market demand is to provide a set of initial core services, and then revise and expand as knowledge is gained about consumers and costs. A strategy of offering a wide range of services from the beginning is motivated either by the belief that someone else will get there first otherwise, or that the full range is so synergistic that the advantages outweigh the risks of failing in some market segments.

A list of market segments is given in Table 4-4, along with the space station components each market would be most interested in. Listed below are several different alternatives as to which market the initial space station might serve and hence what services/ capabilities the initial station would possess:

(1) Full Range at Startup. The station can seek to be all things to all people, offering a full array of services from opening day, and later evaluate which activities should be retained, spun off, or dropped. This maximizes the number of potential users and minimizes the likelihood that there will be insufficient interest in working on the station to utilize its full capacity. Costs may be incurred, as a result, for which there turns out to be weak demand.

(2) Life Science and Manned Spaceflight. If a major motivation for the space station program is manned space science and exploration, then an initial orientation toward life sciences would seem natural. The manned base could then provide a laboratory for testing alternative ways in which the scope of services might be expanded beyond life science. Which alternatives get emphasized depends on the

Table 4-4.

MARKET EMPHASIS ALTERNATIVES

Market Segment	Major Requirements
Life Science	Pressurized volume, partial gravity Man rated transportation, sample return Manned base
Astrophysics	Platforms, attached payloads (booms) High data transmission Automation, opportunistic reorientation Inertial pointing
Earth Observation	Polar platforms Data transmission Automation Earth pointing
Material Science	Pressurized volume, microgravity Man tending and servicing Sample return
Manufacturing	Pressurized volume Unpressurized attached volume Up and down weight Man tending, low gravity
Servicing	Man tending, robotics Extravehicular activity (EVA) Orbital maneuvering vehicle, docking
Technology	Manned base, high EVA Man rated transportation Attached payloads Large structures, assembly Automation and robotics
Planetary Exploration (Staging/Assembly)	Large manned base Up and down weight Man rated transportation Rescue/garbage vehicle
Proprietary Commercial	Man tended or manned base (see material science) Confidentiality
Military	Unspecified; depends upon activities Military crew Security

national consensus regarding program directions.

(3) Hard Science and Platforms. An emphasis on physical sciences would demonstrate a priority toward research, and would allow the resources and systems to be tested gradually during the station's shakedown period. Knowledge would be gained from this about the types of services and uses that could be most productively expanded. Commercial activities might be added as operating experience permitted reductions in unit costs.

(4) Manufacturing Facility. A commercial orientation could be taken from the start, for the purpose of establishing the economic market benefits from the station at the earliest date. Concern for international competitiveness, productivity, cost reduction, and judicious selection of market-valued services could create incentives to maintain a lean and productive organization. As the commercial viability of uses became demonstrated, activities could be spun off into the private sector, leaving NASA to concentrate on research and technology development.

Choosing a Startup Emphasis

A sensible way to begin operations on the space station is to select a set of services to offer that will be most likely to serve a strong market, at a reasonable cost, with the least risky technology. Knowledge thus gained will help design the means for serving additional markets. Although which market or markets to start with is an open question, those scientific and technology experiments requiring human intervention would appear to be the place to start.

The Mission Requirements Data Base (MRDB) contains useful information on the characteristics of potential users and usages. It does not address the question of value to the user, however, nor alternative means for supplying the same demand, so its value for prioritizing station usage requires additional interpretation.

Matching Supply and Demand

The problem of choosing users to best utilize Space Station resources and services, and the problem of designing the Station itself to best serve user needs, are two sides of the same problem. This problem can be described as matching supply and demand. Demand is the benefits users (as a group) derive from use of the space station, under alternative configurations. Supply is the cost of producing various kinds and amounts of space station services. The matching is, ideally, simultaneous, in that an equilibrium is reached without big fluctuations and with few iterations.

In the abstract, the problem can be represented by the familiar "supply-demand" diagram, shown in Figure 4-1. Assume that there is one generic output of the station, such as if all services are always used in fixed proportions to each other. Users are arrayed in Figure 4-1 in order of the benefit they would receive from each unit of consumption, from high unit benefit to low. Thus the demand curve shows the marginal benefit obtained from each level of output. Similarly, the supply curve shows the marginal cost of each additional unit of production. The optimum production level is that level where marginal benefit equals marginal cost, making net benefit (total benefits minus total costs) the largest it can be. This is called the efficient level of output. In the diagram, net benefits are represented by the shaded area, i.e. below the demand curve, above the supply curve, and to the left of the output quantity.

In the short run, the capacity (element configuration) of the space station is fixed, and the efficiency problem is to allocate that capacity to users so as to maximize net benefits as constrained by capacity. In the long run, the problem is to evolve the configuration of the station to optimize the amount and characteristics of space station services available. The short run problem is called "utilization," and the long run problem is called "investment."

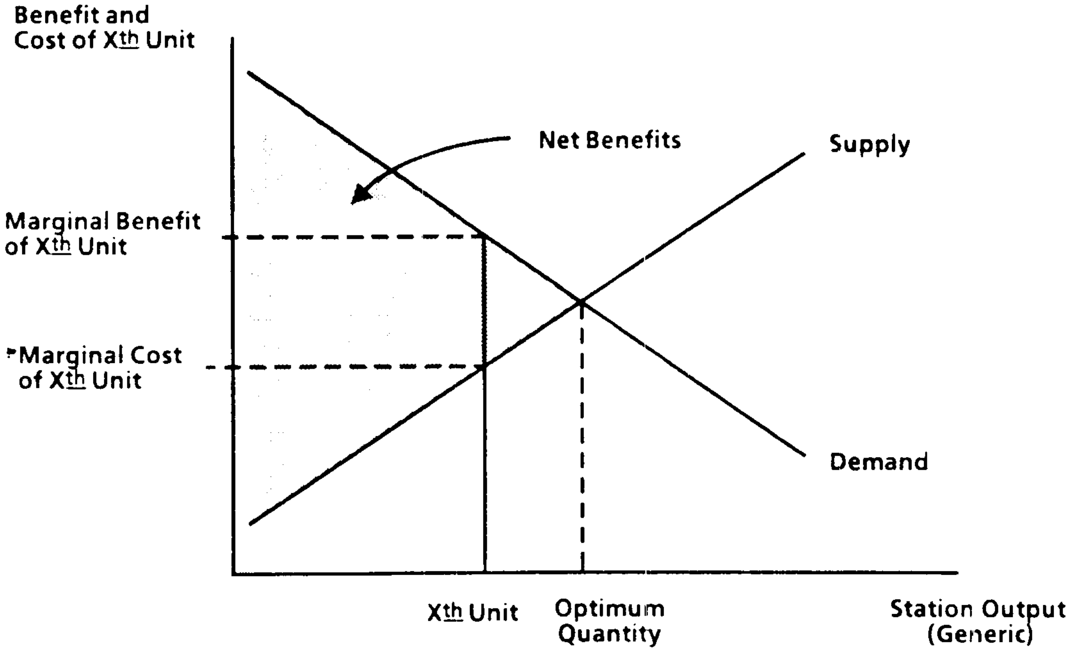

Figure 4-1. Supply and Demand for Station Resources

Selecting Users Within Categories

Which users end up getting on the station is a situation with many dimensions. Balances must be struck between the various categories described above, such as commercial and non-commercial users, between military and civilian uses, among scientific disciplines, and among international partners. The number of boundaries or partitions that are established, the flexibility or rigidity of those partitions, the process for defining the partitions, and the processes for selecting individual users within the partitions, are all questions that must be answered in choosing payloads for the station.

User Categories and Characteristics

Two dimensions tend to determine the nature of the alternatives. One is the order in which the partitions between primary categories are applied, e.g., international first and discipline second. The second is the balance between political processes versus market or market-like allocation processes.

In order to make a selection among a group of users, it is necessary to have a roster of candidates that is much larger than the number who can actually be served. Such is the apparent situation for the space station. The objective is to find that subset of users whose total benefits minus total costs is collectively larger than any other subset of users, within the capacity of the space station to supply.

One approach for estimating usage benefits is to group users into categories of like usage (such as Disciplines), separating academic research from manufacturing, and astronomy from life science. Quotas or shares can be allocated among the groups, and the lowest priority projects in each group compared political (Congress, President, NASA managers, or, if permitted by the political system, peer groups) or market (subsidized or not).

(1) Multilateral User Board. This multi-national alternative starts with the fewest partitions and relies on political negotiation and peer review allocation processes. Shares of resources available to partners would be determined separately and adhered to, but neither disciplines nor resources would be given a priori partitions. Payloads could be accepted in whatever order and in whatever categories the Board chose, so long as the balance was acceptable when it came out at the end.

User advocacy groups would play a dominant role, and their relative strengths would depend in part upon the perceived value of space research to the group and the availability of substitute facilities (e.g., ground, or unmanned). Advocacy strength would also depend upon political access and institutional mechanisms for organizing and expressing a common voice. Selection of individual users could be accomplished by these groups.

Composition of the Board would be representative of the partners' stakes, and would tend to reflect national over other types in interests. If the US is the largest partner, to the extent that no coalition of other partners could overrule it, then the Board would be US-dominated. Allocations to discipline and other categories would be influenced by international political pressures, and might be difficult to stabilize. It appears difficult to prevent such a Board from engaging in a great deal of posturing, and its (desirable) flexibility would not be utilized effectively.

(2) National User Boards. Each partner would allocate its station resources within pre-negotiated partner shares. Disciplinary and other user advocacy groups would be partitioned nationally (e.g. by the US Space Station Users Board), although they might reach informal agreements internationally (e.g., to trade "foreign" users). Individual users would be selected by the user groups, with allocations to user group categories determined through national-level political processes. Commercial users would be one (or perhaps more) user group, as would the military.

(3) Mixed Subsidized and Unsubsidized Users. There are two levels of subsidy: Space-station-sponsored users, defined to mean internal to the space station budget, and all other taxpayer-sponsored users, to include NASA-sponsored users from other programs, payloads sponsored by other agencies, and DoD payloads. Either Congress, NASA, or space station managers could decide how to allocate shares of resources to categories of users, in consultation with user groups and/or a user board, leaving the groups to select individual users.

Any user willing to pay the full cost of their usage could receive priority above their place as a subsidized user, and "proprietary" users might be accommodated in this manner. Caps could still be placed on categories of users or usages.

(4) NASA Selection. Various user groups that already exist, will develop spontaneously, or will be established by NASA, can accept and review applications for space station usage and recommend user selections to NASA. In most cases, these recommendations will be accepted, but in cases of conflict, overall priorities, or special National interest, NASA will make the necessary choices.

Characteristics on Which Selection is Based

Three extremes help portray the possible differences in emphasis in selecting users. One extreme is the scientific peer group process, generally preferred by NASA technical staff. The second extreme is a political process, whereby station resources and services are divided up along geographic and political equity lines. The third extreme is a market process that balances the supply of resources with the demand for them reflected in willingness to pay.

Each of these extremes would be a poor choice. A pure science strategy might produce some good science, but it will not help the Nation's economic position and it will become increasingly expensive and, hence, tend to favor large scale projects. A public agency is necessarily responsive to political goals, but it, too, will fail to improve overall competitiveness in the international market. A pure market strategy is currently unworkable and will remain so without considerable effort to reduce unit costs. Moreover, a subsidized scientific and basic research component is an essential contributor to economic growth as well as international prestige.

User selection is thus a major driver for what the space station becomes and what its impacts will be. Political criteria should not be eliminated, but they should remain a minor factor in user selection. Scientific merit as judged by scientists should be a major determinant, but market processes need to be introduced early on and expanded as station operations become routine and the configuration evolves.

Editor's Note: A more extensive discussion of user selection is found in the SSOTF Summary Report (p. 37, 81-82) and Chapter 4 and Appendix E in the Panel 3 Report.

4.7 COMMERCIALIZATION OF SPACE SERVICES by Kevin Barquinero

Efforts to encourage and promote commercial participation in the Space Station program play a key role in the government's involvement in commercializing space services. This section discusses the issue from two perspectives. First, it covers the concept of allowing commercial firms to provide services and systems to the Space Station program, thereby complementing the infrastructure provided by NASA and international partners. Second, it outlines how the Space Station program supports the overall role which the government plays in private sector space development.

Complementing NASA Provided Space Station Infrastructure

The Space Station program will promote the commercialization of space services by providing the opportunity for private sector investment in a number of systems and services. These include services which supplement existing NASA provided capabilities, such as communications and data management. They also include those services which could be provided entirely by the private sector, such as logistics services, payload processing, and medical diagnostics.

Commercial ventures investing Space Station systems and services have the potential to become successful examples of private sector in space ventures. Commercial firms will provide focused, clearly defined services to a potential market which includes:

- NASA
- Other U.S. Government Agencies
- International Partners
- Commercial Users
- Providers of Other Systems or Services

An important issue in determining how successful commercial providers of Space Station systems and services will be is the degree to which the contractual arrangements between NASA and the commercial provider resemble "business as usual" for the firm. The arrangements will differ from those under traditional NASA procurements. Instead of procuring hardware or software, NASA will be entering into business arrangements and procuring services, something in which the Government as a whole does not have a great deal of experience.

Government Role in Commercial Space Development

Three primary ways in which NASA's Space Station Program contributes to the government's role in helping to promote commercial space development are:

- o Serving as a "good" customer for commercially provided services
- o Promoting the transfer of Space Station technology to private sector applications
- o Providing the infrastructure for commercial space opportunities

An important key to facilitating successful commercial space development is for NASA to learn how to be a good business customer. Under such an approach NASA would find the most qualified provider of selected services, negotiate fair reimbursement, and then buy the service, rather than attempting to provide all services itself. This would allow NASA to concentrate its capital and personnel resources on R&D, and leave routine, repetitive, and commercially viable operations to the private sector. The ability of the government to provide a consistent market to commercial ventures, however, is the uncertainty and fluctuation in government funding levels.

The utilization of technologies and applications developed by the Space Station, and space program in general, for private sector applications is a second major area in which the Space Station program may contribute to the commercialization of space services. Strong efforts are underway to promote the application of current space technologies (e.g. automation and robotics) to commercial space and terrestrial applications. A historical example of technologies and applications developed to support the space program which are just beginning to show commercial promise is the expendable launch vehicle industry.

A third role which the Space Station program may play in promoting the commercialization of space is to provide an infrastructure for space development activities. This infrastructure is likely to consist of systems and facilities such as:

- o Transportation capabilities including the Space Shuttle, OTV, and OMV.
- o On-orbit facilities including the Space Station and TDRSS. This also includes those commercial systems and services which the government helps to support (e.g. Space Station based commercial services, a commercially developed space facility, etc.).
- o Ground support including facilities and assistance to firms entering the commercial space field.

The Space Station program is likely to serve many roles in promoting the commercialization of space including an opportunity for investment, a market for space services, a source of space technologies, and a facility to support prospective commercial space ventures.

4.8 COMMERCIAL MARKETS AND SPINOFFS

Traditionally, NASA has been a research and development organization, as opposed to one involved in operations or commercial activities. Major missions in the past were approached as large single events, and components often were built from scratch, either because project-to-project continuity was lost or was not intended.

A program that is expected to perform in steady-state long term operation requires different methods and procedures. With the shuttle program, many of these adaptations have taken place, especially at the tactical and execution levels, although NASA is still working to improve its day-to-day operational mode. There are good examples of how the process can work successfully, and certainly NASA should not give up its core capability in operations, nor research. The problem is to be able to transition at least some activities from research to application, and from public to private sector, when that would be in the National interest. It cannot be forced, and it may not occur soon, but the transition of operations to the private sector for "a version" of the Space Station is a clear indication of the economic viability of such a venture. As part of a transition, the Station may become a government-owned contractor-operated (GOCO) at some point in its evolution. Such a "handover" should be established as a long-range NASA goal.

Unit Cost Reduction: Down the "Learning Curve"

Designing the station with this potential in mind would result in an emphasis on long-term testing and refinement to improve performance and reduce costs. Not only would scientific and research objectives not suffer, they would benefit from the associated stability and sharing of common costs. Specialized commercial space stations and large platforms could evolve from the initial manned base as experience proved the feasibility and demonstrated the demand.

Current missions, whether research or commercially oriented, call for stable continuous operation rather than one-shot efforts. An ideal process would be one in which NASA did the initial design and construction, carried the testing and development cost burden, demonstrated the feasibility and viability of the concept, prepared the procedures for continuous operation, and then passed the results to another organization.

Evolution from Research to Commercial Production

Once the commercial utility of pressurized volume and attached payload services are established, space station services also could be commercialized. This could extend from private purchases of NASA space station services (perhaps for resale with value added) to private space stations.

Public-Private Partnerships

Joint undertakings in which government agencies and private firms team up to achieve common objectives has been sometimes successful in other countries. Private firms expect to obtain technical knowledge and expertise that they can apply to commercial activities. Public agencies achieve research goals and stimulate new activities in the private sector.

Editor's note:

A true commercial space activity is one which is financed by the willingness-to-pay of private sector buyers and investors. The President's NSDD (National Space Policy) contains a number of proposals of this sort, untested at the present time. They include a private sector space facility (station), Spacehab, a Microgravity Research Board, free External Tanks, and commercial remote sensing (LANDSAT is an existing example). Each of these ideas takes a somewhat different approach to stimulating and testing the transfer of research through development into commercially profitable production and services.

5.0 PROGRAM MANAGEMENT EMPHASIS AREAS

This chapter consists of eleven parts addressing a variety of areas that received special emphasis from the Task Force and the Management Integration Panel.

5.1 OPERATIONS MANAGEMENT STRUCTURE[1]

This section describes alternatives in a variety of areas: the organizational entity which will operate the Station, commercialization of operations, platform operations, strategic management and control, NASA field center consolidation, and STS/Station consolidation. Many of the organizational options considered by the SSOTF are presented here for completeness. For a number of reasons including lack of time the Panel made no effort to substantiate or reconcile the intuitive analysis of some of the options presented in this section.

5.1.1 Station Operator Organization

Concerns involved in designing an operator organization focus on optimizing pressures from various interests and creating incentives for desired performance. Some political pressures should be transmitted to management, while others should be defended against. Incentives for the further development and unit cost reduction of demonstrated ideas and technology should be built in to the operator organization, whereas incentives that resist innovation should be kept out.

A space station operator organization can be isolated from the political process to varying degrees, and it can be oriented toward different political constituencies. Because the station will be publicly funded, political interest groups must be recognized. These include scientific user groups, commercial users, station supplier contractors, NASA centers, and elected representatives with space interests. Most of the pressures created by these groups are desirable and necessary, to some degree, and the problem is how to balance them.

The options listed below all provide government control of operations, but in varying degrees. In contrast, privatization is an approach which requires complete change from public (NASA) control to private (contractor) control, i.e. a facility that is contractor owned and operated. For instance, a remote Payload Operations Control Center (POCC) could conceivably be constructed with private funds and be operated for profit. This is certainly a viable option in some cases but is beyond the scope of this paper and will not be addressed.

The options for government control are as follows:

(1) <u>NASA Office of Operations</u>. A line organization within NASA charged with operating the station would have the advantage of starting in the mainstream of space station construction and policy making, and could draw upon an experienced staff. The disadvantages are the vulnerability to political wind changes, and the administrative and regulatory overhead that goes with the normal government agency. This Office might be Space Station only or Shuttle as well.

(2) <u>Independent Authority</u>. A quasi-public agency with an appointed board of directors with a management team serving at the discretion of the board

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[1] This section resulted from contributions by Kevin Barquinero, Bill Brooks, and Doug Lee

would have more day-to-day operating autonomy than a government line agency. Its character would depend in part on the kinds of people appointed to the board, and the incentives and constraints built into the agency's charter. An example might be the Federal Reserve Board or the Tennessee Valley Authority.

(3) **Research Institute**. A non-profit research organization established for the sole purpose of operating the space station could achieve some autonomy in the research area, but could have difficulty in transitioning research into the commercial sector. An example might be the French CNES which runs the Ariane program.

A research or science institute would be run by permanent and visiting scientists, support staff, and contractors. Funding sources would exercise some general guidance, but payload selection and operations would be under the control of the management of the institute. Its orientation would be scientific, and largely free of political and commercial pressures. While its scientific productivity would probably be high, programs leading to more production-oriented commercial applications could be less effective. An organization staffed primarily by individuals from research oriented backgrounds might have difficulty coping with the complexities of operating in a remote, hostile environment over extended periods of time.

(4) **Combinations**. An independent authority provides the right setting for strong management and isolation from political micromanagement, while a research institute offers the best arrangement for resolving conflicts within the scientific community. Hence, a fairly independent organization for management and operations joined with a science institute for handling the research end could provide an ideal balance.

5.1.2 Alternatives for Commercial Ownership and Operation of Space Station Systems and Services

In this context, commercialization is a profit-oriented approach to conducting business while allowing the government (NASA) to maintain control. A facility can be government owned and contractor operated by means of a competitive arrangement. For instance, the Space Station Control Center (SSCC) maintenance & operations could conceivably be done by a commercial firm while balanced by NASA authority.

Commercialization is not a new approach to doing business in the NASA environment. Contractors have performed work at all Program levels and in various capacities (operations, engineering, maintenance, management support, et al) under direct NASA supervision and direction.

Three approaches for commercialization have been identified and briefly are addressed below:

(1) **Facility Level.** Maintaining and operating an actual "brick and mortar" facility (e.g. SSCC, POCC)

(2) **Center Level.** Consolidation performed at a space center under one contractor team (e.g. Space Transportation System Operation Contract at the Johnson Space Center)

(3) **Function Level.** Executing a specific specialized process in support of Program operations (e.g. Station logistics at the Cape).

Certain Space Station systems and services are candidates to be provided by the commercial sector. This opportunity will allow private companies, in lieu of NASA, to provide the initial capital investment necessary to construct and operate services and systems. Areas of the Space Station with commercialization potential range from the production and operation of entire facilities, such as a platform or laboratory, to more focused service oriented operations such as communications and medical diagnostics. Opportunities exist for commercial investment in both ground and space segments of the Space Station program.

Commercial involvement and investment in the Space Station program is a new initiative which poses many difficult questions and issues to be addressed by both NASA and industry including the following:

- o How will NASA integrate the activities of independent companies into the overall Space Station operation?
- o What level of business, market, and policy risks will commercial firms (and their investors) be willing to accept? What steps can NASA take to help minimize those risks?
- o How can arrangements be structured to ensure that crew safety is not compromised?
- o What form should the business arrangements between NASA and the commercial providers take?
- o How should NASA select which commercial firms will be allowed to provide systems or services?
- o What measure of control should NASA maintain over a program for which billions of dollars of public funds will be spent?

Regardless of the degree of commercial participation, NASA will continue to perform program integration functions to ensure both program success and safety. Success for both NASA and the private sector will be based on equitable sharing of financial risks, understanding of the concepts, mutually beneficial deals, and enabling policies or procedures.

5.1.3 Utilization Planning and Transaction Management

Once users have been selected (at least tentatively), a potentially long and complex process begins for scheduling the usage, manifesting the payload on the station and on transportation, and arranging for all the necessary support services. Users would like this process to be flexible and have few, but authoritative, interfaces. The space station operator would like to please the users with the least cost and disruption to the operator.

Fragmentation is undesirable from both the user and the operator perspective. Convenience to the user, however, means dealing with an organization that is close at hand and preferably familiar. Flexibility is also always desirable, but it comes at some cost, and arriving at the proper tradeoff requires weighing user costs and operator costs together. Two options for utilization planning are:

> (1) <u>Centralized at NASA</u>. A Headquarters organization would receive planned operating events by category (time critical, routine, etc.) from the user selection function, along with requirements (Form 200) from users. Transportation would then be procured (STS, ELV), and a preliminary manifest developed. This plan would be refined in conjunction with station operations, users, and transportation providers.
>
> (2) <u>Distributed to Partners/Functions</u>. Manifests would be developed by organizations representing operations, transportation, and users, for each partner. Initial resource envelopes would be provided to each group, and conflicts resolved by a coordinating board or committee.

Initially, a centralized process is necessary for control, until bugs are worked out and a store of experience is accumulated that will allow coordination and replanning to take place by different organizations in dispersed locations.

Rather than attempting to control or even participate in all tactical (and execution) decisions, the Station operator might choose to emphasize control over the process of decisionmaking. This might be accomplished by intervening in or monitoring selected transactions, as they occur, according to predetermined rules and guidelines.

5.1.4 Separate Platform Operations

As a general management problem, there is frequently a tradeoff between economies of scope (being able to control a broader range of relevant factors) and span of control (effective communication between decision points and top management). In this instance, the question is whether the synergistic effects of operating the manned base and the platforms in the same program outweigh the management burdens of a more complex and disparate program.

To begin to answer this question, the following two key questions must be examined in further detail:

> What are the common operations possibilities between these Elements? The Summary Report (p. 60) identified a preliminary set of those areas:
>
> . Co-orbiting platform servicing at the manned base
>
> . Common support services such as engineering support, transportation and logistics services, and tracking and data relay services
>
> . Some commonality in support requirements due to system/ORU-level commonality
>
> Do these possibilities warrant integration into one facility? In particular, should both the Space Station Control Center and Platform Control Center (and the supporting infrastructure) be integrated into a master Control Center for both the Base and Platforms support? Implicit in this question is the level of controller work required to support the Platform, i.e. are Platform operations mostly autonomous and require little controller monitoring or will it require frequent control? If the answer is the former then certain common (Manned Base and Platform) controller positions could be candidates for consolidation as should the facilities. If the answer is the latter, then controller positions and facilities should be kept separate.

The relevant issues are the following:

> . Should the controller function be element-dedicated (advantage of concentrating on nominal/off- nominal operations; superior support to on-line users requiring dedicated support)?
>
> . Does economy of consolidation required by this approach exist (though construction of facilities may be reduced and possibly the division of labor, this requirement would also demand that a controller be an operations expert on both systems and consequently would reduce his or her effectiveness at the console)?

At the execution level, only the two aforementioned requirements are common and, therefore, may not justify consolidation. As an initial assessment, it seems plausible that platform activities are sufficiently independent of those involving the manned base that greater productivity would occur by forming separate programs for operations. The resulting interfaces between programs would be less difficult than trying to run them as a single program. However, given the complexity of each element and the potential real-time demands for resource utilization, the question of consolidation should require further study for common operations requirements.

5.1.5 Program-Level Management and Control

Success of previous NASA programs has depended to a significant extent on having a clear mission and strong lines of communication. Problems have occurred when the direction was ambiguous and authority diffuse. Steps have been taken in response to the Rogers Commission report to provide an increased measure of technical oversight at Headquarters. Establishing a management structure that is up to the task of running the space station is the current challenge.

NASA has the opportunity to not just strengthen its management structure, but to use the space station program to construct an entirely new management philosophy and accompanying set of procedures. Making the most of this opportunity will undoubtedly cause some stress and strain, but the window may not reappear if the present chance is missed.

There are four principal options concerning the centralization of control:

(1) Distributed Program Control. Because most of the technical expertise resides at the centers, technical management has also devolved to the centers. Joint activities are worked through formal and informal interfaces among the centers. HQ provides policy direction, largely in response to political instructions from Congress and its constituencies, including NASA centers. Technical planning at strategic, tactical, and execution levels is distributed to centers.

(2) Strategic Control at HQ. Sufficient staff technical resources are assigned to a HQ support organization to provide analysis and evaluation of strategic issues. This capability is used to address Congress and to give direction to the programs, but tactical planning is decentralized and program control lies with the centers.

(3) Strategic and Tactical Control at HQ. Additional resources in support of HQ permits tactical planning as well as strategic policy and management control. Performance of centers on tactical implementation and execution is monitored and evaluated by HQ.

(4) Centralized Management and Production. Strategic and tactical planning and management reside at HQ, and production is concentrated in a single major center, with small support centers in distributed locations. The bulk of core activities are co-located.

5.1.6 NASA Field Center Consolidation

Possible savings or synergies might occur from consolidating organizations, both geographically and functionally. Dispersed NASA Centers permit many regions of the country to participate in Space activities, but also impose administrative coordination and management costs on the various programs. Some of this burden could be lessened for the Space Station by consolidating some groups of functions. There are at least four different consolidation options: co-locate production and launch facilities, co-locate all operations facilities, maintain distributed but non-redundant facilities, and maintain multiple centers with backup capability.

The second option is implicitly the issue of whether all flight and ground operations should be centralized at KSC. To begin to answer this question, the following two key questions must be examined in further detail:

What are those flight and ground operations functions to be performed? Those include, but are not limited to, the following areas:

. Proposed Space Station Program (SSP) functions (e.g. the Space Station Control Center, the Platform Control Center, the

Payload Operations Integration Center)

. Existing National Space Transportation System (NSTS) functions at JSC and MSFC (e.g. the Mission Control Center, various training and simulations facilities, and support personnel)

What are the benefits of centralizing? Those include, but are not limited to, the following:

. Ease of user integration (e.g. minimize number of Program contacts to deal with)

. Facilitation of end-to-end prelaunch checkout activities

. Economy of certain resources (e.g. lower travel costs, potentially higher frequency of meetings)

. Unification of training activities (e.g. consolidated modelling and simulation efforts).

The following are relevant issues:

. Costs of relocating existing NSTS functions (immediate budgetary risks/impacts to existing and planned programs)

. Disruption to ongoing operations (a transition phase for migrating existing NSTS functions would occur possibly resulting in a reduced level of efficiency).

. Degree of common NSTS and the Space Station operation (as driven by Program integration activities and interfaces and joint facility usage requirements).

With the exception of logistics and payload integration, most existing NSTS and Space Station operations are not required to be at or near the launch area, i.e., these functions appear to be launch pad location independent. Therefore, the requirement for centralizing functions at KSC appears to be lessened.

5.1.7 Shuttle/Station Consolidation

Should the NSTS and Space Station operations development and conduct be kept separate or should they be combined? Similarities (e.g., on-going operations, reusable components) between the two programs, their degree of interdependency, and their distinctness from other NASA programs, suggests possible synergies from consolidation. The principal options are the following:

-Combined Shuttle and Space Station Organization.

-Separate Arms-Length Organizations.

The advantages and disadvantages of one large Program versus two separate programs are listed below:

Advantages:

. Simplification of facility/system integration

. Enhancement of interdepartmental communications flow and collaboration

. Minimizing the duplication of effort.

Disadvantages:

. An operational and a developmental programs under one roof (the NSTS Program is well-defined and established relative to the Space Station Program)

. A joint Program would constitute roughly 2/3 of NASA's entire budget (competition and allocation of funds)

. Program charters are inherently different and potentially incompatible, i.e., NSTS and Space Station have unique user support requirements and operational objectives

. Differing lifecycles, i.e., Space Station up to 30 years

. International partnership in Space Station (different motivation)

. NSTS for civil/ military vs. Space Station civil only.

Summary of Impacts Of Combined NSTS/SS Operations

The list of impacts below was developed on the basis of a combined NSTS/SS Operations Program whose strategic, tactical, and execution structure follows the SSOTF recommendations regarding the SS Program that are described in the Summary Report. User accommodation/integration including payload/element integration would all be performed at a consolidated site. Rack integration would be done at DOC or at science/technology site. Execution would occur via DOCs/telescience. The SSSC and POIC would be located at the site.

Impacts that Favor Consolidation

-Symbiosis of techniques among sustaining engineering disciplines

-True retention of "corporate memory" through disciplined management and data collection

-"One stop" user shop at consolidated location ...especially if at KSC

-Quicker response to remanifesting requirements

- Log Module

- Launch Vehicles include KSC-launched ELVs, i.e. reduces stress on launch vehicle processing consistently in long-term routine operations processing

-Accepts reality that true corporate memory departs after a few years and that details must be reconstructed in any case through ownership of a "corporate" responsibility to respond.

-Much more consistent management process and data simplify top-down resource allocation decisions and monitoring success of efforts

-Should reduce number of interfaces, therefore decrease organizational response time.

-Reduces reasons for, or opportunities for, ad hoc political (or other) intervention once the scarce resources are allocated

-Simplifies users' interfaces significantly

-Provides "quicker" response to politically-inspired resource allocation considerations

-Reduces opportunities for uncertainty to "propagate" and affect other decisions

-Simplifies therefore planning process

- Pricing concept decisions
- Resource reallocation

-Supports concept of decentralized rack integration

-Continues to enhance opportunities for commonality of hardware and procedures and other aspects of supportability

-Reduces overall annual operations costs

-Centralizes operations oversight and control-checks in operations era when activities will become more routine

-Centralizes training facilities (except for EVA)

-Separates Space Station crew training from Orbiter (pilot) crew training allowing professional paths to evolve more logically

-Increment management greatly, is simplified. All parties work through, or at, one site during planning reviews.

-Better integration of manned base/platforms functions where common

-Avoids unnecessary competitive tension between NASA centers

-Simplifies international coordination; reduces integration costs

-Significantly improves ability to understand and (probably need a study to prove this) manage operations costs

-Allows NASA Centers to focus on new development project and programs... becoming a "station user" rather than operator

Impacts that Favor Separation

-Separation of "Program Controlled" operations discipline with development organization---loss of symbiosis

-Loss of "Program" control over all aspects of operations ...attendant loss of "ownership" and sense of responsibility for "full" program success

-Centralization of responsibilities tends to broaden responsibilities of individuals covering various functional areas... depth of knowledge suffers in any one function, i.e. "you pay for what you get". Management challenge is to put in place a process which can quantitatively and qualitatively decide how to make the tradeoff and when to exercise it

-Reduces (eliminates) opportunities for multiple NASA centers to establish unique operations skills

-Reduces opportunity to use operations situations for enhancing development staff skills and for leaving a sense of ownership for tough engineering development decisions

-Reduces opportunity to share professional skills required for complementary functions at each NASA center, e.g. crew health

-Doesn't take advantage of existing center capabilities and facilities

-Use of a single site vulnerable to catastrophe

-Some functions still must be redundant at other launch sites, e.g. Vandenburg

-Loses "creative tension" between centers

-Loses NASA-Center sense of "ownership" of Space Station manned-based elements and support systems

C-2

5.2 PERFORMANCE ASSESSMENT PROCESS by Doug Lee

The purposes, rationale, and concepts of monitoring and assessing performance as a management activity have not been established as an integral part of the Space Station Program, and the issues, benefits, and costs of such monitoring need to be presented and reviewed. While giving proper weight to cost considerations, it is vital that costs not be overemphasized to the point that performance, safety, or other outputs are sacrificed or excessively compromised.

Need for Performance Assessment

In funding NASA and the space station, Congress has expressed a desire to ensure that selected categories of costs (e.g., station operations) are not excessive, and that particular outputs (e.g., unmanned space science) are not slighted. In part, this reflects some doubt about NASA's ability to monitor and control costs, and to produce the results that have been promised.

To respond, NASA needs to communicate to its sponsors that it has the management tools that will ensure that its end of the bargain is kept. A well-focused cost and performance management effort would encourage good practices and provide useful information to Congress. This would require that the Space Station Program develop a monitoring system that generates timely information on costs and performance. Costs should be broken down along functional, element, and center lines that permit separate estimation of costs by these units, to a suitable level of detail. Performance measures will be developed that allow the Program's progress toward its goals to be reasonably assessed. Measures of performance can be such things as percentage of crew time available for user tasks (as opposed to housekeeping), and the average elapsed time from the user's request for service to the user's arrival on orbit.

However, assessment of performance must be coupled with incentives for good performance. One useful step is to establish performance and cost objectives for key managers. Execution level managers should be encouraged to take actions that are within their domain while passing information upward that pertains to actions needed at higher levels.

Editor's note: The Panel believed that while the creation of appropriate incentives is very important, the issue is very difficult and complicated. For this reason, the Panel did not attempt any general treatment of this issue (such as might appear here) but rather attempted to deal with it in specific contexts. For example, the discussion of operations cost sharing among the international partners in Section 5.11.3 reflects the belief that the concept of "element-unique" costs is important to maintain incentives for cost control. Other incentives for how the partners relate to each other should also be considered.

Performance-Cost-Risk Assessment

In many decisions relating to station construction and operations, risk or uncertainty is an inherent factor. Making sound decisions will require an understanding of the risks associated with a given course of action as it is affected by a variety of seemingly unrelated considerations such as crew safety, operational supportability, international and space law, systems designs, logistics strategies, and supporting systems contingencies. Because the risk cannot be completely eliminated, acceptable levels of different kinds of risk must be explicitly determined and stated.

The implied performance-cost-risk process can be implemented incrementally, and experience derived for guiding subsequent directions and emphases. The kinds of information provided should be these:

-Inputs: Amounts of labor, materials, and other resources, categorized by function and ordered from direct inputs (e.g., direct labor) to indirect (overhead). These can be forecasted, and used to anticipate needs as well as to validate cost estimation methods.

-Gross Outputs: Both intermediate outputs (components, structures) and final outputs (volumes, consumables, resources, services) can be tracked over time.

-Net Outputs: Shares of outputs used up in production and operation, such as volume occupied by Station equipment, operating power consumption, crew time spent in operation and maintenance, etc., yield the net resources available to users.

-Rates and Ratios: The value of a comprehensive performance monitoring system is the ability to relate various measures to each other. The most obvious of these are unit cost rates, or cost-effectiveness measures. Others include utilization rates (per cent available that is used), availability rates (per cent of intended capacity that is in service), productivity (inputs required per unit of output), and trend paths. Some of these can be compared against external reference norms.

Examples might include monitoring of (1) actual crew time allocation to determine productivity at different activities and identify areas for application of automation; (2) levels of effort spent on testing and verification, at user and NASA sites, to reduce overlap and seek economies; (3) ground transportation costs and requirements to determine optimal assembly locations and transportation procurement policies; (4) effects of delays, changes in schedules, and remanifesting, to evaluate which costs are acceptable and which decisions should be treated as final; and (5) evolution options, to plan ways to improve operational efficiency through redesign.

Most of the inputs for performance monitoring must come from the data systems and analytic tools discussed in Sections 5.3 through 5.7 which follow. Management reports from the performance monitoring system will be produced at frequent intervals for internal use, and summary publications for wider use generated annually.

Principles of Performance Indicator Design

Continuous monitoring and surveillance are needed to ensure that costs are in line with achievements, and that trends are in favorable directions. Performance monitoring is the process of relating inputs, outputs, and costs to each other in a quantitative system that provides management with current information on whether the program is working in a satisfactory way. Major labor cost areas are ground personnel in operations, sustaining engineering, and administrative overhead. An objective of performance monitoring is to eliminate unnecessary labor, improve productivity through more efficient procedures and scheduling, and reduce labor requirements through automation.

A sound performance monitoring and financial management system needs to possess numerous properties that ensure that suitable information continues to be generated, that the information is useful, and that it gets used. There is some overlap in the list below, but all the properties are essential. The first six pertain to the information content and structure, and the last five apply to the process for generating and maintaining the information.

-Measures Partition a Set. A "partition" is a categorization that divides a group of items so that no item falls in more than one category (mutually exclusive) and every item falls in some category (exhaustive). There can be many partitions of the same set, and many different levels of detail. For example, all services available to users would be one set (see Table 4-4), station elements would be another, and each of these could possess a hierarchy of detail.

-Nesting. Indicators at one level should be aggregatable into summary measures at higher levels, and disaggregatable into lower levels of detail. Thus the set of indicators form a hierarchy, or several hierarchies.

-Multiple Perspectives. It should be possible to view the same activities from several perspectives, or in relation to several dimensions of performance.

-Balance. Each partition should consist of categories of approximately equal importance or interest, with respect to the persons using that set of measures. For example, cost categories at one level should be of roughly similar magnitudes.

-Common Interpretation. Indicators should be made up of components that can be unambiguously and universally defined, and should be designed to be interpreted in the most direct and self-evident way.

-Management Control. It is desirable that each indicator be affected or determined by a progressively smaller number of factors, with increasing detail, and that the factors be clearly either endogenous (under the control of the organization) or exogenous (largely determined by factors external to the organization). This should be true at all levels, i.e., factors internal to a given organization will be external to some of its suborganizations.

-Natural Data Collection. All data required for performance measures should be data that are or ought to be collected for other reasons, and the point of collection should be the most normal or least disruptive location for the collection. One-shot and special purpose data collection should be minimized.

-Self Correcting. Internal data processing procedures and organizational transfer and use of the information should tend to locate and identify errors and anomalies. Numerical inconsistencies among data items can be flagged mechanically, and reports should be presented in formats that help users see outliers.

-Cumulative Value Added. Managers at all levels should find the information useful to themselves. Few data need be collected solely because higher management wants them. First line managers should use the information about their organizations both for control within their domains and for articulating external problems to higher level managers. Much of the information useful at one level will not be passed up to higher levels, except in summary form.

-Participatory. A wide range of levels, interests, and perspectives should be involved in the design and refinement of the data categories and the indicators. The process should be under management control, but solicit discussion and absorb inputs from many sources.

-Continuous Refinement. No system is designed correctly the first time and conditions change anyway. A standing advisory committee should be formed of users and suppliers, to continuously review and refine the data collection, measures, report forms, level of detail, and other relevant matters. A good deal of experimentation is inevitable. It is essential that this process lead to stable improvement, not random fluctuations. Failure to accomplish this means that one or more of the above properties is not being satisfied.

Most of the properties tend to reinforce each other, but ultimately they must all be present for the system to work well and benefit the organization. Perhaps it goes without saying that the process must be fully integrated into the organization, that responsibilities for production and maintenance must be clear, and that higher levels of management need to support the process as well as use the information.

Recommendations:

- Establish an operations evaluation assessment system that includes performance and cost criteria and provides key facts (status and trends) to all levels of management. The methodology should be used to evaluate any proposed approach to conducting and supporting operations as the Program develops or modifies operations capabilities.

- Develop hierarchically consistent operations performance indicators at all organizational levels. Indicators should measure services produced, services and capacity utilized (planned vs. actual), input resources consumed for each type of service produced, and unit costs. The indicators will allow investigation of tradeoffs along many dimensions, such as shifting from attended operation to automated, from pre-planned schedules to adaptive control, or from low-demand high-cost services to high-demand low-cost services. See specific suggestions in Chapter 2 relative to implementation of a Performance Assessment System.

- Develop incentive programs tied to performance-cost management. Establish performance and cost objectives for key managers. Consider incentives for how the international partners relate to each other.

5.3 OPERATIONS COST MANAGEMENT by Doug Lee

Success of the Space Station will depend heavily upon how well the Program is able both to design elements and systems so as to minimize life-cycle cost for a given level of performance, and to operate the Station so as to reduce costs through learning and experience. Thus it is necessary to inject a consciousness of costs into all Program decisions, starting with design and construction.

The first section, Challenge and Importance of Cost Management, explains why the operations cost management challenge in the Space Station Program is unprecedented in NASA's history. Because this is an area in which NASA has not had much experience, the second section, Requirements for Effective Cost Management, develops the necessary background. The final section, Implementation of Cost Management Planning, describes the recommended steps for the Space Station Program.

5.3.1 Challenge and Importance of Cost Management

Recurring costs first became important in the Shuttle program, as manned missions shifted from single-event efforts to repeated flights of a similar nature. The expectation that unit costs would decline with additional experience has not yet been achieved with the Shuttle, and there are many possible factors contributing to this result. Much has been learned and put into practice, much remains to be put into practice, and much remains to be learned.

Several characteristics of the Space Station Program add to the difficulty of design and operation. Some are common to any large organization engaged in a complex task. Others are unique to the specific task or the specific organization. All must be addressed if satisfactory cost control is to be achieved.

Long Lifetime. With an expected time horizon of over thirty years, operating costs will dominate the total cost picture. Even when discounted back to present-year dollars, operations costs are over half of life-cycle costs (LCC).

User Interactions. The intention is to make the Station "user friendly," with short lead times for payload decisions, single point of contact for users, minimum user costs, and extensive user involvement in design, utilization planning, operations, and evolution. Such high quality and open-ended service levels tend to be costly, as well as hard to estimate beforehand.

Engineering Integration. The Space Station will be composed of many complex systems and subsystems. Each system and element must be integrated with the others, e.g., command and communications systems must be interwoven with hardware elements and life support. Coordination and synthesis of these systems requires a great deal of consultation and interaction among skilled professionals.

Multipurpose Facility. The Station will supply multiple services to a diverse array of users, whose needs are only partially understood now and will change in difficult-to-predict ways in the future. There is little a priori experience inside or outside NASA on which to base forecasts of service and resource requirements.

International Partners. Participation by several independent nations in the Station creates cost management challenges on both the development side and the user side:

- Commonality. Coordination of international standards exacerbates an already difficult design problem.

- Duplication. Each nation wants to increase its knowledge and capabilities in all aspects of space research as quickly as it can; centralizing functions in single locations has already met with substantial resistance.

- Development and Logistics Coordination. Decisionmaking and knowledge transfer are another level more difficult, hence costly, when different governments, cultures, and languages are involved.

- Cost Sharing. Shared costs will be suspect unless all partners are convinced that cost management is sound and equitable. Effective cost control incentives need to be built into each partner's management.

- Utilization Planning. As with construction and operations, each partner desires to gain as much independent experience as possible in areas of interest and potential economic benefit, tending to result in inefficient division of labor and functions if not properly managed.

Evolutionary Design. The configuration of the Station and the operating systems and procedures will need to evolve over time in response to advances in technology and user demands. It is much easier to gradually reduce unit costs for the production and operation of a static design.

Commercial Potential. To maintain its role as a research and development agency, proven processes and technologies must be spun off into the private sector as they become viable. Accomplishing this requires -- as the feasibility of conducting various activities becomes proven -- that hardware and procedures evolve from a research mode to a commercial mode. Unit costs must decline correspondingly, at the same time.

Continuing Research. There is now and will continue to be a major research component to Station design and operation, and specifying research results and costs in advance is difficult at best. Nonetheless, it is essential to improve the Program's ability to anticipate research progress and results, estimate costs accurately, and create incentives to solve research problems efficiently and then move them into a routine production mode.

Dispersed Centers. The Space Station will be designed and produced at roughly half-a-dozen NASA Centers around the U.S., plus some additional number of locations in other countries. At each Center, production is carried out by a mix of public and contracted private organizations. From the standpoint of efficiency, a single site of production and launch and a single producer probably would be the least costly, but the nation prefers to involve many regions and many participants in such major endeavors. The Program has identified specific development assignments for the Centers that have the requisite technical expertise. To the extent that distributed production remains the norm, the Program must craft a very responsive management approach to deal with the natural autonomy of the Centers, the tendency toward competition and possible duplication, and the variety of administrative practices that currently exist.

Performance Demands. Perhaps more than any other public sector agency, NASA has extremely high performance expectations demanded of it. Safety must be uncompromised, often at very high cost, to avoid public outcry. Any and every malfunction is all too readily apparent and immediately visible through the national and international press. Routine accomplishments and extended periods of faultless operation are never sufficient to outweigh the errors and accidents. Revealed flaws often result in political micromanagement that is counterproductive. All of these considerations create enormous upward pressures on costs, and only a highly disciplined organization can exercise effective cost management in the face of such conflicting demands.

Each of these potential obstacles is addressed in the next sections, to determine the best solution to the problem, and to enumerate the steps that have been and need to be taken to implement the solution.

5.3.2 Requirements for Effective Cost Management

To deal with these challenges, it is necessary to structure the Program to be flexible and adaptive. Ideally, the space station program should move up a learning curve, starting with the best balance of estimated up-front construction costs plus long term operating costs, and refine that initial approximation toward longer design life and lower unit operating and maintenance cost.

Conditions needed to achieve effective cost management can be grouped into four areas. Organizational measures, process controls, and analytic tools are described below in this section. Financial data requirements and performance monitoring objectives are described in later sections.

Organization

A basic requirement for cost management is an organizational structure within which the cost management function is an integral part. As elaborated below, cost management is far more than simply auditing, and demands much more than simply accounting. Thus cost control is not achieved by having a normal budgeting and financial reporting unit charged with the broader cost management function.

The Cost Management Function. Effective cost control involves numerous routine and non-routine decisions made at all levels of the organization, with data and analyses that are also drawn from all levels of the organization. Hence, cost management is dependent upon a complex system of information flows and decision points, each incorporating incentives that are appropriate for the decisions being made at that point. In private firms, decisions are delegated to cost or profit "centers" that are intended to permit decisions to be decentralized yet made in the interests of the larger organization.

Thus the challenge to the Space Station Program is to create a functional structure that includes the necessary components of cost management at the appropriate levels and in the most suitable units. All aspects of the cost management function need to be recognized, assigned to an organizational unit, and supported by explicit mission statements and the necessary human resources.

Separate Identity for the Space Station Program. Cost management cannot begin until Space Station funds are separated from other NASA programs, at the highest feasible level. It then becomes the responsibility of the Program to achieve its objectives within an agreed-upon budget. The Phillips Commission, the Rogers Commission, and the Space Station Operations Task Force (SSOTF) all strongly recommended this separation of identity for each program, along with the associated responsibilities.

With performing Centers working on several programs at once, this separation is hard to enforce. It must be possible, nonetheless, for management accountability to be separately identifiable for each major program and subprogram.

Clear Lines of Authority. Not only must responsibilities be clear and unambiguous, those with responsibility must have the authority to take actions that will allow their tasks to be achieved, and they must have the analytic and information resources needed to exercise that authority in an enlightened manner.

This means that responsible organizations must be both informed and empowered, whatever their place in the organizational hierarchy.

Process and Procedures for Decisions

With organizational functions and units as the building blocks, processes for making decisions need to be explicitly designed and implemented to give cost considerations their proper emphasis. This applies whether decisions are routine or special. Decision processes include single-purpose task forces and panels, broad-purpose commissions, internal change review procedures, standard operating procedures, management of exceptions, pricing and cost assignment algorithms and incentives, and forums for negotiating agreements.

A number of characteristics can be considered for evaluating the desirability and effectiveness of such processes:

Response Time. It should be possible for the process to produce a workable decision in a timely fashion. Routine decisions should be made quickly, yet incorporate relevant information, meaning that the information -- including cost -- must be readily available. Major evaluations of plans and directions will take longer, and require deeper and more specialized analysis, but such requirements should be anticipated and accomplished without imposing delay on the Program.

Decision Level. A fact that is seldom recognized in government is that kicking cost approvals to a higher level does not necessarily lead to better decisions. It may slow the rate of expenditure, but it does not result in lower costs. The appropriate level is that which encompasses the major consequences of the decision, and expenditure authority as well as management responsibility should reside at that level. Higher management levels need to be able to monitor and evaluate decisions at lower levels, but not by substituting for or replicating the context that is the optimal one.

Participants. Each decision should be made or influenced by those having the greatest stake in its outcome. Most decisions have both cost and performance impacts, so those persons having knowledge of the performance tradeoffs should also be given incentives to address the cost side as well.

Information Support. Sound decisionmaking must be based on accurate and current information. Procedures for acquiring, storing, retrieving, and analyzing cost management data need to be developed as an integrated system, similar to other systems. With numerous dispersed sources of data and numerous dispersed users, the design and coordination requirements are strenuous.

Development Phases. Different cost considerations and incentives will be relevant during each phase of the Station's life. During the Development phase, emphasis will tend to be placed on minimizing initial design and construction costs rather than life cycle costs. Hence, counterbalancing incentives are needed. During Space Station assembly, operating costs will become more apparent, but the emphasis will tend to be on short term fixes so as to meet schedule milestones. During the Operations phase, improvements involving several elements or systems will be difficult to implement, and thus are unlikely to occur without strong supporting documentation.

Analytic Tools

Successful cost management is supported by analytic tools that permit costs of varying scopes to be estimated from available data, that generate forecasts of cost time profiles under alternative scenarios and conditions, and that model the tradeoffs between cost and performance for many critical decisions. These analytic tools take time to design, develop, test, validate, and place in operation, similar to hardware elements and software systems. Efforts to create and install these tools should proceed in tandem with development of the Station itself.

An important reason to develop such tools is that it leads to independently replicatible results (anyone can go to the model and get the same results from the same inputs), as opposed to repeated "grassroots" budget re-estimates. However, to obtain maximum return from such a tool, it should have a number of characteristics. These are described in Section 5.4.2. Once developed, there should be a single "official" version of the model and database, continually refined and updated, used as a consistent reference for crosschecking. Model analysis should be cited in change requests and other documentation.

The types of tools used for short term forecasting may be very different from those appropriate for long term forecasting (or cost estimation). Short term forecasting emphasizes short term extrapolations under most-likely conditions. It is closely tied to current financial data, and is used to track current expenditures and assess deviations from planned figures. Cost allocation is frequently involved for the purpose of breaking aggregates into various functional and institutional categories, either because the breakdown is an inherently arbitrary distinction among overhead expenses, or because the detailed data to support the categorization are not yet available.

Long term cost forecasting, rather than a projection of current data, attempts to model the cost object and provide estimates of key model coefficients based on historical experience with similar programs. Cost estimating relationships (CERs) are generally derived through a statistical analysis of related programs. The statistical analysis is used to derive the coefficients of key parameters and these are then combined with estimates of these parameters for the program in question to produce a cost estimate. Some other forecasting models are activity driven and are not derived from statistical analysis.

Both short term and long term cost forecasting in the Space Station Program currently tends to be done in an ad hoc and non-replicatible form. Existing management practices frequently do not place a high value on the collection of cost and schedule data that will support either the use of existing models or the development of new ones.

Producing a research facility that is designed to operate for a long time, with continuous modifications to procedures and components, at a declining cost over time, is a major challenge. In part, this is a problem of design emphasis, placing high value on simplicity, basic reliability, modularity, and flexibility for growth, instead of high-performance, highly redundant, custom-built, one-shot devices.

It is also a problem of increasing initial cost to obtain lower long run operating cost. Most importantly, the problem is one of creating incentives for such design from the start. At this point in the space station program, steps must be implemented to institutionalize the concept of designing to life-cycle cost into the next phases of engineering and construction. Headquarters levels need to create a program requirement for lifetime cost-effectiveness, and the mechanisms to enforce it. System-level contract proposal instructions must indicate to bidders how long term costs will be evaluated. Finally, budget constraints on the construction phase of the station must result in reduced program requirements, not in up-front cuts that add to costs later on.

Evaluation of engineering and operations alternatives must incorporate design, construction, launch, assembly, operation, and user costs, and explore tradeoffs (initial cost, operating cost, net station output) through modeling. Models should consider all operation and maintenance costs and do this early in the design phase. The database should be updated continually on the basis of improved information. A more detailed discussion of cost modeling is contained in Section 5.4 below.

The innovation here is the addition of "life cycle" to the Design-to-Cost process, which previously only considered development costs. DTLCC is intended to be an iterative process, which requires coordination, common ground rules and data, and strong management incentives. Cost-design tradeoffs must be made continuously, in the light of experience and forecasts.

5.3.3 Implementation of Cost Management Planning

The major components of a cost management system were outlined above, along with objectives and criteria for each component. In the three areas presented, actions are being taken by the Space Station Program to implement a strong cost management capability. Some actions and decisions have already been taken. Other efforts are in progress, and initial systems or models are in place. Yet other steps are in various stages of consideration, problem formulation, proposal, review, recommendation, and commitment.

As enumerated and described below, these actions are listed in order, within each of the three (Organization, Process, and Analysis Support) areas, from past to future. Thus, those at the lower end of each list are more tentative than those at the top.

<u>Organization Recommendations</u>

Organizational changes consist of permanent reorganization of the Program's management structure. Included are newly defined functions, roles and missions, and information flows.

<u>Design and Implement SSOTF Functions Structure</u>. In the recommended operations concept presented by the Space Station Operations Task Force (SSOTF), cost management is integrated into the functional hierarchy at the strategic, tactical, and execution levels (both for mature operations and for the transition period from development to mature operations). Implementation of the SSOTF operations concept will greatly enhance the Program's ability to conduct strategic planning and cost analysis, and to exercise management control. Further success in managing costs will depend upon the fidelity with which this recommended structure is put into place. The Program management structure recommended by the SSOTF separated the operations and development functions to provide a counterbalance to pressures to minimize upfront DDT&E expenditures at the expense of larger expenditures during later years.

This functional organization provides a strong, hierarchical superstructure at the upper levels of the Program, to counterbalance the matrix organization at the execution levels.

<u>Centralize (at a single location) Sustaining Engineering</u>. The SSOTF recommended gradual centralization of sustaining engineering functions at KSC, commensurate with Program management determination that the corresponding space systems have reached their performance maturity. Depot repair activities would eventually be located entirely at KSC, but the analysis and assessments portion of sustaining engineering would remain at the Centers where the components were developed. Logistics support will be transferred to KSC within one year after the system or element has been delivered to the Program.

<u>Establish Logistics and Supportability Function</u>. A high-level focus is needed within the program on logistics and supportability concerns, which is being implemented in the form of Logistics Support Analysis (LSA) at HQ. This is consistent with the focus on life-cycle costs throughout this cost management section. The RFP for the PSC (Program Support Contractor) includes LSA among its tasks.

Establish A&R Advocate at HQ level. NASA proposes (and the SSOTF concurs) establishing a position within the Operations Division (NASA Headquarters) with responsibility for advocating automation and robotics. This position is to ensure that artificial intelligence and automation receive the appropriate emphasis during the technology evaluations and during the efforts to prepare for the operations phase.

Management Information. Several information systems are being designed to provide managers with improved cost and performance information in a timely manner. These include TMIS (the Technical Management Information System) and SSIS (the Space Station Information System).

Recommendations Concerning Process and Procedures for Decisions

Where numerous decisions must be taken, at all levels, in which cost is one of several factors, the processes by which decisions are made and the incentives affecting the decision makers are more important than the specific substance of each decision. Having a good process in the right place is better than having the right answer in the wrong place.

Institute Formal Change Request Review and Approval Process. A formal change request review and approval process should be instituted to evaluate impacts of proposed configuration and service changes. Review includes impacts on safety, net station outputs, reliability, international agreements, as well as costs. Requests would be submitted by Centers/contractors and approved by the Space Station Control Board (SSCB), in consultation with other HQ units.

NASA utilized a formal change request review and approval process in Phase B. Change requests were reviewed by Level B, in conjunction with Headquarters and the four Work Packages. Changes to program requirements required approval by the Space Station Control Board (SSCB, chaired by the Program Director).

Although the following description does not represent a complete plan for processing change requests, these elements should be covered:

- o Use of a model, such as the System Design Tradeoff Model (SDTM) discussed below, a tool for analysis and accounting of the many impacts of such changes, in particular:
  - Lifecycle cost, including DDT&E and operations cost
  - Net station outputs
  - Size of systems/elements
  - Effects on other systems/elements
- o Evaluation of these and other important impacts, e.g. the impact on safety, reliability, and international agreements, which may be difficult to capture within a modelling framework. Evaluation criteria include feasibility, user friendliness, and cost effectiveness.
- o Life-cycle cost data should be reported in levelized annual cost (levelized in either constant or current year dollars), base year LCC, and current year dollar LCC terms.

Formalize the Operations Cost Management Process

The Task Force concluded that the Space Station Program should adopt an annual operations cost estimating process which accounts for all major activities required for Space Station operations.

- o All operations costs considered to be significant should be identified, including on-orbit and ground facilities, hardware, support systems, and procedures development.

- o User costs influenced by Space Station policies and procedures should also be identified and tracked.

- o The cost analysis process should be formalized at the Program Requirements and Analysis (PR&A) level.

- o To facilitate a formal cost management process, the Program should attempt to establish a logical consistency between the Program Work Breakdown Structure (WBS) and the Unique Project Number (UPN).

Establish Design-to-Life-Cycle-Cost Process (DTLCC). This would be a Headquarters management technique to define Space Station system and element designs that minimize the life-cycle costs of meeting prespecified performance requirements, given the annual program funding constraints. DTLCC would begin during the design and development phases and iteratively approach the best design as information is passed back and forth between headquarters, NASA field Centers, and contractors. The process would continue until all system/element interface and design choices have been made.

NASA should require WP and PSC proposers to offer an integrated life-cycle cost evaluation process as part of the design-to-cost effort. This integrated effort should reflect an LCC subprocess which permits evaluation of the WP unique issues and evaluation of system unique changes that cut across all areas of Station operations and may impact several work packages.

Contract Incentives and Evaluation. NASA should require proposers to suggest an incentives and awards schedule based on validated prototyping of specific supportability concepts such as the reduction in IVA maintenance hours across the station as a result of improvements proposed for one WP. NASA should direct the PSC to develop a two-tiered concept for proposal evaluation which provides awards for contractor proposals which may reduce overall operations costs but which may increase a particular WP contract costs. Suggestions by one WP contract may affect costs and performance by another. Contract clauses must be drafted to allow for such synergism. Supportability and operations costs goals (bogeys) may be suggested for each WP functional area prior to final contract negotiations.

Establish Operations Cost Benchmarks. An array of operations cost targets/benchmarks would be established for each element and system, to be used to evaluate proposed changes. A process should be established for comparing cost projections with cost estimates from contractors, at scheduled Program milestones, and the results reported annually or as needed.

Life Cycle Cost Reserve. Without a reasonable expectation of funding for design changes, Program managers and their contractors can not be expected to diligently search for life-cycle cost-reducing innovations. Because significant operations cost reductions are most likely to be achieved early in the design process, it is important that a life-cycle cost reserve fund be set aside early in Phase C/D to support improvements in design.

This reserve pool might function as follows. The Program Director would allocate development funds, over-and-above initial work package allocations, to fund approved life-cycle cost saving DDT&E investments. Any work package could propose DDT&E investments for its systems/elements that yield projected Station life-cycle cost savings. Typical investments might include higher efficiency motors (requiring less electrical power), lighter components (requiring less launch capability), and higher mean time between failure components (requiring less astronaut maintenance and logistical system capacity). Proposals for more complicated design changes would also be expected. The primary criteria would be the degree to which total station costs are reduced. Those investments with the highest life-cycle payoff per dollar invested would be approved and funded first.

Alternative Contractual Management Mechanisms. Current cost-plus format may be suitable for R&D efforts, but recurring or routine cost items should be obtained through contracts with different incentives. Some alternatives have been explored, and success is mixed to date. Distributed projects might be managed by HQ SE&I rather than Centers.

A recent change has been to make Work Package managers responsible to HQ Program managers rather than to the Center Directors where the Work Packages reside. This reorientation will give strategic-level managers greatly increased control over costs and performance.

Annual Operations Cost Summary Report. A regular report should be prepared annually for informing management and Congress of historical cost profiles, current expenditures against previous estimates, and projected costs. These figures will offer several types of breakdowns, but not in great detail, so as to provide a clear overview of how well the Program is succeeding in its effort to monitor and control costs.

This cost management report will be closely tied to performance measures (output, productivity, utilization, etc.) generated by the performance monitoring system.

Recommendations Concerning Analysis Support

Development of tools and procedures is necessary to predict operations costs, to factor operations cost considerations into the design and development process, to encourage NASA managers and their contractors to actively search for ways to reduce life-cycle costs, and to monitor progress toward achieving cost-effective Space Station operations.

Cost Estimation and Forecasting Methods. A group of simple estimating and forecasting tools should be constructed for establishing targets (or benchmarks, or "bogeys") and monitoring progress. These tools can utilize spreadsheets and other off-the-shelf software, until specific needs go beyond these capabilities. Emphasis will be placed on utilizing data that are currently collected and available through normal budgeting and accounting channels.

NASA has developed, or is developing a number of tools in this area. One such tool, an operations cost model, is described in detail in Appendix A.

Software Costs and Cost Estimation. Software is a major cost component, and one that is difficult to estimate. Also, success at improving productivity through automation will depend upon the effort expended on developing and implementing software.

Recent NASA experience indicates that the size and complexity of flight and ground software is increasing, and software is playing an important role functionally and costwise. It is central to automation, robotics, expert systems, data handling, and communications, both on the station and on the ground.

Software cost estimation poses a major challenge for several reasons. Most importantly, all work packages will use a common Software Support Environment (SSE) and the Ada language. Unfortunately, there is no software costing database for this combination of technologies. Therefore, it is necessary to either develop new models or modify the existing ones to reflect the unique Space Station software characteristics.

Efforts are being funded to improve software cost estimating techniques. Models of the software development and maintenance process that reflect NASA's characteristics are needed to facilitate software management efforts and improve the capability to assess automation and robotics applications. When operational, these models will be integrated into a life cycle cost model for the entire station.

Construct System Design Tradeoff Model. Implementing the DTC process will require the development of a system design management model that calculates each system/element's indirect costs. The system design model would calculate the gross system/element sizes required to provide prespecified net user services (net of housekeeping requirements), and estimate the housekeeping consumption costs for each system/element. This enables each designer to consider the cost impact of using services provided by other systems/elements.

In Phase B, NASA developed very preliminary prototype versions of such a model, in the System Accounting Model (SAM) developed at JSC and the System Integration Model (SIM) developed at JPL. The System Design Tradeoff Model is a more refined version of these models. *Editor's note: This model was initially called the System Design Management Model (SDMM) and later the System Accounting Model (like the earlier model developed at JSC). SDTM is the usage within the program in 1988, and references to this model have been changed throughout this report to conform to this.*

Establish a Performance Monitoring (Program Diagnostics) System. A performance monitoring (program diagnostics) system should be established to aid managers in monitoring production and utilization, as well as evaluating costs and cost effectiveness. The system can be implemented incrementally, and experience derived for guiding subsequent directions and emphases.

Most of the inputs for performance monitoring must come from the data systems and analytic tools previously described. The activity can be incorporated into an MIS system. Management reports from the performance monitoring system should be produced at frequent intervals for internal use, and summary publications for wider use generated annually.

References

1. Committee on Science and Technology, U.S. House of Representatives, Report accompanying H.R. 1714, 1986 NASA Authorization, March 1985 [Congressional request that led to December 1985 Space Station Operations Cost Management Report-see reference 3]

2. Committee on Science and Technology, U.S. House of Representatives, Report accompanying HR 5495, 1987 NASA Authorization Act, September 1986 *(Editor's note: This contains a Congressional request for an update to the 1985 report. NASA submitted this report in October 1987)*

3. "Report on Space Station Operations Cost Management," NASA (December 1985).

5.4 MODELING SPACE STATION COSTS by Robert Shishko

This section focuses on methods and models of estimating Space Station costs and on their use within the Space Station Program. The principal conclusion is that a variety of design and policy questions can be addressed in a cost-conscious environment only if costs can be confidently estimated. While the effort required to build the methods and models for such estimates may be high, the payoff to the SSP is significantly higher. Appendix A describes a particular operations cost model in detail. Appendix B describes some results from this model that were generated for, and presented to, the Task Force.

5.4.1 Why Model Costs?

A life cycle cost model, when properly constructed and supported, can provide a systematic link between program design and operations decisions and policies on the one hand and the LCC implications on the other. Another advantage of using a model arises from the fact that the answers one obtains are independent of who runs the model--that is, are reproducible by anyone in possession of the same input data.

An alternative to a cost model is to conduct a continual series of "grass roots" estimates. Each time a new "what if" question was raised, a new estimate would have to be made. Each change of assumptions voids at least parts of the old estimate. Consequently, such cost estimating "exercises" have transitory value only. Because this process is time-consuming and labor-intensive, the number of such exercises that can be conducted is in reality severely limited. Reproducibility is not guaranteed either. Even if costing assumptions were held constant from exercise to exercise, those interpreting the assumptions and making the estimates may be different as organizations change over time.

One-time cost exercises do have value in two ways. They may provide a way of validating a cost model (or its parameters), and second, they may provide the cost modeler with special insights into the true sources of costs.

5.4.2 Characteristics of a Useful Model

All models are not created equal. There are a number of very desirable characteristics that determine the long-run usefulness of a model. These are described below.

Multiple Use Capability

More often than not, models are developed and used for a particular project or study and then are discarded. Generally, this occurs because a model tailored for one purpose or study is unable to address a different, though related, issue. Space Station cost models should be able to address a number of cost issues and support a number of applications. Some of these applications might include: (1) supporting design-to-life cycle cost studies, (2) aiding international cost sharing negotiations, (3) supporting pricing policies, (4) helping budget preparers, (5) performing operations cost risk assessments, and (6) evaluating contractor estimates.

These applications will occur during Phase C/D, and some will continue into Phase E. It will be necessary to have the appropriate interfaces so that each Space Station organization will be able to extract the particular data it needs, but there is a clear benefit to having a single high-level cost model off of which the entire program operates.

Transparency

A second desirable characteristic is that of transparency--that is, the algorithms, parameters, supporting data, and inner workings of Space Station cost models should not be hidden from the user. The clear benefit of this is in the traceability of the model's results. Not everyone may agree with the results, but at least they know how they were derived.

Transparency also aids in the validation process. It is easier for a model to be accepted when its documentation is complete and open for comment. Proprietary models often suffer from a lack of credibility because of a lack of transparency.

User Friendliness

User friendliness, clearly a desirable characteristic to a new user, is often used to describe models that are not. What is user-friendly to one person may be a nightmare to another. Notwithstanding this abused term, Space Station cost models should contain on-line help and definitions, should be menu-driven where possible, have a clear logical structure, come equipped with clear documentation, and should require only a few days training for the first-time user. The model should be furnished with a complete default or baseline case so that users with narrow specialized interests should be able to use the aspect(s) of the model of interest without having to specify other aspects.

One aspect of user friendliness is portability, such that it is possible to install or access the model with minimum equipment, cost, and hookup effort, so that it can be widely used for analysis. The ideal is compatible PC-based software, or time-share if the code becomes too large.

Growth Potential

It is likely that as the Space Station program moves from Phase C/D to Phase E, our understanding of costs will improve. This can be expected because of improvements in the quality of data and our understanding of the underlying processes. Space Station cost models should be designed to make data and algorithm updating routine.

A growth potential also means that the appropriate scars and placeholders be available to accommodate new Space Station hardware elements. This capability should allow the user to define alternative evolutionary growth paths for the Station itself.

Responsiveness

Responsiveness of a model is a measure of its power to distinguish among different options. This is probably the most important of the characteristics discussed. Space Station cost models should foremost be responsive to changes in the Space Station design--that is, to changes in the number of characteristics of its subsystems and components. The models should also be sensitive to alternative operations concepts, and to different logistics policies and structures during the operations phase. The models should have the capability to model development-operations cost tradeoffs.

It is possible that changes in the design or operations concepts do not give rise to great changes in costs, but instead act to alter the value of Station operations. This may occur, for example, if a design or operations concept change decreases the amount of available on-orbit crew time. Space Station cost models should quantify such value changes along with projected cost changes.

5.4.3 Modeling Life Cycle Cost

The Space Station is intended to be a multi-purpose facility whose operational life may extend well into the 21st century. While is may be difficult to say exactly how long the Station will remain a productive component of NASA's long-term program, it is instructive to note that the Air Force's B-52s have been active for more than 35 years, and the Navy's Forrestal-class carriers with life-extending improvements will have been active for over 50 years by the time they are retired. It is therefore very likely that the Space Station we build in the 1990s will last for decades before it too is deactivated.

While the appropriate concept of cost for decision purposes is always life cycle cost, that is, the total cost of a project, as opposed to development cost, the importance of this distinction will clearly depend on the relative magnitude of development and operations costs, the two constituents of life cycle cost, in the project under consideration. In the past, cost modeling for space systems has largely focused on the development costs. Such a focus would be inappropriate for Space Station, since over the time horizon envisioned for Space Station, operations costs represent more than half of the LCC, even when those costs are discounted.

The ability to estimate Space Station operations costs systematically is an important part of doing LCC analysis. Without this ability, NASA would be severely hampered in determining what design and operations tradeoffs to make. In short, it would not be possible to determine the minimum amount of resources needed for the Space Station Program (SSP) to provide a given level of capability to users.

Congress has expressed concern over Space Station operations costs on several occasions--for example in a letter to Administrator Fletcher from the Chairman of the House Subcommittee on Space Science and Applications in June 1986. That letter urged NASA to "emphasize the reduction of operations costs" for Space Station, and to expedite "the development of an operations (cost) model" so that appropriate tradeoffs can be made now.

For these reasons, the Space Station cost model must be a life cycle cost model. Supporting this model may be models of development or operations costs, or particular elements of costs, e.g. software costs. Work within the Program to develop this comprehensive Space Station cost model is still in its early stages. Modeling of particular components, e.g. software costs, is not much further along. These tools were therefore not available to aid the Task Force in their work.

Fortunately, the situation regarding operations costs was brighter. As described below in part IV, both Rockwell and the Jet Propulsion Laboratory briefed the Task Force on their respective cost models, and the JPL model became the only comprehensive model used by the Task Force.

Because of this use, the remainder of this section will focus solely on the use of an operations cost model. Appendix A focuses on MESSOC in particular and Appendix B describes an application of MESSOC to a Task Force issue.

5.4.4 Integration of an Operations Cost Model into the Space Station Program

As noted earlier, the Space Station operations cost model for the SSP should be capable of supporting several applications. These applications will naturally shift as the program moves from Phase C/D into Phase E. It is useful at this point to describe in some more detail how the operations cost model fits into the SSP. This description is divided into two parts: (1) maintaining the fidelity of the model and associated databases, and (2) using the model in a coordinated manner across the SSP's interrelated decision processes.

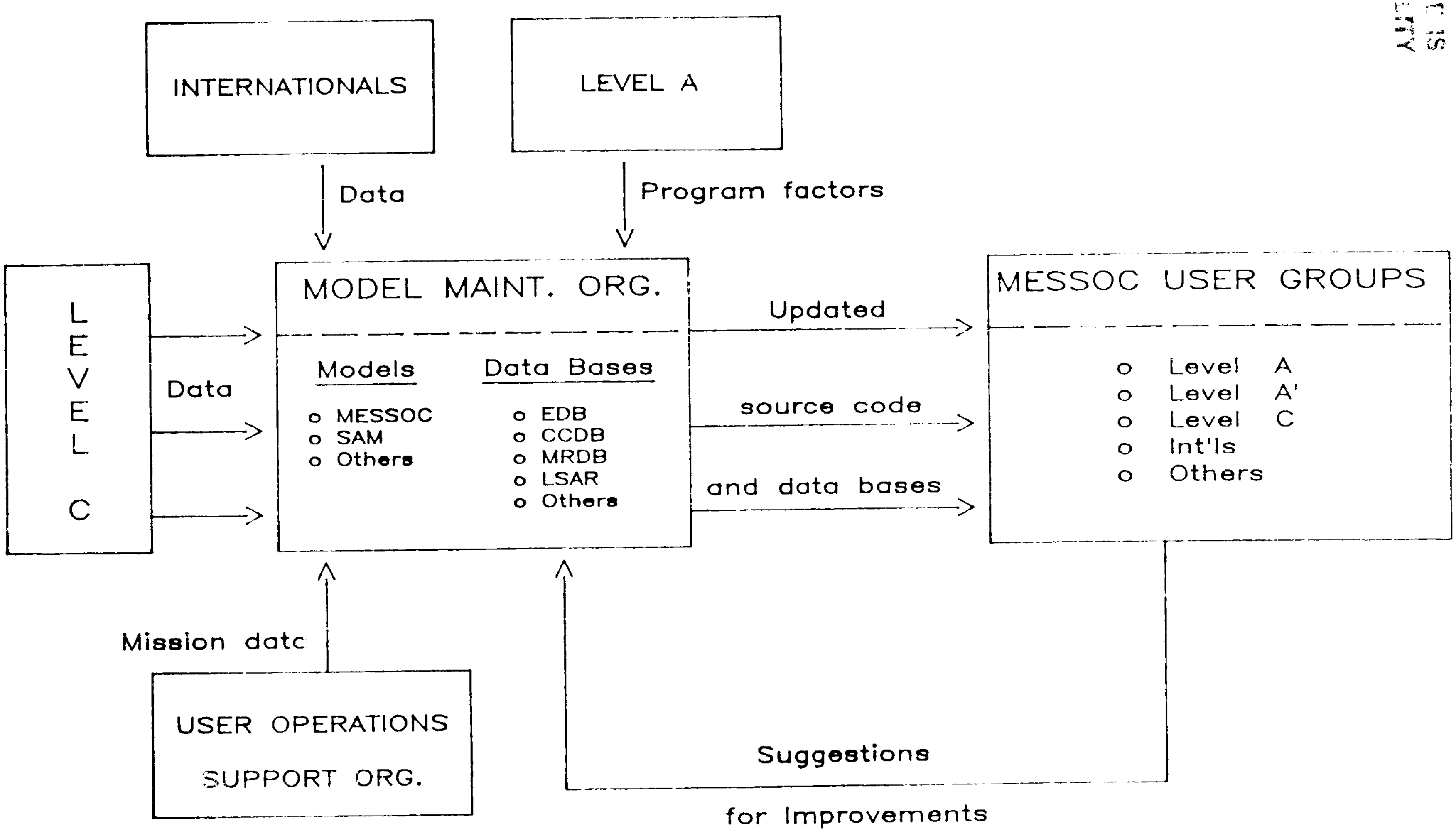
Maintaining the Cost Model

A proposed process for maintaining the operations cost model and other models is described in Figure 5-1. Inputs to the process are specific data from a variety of sources, while the outputs are updated model software and databases to be used in conjunction with the model. The process should be facilitated by the use of the Technical and Management Information System (TMIS).

The heart of the process is conducted by a Space Station Program Model Maintenance Organization (SSMMO). Its job is to ensure the quality of not only the operations cost model, but of all the SSP high-level cost management models. (This function could be extended to engineering and other

Figure 5-1

OPERATIONS COST MODEL MAINTENANCE



EDB = Engineering Data Base
CCDB = Cost and Content Data Base
MRDB = Mission Requirements Data Base
LSAR = Logistics Support Analysis Report

MESSOC = Model for Estimating Space Station Operations Costs
SAM = System Accounting Model

management models as well.) To accomplish this, the SSMMO updates source codes to ensure that algorithms reflect the current program, receives and implements (appropriate) suggestions from model users, maintains copies of key SSP databases such as the Engineering Data Base (EDB), and updates as needed other databases on which the operations cost model may depend.

At such regular periods as may be deemed appropriate, the SSMMO promulgates new source codes and associated databases. For example, the operations cost model may be updated every six months at first, and then annually as Phase E approaches. The associated databases may be updated every month at first, and then quarterly. Dissemination of both source codes and databases could naturally be done through TMIS.

The placement of the SSMMO, while independent of the process, is an important management issue. The SSP-wide and technical nature of the SSMMO function suggests that it initially belongs in Level II. It is recommended that it be located there within the Program Requirements and Assessment (PR&A) organization to facilitate a strong analytic capability.

Using the Operations Cost Model

The relationship of different operations cost model uses during Phase C/D is shown in Figure 5-2. In a sense, it is an elaboration of the NASA portion of the MESSOC User Groups box in Figure 5-1. To describe the relationships in a few sentences tends to understate the complexity of the processes, but the figure alone is insufficient as well.

The Level II Design-to-LCC process would integrate costs (DDT&E and operations) with the engineering and technical decision-making at the system level. The Level III Design-to-LCC process integrates costs with the engineering and technical decision-making at the subsystem level. At both Levels, operations cost estimates (expected values and distributions) are passed to the budget and cost risk estimation process. The budget and cost risk processes are naturally linked vertically in the Program Operating Plan (POP).

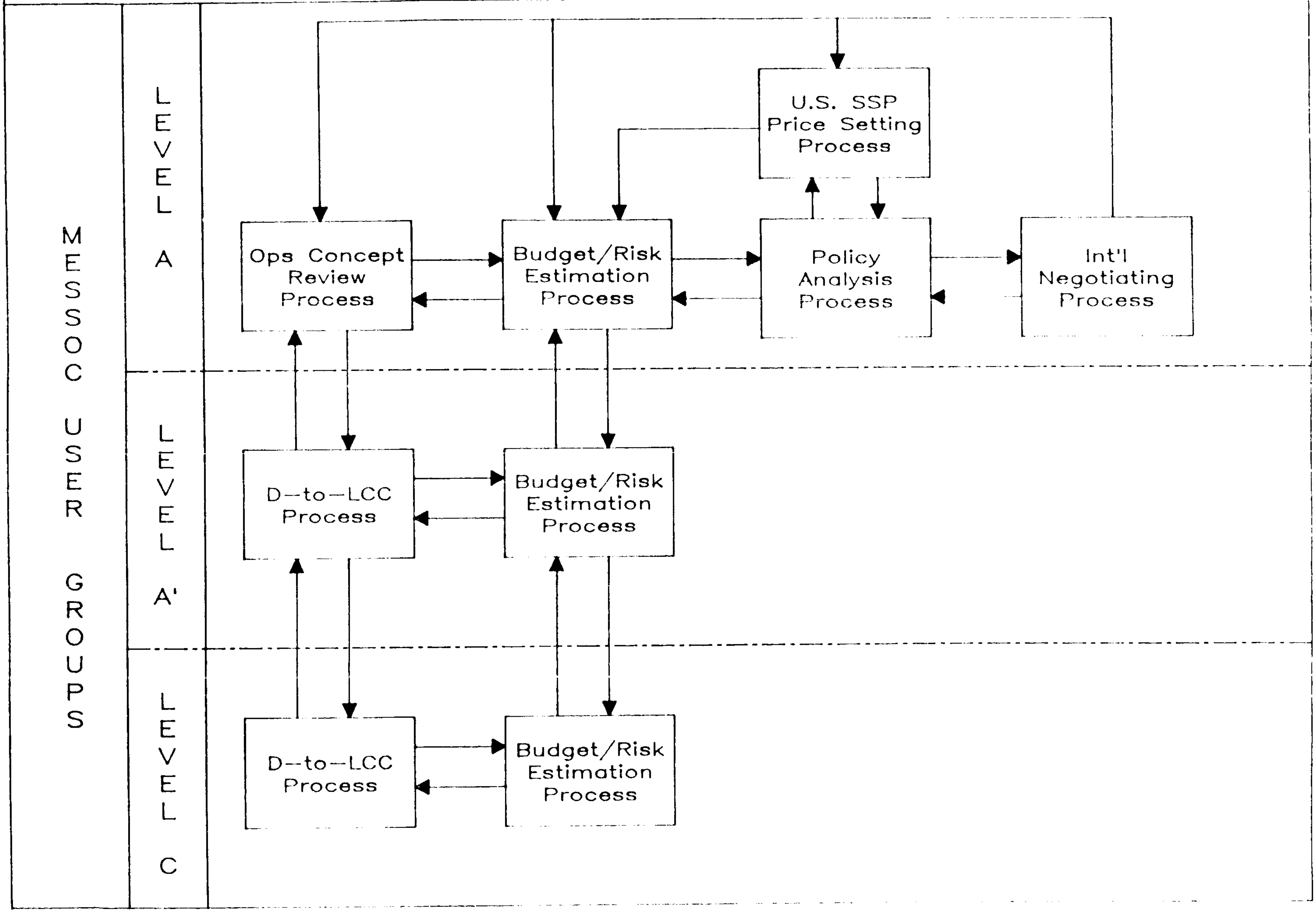
The Level II Design-to-LCC also operates directly in the Operations Concept Review process. Should the Station design change in response to LCC considerations, the operations concept should be recertified against the changes. Similarly, if the operations concept should change due to some exogenous factor, then the Design-to-LCC process should alter the Station design requirements and operations cost estimates.

The policy analysis process at Level I may address a variety of issues during Phase C/D. Almost certainly, these should include Station pricing options and international cost sharing options. U.S. proposals for international cost sharing should be analyzed--that is, have their budgetary effects estimated using the operations cost model--before placing them on the negotiation table; similarly, partner proposals should be evaluated for their budgetary implications. The international negotiating process is expected to converge on a particular operations management scheme and operations cost sharing mechanism. As this occurs, there should be feedback to the Operations Concept Review process, the top-level budget and cost risk estimation process, and the price setting process as well.

Lastly, the operations cost model can be used to determine data useful to the U.S. Station price setting process. What pricing policies emerge from this process will bear directly on how much of the Station's operations costs will be paid by (non-NASA) users. This information also needs to be passed to the budget process.

During Phase E, some of these processes will undergo a transmutation. The Level II Design-to-LCC process may be absorbed by a Level I operations organization that concentrates on the growth and evolution of the Station. The operations cost implications of alternative evolutionary paths can be addressed by the operations cost model

Figure 5-2 OPERATIONS COST MODEL USES DURING PHASE C/D



through the policy analysis process. In that process, the Level III organizations that dealt with LCC will probably still be needed to develop detailed data on proposed new hardware elements. Once such a new element is approved, the budget and risk estimation process comes into play at all levels.

The international negotiating process during Phase E is likely to be less intense to the extent that management-by-exception is successful. There may be a need, however, to adjust the operations cost sharing arrangements as true costs become evident and Station growth is considered. The operations cost model can be used to evaluate proposed changes in the cost sharing agreements.

5.4.5 Assessment of Alternative Operations Cost Models

The Space Station Operations Task Force was briefed by Rockwell International Space Station Systems Division. Rockwell has developed a collection of interdependent on-line simulations and programs. Together these generate operations costs in a variety of forms. Their approach was described as "mission-driven"--that is, given a set of mission payloads to the Station, what are the up-weight transportation requirements, ground requirements, and on-orbit requirements precisely needed to support that set. It was evident that Rockwell had done much to improve the Mission Requirements Data Base (MRDB) to support their approach, and to demonstrate the role of their approach in evaluating different user charge policy options, growth scenarios, and potential Station productivity enhancements.

The Task Force was also briefed by JPL (Jet Propulsion Laboratory) on their model, MESSOC (Model for Estimating Space Station Operations Costs). This model has been developed under funding from Level I and previously from Level B. MESSOC is an "activity-driven" model. In brief, MESSOC asks what activities are programmed for each year; activities may be classed as missions/payloads, transportation, and ground support. MESSOC then calculates what those activities cost, and how much is still available for additional activities or as a reserve. The JPL presentation included examples of how the model could be used to investigate alternative maintenance policies and training policies.

The Task Force noted certain similarities and differences in the two approaches. Both approaches recognize that transportation to the Station will be about half of the annual operations costs, and that the budget impact of Space Station is not the same as the operations costs. Both approaches evidence a common heritage in modeling spares, and both approaches could be used to evaluate certain productivity enhancements such as automation and robotics. Lastly, both approaches could support a Design-to-LCC process.

The differences tend to reside in the details of the models, but two stand out. First, Rockwell's approach represents a collection of models and programs, whose relationship to each other is not wholly recognizable, while the MESSOC approach is a single integrated program under a common user interface that deals with the core Station, platforms, and ground support. Second, the Rockwell approach does not give the same detailed approach to ground support activities as does MESSOC.

5.4.6 Model Recommendations

The SSOTF recommended that MESSOC be adopted as the high-level Space Station operations cost model. In addition to the reasons discussed above, MESSOC has a high degree of transportability across the SSP and lower training requirements for first-time users. Most important, the SSOTF believed that MESSOC will meet the requirements set out earlier in this section, once development is completed. This recommendation is not in any way meant to preclude the use of other contractor-developed operations cost models and programs for specific studies.

Supporting this general recommendations, Panel makes the following additional recommendations:

1. Continued MESSOC Development. MESSOC should be supported into Phase E.

2. System Design Model. The SSP should develop a system design tradeoff model (SDTM) to model life cycle costs and performance. This model should be compatible with MESSOC so that the representation of operations costs in this system accounting model reflects MESSOC results. A validation plan for both models needs to be established and executed.

3. Databases. Both models need accurate data to be of value in the cost management process. While they may require data in a specific format, the databases off of which MESSOC and SDTM run should not exist independently of the rest of the SSP. Instead, the MESSOC or SDTM databases should be reflections of well-established, well-maintained programmatic databases that represent the state of the SSP. The key databases for MESSOC include the following:

(a) Logistics Support Analysis Report (LSAR). This database contains the detailed data necessary to establish and run an integrated logistics system. It must be viewed as one of the highest priority operations-oriented databases within the SSP, and should be placed in service as soon as practical. The maintenance of the LSAR is logically the responsibility of the SSP Logistics Operations Center (LOC).

(b) Mission Requirements Data Base (MRDB). This database contains detailed data on proposed user payloads and servicing events. It is the recommendation of this Task Force that the MRDB be continued, and that it be expanded by adding data elements that would make the estimation of user integration and logistics costs more accurate. The maintenance of the MRDB in the long run is logically the responsibility of the User Support Organization (USO).

(c) Cost and Content Database (CCDB). This database does not formally exist at the present time. It is the Operations Task Force's recommendation that it be established and maintained through at least Phase C/D. This database allows the systematic identification of all flight and ground elements and facilities in the SSP along with their associated DDT&E costs. Certain operations parameters for ground elements and facilities would be available as well, providing the logical link between their DDT&E and operations costs. This database could be initialized with data from the Cost Assessment Activity reported in January 1987. Its maintenance as the SSP changes and matures is logically the responsibility of the Level II Program Control Group (PCG).

(d) Engineering Data Base (EDB). This database contains basic mass, volume, center-of-gravity, and related mass properties information. The maintenance of the EDB is logically the responsibility of the Level II SE&I organization.

International partners should be required to contribute to these databases. This recommendation is obviously non-controversial for the EDB, but some data in the other databases might be considered proprietary or sensitive, and thus might be excluded. In particular, the CCDB might contain only content data for the international partners. In any case, appropriate safeguards could be build in to prevent unauthorized disclosure of sensitive data to the other partners.

4. Standards should be established for analytic studies involving (1) LCC trades during Phase C/D, and (2) Station growth or evolution during Phase E. It is not the intention to list those standards in this report, but only to suggest some examples. The benefit to the SSP is that the cost management process can be made more rational when the alternatives for the Station are presented in a consistent manner with a consistent set of groundrules.

One useful standard might be that all LCC studies involving a change in the Station baseline design or content be required to report results in terms of the net present discounted value of such a change using a SSP-agreed discount rate. This would allow an easier ranking of such changes given the funding constraints the SSP is likely to face. A standard for growth studies might be that all analyses of the operations costs for new elements or hardware be required to submit a MESSOC-compatible database. That would mean, for example, a list of proposed ORUs along with reliability and maintainability data.

5. Organizational Support Recommendations. A Space Station Model Maintenance Organization (SSMMO) should be established, whose function is not only to ensure the quality of the operations cost model, but of all high-level cost management models. The appropriate interfaces between the suppliers of data to the models and the SSMMO should be established. This includes not only the various Level III organizations, but the responsible international organizations as well, for example, ESTEC. Additional interfaces need to be established between the SSMMO and the model users.

Second, within the SSP there needs to be established appropriate mechanisms to ensure that when LCC trades are made, the budget process responds accordingly. For example, suppose that a proposed change in one of the Station's subsystems or in a ground facility is made and justified on the basis of a LCC savings. The change requires an upfront investment, which is to be recovered during operations. If the funds are allocated to implement the change, then the budget process should decrement the outyear operations budgets of the appropriate organization according to the projections of the LCC analysis used to justify the investment.

This requires an enormous amount of budget discipline, and sufficient attention in the annual budget process to the outyears. It also requires a capability to spread operations cost projections to major SSP funding categories. It is therefore recommended that a linkage between operations cost projections and budget UPNs (or group of UPNs) be established as a part of the cost management process.

Appendix A provides a detailed description of MESSOC. Appendix B contains a model analysis generated for, and presented to, the Task Force. This study examines the minimization of life cycle cost with respect to the repair in orbit of electrical and electronic Orbital Replacement Units (ORUs).

5.5 RISK MANAGEMENT/SAFETY by William Pegram[1]

Risk has two common, and related meanings. The first is the possibility that outcomes may differ from their expected value. This is the economist's definition of risk, and is useful for explaining a wide variety of economic activity. Most individuals are risk-averse in most aspects of their personal lives: they buy insurance and they demand (and receive) higher return from stocks than from bonds since the former are more risky. In some ways, however they are risk-seeking; hence the desire to gamble.

One might argue that a public sector agency such as NASA would be risk-averse as well for a couple of reasons. First, if individuals are risk-averse in their personal investment decisions, they similarly might have the same preferences in their collective, public investment decisions and agencies might therefore reflect this. Second, the common conception of the incentives of public sector managers ("bureaucrats") is one of risk avoidance.

Since NASA presumably faces a risk-return tradeoff in that higher returns are accompanied by greater risk, it might therefore be interesting to examine the projects NASA selects and rejects in terms of their perceived risk and return and how this squares with the public's and NASA managers' risk preferences. However, the approach taken here is quite different and relates to a second meaning of risk, bad outcomes.

In this context, risk management generally means minimizing bad outcomes, not uncertainty. Risk management in NASA generally does not assess the tradeoffs between minimization of uncertainty and program/mission benefit.

Possible Approaches to Risk Management

The past and current NASA approach to Space Station risk is a combination of four approaches:

1) Blind optimism

2) Maintain optimism in order to control slippage

3) Deal with unfavorable events after they occur

4) Plan for uncertainty: analyze contingencies (current tools in the safety area are failure mode effect analyses, hazard analyses, critical items lists, problem reporting and corrective action), purchase "insurance", mechanism that yields improved risk information as time progresses. "Insurance" should be interpreted in a broad generic way. It includes redundant systems, alternative ways to achieve an objective, and financial contracts should a loss occur.

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[1] The analysis presented below reflects an economic perspective. Because this perspective is unfamiliar to many within NASA, the arguments are presented in greater detail than if presented to other economists. Despite this, some of the arguments may still seem somewhat curious. There has also been no attempt to update this section, written in May 1987. If this were to be attempted, the place to begin might be with the following:

1. Post-Challenger Evaluation of Space Shuttle Risk Assessment and Management, Prepared by the Committee on Shuttle Criticality Review and Hazard Analysis Audit of the Aeronautics and Space Engineering Board, National Academy Press, January 1988.

2. Feynman, Richard P. "An Outsider's Inside View of the Challenger Inquiry", Physics Today, February 1988, p. 26-37.

Recommendation:

The Space Station Program should plan for uncertainty, purchase "insurance" (interpreted in a broad way), and utilize mechanisms that yield improved risk information over time. NASA should develop new tools to accomplish this.

The remainder of this section will address three different kinds of risk: safety, cost, and performance. The Appendix summarizes a model for assessing reliability resulting from different levels of redundancy.

5.5.1 Safety Risk

There are several generic issues in NASA risk management that span most NASA programs:

-What is NASA's objective with regard to safety?

-What organizational structure promotes this objective?

-What role should quantitative probability assessments play?

These are discussed in the sections below.

What is NASA's Objective with Regard to Safety?

Zero risk (perfect safety) is unattainable, and therefore is not a sensible goal. From an economic perspective, there are at least three possible goals:

1) Attain the "efficient" level of safety, i.e. the marginal cost of a life saved equals the "value of a life".

2) Attain any particular level of across-the-board safety in a cost-effective manner, i.e. at least cost.

3) Attain any particular level of safety in a particular activity in a cost-effective manner.

There may be additional considerations-political, moral, religious--that are relevant, but analytically not much can be said about these.

In evaluating the first objective, it should be noted that NASA must face, explicitly or implicitly, the question of "How safe? How much is enough?" The first objective provides a mechanism to answer that question. But this framework requires that one be able to "value of a life". Economists generally believe that this question should be answered in terms of "willingness to pay" rather than "human capital" (value of foregone earnings). They also assert that the way to determine "willingness to pay" is to look at the choices people make regarding prevention of injury or death.

The choices people make regarding prevention of injury or death indicate that a single number for "value of life" is not used to decide on safety risks. Instead, risk-acceptance by individuals seems to vary by factors such as voluntariness of exposure, familiarity, control, catastrophic potential, equity, and level of knowledge (see Slovic). Similarly, the cost per life saved resulting from various kinds of government regulation (see Morrall) also varies considerably, and this may or may not reflect systematic preferences concerning type of risk.

The interpretation of these choices made by people in their ordinary lives and by government regulators is important. Spending different amounts in different areas to save a life is not necessarily irrational, or an indication that none of the three objectives listed above are achieved. On the other hand, the efficiency notion is vacuous if one attributes, without other evidence, any set of choices to differences in willingness to pay. As with any theory, it must have predictive power; one must be able to generalize beyond the data used to develop the model.

For these reasons, a "global" answer to "How much is enough" may be difficult to provide.

However, it may be possible to attain a consensus on more limited questions. Within a sufficiently restricted class of safety threat, it is reasonable to suppose that cost-effectiveness would be generally desired. For example, the question could become one of the most cost-effective way to achieve a particular level of astronaut safety. This would include decisions to build a CERV, recognizing that NASA would be forced by public opinion to utilize a CERV (if one existed) or an emergency shuttle flight under some situations.

The cost-effectiveness criterion is attained when the following condition is satisfied: the last or "marginal" dollar of each safety expenditure should contribute equally to astronaut safety. This maximizes safety for any given level of expenditure. Thus if the marginal condition isn't satisfied, it would be theoretically possible to reallocate expenditures and increase safety.

Recommendation:

NASA expenditures on astronaut safety should be cost-effective, i.e. safety expenditures should contribute equally to safety. Deviations from this rule bear the burden of proof in showing that the deviation is consistent with society's willingness to pay.

<u>What Organizational Structure Promotes This Objective?</u>

There are at least five options that are possible candidates for cost-effective achievement of safety. The Space Station program currently does not consider the role that economic incentives can play in increasing safety. Options 2, 3, and 4 below are specifically designed to incorporate economic incentives however.

(1) General Decision Rules

Because of the multitude of decisions regarding safety, it is possible that in order to economize on information processing costs, that the best management approach is to develop general decision rules that result in good approximations to the "marginal condition" stated above (all expenditures contribute equally to safety at the margin). Deviations to these decision rules should be analyzed in terms of the cost-effectiveness rule.

The nature of these rules is unknown at the present time. Rules such as critical items having triple redundancy, or mechanical items designed for loads TBD greater than anticipated during use, may or may not be satisfactory as general rules.

(2) Design/Performance Specifications (e.g. General Decision Rules) but Incentives for Contractors or Work Packages To Do Better

Dr. Fletcher testified in early 1987 that NASA was studying the addition of SRQ&A incentive awards to contracts. NASA may want to use design specifications but performance specifications are generally more cost-effective.

(3) No Explicit Design/Performance Specifications

Option A: Allocate Safety Threats as a Resource

Under this alternative, safety threats are treated like all other resources in a "cost management" approach. Under this approach, a subsystem designer is given a cost "bogey" and an allocation of resources. Increases in resource usage are charged at the marginal cost of these resources and decreases are credited to the subsystem.

Allocation of safety threats may be difficult to sell politically since it gives the impression that a subsystem has a "right" to threaten safety up to its allocation. This is exactly the same problem that marketable permits have in environmental regulation: a "right to pollute". However, there has been growing acceptance of this device by environmental groups, and thus there is some hope for the analogous concept for NASA.

Option B: Safety Ratings for Subsystems and Payloads with Dollar Fines or Rewards or Other Incentives to Improve Safety

This "safety tax" is similar to the allocation of safety threats. The standard analysis of a permits vs. a tax scheme is that they are both economically efficient but result in different uncertainty. The permit scheme fixes quantity but leaves cost uncertain. The tax scheme fixes the per unit charge, but leaves the quantity uncertain (left up to the subsystem responding to the tax). Which is preferable depends on what uncertainty one is more comfortable with. In either case, of course, one can adjust the permit or tax level so that the differences over time between these approaches becomes less stark.

Based on the above, an allocation scheme may be better for NASA because NASA may be more comfortable with fixing the safety level ("quantity") and leaving the cost uncertain. However, because risks are only projected, one is only controlling the level of projected risks, not the actual level.

(4) Liability

As an alternative to payment of a tax based on the estimated safety threat, in which payment occurs whether or not an accident results, one can use a liability system in which payment only occurs if there is an accident. Responsibility for accident costs will lead the designer/operator to make decisions that result in the "right" level of safety.

Such a system might lead subsystem or payload designers to seek insurance to cover the large liability that might result. In such a case, the insurance premiums would function like a safety tax, reflecting the projected degree of hazard that the subsystem or payload contributes. Since NASA self-insures, a liability system only achieves the desired objective if the internal safety evaluation done by NASA functions like a safety tax (i.e. payment, or other incentives to better one's safety evaluation).

(5) Centralized Evaluation of Safety Alternatives

Some may be uncomfortable with alternatives 3 and 4 because they decentralize the safety process and rely on economic incentives of those responsible for the subsystem or payload to maintain safety levels. One alternative is to centralize the evaluation of safety.

There may be a technical reason for centralized evaluation as well. Decentralized solutions (such as the permit or tax scheme) depend on a decomposition in which interactive effects between subsystems are not important. This may not be true for safety, in which the effect of a failure in one subsystem may depend on the state of another subsystem.

What is necessary for cost-effective centralized safety management is evaluation of safety threats across the organization with resources devoted to areas where they will be most effective. The danger is that such a "command and control" centralized regulation of safety will not provide incentives for increasing safety beyond the constraint. Such incentives are necessary because the centralized safety management group will not have the information regarding possible improvements to safety.

Recommendation:

NASA should seriously examine the use of economic incentives to improve safety, for example, contract incentives to do better than a safety standard, a safety tax or allocation of safety threats, or a liability system.

All five options require the quantitative assessments of risks. They differ in the extent to which this quantitative assessment becomes a lower-level function. Alternative one (general decision rules) uses quantitative analysis to develop these rules but then subsequent decisions are made without a quantitative assessment. The other alternatives employ quantitative assessments routinely in decisions.

Recommendation:

The entity ultimately responsible for risk assessment should be outside of the space station program. This entity (e.g. a NASA or manned-flight safety office) may do the entire assessment or audit the assessment performed by the program office.

What Role Should Quantitative Assessments Play?

Quantitative risk assessments are generally not used in NASA. However, their use is now standard practice in regulatory agencies, partly due to executive orders. Morrall (1986) lists a number of regulations for which quantitative risk assessments have been made.

There have been a number of recent recommendations that NASA use quantitative assessments to a greater degree. For example, the Aerospace Safety Advisory Panel Annual Report for 1986 (February 1987) suggests their use be increased:

> "Criteria for quantitative risk assessment and explicit definition of the operating constraints to which the waiver is subject are not explicitly required by NASA's safety program guidelines. Although the Panel is quite aware of the pro's and con's of trying to establish "likelihood" or "probability" of failure, we believe a more realistic quantitative assessment of the critical hazards is crucial to overall risk management." (p. 73-74)

However, reflecting NASA's traditional skepticism toward quantitative risk assessments, the recent draft "Risk Factor Assessment--FMEA/CIL Criticality Category 1, 1R Ranking Process", Office of Safety Reliability, Maintainability, and Quality Assurance, Code QD, NASA Headquarters, proposes an assessment scheme without the use of probabilities.

This approach rates a safety risk along a number of dimensions that are correlated with safety risk. This may be useful as a rough screening device but it has several problems for finer decisions. First, the ratings are based on the connection between the rated dimension and safety in the abstract (or a sample of cases) rather than in the particular risk being rated. Second, the ratings weight all factors equally.

The value of quantitative safety risk assessments is primarily as a method of attacking safety problems in a structured way. A quantitative framework makes assumptions explicit and focuses attention on the assumptions or parameter values that most affect the analysis. Such a framework also provides a basis for discussion; different analysts can determine where they agree and disagree, and thus focus their attention on areas on which they disagree and which most affect the analysis. Such focused attention is important for improvement of the reliability of the estimate over time; resources can be important for improvement of the reliability of the estimate over time; resources can be devoted to ascertaining further information regarding key assumptions or parameters.

Recommendation:

Quantitative safety risk assessments should be utilized in order to address safety problems in a structured way.

Although it is common practice in regulatory agencies to employ conservative (worst case) assumptions in these analyses, this is not appropriate for regulatory agencies or for NASA. As discussed by Nichols and Zeckhauser (1986), use of conservative assumptions may lead to two problems:

- -Continual exaggeration of risks is likely to lead policy makers to discount estimates. Their discounting is likely to be crude, thus yielding poor estimates of overall risk.
- -The degree of exaggeration is likely to differ across risks. This occurs for a number of reasons:
    - -Sometimes the risk is estimated based on the worst example tested. In these cases, the degree of bias will rise with the number tested.
    - -Conservatism is less likely to be used for the risks that are believed to be best understood. Thus the greater the perceived uncertainty about a given effect, the more likely it is to be overestimated.

With different degrees of conservatism (exaggeration), cost-effective safety management is not possible.

Recommendation:

Quantitative safety risk estimates should present expected-value estimates of morbidity and mortality, rather than using conservative assumptions.

Quantitative decision models are also appropriate for analysis of general decision rules for cases in which a variety of variables interact. An example would be a rule requiring triple redundancy for critical systems as the standard of reliability. In order to determine whether this rule is superior to other approaches, it is necessary to understand the factors that affect the reliability of such systems. A partial list of these factors would be:

- -the reliability of an individual unit
- -the degree of redundancy and whether the system is restorable
- -the length of time between scheduled Shuttle flights that could bring up spare parts
- -the degree of on orbit sparing
- -the probability of Shuttle unavailability
- -the length of time required for an emergency shuttle flight
- -the length of time between failure of an item and placement of a spare in the Shuttle for launch to orbit

Recommendation:

NASA should utilize quantitative decision models to analyze safety decision rules.

One of the popular conceptions after the Challenger accident was that NASA had become lax based on past successes. The Feynman appendix to the Rogers Commission Report argued that revision of shuttle risk assessments was done in a faulty way. Restrictions were weakened over time based on the results of previous flights rather than viewing these flights as favorable draws from nature. Even worse, disturbing experience from previous flights was ignored, as long as the rocket worked.

However, successful performance in flights provides valuable information to revise risk assessments and operations procedures.

Recommendation:

NASA should utilize actual flight experience to revise risk assessments and operations procedures. However, such revisions must be done with care, with an understanding of the statistical processes that generate successful flight experience.

5.5.2 Cost Risk

There are two major generic cost risks in the space station program. The first is that the space station as a "pioneer project" is likely to develop cost overruns. The second is that special care must be taken to control total lifecycle costs of the program, rather than just DDT&E costs or the costs of particular components. These risks, and possible remedies, are discussed in the sections below.

The Space Station as a Pioneer Project

"Pioneer" projects such nuclear plants, the space shuttle, and the space station generally involve considerable cost risk (see Quirk and Terasawa). Analysis of cost growth in Army weapon systems by Terasawa and in Air Force weapon systems by Pegram suggests that cost growth tends to occur at particular points in the procurement process, i.e. at the time of production approval. Before this period, cost estimates exhibit stability because cost growth during this period would endanger the success of the proposed system versus possible competitors. Furthermore, low estimates during this period can not be rejected as unreasonable because of the high degree of uncertainty involved. Cost growth occurs at the time of production approval for a number of reasons. Subsequent cost growth might come out of contractor's profits. Also, the production approval process typically entails analysis of cost estimates by additional groups not closely identified with the proposed system and thus whose estimates may be more objective.

The recent escalation of space station cost estimates from $8 billion to approximately $13-14 billion should therefore not be too surprising. The source of these higher estimates is also consistent with the explanations given for weapon systems. Contractors and the Level C centers (which function somewhat like contractors to Headquarters) have been responsible for much of the recent escalation. However, independent analysts, such as from the NASA Comptroller's Office, have also taken a careful look at cost at this point. Indeed, their estimates reportedly were even higher than the $13-14 billion number.

Control of Total Lifecycle Costs

There are two particular aspects in which control of total lifecycle costs of the station is difficult. The first is that there are numerous space station design and development decisions that present a tradeoff between DDT&E and operations costs. During the DDT&E phases, DDT&E costs have more visibility and are more controllable than operations costs. For both of these reasons, there is a natural tendency to attempt in the DDT&E phases to control DDT&E costs, rather than total lifecycle costs. Given that DDT&E and operations costs often trade off, these decisions may not be made in a way that minimizes lifecycle costs.

The second difficulty in controlling lifecycle costs is the tendency for subsystems designers, facing DDT&E or lifecycle cost constraints for their subsystems, to ignore the indirect costs they impose. In particular, they are likely to overcome resources for which they do not pay the full cost. If such housekeeping consumption is excessive, the station will have to be larger (and thus more costly) than otherwise need be, in order to meet given user performance constraints.

Cost Risk Remedies

There are a variety of strategies to deal with this cost risk:

1. Contract incentives--JPL has studied, in a limited fashion, the use of incentives to control costs.

2. Pricing incentives--As discussed in the pricing section of the Panel 3 report, use of a cost-based pricing scheme provides an incentive for the program to control costs. Cost escalation, since it results in higher prices, decreases demand (and thus political support). However, although the pricing panel report does not indicate this, demand-based pricing also provides incentives for cost-control since reduced costs lead to more net revenue for the government.

3. International cost allocation

The current MOU adheres to the principle that costs are best controlled if they are allocated to whoever is in the best position to control them. Thus each partner is responsible for the DDT&E costs of providing their element, and the actual costs incurred do not affect the utilization share of the partner. Thus there is the appropriate incentive to minimize DDT&E costs.

However, minimization of life cycle costs is the appropriate objective, and thus partners are also given responsibility for partner specific ops costs. Although there are obviously other reasons for the MOU provision that partners will receive utilization in their lab (except that the U.S. gets approximately 50% of the ESA and Japanese labs in addition to their own), it lessens the possibility that the cost-minimization objective would lead a partner to shirk on performance.

4. Cost Management Approach

A cost management approach for the Space Station program must require that lifecycle costs be used in making program decisions. Furthermore, these lifecycle costs must include all indirect costs, such as the cost of resources consumed that are produced by other subsystems.

Recommendation:

To deal with the sizable cost risk of the space station, NASA should employ contract, pricing, and international cost allocation incentives as well as a cost management approach that considers indirect lifecycle costs, in order to control lifecycle costs.

5.5.3 Performance Risk

Tradeoffs exist, both in terms of technical feasibility and station/user preferences, between nominal performance levels and the probability that these levels will be obtained. On the feasibility side, one can increase the probability of success with redundant systems; if one holds cost constant, the addition of these systems lowers the nominal performance level. Similarly, lower chances of mission success may be acceptable for more ambitious missions.

The SSOTF believes that the Program is characterized by an undesirable lack of redundancy in a number of key areas (see chart on next page). Some sacrifices in nominal performance to assure greater confidence in meeting lower performance levels are therefore warranted. These items are discussed in more detail in the Panel 1 report. The transportation issue is probably the most important of these. One way to examine this is through historical data (presented in Table 5-1) on failures in unmanned civilian launches to geostationary orbit and delays in shuttle launches.

Delays in Shuttle Launches

Delays in shuttle launches also provide useful data on performance risk. The length of the delay is dependent on which schedule is being used--e.g. one could show a delay of 3 years for the first launch. The delays shown in Table 5-2 attempt to capture the

TABLE 5-1
CIVILIAN LAUNCHES TO GEOSTATIONARY ORBIT
(1963-October 1985)

	FAILURE CLASSIFICATION				
	BEFORE LEO	ORBIT TRANSFER	AKM	SATELLITE	TOTAL VEHICLES
Delta	3	2	4	2	77
Atlas	2	3	-	1	38
Ariane	-	2	--	-	12
STS	-	4	1	2	10
Long March 3	-	-	-	-	1
N Vehicle	-	1	1	-	8
Titan	-	-	-	-	1
	---	---	---	---	---
	5	12	26	5	147

Source: Surles (1985)

TABLE 5-2
DELAYS IN SHUTTLE LAUNCHES DUE TO OPERATIONS

FLIGHT	ACTUAL LAUNCH (MONTH/YR)	DELAY (DAYS)	FLIGHT	ACTUAL LAUNCH (MONTH/YR)	DELAY (DAYS)
STS-1	4/81	2	51-A(14)	11/84	1
STS-2	11/81	34	51-C(15)	1/85	1
STS-3	3/82	0	51-D(16)	4/85	0
STS-4	6/82	0	51-B(17)	4/85	0
STS-5	11/82	0	51-G(18)	6/85	0
STS-6	4/83	74	51-F(19)	7/85	17
STS-7	6/83	9	51-I(20)	8/85	3
STS-8	8/83	26	51-J(21)	10/85	0
STS-9	11/83	59	61-A(22)	10/85	0
41-B(10)	2/84	5	61-B(23)	11/85	0
41-C(11)	4/84	2	61-C(24)	1/86	25
41-D(12)	8/84	6	51-L(25)	1/86	6
41-G(13)	10/84	4			

Source: JSC 19413, September 1986.

delays "from operations". Even this definition is ambiguous, for some would argue that replacement of shuttle tiles isn't an operational delay since it reflects the fact that the shuttle wasn't "operational". Table 5-2 neglects such distinctions and tries to capture the delays in the last part of the process.

The data is taken from JSC 19413. These reflect the delays occurring within approximately 60 days of a scheduled launch date. The KSC and Lockheed sources cited in the references show somewhat different delays. The KSC press release reflects delays in publicly-announced launch dates (i.e. the originally scheduled launch date as shown in the press kit for each flight). The Lockheed data reflects delays following arrival on dock at KSC. The differences between the JSC and KSC data occur only in five flights, as shown below:

DIFFERENCES BETWEEN JSC AND KSC DOCUMENTS IN LAUNCH DELAYS

NUMBER OF DAYS DELAY IN LAUNCH

	JSC	KSC
STS-7	9	0
STS-8	26	0
STS-9	59	1 MONTH
STS-41C (11)	2	0
STS-41G (13)	4	0

Role of International Partners in Performance Risk

Finally, the role of the international partners in providing essential needed capability, additional capability, or redundant capability, needs to be assessed. Currently, the partners provide additional capability or in some cases, redundant capability. (The Canadian contribution is essential but could be procured directly from the contractor without the involvement of the government of Canada.) However, operations cost sharing without transfer of funds can only be reasonably accomplished by launch of either US payloads or station logistics by the internationals. If this launch responsibility is developed by the internationals without a corresponding US responsibility, the US is somewhat vulnerable to international withdrawal.

As explained above, the program implicitly chooses an overall level of performance and reliability through decisions concerning unit reliability, on orbit sparing, choices with respect to specific technologies (e.g. PV vs. solar dynamic), etc. These decisions collectively will result in a probability distribution over the level of net user station availability.

Allocation of Performance Risk through Resource Allocation

There are in addition resource allocation policies that affect how this aggregate uncertainty concerning performance is allocated among users. There are four main issues:

1. Will priorities be decided in advance or in realtime operations?

The Panels were divided on this issue. Panel 1, quite rightly, argued that the best information concerning which payloads could benefit from available resources would be available in real time operations. Panel 3 would agree, but argued that priorities should be decided early enough so that payload (and system if station systems are allocated resources with priority) design could occur against a known level of priority, and that the potential benefits from optimizing design in this fashion exceed those from being able to optimize in real-time, once designs are fixed.

The traditional way is for priorities to be assigned to categories of users, or particular payloads. Panel 3 argued that priorities should be assigned to resources with payloads allowed to choose the priority level desired for each resource. This permits a payload to have differing amounts of different priorities of the same resource, or different priorities across resources. This permits much greater flexibility in design and operations than assignment of priorities to users/payloads. Since high priority resources will be more desired, opting for lower priority will enable payloads to secure more of a given resource. The user, at any point, may relinquish through trade or sale resources (together with attached priority) assigned to him. The user is in the best position to make these decisions.

3. What level (of rated capacity) should be allocated?

The Panels were less clear on this issue. Some sentiment was expressed for underbooking to avoid the hassle from trying to schedule everything to the hilt (e.g. the extensive replanning that would result from the ripple effects of a "small" change). However, given that some payload demand may not materialize, or the fact that the system may function at times at rated capacity, such an underbooking policy may leave resources available. What procedure will be used to allocate these available resources? Overbooking was attractive to some within the SSOTF, and appears to be a better alternative, particularly when combined with a prespecified bumping rule (issue #1 above).

4. Should this system apply to station systems as well as user payloads?

Although Panel 3 was silent on this point, the resources allocated to station use should also have a priority--all of the station resources need not be of the highest priority. (This is increasingly true the more narrow the time period by which the resource is defined; much station housekeeping can be delayed for some period of time.) The station will want to reserve margins for itself through the priority scheme so that massive changes in manifests or timelines do not occur through small changes in payload requirements.

Recommendation:

Priorities for space station resource use should be decided in advance. Station systems, as well as user payloads, should be able to self-select resources of different priority. Resources should be overbooked.

SUMMARY OF RECOMMENDATIONS

Recommendation: The Space Station Program should plan for uncertainty, purchase "insurance" (interpreted in a broad way), and utilize mechanisms that yield improved risk information over time. NASA should develop new tools to accomplish this.

Recommendation: NASA expenditures on astronaut safety should be cost-effective, i.e. safety expenditures should contribute equally to safety. Deviations from this rule bear the burden of proof in showing that the deviation is consistent with society's willingness to pay.

Recommendation: NASA should seriously examine the use of economic incentives to improve safety, for example, contract incentives to do better than a safety standard, a safety tax or allocation of safety threats, or a liability system.

Recommendation: The entity ultimately responsible for risk assessment should be outside of the space station program. This entity (e.g. a NASA or manned-flight safety office) may do the entire assessment or audit the assessment performed by the program office.

Recommendation: Quantitative safety risk assessments should be utilized in order to address safety problems in a structured way.

Recommendation: Quantitative safety risk estimates should present expected-value estimates of morbidity and mortality, rather than using conservative assumptions.

Recommendation: NASA should utilize quantitative decision models to analyze safety decision rules.

Recommendation: NASA should utilize actual flight experience to revise risk assessments and operations procedures. However, such revisions must be done with care, with an understanding of the statistical processes that generate successful flight experience.

Recommendation: To deal with the sizable cost risk of the space station, NASA should employ contract, pricing, and international cost allocation incentives to control life-cycle costs.

Recommendation: All space station resources should be allocated to users and station systems with a priority that defines how resources will be allocated should available supply be less than the allotted amount. Margins should not exist or be withheld for this purpose.

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5.6 FINANCIAL MANAGEMENT by Johanna Gunderson and Doug Lee[1]

As the Station is designed, constructed, and operated, it is increasingly important to be able to obtain cost information that is not only detailed, but focused on the cost tradeoffs that will allow unit operating costs to be reduced over time. The types of tradeoffs include crew operating labor versus hardware investment (automation), crew time versus software development labor, capital versus operating cost, reliability versus spares, and scars versus modification. If the Station is to grow from a modest base, in response to future demand as it becomes known, then the need for functional cost data is vital.

All financial management systems exist primarily to provide the appropriate levels of management with the information required to make the best decisions possible. As in most large organizations, NASA managers are held responsible for their decisions both internally and externally. The management tools that comprise the financial management systems must provide them with the products required to support and explain those decisions.

External Requirements for Financial Management

Some external requirements have fundamentally shaped the Agency's financial management practices through the design and utilization of NASA's accounting and budgeting systems. These include:

- Provision of information to inform the Federal budgetary process (appropriations) in general and Congressional oversight (authorization) in particular. Practices must conform to standards established by legislative and executive directives, e.g., Congressional budget cycle and reporting requirements (monthly, annually, other) that compare actual with planned expenditures and accomplishments.
- Requirements to relate technical performance to expenditures, in specific areas, e.g., automation and robotics, spares, cost sharing, pricing policy.

In addition to the external requirements which support the construction and management of the Agency's budget, other requests are made to support the authorization process. The Congressional oversight of the technical content of NASA programs frequently results in requirements for the Agency to provide financial information on topics of special interest to individual legislators, such as the planned expenditures for automation and robotics.

Internal Requirements and Functions

While external requirements have had a powerful influence on the structure of NASA's financial systems, internal needs generate the most significant requirements. With the numerous organizations in NASA, and many levels of management, there are many informational needs which must be met by a single accounting and information system. Each user must get the right items in the most useful form. Ideally, these can be aggregated upward, while deleting detail.

- **Planning**. NASA has a five-year horizon within which planning can take place but, as with many large Federal programs, long range planning often gets too little attention because of short term funding conflicts. Planning also encompasses the use of cost information for pricing, cost

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[1] Doug Lee wrote this section, essentially condensing a longer paper by Jo Gunderson.

sharing, and other policy analysis.

Performance Management. The relationship of cost, schedule, and performance (as stated in terms of quantifiable measures of accomplishments) data should allow each level of management to identify problems, develop plans to correct problems, and assess the likelihood of accomplishing tasks planned in the baseline requirements, cost, and schedule. It is here that fiscal and performance accountability are linked to function, product, or organization. Within most major programs, all levels of management review their performance against planned technical, cost, and schedule milestones on a monthly basis.

As the authority or responsibilities vary, so will the requirements for aggregation or disaggregation of the data. The lowest level of collected data should not be automatically provided to the top level of management. The financial management system and control structure should be set up to provide the Program Manager with the appropriate indicators of trends rather than a compendium of unevaluated information.

Distribution and Control of Funds. The Comptroller and the Headquarters Program Office must ensure that the initial distributions of funds comply with the appropriation and authorization requirements, but the responsibility for the assignment of further controls should be delegated along with the technical responsibility, from one level of management to the next. This is the exercise of fiscal responsibility. Funds are distributed by the NASA Comptroller to Unique Project Numbers (UPN), and all funding codes must be established in the Agency Wide Coding Structure (AWCS). Distribution must comply with additional appropriations and authorization instructions. Fiscal management should be delegated to the same level as technical responsibility (holding fiscal controls at higher levels does not work).

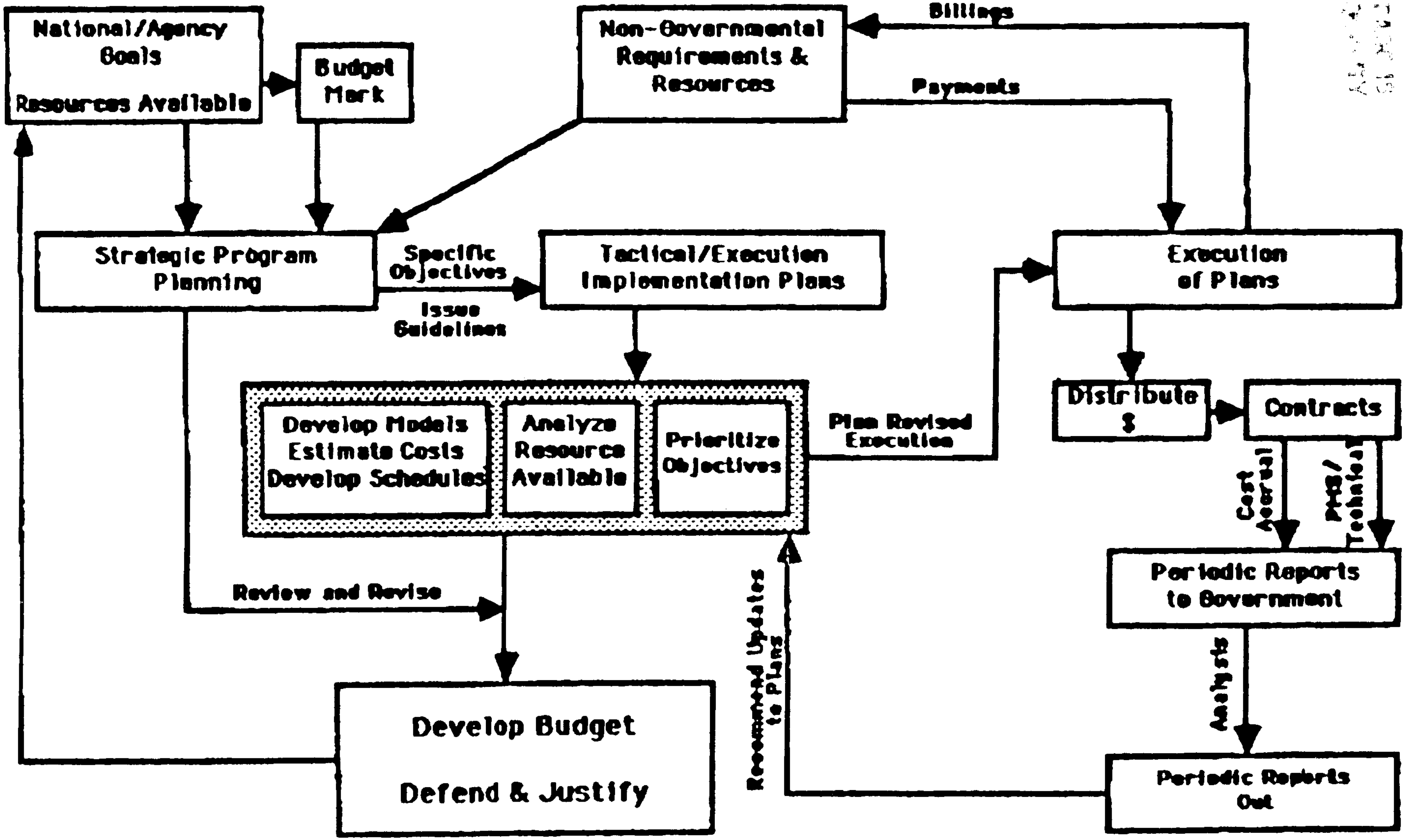
Many managers mistakenly believe that they are able to gain additional insight into, or control of, the performance of the work only through the assignment of additional funds controls and through the distribution of funds at those lower levels.

Audit Capability. Official financial management records provide an archive of cost information to trace past performance and costs, as needed. It gives a last resort accountability, and a baseline for interpretation of financial data. The audit capability is one measure of fiscal accountability that must be supported through documented financial records, but the accounting systems are only one aspect of the audit capability. The archived information must also include sufficient data on the program baseline to allow ex post interpretation of the financial data. The archives should include presentation materials, special analyses, working papers, etc., to be of maximum benefit to those attempting to understand what occurred in the past.

These four functions are related and are a part of the cyclical process of financial management, as illustrated in Figure 5-3. Each level in the management hierarchy participates in the execution of these four functions, although their specific involvement

Figure 5-3

FINANCIAL MANAGEMENT FUNCTIONAL FLOWS



depends on the authority delegated to their respective organizations.

Tools for Financial Management

Because the agency is composed of field centers which operate relatively independently, the full array of tools available to provide financial management is rather broad. The standards for accounting and budgeting systems are established by the Comptroller and each of the Centers must obtain approval for their systems. The NASA Comptroller has established an Agency Wide Coding Structure which must be used in all aspects of financial management. Most managers deal with only a subset of the full set of codes and controls utilized. Among the tools available for financial management within NASA, the following will be used to support operations cost management.

- Unique Project Numbers (UPNs). The UPN must be used in budget formulation, and it allows anyone in the agency to readily identify the general content and associated cost from standard reports and management documents.

  The Headquarters (HQ) Program Office works with the Comptroller's staff to establish the UPN structure for the program at the three or five digit level. It is then left to the HQ Program Office to either assign additional digits or to allow the implementing organization to assign those digits. This delegation of fiscal control should be consistent with the management delegations of authority, because the UPN also must serve as the control and reporting mechanism for the implementing organization. Centers sometime make use of the last four digits of the nine-digit code to identify support contractors and facilities.

  Costs are accrued in the center and agency accounting systems against these UPNs. Contractors may or may not be required to provide their cost accruals against the expanded nine digit coding structure. In those instances where the contractor is not required to report monthly expense data at the lowest level of detail, the office with technical and budgetary responsibility is required to provide an assessment of the reported cost accruals against the funds obligated for the contract. A major contract will, generally, either report against the most detailed funding controls or provide another mechanism for supporting the NASA managers' requirement to cross-map the costs.

- Form 533. NASA has established the Form 533 as a standard tool for contractual cost and performance reporting. Monthly and quarterly reports must be completed for cost and performance information, relative to the Work Breakdown Structure (WBS) negotiated for that contract.

  In addition to internal corporate accounting systems, the contractor will establish a Performance Measurement System that is used to relate and report performance to the Government, against parameters specified in the contract. The 533P format is utilized for these reports.

- Scheduling and Monitoring System. Beyond the standard agency mechanisms for cost accrual, there are a variety of management tools used to provide additional information to decisionmakers. There is generally a separate scheduling system which is used to identify and track critical programmatic milestones. Although some of these systems also offer a capability to incorporate resources analysis, they are rarely used to link schedule accomplishment with costs because cost information is often neither developed nor aggregated at the same levels as the critical path milestones.

-Estimating Models. Each program also makes use of estimating tools and models which help them to estimate the cost of new tasks or the impact of changes to an established program. A model's ability to provide a decisionmaker with a relatively rapid response to "what if" questions that require the correlation of many variables can be invaluable. Unfortunately, the quality of the model is ultimately determined by the quality of the data that are provided to develop and update its algorithms. Standard management practices frequently do not place a very high value on the collection of cost and schedule data that will support either the use of existing models or the development of new ones.

The Space Station Program has already developed a model to help perform engineering trades by projecting the lifecycle cost impacts of those changes to flight hardware or ground systems. If the Program intends to continue to make use of this model, it is imperative that either the required data are made available to update the model or the resources are provided to modify the model.

Improvement of Existing Financial Management Tools

The financial management systems and practices employed by the agency provide the flexibility and the capacity to support cost control efforts, but several additional steps can be taken to optimize the type and quantity of information provided to the Space Station Program. The program has both a Work Breakdown Structure and a Unique Project Number (funds control) system which need not be mirror images of each other. The WBS is developed to describe, organize, and manage the tasks that are to be performed by either the prime contractors or the Center institutions while the UPN structure is created to manage the finances of the Program and to support any externally imposed reporting requirements. By structuring the two sets of tool to complement one another, the program can increase the amount of information available to its managers.

Unique Project Numbers may be assigned on the basis of the following criteria:

- Relative size of the cost center. (small costs can be combined, even if unlike)
- Importance on the critical path. (critical elements call for careful monitoring)
- Distribution of organizational activity. (dispersed projects need greater control)
- Existence of externally imposed reporting requirements. (e.g., OMB, GAO)
- Requirements for pricing, cost sharing, performance, etc. (assure taxpayers money is well spent)

The WBS which the program has baselined for the development phase of the program is organized by both end item and subsystem to support requirements to aggregate data in either format, across the work packages. The supporting development (non-prime) portions of the WBS have not been established to support a similar ability to provide a functional aggregation across the program. There are also substantial discrepancies in the significance and level of detail addressed at comparable levels of the supporting development WBS. The program can enhance its analytical capabilities by reexamining its use of both of these tools and restructuring them to better support operations cost management.

Organizational Support Requirements

Financial management occurs at each of strategic, tactical, and execution levels, in different proportions depending upon the function. The types of skills required and levels of effort need to be delineated for each function, and described specifically for the strategic and tactical levels. Roles and responsibilities for financial management need to be allocated among the Centers and HQ organizations, with recommended support staffing plans. A recommended distribution of responsibilities is provided in Figure 5-4.

Current organizational structure and pattern of nominal HQ management combined with field center execution have created a number of problems from the standpoint of financial management:

> Matrix management sometimes makes it difficult to trace lines of authority. Both effort and control are widely distributed, not necessarily in consonance.
>
> Institutional planning at the tactical and execution levels has been separated from programmatic planning. For example, separate planning cycles and organizations may be used to support R&D (programmatic), construction of facilities (bricks and mortar), and Research and Program Management (Center personnel and maintenance) budgets. The result often is a lack of responsibility for the consequences of decisions and conflict between institutional versus programmatic organizations. Long range program planning is not well served by splitting these responsibilities within the institutions.
>
> Center contracts and agreements are often written around skill types and levels of effort, rather than program specific tasks to be accomplished. These mechanisms do not generate information that can readily be used for program oriented cost management or performance evaluation. It may be necessary to superimpose project-by-project reporting systems or separate schedules.
>
> Program Office imposition of more levels of funds distribution controls and detailed reporting requirements has not necessarily enhanced cost control or performance visibility. Instead, higher administrative costs and increased potential for overruns have resulted.

RECOMMENDATIONS

The Space Station Program and relevant institutions should:

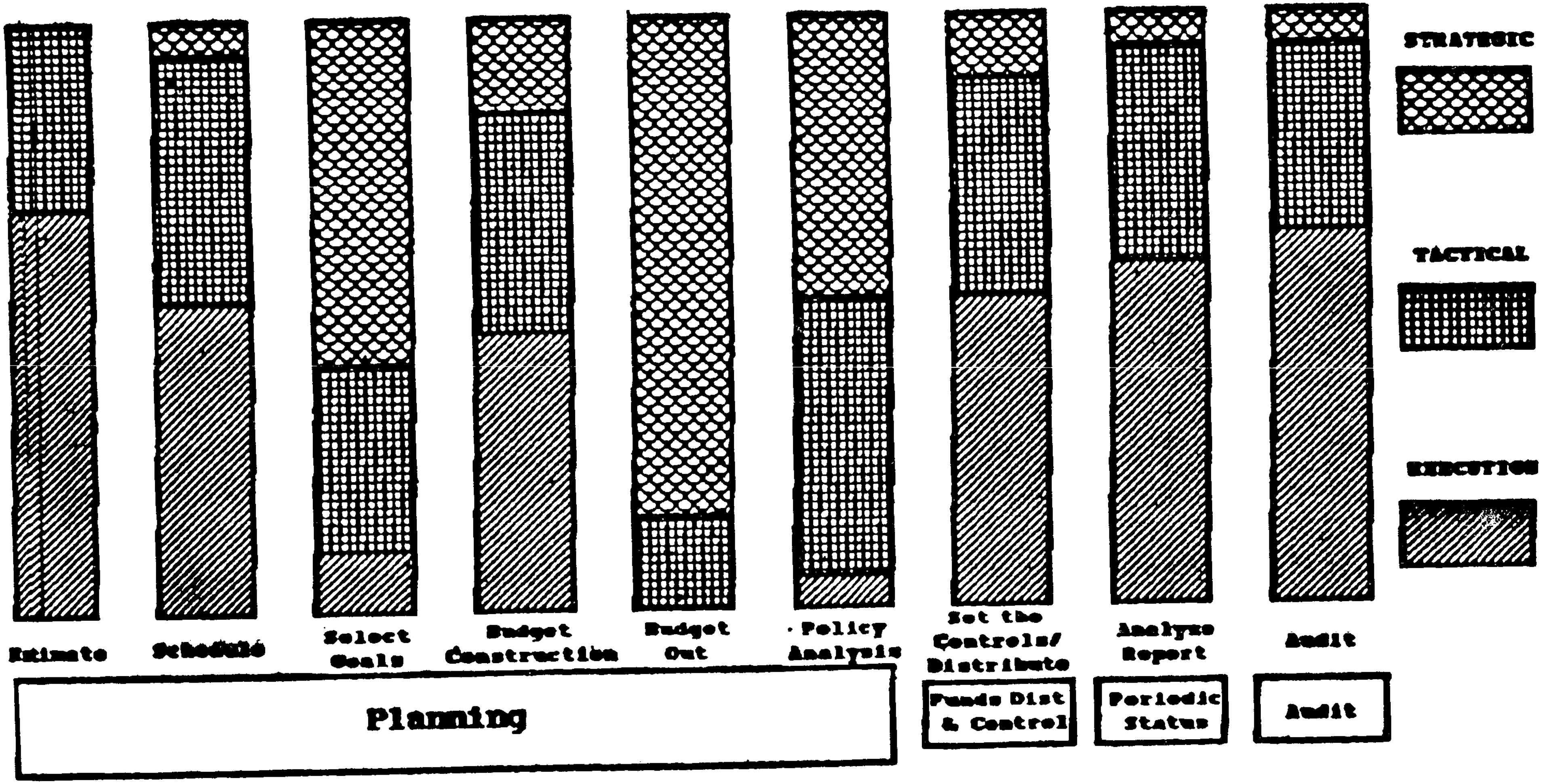
Redefine the functional structure for operations, establishing a WBS related to costs and outputs. Design the funds control structure to complement the WBS. Develop other management tools (a financial management system is only one of an array of tools) to specifically interact with one another.

Rethink the organizational structure. Structure organizations to better support delegations of authority through a clearly understood chain of command. Staff each level with an appropriate mix of technical and business management personnel. Utilize personnel performance reviews to enhance the responsiveness of projects to the program.

Provide an alternative focal point for long range planning which will work with the financial management processes. Reliance on a budgetary process taxed by immediate problems and institutionally divided by appropriations categories has proved unsatisfactory.

Explore use of other contractual arrangements. Use of incentive fees has yielded mixed reviews to date. Follow-on operations era contracts may be more effective if handled as subcontracts to a tactical level integration contract.

Figure 5-4 **FINANCIAL MANAGEMENT PROCESS**



5.7 INFORMATION MANAGEMENT by Doug Lee

An essential character of the Space Station, both manned base and platforms, is its nearly total dependence on efficient and effective data handling and information management. This key feature was considered throughout the SSOTF deliberations. A task force objective was to assure that the design and development of end-to-end communications and data systems consider the full range of user and station system operations for both the development and the mature operations phases. The general consensus was that the Program must formalize its approach to integrated information resource management. Chapter IV of the SSOTF Summary Report includes two summary sections relevant here: SSIS as a system, and the general topic of management information systems. In developing those two summary report sections, the recommendations listed at the end of this section emerged.

Information Management Tasks and Approaches

Space station operations will encompass a complex range of functions, carried on by at least six separate NASA centers, plus the station itself, and three international partners. Coordination among these producers and users must be both efficient and flexible. Operations management will require information from engineering, cost, scheduling, and other databases in order to assess and improve performance of the station and its support facilities. The SSOTF recommended Functions Structure describes a complex flow of information between related functions and between levels of management. For this to create order rather than chaos requires that standards be imposed, that databases be controlled for updating, and that common information be consistent from one location to another.

Before describing the Panel's recommendations, this section will describe management objectives, types of decisions, principles of MIS design, pragmatic tests, and two examples of information problems.

Management Objectives

General purposes to be achieved in the management of information resources can be described in terms of efficiency, autonomy, and sequencing.

- **Efficiency**. Overall, to produce the most valuable output (space station resources) for the resources (inputs) consumed.
- **Autonomy**. Each decision should be made at the lowest level that can encompass the relevant factors.
- **Sequencing**. Decisions should be made in a sequence that permits the results of one decision to become the assumptions for the next.

Types of Decisions.

- **Planning**. Identify problems, generate alternatives, estimate impacts of alternatives, and evaluate impacts.
- **Management**. Seek organizational efficiency through monitoring activities, identifying cost vs. performance tradeoffs, and evaluating input levels within a cost-effectiveness framework.

Principles of MIS Design

- **Targeted Information**. Information should flow to those organizations, levels, and individuals possessing the authority to act upon the information.

- Screened Information. Unnecessary information (irrelevant, excessive detail) should be filtered out.

- Organized Information. Relevant information should be digested, structured, and presented so as to provide the most revealing insights with respect to how well the function is being performed (performance measures).

- Accounting Consistency. Accounting frameworks (e.g., costs, inputs, outputs) should be mutually exclusive and exhaustive; detail breakouts should fit within higher categories (nesting); several comprehensive systems may apply to the same items, each system having the required properties but not necessarily across all systems at all levels (relational).

- Upward Flow. Solutions to problems (decisions, or proposed decisions) should flow upward, along with other information needed for higher-level decisions.

- Downward Flow. Policies, constraints, and solutions to higher-level problems should flow downward, to be embodied as assumptions and tradeoff incentives for lower decisions.

- Incentives. Managers should have reward incentives (e.g., bonuses) to use the information for the benefit of the organization as a whole, and its objectives.

- Management Control. Key databases used jointly by several activities or by management should be controlled as to how they are modified and updated.

Pragmatic Tests

- Is the process producing decisions at an acceptable rate, and decisions that hold up over time?

- Is the process itself efficient, in that time and effort costs are reasonable, and the quality of the decisions is high from the standpoint of maximizing benefits from the station resources?

- Are there alternative decision strategies that ought to be tried?

Example: System versus Element Controls. A system provides a single group of functions (e.g., power, data transmission) at many locations, while an element provides multiple functions at a single location (e.g., a laboratory). Generating cost and associated performance data on both (or more) dimensions is likely to be a heavy burden, and also unnecessary. In selecting which dimensions to emphasize, or take as the primary structure, the following guidelines are proposed:

- Production-Driven Costs. To the extent that costs of a system are a consequence of the hardware, software, labor, procedures, and other input choices made in the production of the output (power, life support, communications), management controls should be oriented toward the system.

- Consumption-Driven Costs. To the extent that costs are driven by the ways in which the outputs are consumed, particularly if a single activity places variable loads on several systems, controls should be element-oriented.

Where both apply (e.g., communications) both dimensions need to be maintained.

Example: Minimization of Housekeeping Resource Consumption. In order to preserve the greatest amount of resources for users, housekeeping consumption has to be carefully balanced against the needs of users. Ideally, the marginal cost of reducing the consumption of a resource for housekeeping should be the same as the value of the resource to the user that places the highest value on having another unit. The marginal cost of reduction should also be the same for all station functions requiring that resource.

If, say, one kilowatt hour of power for air conditioning could be saved by spending $50, and the same could saved on data transmission for $200, while the marginal user values the power at $100, then data transmission should use more power and air conditioning less.

RECOMMENDATIONS

1. Establish operations requirements for MIS design. A statement of the requirements for Station operations should be prepared, as input to the design and construction of the TMIS (Technical Management Information System), SSIS, and SSE (Software Support Environment) systems. Requirements should identify information flows, key databases, and mechanisms for controlling databases (ICDs, or Interface Control Documents), based on the functions tree produced by the SSOTF, and assuming the participation by several centers and partners.

2. Establish a single architect for SSIS and TMIS. Data and information management will be critical in the Operations Era. The technical architecture of both the SSIS and TMIS must be consistent and complementary since real-time data obtained during operations will be the source of planning data and information for the pre-execution and post-utilization analysis periods. A single architect for both systems is the ideal but a jointly managed effort is absolutely critical to assure the appropriate synergy between the two systems. Both must provide for compatibility to software systems such as the onboard Data Management System (DMS) and the ground-based operations support centers such as the SSCC and the POIC.

3. Provide optimum data system transparency to users. This recommendation embodies a number of important corollary recommendations related to system transparency and user flexibility which are summarized here and reemphasized in the Special Topics section of the Task Force Summary Report:

(a) Close the TDRSS ground coverage gap. Having less than 100% coverage for any real-time ground-to-onorbit activity adds a long-term planning and scheduling burden to most user activities and routine operations activities. The opportunity cost over time can be significant and the planning process will be unnecessarily constrained. A life-cycle cost study of various options to close the zone-of-exclusion should be conducted and should consider a number of Space Station user and operations scenarios.

(b) Consider the use of a variety of space-to-ground communication links. This recommendation stresses the potential for communications developments clearly underway in the private sector and by organizations within the international partnership. Within the next decade a number of space-to-space and space-to-ground capabilities will move into operational status and the Space Station should be prepared to exploit them. The ability to move large volumes of data and information from point-to-point on the ground will be relatively limitless and inexpensive. The Program should search for every opportunity to assure that links between the Station and the ground are not limited by lack of foresight which gives fair thought to these future possibilities. The Station systems, such as the DMS and the on-board communications and tracking systems, and related ground support systems should be scarred with such evolution in mind.

(c) Consider the use of a variety of ground-based data handling services. During Task Force deliberations and review of operations scenarios it became clear that the operations concept should be designed to support the explosive growth of data and information needs in the future. The prior recommendation focused on developing the data handling links to accommodate this expansion. This recommendation suggests providing similar access to cost-effective, commercially available ground-based data handling facilities. The objective would be to bring as much of the data to the ground with limited preprocessing and allow the user or international partner to "purchase" the most cost-effective ground processing at whatever facility they choose to. This would free NASA's owned and managed data facilities to be used for the safety related and operationally time-critical data needs.

4. Consider operations and utilization during TMIS design efforts. During the TMIS design effort the following should be major considerations: the implementation of Assembly Phase and Mature Phase Utilization and Operations scenarios; the provision of standardized CAD/CAM/CAE/CAI file formats or translation procedures; and, the full use of relational database management concepts for all applications and operational interfaces. The Development Phase Program should provide formally for the proper delivery to NASA of all engineering databases from Development Phase contractors. These will be the basis for long-term configuration management and for continued operational use in sustaining engineering efforts.

5. Identify and provide for Program control of key databases. Conduct a study which identifies engineering and operational databases which will ultimately be established as reference databases for operations planning and execution. The study should identify databases to be developed and used by contractors during the engineering development phases and which will be essential to long-term sustaining engineering, system maintenance, and logistics support such as CAD/CAM/CAE/CAI files. The study should examine all functional users of these databases, develop illustrative uses of the databases in the conduct of operations, define configuration control mechanisms, and recommend what organization should be assigned the data administrator function and the handover process from engineering development to operations program managers.

6. Develop a telescience scenario to guide and test operational concepts. Establish a reference end-to-end telescience scenario(s) and evaluation methodology against which information systems designs and information resource management concepts can be assessed as the development phase progresses and as technology evolution studies are conducted. The scenario(s) should include evaluation criteria and support the assessment of end-to-end command, control, and data flow requirements for systems developers, station users, station system operators, and operations planners. All aspects of TMIS, SSIS, and SAIS should be considered in this process.

7. Produce an Annual Information Resources Management Plan. To assist in the formal review of such efforts the Program should provide an Information Resources Management Plan which includes:

(a) Identification of key program information sources,

(b) Accountability and responsibility for the program controlled information and databases that are essential for operations and that indicate the assignment with end-to-end functional flows and management control points,

(c) Provision of a process and schedule for transferring or adapting program-developed engineering databases to the organizations responsible for operations support,

(d) Identification of all non-program-controlled databases, that is, those requiring program level agreements for access and long-term support, and

(e) Plans for the "knowledge-capture" essential to development of expert systems.

The Program should update the Plan annually as part of the Program Plan update process.

5.8 HARDWARE AND SOFTWARE SYSTEMS DESIGN ISSUES by Joe Joyce and William Pegram[1]

One of the main reasons to create the SSOTF at this point in the Space Station Program is the importance of carefully considering operations during the design and development phase of the program. One of the tasks of the SSOTF was therefore to consider changes in the proposed Space Station design that might be beneficial given operational considerations.

In the fall of 1986, the leadership of the SSOTF was faced with an important decision. The Task Force had just been formed and the work of the panels was just beginning. 5 Phase C/D draft RFPs, one for the Program Support Contract and one for each of the 4 Work Packages, were to be released for public review in late November with comments due in December. Should the Task Force review the RFPs? Would such a review interfere with the main work of the Task Force? On what basis could the SSOTF review these, given that its work had just begun? The SSOTF decided that due to the importance of design decisions, that a significant review of the RFPs would occur. To interfere with the other work of the panels as little as possible, each of the panels formed a group of reviewers to develop comments. These were then integrated by representatives of each of the panels and discussed with the SSOTF leadership. This process resulted in two outputs:

- A viewgraph presentation to the Associate Administrator for Space Station on December 17, 1986 on major concerns with the RFPs, and

- Detailed changes to specific portions of the RFPs.

Both of these were sent to the Chairmen of the Source Evaluation Boards for their use in revision of the RFPs. When the RFPs were redrafted for an internal NASA review in January 1987, the SSOTF reviewed these and submitted detailed comments as well.

5.8.1 RFP Issues Presented to the Associate Administrator for Space Station

This section will summarize the major issues, as presented on December 17th. This presentation identified a number of RFP policy issues--for each, the presentation identified the RFP status of the issue, the SSOTF concern, and the SSOTF recommendation for resolution of the issue.

The major issues identified in this presentation were the following:

-Operations roles and missions

-Program Support Contractor role

-Life cycle costs including supportability concerns

-Logistics support

-Integrated transition planning

-Automation and robotics planning

-Purchase of second copies

-Operations concept verification

-Interactive information systems

-RFP deliverables

These are discussed in turn below. The presentation concluded that the draft RFPs did not present an integrated operations

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[1] Joe Joyce coordinated the SSOTF effort to develop comments on the RFPs (viewgraphs plus detailed suggested changes) and provided input into the non-RFP design issues section. Bill Pegram wrote the chapter based on this input.

concept. The SSOTF therefore recommended that NASA redraft the five RFPs before releasing to potential bidders.

Operations Roles and Missions

The SSOTF stated that their recommendations for assignment of operations and utilization roles and responsibilities might differ from that assumed in the RFPs, and that the RFPs should therefore state that the roles in the RFP were to be assumed for bidding purposes only.

Program Support Contractor Role

The presentation listed a number of cases where the RFP Statement of Work language implied that the Program Support Contractor would have a directive role. The presentation recommended that the PSC be in a supportive role to NASA, rather than a directive one.

Life Cycle Costs Including Supportability Concerns

The presentation stated that the RFPs did not require the contractor to propose an approach to control life cycle cost, nor did they indicate clearly the current program approach. The SSOTF recommended that NASA use the responses to the RFP as a guide in implementing the program approach to life cycle cost, thereby tapping the wealth of contractor experience with cost management. Because of the wealth of thinking that had been done on these topics for Levels I and II, the presentation proposed specific language for inclusion in all 5 RFPs:

> -"The appropriate concept of cost in Space Station program decisions is life-cycle cost which is the cost of developing, building, and operating the station, where all costs are adjusted for inflation and appropriately discounted. Ideally, costs born by other parties, such as other parts of NASA or non-NASA users, should be incorporated as well, although in some instances the program may have to make decisions based on space station costs alone.
>
> -The program recognizes the importance of providing incentives to program participants to minimize life cycle costs to the entire station. One way to do this is to levy LCC bogeys on individual work packages/ elements/subsystems and provide incentives for these components to achieve a lower LCC. The LCC resulting from any of these components must consider the consumption of resources provided by other components and the marginal cost of these resources.
>
> -The Space Station program has developed a number of models that may be useful in controlling LCC. These include the System Accounting Model (SAM), the System Integration Model (SIM) and MESSOC. The program has recently developed a cost management process which is described in JSC 30470, Program Cost Management Process Requirements.
>
> -The contractor should evaluate current program approaches to controlling LCC and propose modifications if necessary. This should address control of LCC within a particular work package and across work packages. The approach should explicitly consider ground support and launch/return requirements as well as impacts on key operations parameters such as on-orbit manpower availability. The responses will be given due weight in the evaluation process and may be adopted for use across the program."

Logistics Support

The SSOTF believed that the treatment of logistics in the RFPs was inadequate in general. Among the deficiencies noted in the presentation were a lack of consistency in logistics planning across the four work packages, failure to request critical logistics documentation, and that logistics plans critical to evaluation and selection are not requested until 90 days after award. The presentation recommended that the WP RFPs be modified as necessary to incorporate the integrated logistics planning as defined in JSC 30000 and 30207.

Integrated Transition Planning

The presentation noted that Work Package 3 was the only WP to request an Operations Transition Plan. The presentation recommended that the PSC provide a transition program to phase-in and qualify an O&M contractor, and develop a Space Station Transition Plan. Work Packages 1, 2, and 4 should do the planning necessary to turn over their work package responsibilities to an operations contractor and should submit an Operations Transition Plan.

Automation and Robotics Planning

The presentation stated that while the RFPs requested that contractors submit A&R concepts, the RFPs provide no clear method for evaluating such concepts nor provide a clear indication that NASA is willing to pay for such concepts if they are not required to provide basic operational capability. The SSOTF recommended that contractors submit a plan for implementation of A&R concepts which should suggest knowledge base requirements necessary for development of the ultimate concept, the design strategy given the knowledge base, and approaches to prototyping and validating the concept over time. In addition, the contract should suggest an incentive/awards schedule based on successfully developing and validating proof of concept.

Purchase of Second Copies

The presentation noted that the RFPs made no mention of the possibilities of buying a second or more copies of any element, subsystem, or long-lead component. The SSOTF was concerned that the loss of key station components at certain points during the assembly phase could jeopardize the entire program, and that continuing planning for growth and evolution may indicate a need for additional elements and/or subsystems at a time when the prime contractors are still in place. The SSOTF recommended that the RFPs require the proposers to suggest contract language and negotiating strategies which allow NASA to order second or more copies. The objective would be to establish the optimal points during the contract for ordering the components given certain program risk and planning assumptions.

Operations Concept Verification

The presentation stated that the RFPs provided no support for verification of operations concept. The SSOTF recommended that the PSC support Level II in development and management of an Operations Concept verification program with management, engineering, operations and user participation. It further recommended that the Work Package contractors support the operations concept verification program with personnel, prototypes, and testbeds.

Interactive Information System Assessment

The presentation stated that the RFPs provided no support for user assessments of information systems design and performance and no specification of rapid-prototyping of SSIS elements and networking of Space Station Program and user testbeds needed for interactive assessments. The SSOTF recommended that the PSC support Level II responsibility for planning, coordinating, conducting, and reporting interactive evaluation by designated user groups and for management of the capability to perform them. The SSOTF recommended that the

Work Package contractors provide network interface to systems prototypes, interface simulators, and other elements and support assessments.

Deliverables

The presentation stated that the RFPs deliverables were incomplete and inconsistent. The SSOTF recommended that the RFPs separately list all contract deliverables and descriptions, and that they establish a standard set of operations data requirements. The PSC and Work Package 2 RFPs were noted as especially deficient. However, the presentation noted that there were collective deficiencies for all WP RFPs:

> -The DR descriptions which were provided do not reflect a common approach for collecting operations related information (e.g. various titles, content and format among WPs)
>
> -The DRs do not reflect an integrated schedule against a common operations implementation plan. Operational need dates for integrating operations products do not appear to have been established.
>
> -In general, the descriptions provided for the content within the operations DRs are extremely broad in scope and as such it is impossible to anticipate either the contractor's interpretation or the government's intention.
>
> -The operations DRs frequently did not cite applicable references to orient the contractor properly to existing program documentation.
>
> -The processing requirements in the DRs reflect a confusing variety of descriptions of the media desired (e.g. paper copy, electronic, fiche, etc.) for contractor presentation.

One area that the Panel examined, but did not present to the Associate Administrator, was the use of contracting strategies to constrain life cycle costs. This topic was not presented for a number of reasons:

> -The topic is quite complex and the time available to comment on the RFPs was very limited. The Panel did not believe it understood the issues thoroughly enough to recommend changes.
>
> -Some of the possible changes involved restructuring the procurements in a massive way that was not practicable given the time constraints
>
> -Some issues could be addressed during contract negotiations following award of the RFPs and were thus best deferred

The analysis of these incentive aspects is contained in an unpublished paper "RFP Incentives: Incentives for Constraining Life-Cycle Cost" by Bill Gates of JPL, December 5, 1986.

5.8.2 Additional Design Issues Addressed by the SSOTF

Following the review of the RFPs, the SSOTF continued to address design issues. In addition to those described above, the principal issues were as follows:

Commonality

The advantages of commonality are many: interchangeability, easier maintenance, less training required, smaller spare parts inventory, generally less design and engineering effort, and lower production costs. The disadvantage of common standards is the restriction placed on design, the coordination or promulgation effort in generating compliance, and the both initial and continuing effort needed to select appropriate standards.

Poorly designed standards obviously can have a negative impact, in forcing design into inefficient forms and increasing costs of design, production, and operation. Also, the initial effort of designing and disseminating standards is considerable.

Commonality alternatives pertain to the depth to which standardization applies. Microcomputers, for example, may be compatible in that they can read the same size diskette, they use the same operating commands ("emulators"), they use the same operating system at the subroutine level (IBM compatibles), or they use the same hardware ("clones"). Standardization of parts can be limited to a few major interfaces or carried to the lowest level of nuts and bolts.

For the space station, a set of commonality standards has already been developed, but they have been declared "reference" rather than "mandatory". Compliance is thus optional. The alternative is to place the burden of evidence on the entity seeking a waiver from the standards.

One example of the need for common and interchangeable interfaces for user payloads within the Space Station Program is power distribution. AC distribution is the approved concept for the U.S. modules, whereas ESA and Japan have chosen DC power distribution. A likely result is variable interfaces, training requirements, and maintenance procedures. Conversion equipment will be required to install a US experiment in the ESA and/or JEM module. Also different procedures for verification, qualification, and hazards protection will be required.

Launch Vehicle Flexibility

A mixed fleet of launch vehicles was recommended for space transportation. The use of ELVs, as a part of this mixed fleet, will complicate design. An envelope of design requirements should be developed (See 1st Logistics Symposium at MSFC, week of March 19, 1987). Compatibility with a mixed fleet of launch vehicle shrouds, environment, g-loadings, and vibration is unknown. The Titan IV will provide conditions close to the STS. However, it is still being designed. There is no Heavy Lift Launch Vehicle.

Although the STS is capable of delivering a significant amount of weight to low earth orbit, it is constrained to downweight limitations of less than half of the upweight. *Editor's note: This statement was based on the STS capability at the time of the Task Force, i.e. prior to the increased downweight capability of the STS and the increased upweight capability of the Advanced Solid Rocket Motor (ASRM).* The program may be reduced to lower than desirable science return capability since STS flights will be concerned with logistics support. The SSP should initiate a study to define and design a downweight management system.

Logistics Module

There must be easy launch pad access to the pressurized logistics module for support of life science. NSTS middeck lockers are limited in the size of animal they can support to about 350 grams. Larger animals must be housed in the pressurized logistics module. Also, power and ECLSS systems must be maintained to support these animals. The support equipment and ORUs must also accessible and repaired.

Power

Discussions of resource allocation seem to focus on the steady state value of resources, principally power. In reality, both the supply and the demand for power will be variable. The supply of power will vary with the position of the Space Station and with the maintenance status of the power system. On the demand side, startup transient power demand of payloads is a key issue. There will probably be power demand spikes prior to reaching steady state. Cooling requirements may also peak in response to the start up spike, and a built-in thermal sink may be needed. Allocation of resources and associated timeliness must consider these characteristics.

Communications

The SSOTF recommended that the core station and platforms have redundant Ku-band antennas since a single point failure in the communications cannot be tolerated. Therefore, NASA should provide an alternate communications path via an S-band link. This could also provide for eventual interoperability with the internationals' data relay satellites.

Crew Environment

Past flight experience and a phenomenon known as the "tight building syndrome" support the need for sophisticated sensors (monitoring system) linked to the health maintenance facility. The SSP should develop procedures, equipment and cleaners to do routine maintenance and cleaning.

SSIS

There is need for NASA to assign a single organization with responsibility for the end-to-end architecture of the SSIS. This organization will be responsible for accumulating and reconciling all SSIS requirements. Implementation of the SSIS will include evaluation and input from user groups. At present the SSIS will be developed through a combination of efforts of several NASA organizations as follows:

Code S	Data Management and C&T systems
Code T	Space-to-ground RF connectivity through the Space Network and ground data transmission through the NASA Communications (NASCOM) and the Program Support Communications Network (PSCN)
Code E	User end-item facilities for payload control and data processing

This split implementation of the end-to-end SSIS could discourage and delay the effective use of this critical Space Station Operational system.

Supportability

Like the Shuttle, but unlike most previous NASA missions, the Space Station must be designed to be operated and maintained over a long period of time. If the initial development phase fails to produce hardware and software that can easily be supported and upgraded, operations costs will be extremely high as major systems are replaced during operations.

Elements and equipment should be designed to be easily maintained and supported at reasonable cost.

- Design modular components with common interfaces to facilitate isolation of problems and ease of replacement. Maintain stock of spares in resource nodes.
- Build in robustness and redundancy so as to minimize requirements for maintenance.
- Reduce on-orbit complexity so that problems can be diagnosed and repaired as failures occur.

5.9 AUTOMATION AND ROBOTICS by Karen Brender

In 1984 Congress mandated the Space Station Program emphasize Automation & Robotics (A&R). Since that time, the use of automated systems and robotic hardware to increase operational capabilities and decrease life cycle costs on-board the Space Station has been looked at extensively. The SSOTF agrees that this is and will be an important area for further study. Because of this importance, an automation and robotics subpanel was formed within the SSOTF.

Automation

The SSOTF Summary report acknowledges the importance of studying further the use of automation and, in particular, the identification of systems that should be automated on the initial Station either because they are vital to all phases of the Program and or because adding them later would be extremely difficult or prohibitively expensive. While several studies have covered the use of automation of on-board systems in general, there needs to be a more specific list of systems that should be automated on the initial Station and a determination of the cost savings to be accomplished by this automation. Some possible applications that should be examined from a cost/benefit standpoint are as follows:[1]

- -Fault Detection, Isolation and Recovery
    - -Subsystem Monitoring
    - -Fault Diagnosis
    - -Reconfiguration
- -Short Term Planning and Scheduling
- -Resource Management
- -Performance Management
- -Training
- -Maintenance

Many of these applications would not be candidates for incorporation on the initial Station, however, they could certainly be considered as candidates for evolution.

A requirement to operate the Space Station in a man-tended mode for long periods of time would create a necessity for a degree of automation more extensive than that envisioned for the initial manned Station. Automation and/or ground control of several Station systems would be required to support the Station during the periods when it will be unmanned.

The Task Force also feels that not enough attention has been paid to the automation of ground based systems (other than such design systems as CAD/CAE) where the life cycle cost savings to the Program could be more significant than those associated with on-board automation. In addition to possible cost savings, ground systems can be used as a test bed for on-board systems at a low risk to the Station. Since the use of such capabilities must be proven to be trustworthy prior to their installation on the Station, their use on the ground would not only improve ground capabilities but would also provide a prototype to build confidence in the design of the software which may migrate to the Space Station.

Existing automation studies tend to stress autonomy of the Station, i.e. independence from the ground. However, increased Station autonomy should be treated not as an end in itself but only as a means to relieve the on-board crew of tedious, repetitive or dangerous tasks and/or as a means of saving costs of operating the Station. Several functions performed by the Operations Management System (OMS) on the ground could be migrated to the Station, however, this migration must be looked at very carefully to assure that it results in cost savings and increased performance. Also, studies are needed to determine the effectiveness and increased performance which might result from the migration of some of the on-board functions to the ground (e.g. ground control of near vicinity vehicles or mobile Station Systems).

While it may not be vital, or even desirable, to design in a high percentage of automated systems before the Station experience base indicates a need for such, or before trust in the automated systems can be established, it is vital to start building a knowledge base which can be used to build automation capability for both on-board and ground systems. For this reason, the inclusion of automation studies in the Phase C/D contracts is very important. Figure 5-5 shows a plan for the use of design requirements to capture system knowledge which can be used to develop automated systems in several areas.[2] In addition, the Operations Groups of the NASA Automation and Robotics Panel makes the following statement on this subject[3]:

> "The development of the system knowledge base is the central, most critical technology development area. This is because it interacts with the most important subsystems and influences the operation of all aspects of intelligent, autonomous systems. Knowledge base development for dynamic, large-scale systems, especially for space systems, such as the Space Station, is still an uncharted area. For application domains with existing operational human expertise, it is usually the most difficult development area to accomplish satisfactorily. For the Space Station, presently without such expertise, it is the most important and urgent research and development area requiring careful planning far into the future.
>
> This process must start during the design phase, where the final design represents a first baseline set of factual information from which factual knowledge for the system knowledge base can be extracted. The knowledge base can be completed with heuristic knowledge obtained in the usual manner--by a question and answer process from humans at a later time. Of immediate concern, therefore, are the development of (1) a mechanism for capturing and storing relevant design information in machine readable format and (2) techniques for extracting operational knowledge for the system knowledge base from this design information."

Design knowledge capture requires a strong operations people involvement along with a design knowledge capture system. Operations personnel must take responsibility for capture of the correct information since they are the people who need the information for future operations and sustaining engineering.

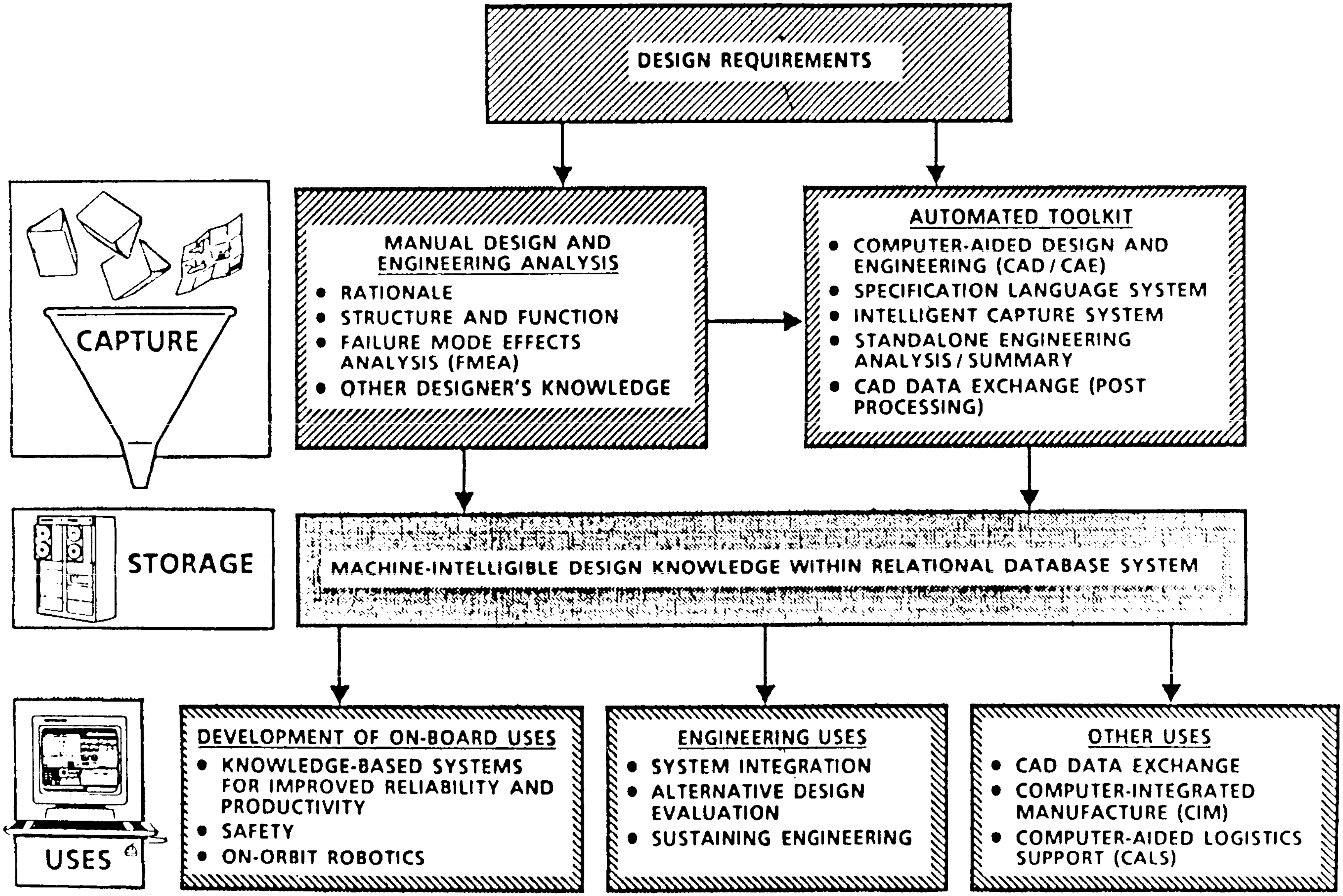
Automation of the operation of hardware and software will be an important part of the Space Station Program and studies should be encouraged, perhaps even incentivised (award fees, etc.) in the Phase C/D contracts.

Robotics

In the study of Space Station operations, it will be important to encourage the Phase C/D contractors to place emphasis on the possibility of using robotic hardware (e.g. light weight arms, "smart" end effectors, etc.) to relieve the crew of tasks that are better done by such hardware. Such tasks are those that are dangerous such as handling hazardous materials, or those that are extremely fatiguing such as long EVAs. The use of mobile robotic arms, operated from a Station module could also alleviate the necessity for long periods of unproductive crew time associated with EVA activities, such as breathing conditioning, donning and doffing suits, etc. Such use could also save some of the time and costs associated with suit reconditioning. As with all mobile hardware, safety considerations will be paramount in the decision to use robotic technology. Caution must be exercised in

DESIGN KNOWLEDGE CAPTURE FOR SPACE STATION

FIGURE 5-5



DESIGN REQUIREMENTS

CAPTURE

MANUAL DESIGN AND ENGINEERING ANALYSIS
- RATIONALE
- STRUCTURE AND FUNCTION
- FAILURE MODE EFFECTS ANALYSIS (FMEA)
- OTHER DESIGNER'S KNOWLEDGE

AUTOMATED TOOLKIT
- COMPUTER-AIDED DESIGN AND ENGINEERING (CAD/CAE)
- SPECIFICATION LANGUAGE SYSTEM
- INTELLIGENT CAPTURE SYSTEM
- STANDALONE ENGINEERING ANALYSIS/SUMMARY
- CAD DATA EXCHANGE (POST PROCESSING)

STORAGE

MACHINE-INTELLIGIBLE DESIGN KNOWLEDGE WITHIN RELATIONAL DATABASE SYSTEM

USES

DEVELOPMENT OF ON-BOARD USES
- KNOWLEDGE-BASED SYSTEMS FOR IMPROVED RELIABILITY AND PRODUCTIVITY
- SAFETY
- ON-ORBIT ROBOTICS

ENGINEERING USES
- SYSTEM INTEGRATION
- ALTERNATIVE DESIGN EVALUATION
- SUSTAINING ENGINEERING

OTHER USES
- CAD DATA EXCHANGE
- COMPUTER-INTEGRATED MANUFACTURE (CIM)
- COMPUTER-AIDED LOGISTICS SUPPORT (CALS)

both the design and operations stages of this technology. The Space Operations and Support Systems Panel of the SSOTF looked at the use of the Flight Telerobotic Servicer (FTS) which is a part of the Space Station Program plans. Table 5-3 presents the description of the FTS and suggestions for development that were developed by that panel and presented to the SSOTF.

The suggestions made with respect to the FTS should be applied to all sophisticated robotic hardware to ensure that it will be used with confidence once it is built.

As with automation, more consideration should be given to the use of robotic technologies for use in Space Station ground operations. Such systems are already used in manufacturing and in the handling of hazardous materials and their application to Space Station ground system operations to relieve ground crews of dangerous and tedious jobs should be expanded. This would, most likely, result in sizable benefits to the program for the costs involved. In addition, ground hardware can be used as a test bed for potential on-board systems to ensure their safe operation and to build confidence in their capabilities.

Summary

Automation of operating Space Station systems, both on the ground and on-board, and the use of robotic hardware to relieve crews of tedious and/or dangerous tasks, should be a vital aspect of the Space Station design studies. Decisions must be made as soon as possible on which systems must be automated on the initial Station, on which robotic technologies are required early and on the hooks and scars which must be added to the initial Station design to allow the addition of further A&R during the evolution phases of the Program. In order to facilitate such decisions, the Phase C/D design efforts must include studies of A&R systems from an operational and life cycle cost basis.

Recommendations

As part of its efforts to plan for advanced automation, the SSOTF recommends that the Space Station Program:

(1) Provide Work Package managers and Phase C/D contractors with guidelines for defining and maintaining Program-based "knowledge capture" databases as they make primary design decisions.

(2) Initiate prototype ground-based and on-orbit expert systems development using life-cycle cost methods for evaluating options.

(3) Require Phase C/D contractors to submit an Automation and Robotics Plan. The Plan should propose knowledge base requirements necessary for development of the ultimate concept, design strategy given the K.B., and approaches to prototyping and validating the concept over time.

(4) Require contractors to suggest incentive and award schedules based on successfully developing and validating proof of concept. The schedule will consider potential life-cycle cost benefits including those which may accrue across the station by broad-based application to multiple systems and modules, as well as opportunities for developing and retaining Station and system evolutionary paths.

(5) During the development and operations phases the Program should prepare A&R Advocacy Plans. As a starting point, the projected levels of operational performance for major functional areas should be evaluated against the life-cycle costs and the associated risks. The plans should be proactive in the use of A&R to enhance long-term operational productivity. System scarring for longer term technological evolution should be highlighted for Program management decisions.

Table 5-3
FLIGHT TELEROBOTIC SERVICER

OPERATIONAL BACKGROUND

The Flight Telerobotic Servicer is being implemented as a multipurpose tool to reduce and/or complement crew EVA during assembly, maintenance and servicing. Tasks planned for execution by the FTS are also designed to be accomplished by EVA.

KEY TELEROBOTIC SERVICER DEVELOPMENT REQUIREMENTS

-Ground Rules (absolute requirements)

(1) Crew safety--complies with Space Station rules and standards for critical and hazardous systems.

(2) Critical Space Station hardware safety--complies with Space Station rules for critical and hazardous systems.

(3) FTS must fail safe and fail recoverable

-Constraints (desirable to have but trade study results may change options)

(1) Teleoperation and limited supervised autonomy operation modes.

(2) FTS operable from NSTS, Mobile Servicing Center, servicing bay manipulator, and the OMV.

(3) Use standard Space Station interfaces.

-Function

(1) Specific functions will be allocated to SS FTS facilities during Phase B.

(2) FTS provides dexterous manipulation capability alternative.

(3) Some functional capability overlaps between the EVA crewman equipped with suitable tools and the FTS equipped with suitable end effectors.

EVALUATION OF FLIGHT TELEROBOTIC SERVICER

-Development of the FTS builds on industry experience and the already demonstrated systems within the nuclear industry (as a result the risk is not so much with delivery of a useful system but with the degree of operational flexibility available by first element launch).

-A combination of NSTS flight demonstrations and simulations are to be used to baseline FTS capabilities and safe, reliable, and efficient operations.

-The development risks are considered to be manageable provided appropriate flight demonstrations and simulations are conducted and the EVA capability to perform FTS tasks is also available.

-The FTS Phase B study effort is to be initiated in the same time frame as other Space Station elements are beginning Phase C/D (this will necessitate close coordination among Work Packages to insure FTS designs are successfully integrated into the SS Program).

(6) In the area of onboard operations automation, the Program should establish fixed procedures and predetermined decision rules that permit maximum operation with minimum on-orbit crew intervention.

> -Use ground control for selection among pre-programmed automated procedures. Use of robotics technology where applicable.
>
> -Facilitate crew intervention by means of computerized diagnostics and easily implemented instructions.

(7) With respect to the FTS,

> -The Program should aggressively pursue development to establish capability in place early, consistent with safe, reliable and efficient operations. The FTS offers significant potential to the Space Station Program to reduce and/or complement crew EVA activities during assembly, maintenance and servicing activities.
>
> -The Space Station operations organization should participate in and maintain appropriate oversight involvement during the FTS Phase B systems definition effort in order to identify FTS operational functions which would provide significant enhancement of the Station's productivity, influence the operational character of the FTS and develop the FTS operational concept.
>
> -The Space Station Program development efforts other than the FTS should accommodate the FTS Phase B and C/D contracts and schedule offset to the extent required to ensure successful integration of the FTS into the SS Program.

(8) Continue the Automation and Robotics Panel (ARP). NASA has taken several steps to ensure that artificial intelligence and the automation of ground control functions receive the appropriate priority. A group of outside experts was organized by NASA to evaluate automation in the Space Station Program. This group, called the Automation and Robotics Panel (ARP), identified current and future expected artificial intelligence and automation technologies and assessed their applicability to the Space Station Program. In addition, the ARP reviewed the work package and Program Support Contractor RFPs.

ENDNOTES

1. Derived from Advancing Automation and Robotics Technology for the Space Station and for the U.S. Economy, Advanced Technology Advisory Committee, National Aeronautics and Space Administration, Progress Report 3--April Through September 1986, NASA Technical Memorandum 89190, Submitted to the United States Congress, October 1, 1986, p. 13.

2. From ATAC Report #3, p. 3.

3. Progress Report of an Evaluation of Space Station Automation and Robotics Based on the Documentation Requirement 17 Reports of Space Station Program Phase B Contractors, Draft 3, provided to NASA Task Force on Space Station Operations by the Operations Group of the Automation and Robotics Panel, California Space Institute, University of California at San Diego at the Scripps Institution of Oceanography, March 20, 1987, p. 12.

5.10 EVOLUTION by Karen Brender

One of the major goals of the Space Station program is to design and build an initial Station that is capable of evolving as requirements for use of the Station change and as technologies become available to enable lower operations costs, higher productivity and increased performance. Both the manned base and the platforms must be capable of growth in order to accommodate increasing numbers of users who will, most likely, have increased resource requirements as the user hardware and the zero g experience base evolves (e.g. materials processing moves from research to production requiring larger amounts of power).

The SSOTF Summary Report presents a concept for Space Station Operations in the mature operations phase (i.e. prior to any major growth in resources). The functions in the evolution category during this phase are those of planning and scheduling for evolution, although the possibility exists for some phase A/B studies during this time frame. Both systems and operations planning must be accomplished to assure an evolutionary program which meets requirements, is workable, is within the budget constraints and does not preclude any viable evolutionary path. In any evolution planning the planners must always be aware that the benefits of evolving the Space Station are to increase capabilities available to the user communities.

Evolution Planning

Planning for growth and evolution includes the provision of scars for possible future alternatives, which can be handled in several ways:

> -Build in hardware components that permit future growth in a wide range of possible directions. Preserve future options by scarring, to the extent that allowing for uncertain alternatives is less costly than making future modifications.
>
> -Consider possible growth configurations, but accommodate only those that appear very likely or will be precluded by specific designs.
>
> -Adapt the station to growth as it occurs.

Another important aspect of evolutionary planning before and during the mature operations phase is planning for the use of automation as an aid to productivity and to lower life cycle costs and the use of robotics to relieve the on-board crew of tasks that are better done by robotic hardware. One of the functions of this aspect of planning is to decide what types of automation should be on the initial Station because they are vital to all phases and/or because adding them at a later time would be prohibitively difficult or expensive. Another planning function would be to determine initiatives for A&R. A&R is discussed more fully in Section 5.9 above.

Evolution Planning Process

The functional structure for "Evolutionary Planning" is shown in the SSOTF Summary Report, along with the necessary inputs into the planning process and the flow of output to other functional processes. Evolution planning will be accomplished under the direction of the Strategic Plans and Programs Division at Level I. All major Strategic functional groupings will feed inputs, such as historical data and results from independent analyses, to the planning process. The planning process would then determine other factors which will affect the policy determined to be appropriate for evolving the station. Determination of the extent and direction of evolution and growth will come from both strategic and tactical functional areas.

These areas include:

- General operations policy
- Transportation policy and planning
- Utilization policy and planning - particularly in the arena of marketing to both commercial and non-commercial sectors to increase Station utilization
- User Priorities
- International policies
- Budget projections
- User requirements, particularly projected user requirements, etc.
- Ongoing studies such as those on Space Station design and those on use of commercial elements and services

The evolution planning function provides feedback to the other strategic level areas and to the required tactical planning areas. Of vital importance is the flow of information from this planning function to the SE&I planning functions and the operations integration function. The transportation and utilization policy and budget feedback loops must be established early in the planning processes so that information flow in both directions is accomplished prior to the actual hardware phase of the Space Station program.

The most vital aspect of evolutionary planning in the DDT&E phase of the Space Station Program is assuring that the initial Station is designed in such a way that it does not preclude growth in systems, resources and operational capability. Specifically, evolution planning must establish what hooks (to allow software add-ons and change out) and scars (to allow system capability increase) are necessary to accomplish evolution without a severe increase in life cycle costs.

Specific functions of the evolutionary planning category include but are not limited to the following:

- Analysis of current and projected Station systems, customer requirements, goals, and policies (has both strategic and tactical aspects).
- Analysis of all strategic plans and policies to determine the direction and extent of evolution (has both strategic and tactical aspects).
- Determine design impacts, particularly hooks and scars on the "current Station" at any phase of the Program, to allow for further evolution (has both strategic and tactical aspects).
- Establish plans for the use of automation and robotics as an aid to operations.
- Set up a performance assessment/ cost assessment system to identify opportunities/requirements for automation and evolution paths.
- Perform life cycle cost studies to guide planning for effective evolution at the lowest costs to the Program.
- Manage Space Station System growth and evolution programs.

Evolution Options

There are optional ways to achieve evolution of both the manned base and the platforms, as well as phasing of Space Station operations functions such as marketing, pricing, information systems, etc. Some of the major impacts of the optional ways to grow/phase can be shown here (many operations options are covered in the Summary Report and the other panel reports); however, much more work needs to be done on the operational impacts of choosing certain evolution paths.

(1) **Systems Evolution - Platforms.** Evolution of the platforms can be

accomplished in two ways. First, existing platforms can be "grown" -- that is, expanded to increase resource capability and accommodate more users. Or, conversely, platforms can be replicated so that growth is accomplished by providing additional platforms. The option recommended by the Space Operations Support Systems Panel of the SSOTF is that of replication. This option was considered to be more "user friendly" for diverse users than the expansion of a single platform.

> IMPACT: The major operational impact of this approach to growth is increased requirements on the transportation system(s) for launch and particularly for servicing of "more" platforms. Increased requirements for servicing would also increase the use of the OMVs resulting in a probable increase in the number of OMVs. An additional impact would be in the increase in competition for common systems such as communication links.
>
> The impacts, to the Space Station Program, to operations cost and to transportation systems, of adding more platforms have not been fully determined and further study is suggested.

(2) <u>Systems Evolution - Manned Base</u>. The evolution of the manned base can be accomplished in one or more of the following ways:

(a) Adding resources, elements and structure to the existing manned base. This evolutionary path requires that scars be added to the initial Station. If scars are not added (e.g. size the alpha joint to accommodate larger power systems) the on-orbit change out and integration to accomplish the growth may be operationally impossible and/or prohibitively expensive. Scar requirements are still under study, however, the following is a list of some of the primary systems requiring growth scars:

Alpha Joint (Electrical)

Radiator Joint (Mechanical & Fluid Transfer)

Power Management and Distribution

Thermal Distribution

Guidance and Control

Element Docking Capability

Health Maintenance Facility

Operations Management System

TDRSS Antenna Mounts

> IMPACT: Growing the Station in a "more of the same" manner will require additional operational capability in logistics, crew habitat, maintenance, etc.

(b) Change out systems (software and hardware) as new technologies become available that will increase productivity and/or lower operational costs. A key area of technology upgrade will be in automation of systems where such automation can accomplish the above objectives. Some hooks and scars may be required on the initial station to allow addition of new technologies.

> IMPACT: Operational impacts of providing new technologies such as automation should be only in the positive direction; e.g. the creation of more crew time for users, reduction of costs of operating ground systems and/or the increase of onboard productivity (work capacity) However, care must be taken that the program does not automate for the "sake of automation". More study of actual requirements is necessary.

(c) Branching to a second (or more) Station with a different utilization purpose, e.g. a transportation node and a "quiet" microgravity station. The 1985 Space Station Evolution Workshop found that branching is likely to be a major evolution node.[1]

> IMPACTS: Operational impacts are the same as those of Option (a), however, this option will have a more severe impact on the transportation systems.

Preliminary studies of the impacts to transportation system due to evolution and growth were done by the Work Package 2 Phase B contractors.

(3) Ground Systems Evolution. Evolution of ground systems will be as vital to the Program as the evolution of the on-board systems to increase performance and lower life cycle costs. Past programs have been somewhat lax in the evolution of the ground systems to upgrade their capabilities and to take advantage of new technologies. Increased capabilities on the Station will require increased capabilities and performance on the ground. Evolution planning must include requirements to build ground software systems (in which the technologies are changing rapidly) for ease of upgrade, for growth in capability and for transportability.

Ground systems can also be used as a test bed for the automation of on-board systems. Since the use of such techniques as Knowledge Based Systems must be proven to be trustworthy prior to their installation on the Station, their use on the ground would not only improve ground capabilities but would also provide a prototype for testing software that may later migrate to the manned base or the platforms.

Operational Phasing

The following paragraphs list some suggested phasing of evolutionary capability/direction for certain operational functions. The suggestions are from the reports written by Panels 1 and 3 of the SSOTF.

o Platforms should gravitate from Station owned and operated to being owned and operated directly by the users (or by private firms which would provide commercial platform services to the users). The impact of this would be to shift program costs from the Station to the user. However, centralized control of common systems (for which all users compete) such as OMV use, servicing flights and communications links will still be required.

o Several functions performed by the Operations Management System (OMS) can be migrated from the Ground to Onboard, however, this migration must be carefully studied to assure that costs are lowered and efficiency increased before it takes place. Also, studies are needed to determine the effectiveness of migrating some on-board functions to the ground where such migration would result in savings and/or increased performance (e.g. ground control of near vicinity vehicles or mobile Station systems).

o A particular pricing policy was not recommended, however, whether the pricing policy elicits responses that are useful in determining how the Station should grow or evolve was used as an evaluation criteria for policies by the pricing subpanel of Panel 3. See Space Station Operations Task Force Panel 3 Report User Development and Integration, December 1987, p. 2-18, 2-38, 2-41.

o Marketing to the commercial sector should probably evolve from an operation that is a contract from a government office to a profit making, independent enterprise with a share of the Station resources. This could impact evolution direction if the policy sets up an increasing share of the resources to the commercial sector.

- Utilization planning should start as a centralized function for both manned base and platforms but the possibility exists to migrate this function to distributed and eventually to independent planning for different user entities.

Summary

The Space Station, by Program goal, will be capable of evolving over time. This evolution must be planned along the lines dictated by policy and budget to obtain the maximum increase in user capability at the lowest possible life cycle costs. To accomplish that objective the evolution planning function of the operations concept must be a part of all phases of the Space Station Program from DDT&E and operational maturity through actual Station growth.

ENDNOTES

1. Proceedings of the Space Station Evolution Workshop Hilton National Conference Center, Williamsburg, Virginia, Office of Space Station, NASA Headquarters, Washington, DC, September 10-13, 1985. Proceedings of the Space Station Evolution Workshop, Williamsburg, Virginia, Office of Space Station, NASA Headquarters, Washington, DC, July 29-August 1, 1986, page ix.

5.11 INTEGRATION OF INTERNATIONAL PARTNERS IN OPERATIONS AND UTILIZATION

Editor's note: Section 5.11 is based on the negotiations and MOUs as they existed in the spring of 1987. The authors note that many of the issues identified here have been resolved in subsequent negotiations and MOUs. The reader should refer to the latest version of the MOUs for current Program positions.

The Panel devoted considerable effort to the analysis of the challenges posed by the international character of the Space Station Program. This work is described in this section. The first part is a high level, somewhat abstract analysis of partnership options. The next section describes the international management option recommended by the SSOTF. The third section discusses international operations cost sharing, and the fourth, the implications of the SSOTF proposed utilization scheme for SS users and module outfitters.

5.11.1 SPACE STATION "PARTNERSHIP" OPTIONS by Richard O'Toole

Introduction

As the United States plans for the development of an international Space Station, there are many options available for how to structure our relationship with the potential partners (Japan, ESA, and Canada). In a generic sense these relationships may be thought of as forming a continuum from a full joint venture at one extreme to an owner-user relationship at the other extreme. Complicating the situation even further is the fact that within the overall structure of the agreements between countries there are numerous specific dimensions which may vary from the central philosophy. Just a few of these dimensions include: technology transfer, legal regime, utilization rights, cost obligations, and operations policy. Thus, while a potential participant may desire to be a "full" partner with its implied benefits of technology transfer, it may be less willing to accept the risk sharing responsibilities of that arrangement.

In order to illustrate this complex set of possibilities, three generic types of international agreements will be discussed: full partnership, limited partnership (franchise), and contractual agreements. The actual relationship among the international participants will, of course, be a product of negotiation which incorporates political as well as technical factors. Thus, after discussing these generic international options, which were deliberately chosen to illustrate the wide spectrum of possibilities, a preferred option will be discussed which attempts to blend the technical, economic, and political constraints into a workable solution.

5.11.1.1 Alternative Generic Partnership Arrangements

Full Partnership

The title "Full Partnership" is used here to convey the concept of a true joint venture with participants sharing in all aspects of the program for an extended duration. In this case, partners should be prepared to commit themselves to the long-term success of a free world Space Station and to plan for continued cooperation and cost sharing of space exploration. The key factors in creating such a full partnership is that the participants must share a common goal and have a commitment to a long term relationship.

Given that there has been a decision to form a full partnership or joint venture there are two very different legal structures which might be employed. The first type of relationship could be implemented through a set of contracts, much like the way American automobile manufacturers purchase components from foreign manufacturers. As a theoretical matter, this is possible with the Space Station and would give the U.S. the greatest potential for retaining virtually complete control. As a practical matter, however, preparing a comprehensive contract specifying the precise prices, quantities and conditions of delivery of items under each of all possible circumstances is extremely difficult, if not impossible. Given the lifetime of the Space Station and the many technological uncertainties, it is either too costly or impossible to conceive of all possible circumstances, much less what prices, quantities and conditions of delivery should apply in each case.

As an alternative, international involvement could be structured by the establishment of a common enterprise. This type of organization, through a pre-determined governance and management mechanism, can deal with actual situations as they arise from time to time. Adaptive, sequential decision-making processes substitute for massive one-time agreement to deal with all possible cases, many of which may never arise. On the other hand, shared governance and management may result in decisions contrary to American interests.

Between the extremes of a comprehensive contract and a common enterprise there are many possible compromises. The contract could deliberately be kept incomplete and allow for a sophisticated arbitration procedure between the partners to govern unplanned-for situations. Certain components could be wholly-owned by the U.S. and others owned by the common enterprise. Alternatively the contracts approach could be used in one phase of the Space Station program and a common enterprise in another. In the discussion which follows the emphasis will be placed on the common enterprise approach for the following reasons: 1) the complexity and uncertainty involving the development of the Space Station makes the contracting approach very difficult to implement, 2) the nature of the participants being sovereign nations also makes contracting inappropriate, and 3) for illustrative purposes it is useful to construct a "pure" full partnership case.

A. Organizing a Full Partnership

In establishing a partnership for a common enterprise there are a set of issues which must be addressed. At the highest level there are nine such issues which are briefly discussed below:

1. Objectives, Scope and Limitations of Activities

Whereas for most private partnerships the objectives and scope of the venture are relatively easy to agree upon, this is not the case for the Space Station. Each participant is looking not only at commercial returns, but also at scientific and political dividends as well. Moreover, the attainment of one participant's goals may be directly contrary to the interests of another participant. In view of this, it is essential for the Space Station participants to define the technical objectives of the partnership rather than just abstract goals. The participant's conflicting goals would, in the give and take of negotiations with other participants, be translated to agreed upon technical specifications.

Agreement on the limitations in scope for the Station will be a key issue in any partnership. The participants will need to specify what kinds of activities will be permitted to be carried out on the Space Station. Are any kinds of experiments, military or non-military, to be prohibited? The partners also need to determine if they are granting any exclusive franchise to the common enterprise which will preclude their right to similar activities in an independent mode.

2. Participants

Although it is currently contemplated that the participants would be the United States, Japan, Canada, and the European Space Agency per se, consideration should be given to the possibility that eventually an alternative mode of participation would be desirable. For instance, in the steady state operations phase, instead of the U.S. being a direct participant, the entity which participates on behalf of the United States could be a quasi-public corporation.

A determination will have to be made on the ways U.S. industry should become involved with the Space Station program. In addition to simple purchases of services, industry may seek to become providers of services through franchises or Joint Endeavor Agreements.

3. Governance and Control

The issue of governance and control is basic to any common enterprise. It is in the interest of each partner to make sure: the venture is efficiently managed, it is safe, the partner receives its fair share of the benefits, and that the venture responds to the partners long-term space strategy. The governance and control mechanisms are key instruments to protecting these interests.

While the character and magnitude of each participant's role in the Space Station is likely to be dependent on its actual technical and financial contributions to the program, legalistic devices are also significant. These devices fall into three major categories. First, management of day-to-day activities in the enterprise. Second, voting mechanisms can be designed to give control to a single participant while still protecting the rights of the other participants. Third, the enterprise can be structured so that it is dependent on the U.S. for some critical element or service.

In the case of the Space Station, the issue of control is especially difficult because the U.S. will be a dominant partner in terms of investment and use while the other participants will seek strong protection of their rights in the enterprise. As a practical matter there are three possible ways to resolve this dilemma: consensus approaches with a fallback to U.S. decision making and an appeal process, weighted voting mechanisms, and special majorities.

4. Tactical and Execution Management

In "dominant parent" private joint ventures, boards of directors are largely ceremonial. Strategic and tactical decisions are made by representatives of the dominant partner either within the joint venture or at the parent organization. In the case of the Space Station, system operation could range from the extremes of national enclaves (elements operated independently onboard and on the ground) to fully integrated onboard operations with centralized ground operations. The final choice of preferable mode in this case must balance the U.S. desire for control to ensure safety and efficiency against the other partners' desires to participate in the operational phase of the systems.

5. Dispute Resolution

A well defined mechanism must be established for resolving disputes which will inevitably arise among the international partners. Streamlined appeal mechanisms which keep decision making at the lowest practical levels will facilitate efficient operations. The alternative is that every dispute elevates up to the highest international decision making body which will mean long delays and a cumbersome operations management process.

6. Financial Obligations

The partnership agreement will have to specify: the nature of the capital contribution to the venture (in this case the elements, lab equipment, platforms, etc.), the timing and manner of making the contributions, and the obligations of each partner during the operations phase.

7. "Ownership" and Specification of Rights & Duties

Ownership in the Space Station partnership relates to the station as a whole, elements in the Station and to the services (i.e. resources) it provides. Many alternative variations on how ownership is handled are possible within this framework. At one extreme, the partners could hold an undivided interest in the Station as a whole, the relative amount of which would determine allocations of each measurable type of Space Station service. At the other extreme, each partner could "own" the element provided to the venture in some way. Once the top level agreements are made on ownership the secondary issues of payload selection, pricing, and scheduling must also be addressed as part of each partner's rights or benefits.

Each partner will also have to accept certain obligations or duties as part of the partnership. These duties relate to allocation of liability, provision of support facilities by each partner and the requirement to abide by certain technical specifications which will permit the Station to be integrated as a system.

8. Transferability, New Partners & Termination

In time, additional countries or private entities may wish to become involved in Space Station activities. These new participants may simply enter into agreements with one or more of the initial participants for the purchase of specific resources. In this case they would have no direct relationship with any of the other initial participants and would have none of their rights and duties. The other possibility is that they seek to purchase all or part of the interest of the initial participant in the Space Station partnership.

The initial partners would be less concerned with the sale of Space Station services than with the transfer of an interest in the Space Station itself. Nevertheless, even in this case a limitation may need to be included. For instance, the U.S. may want to limit its partners from selling services to certain countries.

Withdrawal of a participant from the partnership is more difficult than in a conventional private joint venture even if its interest is transferred to existing participants. Valuing the initial participant's share in the venture would be extremely difficult and may, in fact, be costly if the partner wanted to remove its element.

Two other issues which are important to the formation of a sound partnership are: 1) can partners be expelled for breaches of obligations and what happens to the elements supplied by them, and 2) what is the length of time intended for this partnership?

9. Choice of Substantive Law

The parties will need to decide what substantive law should govern their relationship with each other and with the Space Station and its personnel. As a practical matter, the choice is unlikely to prove a problem with the current participants, since they all have significant experience in working together, including some experience in cooperative space projects.

B. Characteristics of a Full Partnership

1. Premise

Carried to its logical extreme a true full partnership would give all the partners an undivided share in all aspects of the Space Station venture. This share would typically be determined by the contribution of the given partner to the overall investment in the facilities (both ground and flight) associated with the program. All operations costs, risks and benefits would be shared in this same proportion. In effect everything is pooled by the partners and shared in proportion to their interest in the venture.

2. Structure

Such a venture is more likely to be successful if there is an agreement among the partners on a common set of goals and priorities. In a private joint venture the goal is usually to earn profits. This goal is common to all the participants and the venture is structured around that objective. For the Space Station the goals and objectives are much more complex to define. Each participant is seeking to perform scientific research, commercial research, develop its abilities in space infrastructure development and achieve political goals at the same time. The fact that these goals are in conflict for the potential Space Station partners will evidence itself in the hardware negotiations. Duplication of certain types of facilities, unique partner requirements for certain facilities, desire for non-centralized control are some of the manifestations of a divergence in objectives. A full partnership needs a long term commitment to at least a reconcilable and consistent set of goals.

3. Management and Control

The participation of the partners in the management of the Station would be through an international "corporate board of directors" with predetermined voting percentages. This board would safeguard the objectives of the partnership over the objectives of the individual members. A common set of rules would be established for all partners which guarantees equitable access to the cooperative elements for all partners. This type of management is easiest to implement when the partners are nearly equal in the venture since there is no need to negotiate complex voting schemes. A problem does arise, however, with dominant partners as is the case of the Space Station. The legitimate rights of the dominant partner (in terms of investment) must be balanced against the need for the other partners to protect their rights when they could be outvoted if management control is proportional to investment share. This problem can be handled by utilizing "special majorities" which require different voting majorities for specific types of decisions. For example, even if the dominant partner had an 80% investment share and 80% of the votes in management decision making, some important issues could require 90% or unanimity for passage. Issues of this nature might include decisions affecting new partners, reallocation of resources among partners, and other issues of strategic importance.

4. Operating Costs

There are a number of ways to share operating costs among the partners, including: pooling all costs and distributing by share, distributing functions and let the partners incur the associated costs, accepting cost responsibilities associated with pieces of hardware, and combinations of the above options. Any of these approaches might be negotiated among the partners, but there are differences in the implications for cost efficiency and management. As a general principle it is desirable to have the partner who designs and builds the equipment be responsible for its operations costs as well. This arrangement internalizes the incentives to develop hardware systems which are life cycle cost effective. The U.S., as a majority partner, has an important stake in providing the proper operations cost incentives since we will be bearing somewhere between 67% and 80% of operating costs.

There are gains to be made in terms of efficiency by having a full partnership arrangement. By specializing in certain types of facilities it is possible for the partners to save both investment costs and operating costs while also keeping compatible payloads co-located. This concept of specialization has been termed functional allocation within the program and is highly consistent with the concept of a full partnership.

Thus, in the partnership example one representative mode of operation would be to functionally allocate responsibilities to each of the laboratories (e.g., life sciences, material sciences, technology experiments). As owners with an undivided interest in the labs per se, the partners would share the use of the facilities in proportion to their investment shares in the program. In this manner savings would be achieved in non-duplication of equipment. It is also worth noting that in a private sector, profit-oriented full partnership there would probably not be so much duplication of DDT&E among the partners as there is likely to be in the Space Station. In other words, competitive pressures would force the partners to eliminate this unnecessary expense from their venture. The added costs of duplicating design, development and testing in multiple countries for platforms, modules, training facilities, operating centers, etc., is substantial.

5. "Ownership"

The Intergovernmental Agreement (IGA) describes the ownership of the elements as it relates to ownership and control. The MOUs describe the resources that accrue to each partner due to their participation. A partner with a 20% share "of the Station" would have a claim on 20% of the kilowatt hours, IVA hours, EVA hours, etc., reserved for users. Allocations for housekeeping resources would be negotiated among the partners in advance and come off of gross resource availability. Partners would not be forced to stay within the envelope of their allocation at all points in time, but rather to utilize a maximum set of resources over a time period such as one year. In addition, the allocation of resources based on investment shares would permit the partners to barter resources among each other to more nearly match their demands for services during a particular period.

Over time additional resources will be identified which are valuable to the partners and shares will have to be allocated in the same proportion as investment shares. In this arrangement it is still possible for scientists from different countries to pool their resources within a particular discipline. As each partner allocates its share of use resources among its using groups (e.g., astrophysics, material science, life science, technology experiments, etc.) the scientists who receive allocations from each partner country can then pool their resources for cooperative experiments.

6. Advantages of a Full Partnership

a. In theory it could be the most cooperative form of long term venture.

b. It establishes processes to deal with unknown events of the future which avoids making premature commitments.

c. Uncertainties and risks are shared among the partners

d. Functional allocation can be implemented to achieve economies of specialization.

e. Numerous successful models exist in the private sector.

f. It retains U.S. majority partner status.

g. It ensures full utilization of the Station early.

h. Benefits, costs, authority are all shared on the basis of a simple sharing formula (usually investment shares in the venture).

7. Disadvantages of a Full Partnership

a. It requires the formation of an international management organization distinct from any partner.

b. It works effectively only as long as all the partners share common goals and objectives.

c. It can imply complex accounting requirements although there are ways to avoid most of it.

d. It can reduce the majority partner's flexibility to grow, add controversial users (e.g., DOD), and set policies.

e. It increases coordination and integration effort and costs.

f. It may increase technology transfer to competitive trading nations.

Limited Partnerships or Franchise Agreements

1. Premise

Unlike a full partnership or a joint venture a new management entity is not created to form a franchise arrangement. Usually an agreement is formed between a parent organization (or dominant partner in terms of investment) and a franchisee (junior partner in terms of investment). Such organizations arise in cases where the success or failure of the two parties are not as closely linked as in the full partnership. Nevertheless, the agreement typically includes incentives for both parties to promote each other's success.

2. Structure

Franchises tend to allocate costs, risks, benefits, and control much differently than in a full partnership. The majority partner often provides the knowledge, services, or product in return for payment. Usually the failure to perform on the part of the franchisee does not lead to a failure on the part of the parent. In the case of the Space Station the analogy would be to a national enclave type of international participation where the international partners bring laboratories to the Station which they want to operate in a distributed fashion from the core Station. They would need to secure services from the U.S. in order to run their element for which they could either offer payment in currency or in bartered use of their laboratory facilities.

3. Management and Control

The management and control of the Station from the U.S. perspective would be quite different in this case. As majority partner the U.S. would retain total control over the operations management system. Agreements would be negotiated which established certain specifications on the enclave laboratories and limited their performance in real time situations, but they would have considerable control beyond the laboratory bulkhead. In the extreme case users within the laboratory enclave would be integrated and controlled solely by the element with no Station user integration function. Crew operations would be element dedicated. Obviously, there are compromise positions on the level of autonomy given to the franchised laboratory. One could imagine an integrated on-board operations system coupled with a ground operations system which is element specific through element dedicated POCCs.

4. Operations Costs

As explained earlier, in a franchise agreement the links between the success and failure of the two parties is not so close as in the full partnership case. A franchise operator would expect to have a more well defined set of obligations and benefits expressed in the agreement. On the cost side, the franchisee or limited partner would expect to pay a fixed fee or percentage fee (gross or net basis) in return for the services it receives. It would certainly be possible in concept to also have a bartering arrangement in this form of international participation. But instead of a percentage share of the operations cost responsibilities the franchisee would expect to negotiate a fixed share of its laboratory in return for a fixed set of station resources. Such a quid pro quo should be resisted on the part of the U.S. since the risks and uncertainties are still very much present in this case, they are just distributed differently. In return for offering fixed terms to the partners as franchise operators, the U.S. should expect to be compensated in terms of a higher fee for hook-up or in a larger share of bartered volume in the enclave.

5. Ownership

The ownership of each element in the Space Station would remain with the providing partner. The U.S. would retain ownership of the core station and its laboratory while the international partners would own their laboratories. Station resources would be owned by the U.S. and sold to the partners either for monetary considerations or bartered volume. The franchise operators would expect certain guarantees on the quantities of services they would receive from the U.S. Resource use would not necessarily be in a fixed proportion across all the resources. An international partner may determine his needs to be heavily biased towards power with relatively little need for EVA hours, and will thus negotiate for a set of resources which matches those needs.

6. Advantages of a Franchise Arrangement

a. The U.S. would maintain total control of the Space Station.

b. The risks to the U.S. of failure of the international laboratories would be reduced.

c. Technology transfer would be reduced.

7. Disadvantages of Franchise Arrangements

a. Safety might be compromised by lack of an integrated Station safety and operation system.

b. The higher fees which are warranted by the reduced risk of the franchisee would be hard to negotiate politically.

c. Very little specialization (functional allocation) would occur, increasing costs.

d. The U.S. risks an unfair resource distribution if it guarantees user resources to anyone.

e. Accommodations in enclave labs will probably not be user friendly to U.S. payloads.

f. The international participants will press for management influence far beyond what their contribution and risk bearing warrants.

Element Development/Use Contracts

1. Premise

An extreme approach to dealing with the potential international partners would be to separate the development and operational phases of the program. Elements could be developed and turned over to the U.S. for operation. Compensation for the development of the elements could be in terms of specific agreements for use of the U.S. station for a limited period of time. The "partners" benefit in this arrangement by getting a very specific commitment with limited risk while the U.S. benefits by gaining total control over the operations of the Space Station.

2. Structure

When significant divergence exists between potential partners on the goals for a project, the willingness to bear risk, and the commitment to the project in terms of either duration or resources it may make sense to deal with the internationals more as long-term users than as partners. The U.S. would still negotiate bilateral agreements with each country in the "partnership", but this case would truly be a U.S. Space Station with international participation. The U.S. would provide certain services in return for compensation which could be in the form of bartered laboratory volume, ELV launches or monetary transfers. Some cooperation would still occur at the scientific level for specific experiments, but this would be a more arms length venture than in either of the other two cases already described.

3. Management and Control

The U.S. would retain ownership, jurisdiction, control and management of the Space Station and its evolutionary path. It is not anticipated that under this arrangement the internationals would participate in the top level management decisions. As long as the U.S. abided by its "contract" it could make unilateral policy decisions. A participant (commercial firm or international entity) could bring its element to the station and operate it under terms agreed to beforehand. Execution level operations would be consistent with a "one commander" management structure.

4. Operations Costs

Developers of elements brought to the Space Station in this mode would not be expected to share station operations costs. They would pay negotiated fees for hooking up to the station and for services consumed, but these fees need not bear any direct relationship to costs. Innovative agreements could be negotiated which allow participants to bring elements to the station, operate then with U.S. provided utilities for some period like five years at reduced resource fees, then ownership of that element could revert to the U.S. for its use for the remainder of the station lifetime. Many arrangements are possible, but the key elements of partnership are avoided -- sharing the uncertainty of risk, costs and benefits.

5. Ownership

As mentioned above the ownership of the station as a whole would remain with the U.S., but some limited forms of element ownership by international participants could be negotiated for specific periods of time. In return for developing a robotic servicer, for instance, the Canadians could be compensated with volume and other services in the U.S. laboratory for a specific period of time. The nature of the barter would be more specific than in the partnership case and for a limited duration.

6. Advantages of a Contractual Arrangement

a. It gives maximum flexibility and authority to the U.S. in managing and operating the station.

b. It may simplify the utilization and accounting record keeping for resources and costs.

c. Crew safety is enhanced through the integrated flight and ground operations.

d. It eliminates the need for voting schemes and other management complexities necessitated by sharing control.

e. It directly links international element investment to the benefits (in terms of cash or resources) they receive.

f. It would sharply curtail technology transfer.

7. Disadvantages of Contractual Arrangements

a. It may necessitate fixed contractual agreements before enough is known to justify such commitments -- increasing U.S. risk.

b. Greater risk and uncertainty concerning net user resources is borne by the U.S. instead of shared by the partnership.

c. It undermines the concept of a free world collaborative space effort.

5.11.1.2 Recommended International MOU Position

Overview

In order to achieve agreement with the international partners it appears that a compromise position will have to be reached which combines attributes of both the full partnership and franchise approaches. These compromises should stop short of granting concessions which significantly add to the U.S. cost, system risk, U.S. user dissatisfaction with the station, or in any way compromise astronaut safety. Within these constraints there are compromise positions which will increase the prospects for agreement while still achieving U.S. goals.

Space Station Partnership Structure

The space station venture can be structured as a partnership, but not one in which the partners have an undivided interest in the hardware and software systems. For political reasons ESA and Japan want to have a major presence in the laboratories they supply to the program. By collecting the volume to which each would be entitled in a full partnership approach into a single laboratory it is possible to achieve the significant presence they desire.

For example, suppose that for illustrative purposes it is assumed that the investments of each partner are: U.S. $12 B, ESA $2.5 B, Japan $2 B, and Canada $0.5 B. The relative percentage shares of each partner then would be approximately: U.S. 70%, ESA 15%, Japan 12%, and Canada 3%. In the full partnership case the partners would be entitled to this same percentage of each laboratory's volume. If all the labs were the same size the equivalent volume in a single lab would be three times these figures (e.g. 45% for ESA). Of course, ESA would only be entitled to 15% of the other user resources. The international partners will likely press for at least 50% of the volume in the lab they supply so it retains an identity as "their" lab. This compromise can be handled by proportionally adjusting the allocation of all other resources to match the reduction in lab volume supplied to the U.S. as barter compensation. In the illustrative example used above ESA would want to increase their share of lab space from 45% to 50% in one lab or from 15% to 16.7% overall. This "extra" lab space means they are only supplying the U.S. approximately 90% (0.15/0.167) of the volume warranted by the relative investments. Thus, the ESA share of other resources would be reduced to 13.5% (0.15 x 0.9) instead of the 15% share originally planned. Differences in the size of the laboratories would add a slight amount of complexity to the calculations, but the process would be the same. This proportional adjustment clearly ignores the relative values of the resources, but as long the deviations from the investment shares are not too great, the loss is relatively small compared to ease of calculating the resources of each partner. Other physical units than volume could be used in the same manner without any loss in applicability. One obvious possibility would be rack space in the lab modules since standardized racks are in the current designs for each lab. The U.S. can choose the units of measure which results in the greatest allocation of resources to U.S. users and push that view in the negotiations.

Management and Control

As a dominant partner in terms of investment (70% in the example above), the U.S. has a legitimate basis for expecting to exert management control over the operations phase of the program. On the other hand, the partners need to have some means to protect their rights since they would be outvoted in all disputes if voting is proportional to investment or use. The negotiations have moved to a concept where there would be consensus decision making in the high level international bodies with appeal mechanisms which ultimately leave the U.S. with final control. The danger in this approach is that routine decisions are constantly appealed to higher level boards which slows down the management process of the station. The current status of the negotiations are that there three top level boards: the Multilateral Control Board (MCB), the Station Operations Panel (SOP), and the User Operations Panel (UOP). These boards and panels integrate the high level plans of the partners to eliminate overlaps and inconsistencies, but there is nothing in the MOUs about how these plans are implemented at the tactical level. Thus, the MOUs are flexible enough to adapt to an integrated tactical flight and ground operations system, but this could be made an explicit intent of the U.S.

Operations Costs

One of the concerns of all the partners is that they not have to share in the operations cost inefficiency of any of the other partners. This concern can be accommodated by dividing all operations cost into two main categories: element specific costs and common costs. Element specific costs such as sustaining engineering are identified to a specific piece of hardware or software. It makes sense from an incentives point of view to hold the element provider responsible for such costs since having that responsibility may affect the design with respect to reliability and maintainability. All common costs would be shared by the partners in the same proportion as user resources are allocated. The "shares" of common costs allocated to each partner can be politically determined in the negotiation process, but indirectly they may be related to the investment shares as a measure of whether the shares are equitable.

From a practical standpoint the transportation costs of launching crew, logistic supplies and payloads is such a large component of operation costs that the partners will have to share this function if major currency transfers are to be avoided. If each partner does share this transportation mass in proportion to their utilization share, a major risk and uncertainty in the program is also spread among the partners in an equitable manner. In addition, by sharing in physical units the political difficulty of comparing the launch "pricing policy" of the partners is avoided.

Ownership

As a concession to forming the international partnership the volume entitlements of each partner could be co-located into the laboratory they provide. In this type of arrangement the ownership of each element would have a strong identity with the provider. As a result, there would be an ESA lab, a U.S. lab and a Japanese lab, but their use could still be shared for very specialized needs or for scientific discipline experiments where the scientists pool their resources.

Given the investments planned by each partner and the relative sizes of the laboratories it is possible to make a rough estimate of how the laboratory volume in each lab would be distributed among the partners. As a rough approximation the relative volume of the ESA and Japanese laboratories are 80% and 65% of the U.S. laboratory. One possible distribution of lab space would be to have both ESA and Japan take 50% of the volume in the labs they provide. Canada would get the use of 3% of each laboratory while the U.S. would get the use of its lab (less Canada's 3%) and 47% of the other labs. The relative volume figures are shown below.

PARTNER LAB VOLUME ALLOCATIONS

Partner	Lab Volume
U.S.	67.4 %
ESA	16.3
JPN	13.3
CAN	3.0

The allocation of 50% of the ESA and Japanese labs for their use is a useful mechanism for them to have a major presence in the elements they provide, but it must also pass the test of whether it is equitable from the perspective of investment shares. Suppose for example, three levels of investment in DDT&E are considered for the U.S. of $8B, $10 B, and $12 B with investments by ESA, Japan, and Canada assumed fixed at $2.5 B, $1.5 B, and $0.5 B respectively. Then the relative shares of each partner are shown in the chart below for each level of U.S. investment.

PARTNER INVESTMENT SHARES

Partner	U.S. Investment		
	$ 8 B	$10 B	$12 B
U.S.	64 %	69 %	73 %
ESA	20	17	15
JPN	12	10	9
CAN	4	3	3

From this chart it is clear that the "political" allocation of lab volume is quite close to the investment share corresponding to $10 billion for the U.S. For larger U.S. investment levels the "political allocation" is less desireable from the U.S. perspective, but it does appear to be a reasonable negotiating position.

Other resources could also be allocated to the partners in proportion to their investment shares, but the negotiations appear to be heading towards a policy which is not tied to such a difficult to measure concept as investment. Station power is a good example to use for illustration because it is an important resource and has many complexities in making equitable allocations. One proposal which has been proposed is to negotiate housekeeping allocations for all elements off the gross power system. The remaining "user power" would then be allocated to the partners in the following manner: U.S. attached payloads - 20%, ESA internal payloads - 12.8%, Japanese internal payloads - 12.8%, U.S. internal payloads - 25.6%, and Canadian internal payloads - 3%. The net result of this type of allocation is that the U.S. would have approximately 71% of the user power, which once again is approximately consistent with the expected investment shares.

5.11.2 RECOMMENDED INTERNATIONAL MANAGEMENT OPTION by Greg Williams

Editor's note: Section 5.11 is based on the negotiations and MOUs as they existed in the spring of 1987. The authors note that many of the issues identified here have been resolved in subsequent negotiations and MOUs. The reader should refer to the latest version of the MOUs for current Program positions.

5.11.2.1 Management (Strategic Level Summary)

The "Level A Operations Management Concept for the Space Station System" (or, Operations Management Concept, OMC) provided an initial baseline for operations management planning. The OMC is not only a NASA document, but is in an informal sense an international one, both by virtue of its subject matter and by the involvement of all partners in its formulation. As part of its charter to recommend changes to and implementation plans for the OMC, the Operations Task Force must also evolve the OMC's approach to international participation in Space Station operations.

The long term, international, and multi-discipline nature of the Space Station program led to the notion of the three-tiered management structure described in the OMC. It was envisioned that strategic, tactical, and execution levels would be required to adequately plan and implement Space Station operations. The purpose of this section is to further define a recommended management structure based on the more detailed picture of operations described in this document and on the current state of discussions with ESA, Japan, and Canada.

At the strategic level is a strategic operations management group, hereafter referred by its MOU-proposed label, the Multilateral Coordination Board (MCB). Its responsibility is to set policy for Space Station System operation and use in accord with memoranda of understanding among the partners. Initially, this strategic level group shall be chaired by NASA. Included in its area of purview for policy making are utilization planning, resource allocation guidelines, recommendations on evolution, operations cost allocation and funding, user market research, and public information services.

The OTF agrees with the position that the NASA will be responsible for the development of overall Space Station evolution concepts and that each partner will establish independent user resource allocation and pricing policies as suits his situation (MOU Article 13). The OTF recommends that the U.S. and its partners separately allocate utilization resources, at the highest level, along lines of discipline. This is intended to facilitate resource reallocation at the lowest management level by fostering close coordination among users with similar interests.

Supporting the MCB in strategic level planning are a Systems Operations Panel and a User Operations Panel. The System Operations Panel (SOP), chaired by NASA, is recommended as an oversight panel that periodically meets to establish policy regarding the allocation of resources to systems operations (e.g. for maintenance, refurbishment, replacement, etc.), allocation of shared operations cost, and systems management of the Station manned base and Platforms. As envisaged in the current draft MOU's, the SOP is charged with two authorizing documents. These are the Operations Management Plan and the annual Composite Operations Plan (COP). In parallel, the User Operations Panel (UOP) is charged with oversight of utilization activities, including resolution of strategic-level conflicts among partners' utilization plans. The two documents authorized by the UOP are the Utilization Management Plan and the annual Composite Utilization Plan (CUP).

These documents potentially imply a level of autonomy of each partners' systems operations planning inconsistent with the recommendations of the OTF. The recommended concept calls for integrated user and systems payload manifesting, a more interactive process than is implied in the current MOU drafts. The recommended approach is to have an international tactical level operations control board concur in (i.e., accept as "doable") the Composite Operations Plan (COP) and the Composite Utilization Plan (CUP). The CUP may be expanded to cover the COP requirements as well, eliminating the need to reconcile two documents. These should be published on an annual basis and cover a five year period of operations. *Editor's note: The MOUs now specify a requirement for a coordinated Operations-Utilization Plan (COUP).*

No issue is taken with the idea that the Multilateral Coordination Board (MCB) would be chaired by the Head of NASA's Space Station Program Office to establish overall operations objectives and policy. Nor did the SSOTF disagree with the position that conflicts that could not be resolved by the SOP or the UOP be referred to the MCB for final resolution. Japan has suggested that the SOP and UOP be combined in one entity. This may be a sensible grouping, but the program should be guided in this decision by the desires of the user community.

The OTF does not recommend additional international boards or panels at the strategic level over what is proposed in the current MOUs and IGAs. At the strategic level it recommends that a US-only board be established that will represent the users for the US share of the Station resources to the international User Operations Panel (UOP). This board, the Space Station Utilization Board (SSUB) will be NASA organized and run. The OTF recommends that each of the other partners do the same.

Essentially, the role of the MCB (and SOP and UOP) is to integrate the strategic level policy goals of the partners to produce long term (5 years and up) plans. These plans should contain utilization, budget, schedule, and capability requirements as well as plans for new development.

However, the one area where a potential issue could occur would be the amount of executional (realtime) involvement of these boards and panels and the levels at which this board would control the tactical manifest for the station and platforms. The current MOU drafts are silent on most tactical and execution level management issues, leaving them to be worked out in due course by the MCB. The OTF emphasizes that the real time decisions must be made by the executing organizations at the lowest level to ensure a safe operation. The MCB, UOP, and SOP should provide policy level guidance to tactical operations management. The substantive issue, then, is the form and nature of international participation at the tactical level.

5.11.2.2 Governance and Control (Tactical Level Summary)

Policies set at the strategic level are implemented by a tactical level of management, which in many cases will develop the background for strategic level policy decisions. This tactical level of management is the primary detailed planning level for the Space Station Program. It is an integrated activity and functions in nonrealtime. Tactical level management is responsible for Space Station operations planning and integration, including logistics management, support for launch vehicle manifest development, cost and financial management, resource allocation, safety, training, and user market analysis. Nonrealtime activities of the space systems operations and user operations support functions, such as sustaining engineering and user payload and space systems integration respectively, are performed at this level.

The whole character of Space Station operations hinges on the nature of the bridge between strategic level plans and their execution. Four options are considered below for this very crucial issue of tactical level management:

1) One option is creation of a distributed tactical management function.

Each partner produces plans for the operations and maintenance of its hardware. These plans are used by the SOP to develop a Composite Operations Plan. As a strategic level body, however, the SOP can only effectively perform a review and approval function, implying a large degree of systems autonomy and low integration requirements at the tactical level. Crew and systems safety requirements, as well as severe constraints on Station resources such as transportation to orbit and manpower, make distributed tactical management untenable. Subdivision of resources across modules as well as across discipline removes flexibility and adds to resource reserve requirements.

2) A second option is to create an international Tactical Operations Control Board, chaired by NASA and consisting of collocated personnel from all partners. This Board would develop integrated plans for approval by the MCB/UOP/SOP. However, the integration job will be more detailed and more complex than could be achieved by a control board alone. A tactical integration staff must generate the integrated manifests for each mission increment and cargo plan.

3) A third option is an international operations management organization staffed by all partners but independent of each of them. Utilization and systems planning and control would be performed by this group. It would receive direction and funding from the MCB and would contract with each partner's space operations agencies to obtain the execution level support it requires. Groups of Space Station users manifested at the strategic level would work directly with this organization, which would provide them with payload managers who would provide the users with an interface to various executing organization. The option comes closer to meeting the identified requirement for integrated systems monitoring and control, assuming that direct lines of control over executing entities exist. None of the four partners, however, are able to provide a separate operations staff required by this option.

4) A fourth option, and the one recommended by the SSOTF, is a centralized operations management at the tactical level in which integration of the many activities necessary to safely operate and utilize the Space Station System are brought together under one head. The centralized management should consist of personnel from all partners; it would be multinational rather than independent, and would be headed by NASA. The station and platform operations would be controlled by an internationally staffed Tactical Operations Control Board (TOCB) chaired by NASA that would control the tactical plans and the manifest of payloads and systems at the mission increment (45 day) level involving all aspects of the station and platform operations. Platform and manned base planning are coordinated at this level during preparation and execution of platform launches to ensure necessary integrated scheduling of common facilities.

The executing organizations will report directly to the tactical operations manager (international executing agents will do so in accordance with MCB operations plans). Major operations facilities would be internationally staffed. Such international staffing could be specialized within these facilities, for example in dedicated floor space in the SSPF for JEM experiment processing.

In accordance with this option, the OTF also suggests that a Investigators Working Group (IWG) of manifested users from all partners be established for each 45 day increment of station operation. This group would work with the tactical level operations management organization in the development of the baseline tactical manifest, and with the POIC for the execution of payload operations.

This strong recommendation will, if implemented, require significant changes, as shown in the later sections, to the International MOUs and IGAs and to the Operations Management Concept. While it is important to keep the MOU's at a high level, a clear and concise statement describing integrated tactical operations is necessary.

The Space Station Program should consider staffing its tactical level operations organization with ESA, Japan, and Canada's operations personnel early in phase C/D.

The OTF recommends a strong user operations support group be established at the tactical level to support the user integration activities that must occur during and after the station manifesting process. This activity must be closely coupled with the activities in the logistics, sustaining engineering, and systems operations groups. It should be guided by polices set by the UOP, the SSUB and other groups of this nature that are established by the partners. The real-time organizational element of this activity is the Payload Operations Integration Center. The user operations support function would integrate both the launch, station and platform packages. While the OTF recommends a marketing group for the US, no international involvement is recommended and it is assumed that each partner will perform marketing in his country(ies) independently.

Likewise, the OTF recommends continuing strong engineering and logistics support by each of the partners. Specifically, each of the partners should establish an Engineering Support Center or centers (ESC) which will provide near realtime support for the Space Station Support Center and for the Platform Support Center. In the U.S., the OTF envisions each development phase work package center hosting an ESC. Thus, while real time systems monitoring and control of the manned base (and, separately, of the platforms), is centralized, engineering expertise is distributed. Centralization of the engineering activities will also be required for solving technical problems that include more than one element. A centralized logistics activity will be required also at the tactical level to coordinate all of the partners logistics needs for their elements. This coordination activity will organize the STS and any ELV logistics manifests.

5.11.2.3 Operational Philosophy (Executional level summary)

Execution-level operations groups execute the plans and directives issued to them from the tactical level. Separate groups carry out the real-time functions of Space Station manned base and platform operations, except during platform interactions with the manned base. These real time functions are space systems operations and user operations support, such as trajectory management and user resource tracking respectively. Logistics operations and prelaunch/post landing operations for the manned base and platforms are primarily execution level activities. While all these activities are integrated at the tactical level, execution-level operations activities can be dispersed geographically among several separate groups.

User Operations Support

User operations support at the execution level is managed through the Payload Operations Integration Center (POIC). This Operations Center recommended by the OTF has the primary function of supporting the Space Station users in the operation of their experiment. Together with the SSSC, the POIC hosts the implementation of the baselined tactical manifest. Thus, the POIC works with the SSSC, according to the directives of tactical user integration management, to meet the execution needs of the manifested users (primarily through the IWG). Activities conducted in the POIC include the rescheduling of user experiments because of any anomalies in the station or user equipment. The POIC is a service center for users in that it assures that, for instance, command capability is properly routed for experiments that are to be operated in a telescience mode. It will answer routine questions and make sure that the users are kept informed regarding the latest schedules and space systems status. The POIC is the locus of crew activity planning, again using systems operations requirements provided from the SSSC.

The OTF concept acknowledges the users'

expressed desire to organize themselves, where possible, along discipline lines. Also, the OTF recognizes that the international partners may want to organize along other lines and if so, then the POIC would work with potentially different types of user structures such as a Regional Operations Center (ROC). Since the recommended resource allocation scheme is by discipline, partners operating ROCs will likely have to structure them to function internally along discipline lines.

Space Systems Operations

Space systems operations is a combination of on-orbit and ground activities that ensure the safety and integrity of the station and crew. Ground based systems monitoring and control would be conducted from the SSSC with international partner and work package support from Element Support Centers (ESCs). U.S. platform systems operations would be from the Platform Mission Operations Center, while ESA's polar platform and MTFF will be controlled from a European facility. Onboard crew would carry out the systems operations such as rendezvous, maintenance, repair, servicing, appropriate training, etc. The ESCs would be decentralized and would also support the nonreal time sustaining engineering activities. The day to day control of the station would be from the SSSC, which would be responsible for emergency response to anomalous events that might occur on the station. The space systems operations activities would include resource monitoring and allocation, trajectory and rendezvous planning and execution, maintenance and servicing planning, communications control, training, and crew activity planning. When Station systems housekeeping requirements change, the SSSC would report these to tactical operations management, which would in turn inform the MCB on its appraisal of policy impacts.

Crew Training and Selection involves both space systems operations and user operations support. The OTF strongly recommends a unified crew concept wherein a crew commander is identified at the start of a crew team's training period. The crew commander, appointed by NASA, would periodically assess the readiness of the crew as a team and would be in charge of their day to day activities such as training, assignment of functions, public appearances, etc. A team is considered to be one half of the total onboard crew capacity and would serve alternating shifts with the other team. The team is formed when the training commences (up to three years prior to launch). Training in payload operations would be conducted by the user as negotiated with NASA, while the Station program would conduct training on facility-class user support equipment as well as Station systems. The crew commander would give the final go on crew readiness prior to their rotational period on orbit. The commander would also have the authority to abort a crew rotation period and request that the team be returned to the ground. International crew members would be expected to be resident at NASA facilities (except for some training at other partners' facilities) and under the direction of the team commander for the duration of the training period and while on orbit. If the crew member is to serve on another rotation, then they would be reassigned to another team for training for that mission increment. This training is expected to require up to eighteen months.

The OTF recommends that the ground crew that has trained with a specific crew team be assigned to that team until all of the team becomes acclimated to the on-orbit conditions or for a minimum of two weeks. Under this scheme a new team would be place on-orbit every 45 days. The overall station chief would be the commander that was on station when the new team arrived.

The OTF further recommends that NASA make the selection of the Space Station astronauts and that it also make the selection of specific team for a rotational period. Safety is the driving factor in this consideration. It is considered essential by knowledgeable astronauts that the crew be responsive to the team commander and to a single organization (ultimately, tactical operations management). Allocation of crew according to negotiated agreements would be a mandatory consideration in the selection of an astronaut cadre and of specific teams. The OTF recommends that the partners screen and submit crew member candidates following the same screening process used by NASA. The basis for this recommendation is for the safety and integrity of the station and crews.

Logistics Operations

The OTF embraced a philosophy of independence with regard to the logistics system of the international partners at the executional level of management. Wherever possible the recommended Logistics System and its operation attempted to allow for independent partner operations. Integration of independent ELV logistic support by the partners to the station could pose an issue when considering the proposal of a single logistics system. The OTF held discussions with the international partners and factored into this proposal their desires. However, several items that could raise issues were identified. One was the proposal of a single inventory system for the onorbit space station and ground support facilities. A Logistics Operations Center would be established to enable the unification of the logistics operations. An unified logistics system would result in such items as a common barcoding system etc. Resolution of this item will probably be critical to the onboard management of spares and logistical items. Another potential issue is the recommendation of a centralized inventory storage location in order to ensure that critical spares are available at all times to be ready to be shipped to the station. The centralized storage and repair is also coupled with the need to recertify the flight readiness of ORUs that have been returned to the ground for repair. This recertification process will need to be common to all partners to ensure the safety and integrity of the station. A central training capability will be required to train the crew on the onboard activities associated with the processing of logistics items. This training must be stressed to minimize oversubscription of the transportation system.

A key, and doubtless controversial, recommendation in the logistics area is to employ a single contractor for support of a given end-to-end, module-to-module system such as the ECLSS. As with the desirability of identical hardware across modules discussed below, the partners will not readily subscribe to having other nations' contractors responsible for support to systems within their modules. In the U.S., this notion also runs up against technology transfer restrictions. Even so, recognizing the operational efficiency of integrated systems management, the OTF recommends that NASA and its partners explore the possibilities of identical hardware and single supporting contractors for systems operating across modules. The final decisions should be life cycle cost based to the extent feasible given the various international partner objectives.

Sustaining Engineering

Sustaining engineering is envisioned as the configuration control function of Space Station operations, that of maintaining the as-designed functional performance of space systems. Distributed sustaining engineering is recommended, with major design functions performed at engineering support centers. Partners' ESCs perform real-time or near real-time functions at the request and direction of the SSSC. A centralized sustaining engineering organization would be charged with configuration control, maintaining data relevant to systems design and performance. *Editor's note: The SSOTF recommendation that eventually the sustaining engineering function be centralized is not inconsistent with some functions being centralized early on.* Both it and the distributed ESCs would work with the SSSC in failure and anomaly analysis, and with the evolution and growth organization as a principal resource for their planning. The current MOU drafts allocate to each partner the responsibility for "maintaining the functional performance" of its hardware its hardware (Article 9.1.a). Thus, while on-board systems monitoring and control must be centralized in the SSSC, sustaining engineering functions for each partner's hardware may, and likely will be, performed in their own locations.

Prelaunch/Postlanding Operations

The OTF is proposing an execution level prelaunch/postlanding concept that is comprised of two specific activity areas based on a recommendation to allow user racks to be shipped to various sites. One is the launch site responsibilities, the second is geographically dispersed Science and Technology Centers certified to perform payload-to-rack integration of user hardware. Decentralization depends upon the establishment of Science and Technology Centers (STCs) where integration/ deintegration of station hardware would occur. To reduce the international integration activity at the launch site, the approval of international STCs would have to be established. Certification of these centers would be by NASA. The use of STCs also imply that an integrated package could be launched possibly on an international ELV. The OTF strongly recommends that NASA must certify for flight anything that is to be shipped to the Station. Certification of foreign launch sites for station payloads and logistics shipments could be an issue with ESA and Japan. Hardware destined for the station that does not come through an STC would have to be integrated and deintegrated at the launch site, regardless of the point of origin. In this case the launch site would be responsible for all of the safety and verifications checks. The OTF recognizes the need for this capability at the launch site to support both for the internationals. The implications of the STC concept are significant and must be pursued as soon as possible to assure proper implementation by First Element Launch.

Accompanying this assignment of operations responsibilities are hardware implications. The U.S. should explore with our partners the use of identical user accommodation hardware across modules or assume the burden of outfitting its portion of the ESA and Japanese modules.

"Ownership" or Benefits to Partners

Resource Utilization. The approach for dividing utilization resources among the partners currently in the draft MOUs is by a negotiated fiat, allowing Europe and Japan to take their share of resources in their modules while securing for the U.S. and Canada a percentage of user accommodations (rack space) in those modules. Access to all modules by Europe and Japan is preserved through the barter process; user accommodation or other utilization resources owned by them can be traded for user accommodations in the other modules. With this approach, operations costs can be allocated in a variety of ways.

The Space Station Program has yet to define the set of resources to be shared among the partners and priced to the users. This is due in part to the lack of detailed prescience of user activity; while it is known with relative certainty that crew manhours and electrical power will be demanded and must be allocated, it is not possible at this early date to foresee all areas in which scarcity will force users to compete or cooperate. The program is currently funding work to identify resources and ways to track or meter their use.

As identified in the Panel 3 report, an appropriate pricing policy for resources is a function of policy goals. Possible goals are cost recovery, efficient use of resources, and promotion of favored activities such as promising commercial development. This panel believes that the focus of Space Station pricing policy should be on achieving efficient use of Space Station resources, communicating to experiment designers the relative scarcity of resources and influencing their experiment designs accordingly. The concept of marketing priority classifications for resources as well as the resources themselves to payload designers and operators is a useful one and should be employed. By assigning or selling priorities, timeframes become resources, and by discriminating users by urgency of demand, this too is allocated more efficiently. This will allow users and payload manifest developers to take advantage of the flexibility in time of some users to accommodate both time critical and late arriving users.

A more controversial question is who is responsible for pricing within NASA; should the Space Station operations organization be the resource broker, or should blocks of resources be allocated to other NASA offices which represent NASA users. Since at the highest level, resources are allocated to partners, a coordinated, international pricing policy would be difficult to achieve, and probably not even desirable.

Payload Selection. Payload selection will be performed by each partner in accordance with their allocation of Space Station resources. Panel 3 recommended that within the U.S., a Space Station Users Board (SSUB) should serve to coordinate the U.S. input to the international User Operations Panel (UOP) which will produce an international strategic-level target manifest. Chaired by the NASA Deputy Administrator, the SSUB would be comprised of the NASA Associate Administrators for Space Station, Space Science and Applications, Aeronautics and Space Technology, and Commercial Programs, as well as equivalent level representatives of other potential user entities within and without the U.S. government. Appropriate representatives of the SSUB and the Space Station Level I utilization office will carry this U.S. utilization plan in to the UOP, on which the U.S. membership will be headed by the Director of the Space Station Level I Utilization office.

Scheduling. Payload and systems operations scheduling is the responsibility of a tactical level integration office and approved by the Tactical Operations Control Board (TOCB). Receiving strategic level target user manifests and systems operations plans from the UOP and SOP respectively, the TOCB generates tactical level target manifests and baseline manifests. The Space Station Support Center (SSSC), Payload Operations Integration Center (POIC) and various ground operations organizations provide tactical planning support and implementation of approved plans.

Crew Selection. The OTF recommends the concept of integrated crew operation, as opposed to one in which crew members are assigned to certain Space Station Program Elements, primarily laboratory modules. The integrated crew concept emerges as the only sensible approach given STS-based crew rotation constraints, manpower requirements for critical activities such as EVA, efficient crew utilization in the face of extensive housekeeping requirements, and consideration of crew and Station safety. In addition, the integrated crew concept is compatible with the notion that provision of Station crew is a privilege of partnership. Draft MOU policy states that each partner supplies crew members in accordance with its utilization share.

The integrated crew concept identifies differing crew types, not by element, but by predominant function. The recommended crew concept identifies Station operators, Station Scientists, and Payload Scientists. These differ primarily in the amount of specialized training received, on systems operation and maintenance or on payload operation and maintenance. However, much of the training is common, and for significant periods of time a given increment crew trains together to work as a team, partly to determine overall mission suitability. This leads to requirements for both centralized and distributed training, with distributed training early in the training cycle and centralized as the launch date approaches. Common systems training is centralized at JSC, while high-fidelity simulators will exist at each partner's facilities for both crews and ground based users. Training systems and schedules will be established to optimize the amount of traveling required of crew complements in training.

The integrated crew concept also calls for one crew member from each four person shift to serve as Station commander. The commanders are selected from either the Station Operator or Station Scientist cadres, and thus spends most of on-orbit hours performing systems or payload operations tasks. His or her job as Station commander is primarily to give direction in safety and contingency related matters.

Each partner nominates persons to serve as Station crew. NASA selects from among this pool of nominees those who meet the qualifications to be Station astronauts, and will select specific crew complements for each increment.

Operations Obligations

Operations Cost Sharing. Operations cost sharing arrangements have been discussed at length, in spite of the lack of good operations cost estimates, to arrive at the approach currently extant in the draft international MOUs. This approach proceeds as follows:

First, operations functions must be identified at a sufficiently low level of detail as to permit meaningful discussion. Second, functions must be categorized as either element-specific or common; the former are those which can clearly be allocated to a specific flight element provided by a partner, while the latter support the Station as a whole and cannot be allocated on a clear, non-arbitrary basis. Then, these functions and their associated costs must be allocated to partners according to their hardware contributions. The costs of common jobs are allocated to partners according to allocation of utilization resources regardless of who performs the work (many will be done jointly). This will likely result in some transfer of funds across partners, but considerably less than under other options. Cost sharing is discussed in more detail in Section 5.11.3.

Risk Sharing. Risk sharing is seemingly best implemented by a general philosophy of cross-waiver of liability. This is consistent with the alignment of performance and financial responsibility for operations functions. A number of aspects of international law should be studied to assure a clear understanding of this area.

Transportation. Transportation of crew and non-user material to and from orbit is most effectively allocated in terms of responsibility for delivery of some portion of total mass rather than dollars or number of launches. Of the STS capacity allocated to Space Station, each partner will receive rights to a fixed portion for housekeeping requirements, and a percentage of user capacity, for both of which they will pay the going rate for STS services (The mass of the logistics module elements must come off the top). Communications and tracking services will be allocated in the same fashion.

By contrast, allocation of transportation responsibilities, as opposed to rights, should be allocated among partners to correct any imbalance among common cost responsibilities. The program's upcoming logistics studies, to be done in parallel with our partners, should address the partners' launch and return systems and the new hardware required from all partners to employ them in Station operations.

Housekeeping Requirements. Effective utilization of Station resources requires that "housekeeping" allocations be set for each systems and module on the Station. This will yield the highest feasible level of Station resources as utilization resources; those available for user activity. The international MOUs should contain a provision which penalizes any partner whose systems requirements for Station resources exceeds a negotiated housekeeping allocation. The Space Station Program should develop a forum in which international housekeeping allocations can be negotiated and established early in the detailed design phase.

5.11.3 INTERNATIONAL OPERATIONS COST SHARING by Greg Williams

Editor's note: Section 5.11 is based on the negotiations and MOUs as they existed in the spring of 1987. The authors note that many of the issues identified here have been resolved in subsequent negotiations and MOUs. The reader should refer to the latest versions of the MOUs for current Program positions.

The basic dilemma for the international negotiators is to find a mechanism for sharing Space Station operations costs that meets three basic criteria. First, one partner should not have to subsidize another's use of the Station--that is, each partner should pay a "fair" share. Whether that share should be based on investment or utilization complicates the definition of "fair", but is in principle a separate issue.

Second, the allocation of operations responsibilities should be in accord with an axiom of incentives management that financial accountability be aligned with performance responsibility as closely as possible. Thus engineering and cost responsibility for a given hardware maintenance should reside with the same partner, preferably with the one who designed and built it. This criterion is complicated by the desire of the international partners to have "meaningful" operations responsibilities within in the SSP.

Third, the international partners desire to minimize the transfer of funds among partners. Instead, they wish to have an allocation of operations responsibilities sufficiently large to cover their share of the operations cost burden. This requires a careful and imaginative distribution of work, since the center of gravity of operations jobs will be within the U.S. The partners including the U.S. desire to minimize the accounting and bookkeeping requirements associated with the operations cost sharing plan.

The "fair share" principle suggests that each partner ought to benefit in proportion to what it contributes to the partnership. Ideally, then, if benefits could be expressed as utilization resources and contributions expressed as the sum of development and operations costs (life cycle cost) of the Space Station System, each partner should be entitled to a percentage of utilization resources equal to the contributed percentage of Station life cycle cost. Early thinking on this issue led to the position that, because operations costs were so uncertain, the partners would base utilization rights on estimated development cost contributions only. Operations costs would be borne by the partners based on utilization rights, possibly through operations functions performed. The result is that life cycle costs are addressed in the cost and utilization sharing proposals even though total life cycle cost is not the basis for utilization shares determination.

The use of development cost as the basis of determining utilization rights, or shares, fell into disfavor and was finally dropped for two major reasons. One was the uncertainty over what was to be included in investment and over the cost estimates of the included items. The second was the army of lawyers and accountants that such a basis would necessitate. Development costs incurred by the partners remain influential, however, in that subsequent proposals are evaluated in part on the basis of whether the U.S. is better or worse off than under previous, development cost based proposals.

The approach for dividing utilization resources among the partners currently in the draft MOUs is by a negotiated fiat, allowing Europe and Japan to take their share of resources in their modules while securing for the U.S. and Canada a percentage of user accommodations (rack space) in those modules. Access to all modules by Europe and Japan is preserved through the barter process; user accommodation or other utilization resources owned by them can be traded for user accommodations in the other modules. With this approach, operations costs can be allocated in a variety of ways.

5.11.3.1 Cost Sharing Options

The range of possible options may be thought of in terms of the volume of funds flows among the partners. The options considered were:

1. Vest in one organization Station operations responsibility and allocate the cost of operations based on allocation of utilization resources. Each partner contributes a portion of the budget of this organization, which has license to go anywhere to get the job done in the most cost-effective manner. (Perhaps employing the concept of using contractors from each partner for work valued the same as the partner's cost allocation). The potential for the largest flow of funds is represented by this option.

2. Assign operations jobs to each partner and the financial responsibility for performing those jobs. Here we might assume that jobs are perfectly allocated such that no flow of funds across partners is required; the value of the work each performs is equal to the portion of operations cost responsibility based on its utilization share.

3. Categorize jobs as either element-specific or common; the former are those which can clearly be allocated to a specific flight element provided by a partner, while the latter support the Station as a whole and cannot be allocated on a clear, non-arbitrary basis. Allocate to partners the jobs and associated costs according to the partner hardware contributions. The costs of common jobs are allocated to partners according to the allocation of utilization resources regardless of who performs the work (many will be done jointly). These should be predicted, not actual costs, so that the responsible partner bears the costs or benefits of overruns or underruns in performance of the function. This option will likely result in some transfer of funds across partners, but considerably less than under option 1.

Were the Space Station to be organized along the lines of a corporation or general partnership, option 1 might be intuitively attractive. However, this option provides no direct incentives for systems designers to factor life cycle cost implications into their hardware designs. The largest percentage of operations cost for any given piece of hardware is paid by the largest partner, not the partner who built it. In addition, each partner has expressed certain goals for its role in Space Station. Some, such as future autonomous space operations, tend to preclude a homogeneous organization possible under a corporate or general partnership structure. Option 1 also requires visibility into each partner's technical and financial operations to which none will readily commit.

Option #2 directly satisfies the management incentives constraint in the operations era. A first cut distribution would be to assign to each partner the engineering and financial responsibility for sustaining the functional performance of the hardware they provide, which will also set up design and development incentives. However, many operations functions support the Space Station as a whole rather than separately identifiable partners' contributions. These functions will be performed by one or more of the partners, but the cost, in accordance with the stated principle, ought to be allocated among all the partners since all benefit. Option #2 does not provide the flexibility required to match centralized conduct of common functions with distributed financial responsibility. Option #3, therefore, best follows the principle within the constraints.

The U.S. draft MOU does not specify in detail the mechanism by which annual operations costs are to be shared. It does suggest that operations responsibilities and associated costs can be distributed among the partners. To the extent that the costs of such distributed activities do not correspond to cost share responsibilities, compensating cash payments are required by the MOU. The U.S. draft MOU does specify percentage allocations of Station user resources among the partners. Because these allocations are percentages of net Station resources, the risks to each partner's users associated with Station performance is proportional to that partner's allocation. No partner is promised an absolute level of user resources.

ESA has suggested that Station operations activities be divided into those that are common to the Station, whose costs are shared according to partner allocations, and those that are to be borne individually by each partner. Along with this, each partner bears the cost risk associated with any operations activity it performs--that is, each partner absorbs his own cost overruns and benefits from his own savings. This applies to operations functions regardless of whether they are considered common or partner-specific.

The cost risk of each common function falls on the partners performing it because each partner is credited with the predicted cost, not the actual cost, of the common activity. If a partner accepts responsibility for more common activities, its credit for common costs increases. Only if a partner does not or cannot agree to carry out sufficient common operations functions to defray his share of common costs will that partner be required to make cash payments to those partners who cover more than their share.

The U.S. has generally accepted this position, but there remains the problem of sorting out a division of operations activities and associated costs that meets the above three criteria. The Model for Estimation of Space Station Operations Costs (MESSOC) was used by JPL to analyze the implications of several different operations scenarios and three different specific mechanisms on the sharing of costs. See Appendix A for a description of MESSOC.

MESSOC is able to determine logistics costs by hardware element, training costs by crew type, and flight ops and engineering support costs by facility. Without this capability, it would be difficult to separate common costs from those that are partner-specific. Without this delineation, it would be impossible to analyze the general proposals now being negotiated.

The cost of performance of the common cost functions may run in the neighborhood of one hundred and fifty million dollars annually. Yet, most of these functions will be performed in the United States, especially if the strong, centralized role of the U.S. advocated by the OTF is adopted. We thus run headlong into the policy constraint of minimizing the transfer of funds between partners. The functions that can be delegated to the other partners are relatively few. The largest single "big ticket" item in the operation of the Space Station is transportation to and from orbit. The initial conclusion is that the incorporation of partner ELVs into mature Station operations can alleviate the need for large cash payments by the partners to defray the large launch costs associated with STS support of the Station's systems and crew.

These partner launches must consist primarily of Station core logistics--that is, spares and consumables. This implies a distributed logistics system with its attendant management complexities. The required partner launch rates are complex but understandable functions of the launch vehicle capabilities, the cost sharing percentages, and other physical parameters.

It is therefore imperative that multiple launch and return systems, especially those provided by ESA and Japan, be included as part of the Space Station System.

Another conclusion of the MESSOC analysis is that the housekeeping logistics specifications for each partner's systems are very important under certain cost sharing mechanisms.

The third principal conclusion is that a distributed logistics resupply system with both U.S. and partner launch vehicles has several important development phase implications. For the U.S., two are important: (1) an OMV may be required to rendezvous with and dock ELV payloads; and (2) appropriate navigation, guidance, communication, and docking equipment must be in place to accept these ELV payloads. For the partners the implications are more profound. They will need to supply launch vehicles, and develop the appropriate logistics processing facilities. If NASDA uses the JELM, no new program elements are needed by Japan, but ESA will need to develop and procure new canisters for launching their share of Station supplies.

If these new canisters are developed, it appears advantageous to also consider their use as a destruction-upon-reentry waste disposal system for non-toxic materials. This would significantly relieve STS downweight requirements. Such a concept could also alter the development programs of the three largest partners.

A detailed analysis of these conclusions is provided in "Sharing Space Station Operations Costs", by Robert Shishko and Jeffrey L. Smith, JPL D-4564, Jet Propulsion Laboratory, June 24, 1987.

5.11.3.2 Operations Cost Classification

If option #3 is to be pursued, it remains to classify the jobs as partner-unique or common. Two sets of data exist for estimates of Space Station "mature" operations costs. One is MESSOC, which contains twenty interrelated algorithms which model key operations functions. A description of MESSOC and a cost classification scheme based on its results is presented in Appendix A. Also see the Shishko and Smith paper referenced above. As is stated at the conclusion of that paper, an operations cost model is the more useful medium of discussion of operations cost sharing among the partners, once the model is sufficiently mature.

The other data set is a "grassroots" estimate built up from budget submissions of the various NASA centers as part of the program's cost assessment exercise in the winter of 1986-87. This estimate was based (with varying degrees of success) on the program's Work Breakdown Structure (WBS), which is in turn the product of two years of effort in defining operations functions. The development of an accepted set of operations functions is still in progress; the OTF efforts should add significantly to this effort. A third set of operations functions was developed for the purpose of international discussions by Dan Bland. This set is crosswalked with the others in Table 5-4 (No attempt to collect operations cost estimates by this set of functions was made by the SSOTF).

The following matrix (Table 5-5) classifies functions using the cost assessment data set and functions description. The Space Station Program's Operations Management Concept and subsequent work identify seven major groups of operations functions which form the structure of the operations cost data set. These are space systems operations, user operations support, prelaunch/postlanding operations, integrated logistics support, information systems operations, product assurance, and operations management and integration. The characterization of some functions within these groups as element-unique or common depends on the level of activity at which it occurs; strategic, tactical or execution. Thus each function is classified as unique or common for each level of activity.

The Panel also examined a more detailed task listing from the cost assessment data set with a labeling of specific tasks as element-unique or common. In generating the split, guidelines based on the structure of the budget submission and on draft international MOUs were employed. One such guideline is the use of "prime" and "non-prime" categories in the cost assessment data to help in some areas to distinguish between element-unique and common costs. The notion here is that prime costs are associated with the orbital hardware contributions of the U.S., while non-prime costs consist largely of operations infrastructure which supports the orbital hardware. Thus, in the information systems category, prime software

TABLE 5-4: CROSSWALK OF OPERATIONS FUNCTIONS/COST CATEGORIES

WBS/UPN CATEGORY	MESSOC CATEGORY	D. BLAND MATRIX CATEGORY
User Integration	Customer Integration Operations	
Utilization Planning		II.11 Strategic Utilization Planning III.9 Strategic Support to Users
User/SS Engineering Integration		II.5.1 Payload to SS Engineering Integration II.5.3 Payload to Element Engineering Integration III.3.1 Payload to Element Sustaining Engineering III.3.3 Payload to SS Sustaining Engineering
User Operations Integration Implementation		
Assessment/ Accommodation/ Integration		II.4 Integration of Users with SS Operations II.5.2 Payload to SS Operations Integration II.5.4 Payload to Element Operations Integration III.3.2 Payload to Element Sustaining Engineering III.3.4 Payload to SS Sustaining Operations
POIC		II.3 Capability for User Interface III.2 Perform User Operations
SS User Requirements		II.1 Generic Mission Requirements
Space Systems Operations		
Systems Operations Centers	Engineering Support Center Maintenance & Support	I.3 Maintain Ground Support Facilities
Operations Preparation		
Mission Operations Planning & Manifest Development	Flight Planning	I.4 Flight & Ground Support Operations II.4 Integration of Users with SS Operations
Flight Design & Requirements		I.1 Maintain SS Orbital Status I.3 Maintain Ground Support Facilities II.4 Integration of Users with SS Operations
Procedure Development & Training	Training Operations	I.2 Crew Training for System Operations II.2 Crew Training for Generic User Operations III.2 Crew Training for Specifc User Operations
Mission Operations	Flight Implementation	I.1 Maintain SS Orbital Status I.3 Maintain Ground Support Facilities I.4 Flight & Ground Support Operations III.2 Perform User Operations
Sustaining Engineering	Work Package Sustaining Engineering	I.5 Sustaining Enginnering
Prelaunch & Postlanding Operations	Element Processing	I.7 System Prelaunch/Postlanding Processing II.7 User Prelaunch/Postlanding Capability III.5 User Prelaunch/Postlanding Processing

Table 5-4 (cont.)

WBS/UPN CATEGORY	MESSOC CATEGORY	D. BLAND MATRIX CATEGORY
Integrated Logistics Support		
Spares	Flight Equipment Spares	I.6.2 SS System Spares II.6.2 User System Spares III.4.2 User Spares Requirements
Other Logistics	Intermediate & Depot Repair	
	Ground Transportation & Handling	
	Maintenance Documentation, Databases	
	Inventory Management	
	Ground Support Equipment Maintenance & Support	
	Consumables	I.6.1 System Consumables II.6.1 User Consumables III.4.1 User Consumables Requirements
	Customer Logistics & Maintenance	
Information Systems		
Software Support Environment (SSE)	SSE & Technical Management Information System (TMIS)	I.10 SSE Interface II.10 SSE User Interface III.8 SSE Manifested User Interface I.9 TMIS Interface II.9 TMIS User Interface III.7 TMIS Manifested User Interface
	Data Handling & Communication	I.8 SSIS Interface II.8 SSIS User Interface III.6 SSIS Manifested User Interface
(Distributed across other categories)	(Distributed across other categories)	Product Assurance
Operations Management & Integration	Integration Management &	I.4 Flight & Ground Support Operations I.11 SS Program Strategic Managemnt II.4 Integration of Users with SS Operations III.4.3 User Logistics Requirements
Research & Program Management (R&PM)	Flight Crew Pay & Allowances	I.2 Crew for System Operations
NSTS Launches	NSTS/ELV Launches	I.6.3,4 NSTS/ELV System Requirements II.6.3,4 NSTS/ELV Generic User Requirements III.4.4,5 NSTS/ELV Specific User Requirements

TABLE 5-5: ALLOCATION OF FUNCTION COSTS: ELEMENT-UNIQUE (U) OR COMMON(C)

LEVEL	STRATEGIC		TACTICAL		EXECUTION	
	U	C	U	C	U	C
FUNCTION						
User Integration						
Utilization Planning	X			X		
User Integration Pln		X		X		X
User/Station Eng. Int. Imp		X	X		X	
User Ops Integration Impl						
Assess/Accom/Integ Plans		X		X		X
POIC				X		X
SS User Requirements	X			X		
Space Systems Operations						
Systems Ops Centers						
SSSC				X		X
ESC's	X		X		X	
Simulator/Training				X		X
Operations Preparation						
Mission Ops Plng & Manf Dev				X		X
Mission Design & Req Dev				X		X
Procedures Dev & Training				X		X
Mission Operations				X		X
Sustaining Engineering	X		X		X	
Prelaunch/Postlanding Ops						X
Integrated Logistics Support						
Supply Support (Spares)			X		X	
Other logistics				X		X
Information Systems						
TMIS			X			X
SSE			X			X
SSIS			X			X
Product Assurance				X	X	
Ops Mgmt & Integ	X			X		X
STS Launches					X	X
Comm & Tracking					X	X
R&PM (CS Manpower)					X	

tasks are classified as element-unique while non-prime software tasks are classified as common. Work package prime management costs are element-unique, while non-prime management costs are common.

A second guideline is the draft MOU position on allocation of utilization resources. The platforms are considered to operate separately from the manned base at the tactical and execution levels, therefore most platform operations costs are element-unique. The extension of this logic to the servicing facility, MSC, FTS, and attached payload accommodations is less clear. While part of the manned base, ESA and Canada do not have a priori shares in their use. In this presentation, their associated operations costs are considered element-unique.

Taking an aggregate view, the splits among the major operations functional groups are explained below.

Utilization Planning, User Integration Planning, and Space Station User Requirements can just as easily reside in the Ops Management and Integration category. These are primarily partner-unique activities at the strategic level with a common tactical management required for integration by the TBD U.S./international utilization organization. The engineering and operations integration implementation functions are the "nuts and bolts" services the program provides to the users. The recommended user accommodation approach is to have a centralized manifesting of users onto the Station, a decentralized integration of users' payloads into its assigned element, and centralized user operations management. The technical engineering integration is thus an element unique function. With a centralized management of systems operations and user scheduling, user operations integration costs are unavoidably common costs. (These should be directly chargeable to users, if the accepted pricing policy permits/requires it.)

Space System Operations. With the exception of sustaining engineering and specialized real-time or near real-time engineering support (ESCs) to specific hardware elements, space systems operations are by definition an area of common cost, because it supports the entire Space Station Complex (platforms, however, are treated separately per the MOUs). This is true at all three levels of operations, except where no strategic level activity is required. For example, the integrated crew concept implies a common cost classification for crew training, since many training activities are geared toward developing crew teams and on operation of common systems.

Prelaunch/Postlanding Operations consists primarily of processing of the logistics elements to resupply the Station. Given the nature of the processing flow and the data description of it, it is not possible to report separately that activity which supports individual elements from that which supports common systems and crew. Not included in common costs are the prelaunch/postlanding processing of user payloads.

Integrated Logistics Support is readily divisible into hardware spares and other logistics support. The former is partner-unique, while the latter is best captured as a common cost to the partnership.

Information Systems required to support operations and utilization have costs which benefit the partnership as a whole. The maintenance of specific computer hardware and software systems may be delegated to the providing partner, but the operation is by nature a common cost activity.

Product Assurance is generally identified with the provider of the hardware or software system to be assured. An overall safety management responsibility, however, is a management common cost that may be shared.

Operations Management and Integration will have both partner-unique and common elements. Tactical Operations Control Board activities, for example, might be a common cost, while the manpower supplied to user and operations integration functions might be financed by the partner of system or element origin.

Transportation of crew and non-user material to and from orbit is most effectively allocated in terms of responsibility for delivery of some portion of total mass. Of the STS capacity allocated to Space Station, each partner will receive rights to a fixed portion for housekeeping requirements, and a percentage of the available user capacity. The partners will pay the going rate for STS services.

Communications and Tracking Services will be allocated and charged in the same fashion.

The function categories employed in the operations cost model MESSOC (see Appendix A) follow fairly closely those in the program's budgeting Work Breakdown Structure. The assumptions used in these two data sources should be aligned to ensure comparability of their results. The OTF recommends that the operations cost model be used as the medium for discussion among the partners on operations cost sharing. This will serve to provide a consistency of data and analyses not characteristic of budget-driven grassroots estimates. Perhaps more importantly, the use of a model will lend support to the principle that when operations cost sharing occurs by functionally allocating different jobs on the basis of cost equivalence (rather than cost sharing by sharing of the job), the sharing is done on the basis of a cost estimate which is independent of which partner will perform the job rather than sharing on the basis of actual cost determined after the fact.

5.11.3.3 Implications of Proposed Utilization Sharing Scheme For Space Station Users and Module Outfitting

The current U.S position on utilization rights and operations costs allocates the cost of maintaining the power, ECLSS, DMS and other subsystems to the U.S. since the U.S. provides them. This could result in inequities since the outputs of these are used by all partner's hardware. It is on this basis of the U.S. provision of these "common systems" that the U.S. claims the rights to a percentage of the user accommodations in the European and Japanese supplied laboratory module as part of the negotiated fiat allocation of utilization rights.

Such an arrangement, which leaves the U.S. as the only partner supplying a laboratory which has its users spread across the Space Station from the start, has both potential benefits and costs for the U.S. The benefit, which is rarely mentioned, is that the U.S. is in a more diversified position than the other partners and thus is less subject to the variation in performance associated with any one laboratory. The cost, which tends to receive attention, has two components.

First, the SSOTF recommended operations concept states that laboratory element providers will perform the engineering integration of payloads manifested in their elements. Therefore, about half of U.S. users will be manifested in the ESA or Japanese elements. This may impose cost and inconvenience burdens those users. How great these burdens will be depends on a) whether or not ESA and/or Japan perform integration activities at KSC or in their home facilities and b) the need for users to make use of the high fidelity module simulators which each partner currently plans to build on its own soil. Currently, Japan's preferred option is to perform experiment integration in Japan with some functional verification at KSC. If the high-fidelity simulator of the JEM is built in Japan as planned, users may likely want to make use of it.

Second, the U.S. has not reached agreement with ESA and Japan on common laboratory hardware for user accommodation. Nor is there clear definition of or agreement on common user interfaces, interoperability, functional equivalency, and other such abstractions from truly common, identical hardware. This limits the flexibility of users and user operations support personnel for shifting payloads among modules in the manifesting process. Furthermore, all U.S. users may be burdened since some payload development may occur prior to knowledge of which lab a user will be integrated into, and this uncertainty about location may affect payload development.

A potential outcome of international, technical level discussions is that ESA and Japan may not agree to common user accommodation hardware. Rather, ESA and Japan representatives to OTF discussions have said their agencies will build their elements to meet U.S. outfitting requirements. This approach must be carefully managed throughout the program engineering phase, otherwise the U.S. may find it necessary to outfit the portion of the ESA and Japanese modules allocated to it. Thus, the U.S. may be able to achieve a situation of common user accommodation hardware all modules. ESA and Japan may, however, not be willing to agree to such a U.S. role in development of their hardware. Technology transfer constraints will likely exist on such a scheme as well.

The range of possible schemes are:

1) A single contractor is used to build all the outfitting and system interface hardware for a given system across all the partners' laboratories. Identical hardware is thus assured.

2) Each partner contracts separately to provide the systems and system interfaces for its allocated portion of the laboratory elements. The U.S. outfits its lab plus its portion of the ESA and Japanese laboratories. Identical hardware is assured for U.S. users.

3) All partners agree to strict commonality requirements. A user requiring a generic laboratory capability can thus fit in any laboratory module with no changes required to his payload.

4) The three laboratory modules have non-common user accommodations; the magnitude of changes to user payloads, and the cost of those changes, required by the manifesting process increases with the degree of departure from commonality.

The first is the ideal, but is unlikely given the technology transfer issues. It should be the subject of discussion within the program and with the partners. The fourth is quite likely and the least user-friendly. The second and third are possible, but neither is secured by the current level of agreement, even informally, among the partners. The second would require additional U.S. funds to accomplish. This option of having the U.S. outfit a portion of the ESA and Japanese laboratory modules should be broached with them. Such a suggestion should not come as a complete surprise, but rather be presented as a logical extension of the idea of providing hardware for the outfitting of each others' modules appearing in past drafts of agency-to-agency MOUs (not in the current draft since it was part of the now defunct notion of facility-class generic equipment).

Appendix A
MESSOC
by Robert Shishko

A.1 Model Description

Overview

The MESSOC Space Station operations cost model estimates operations costs and net Station outputs, given the Station configuration, mission description, and overall program policies. The heart of the model is the integrated formulas, equations and databases used in making the calculations. To ensure a degree of consistency across model runs, these will be baselined by the Space Station Program. However, the model is designed to provide the user the flexibility to consider alternative Station configurations and mission descriptions. Therefore, the model contains both databases that are easily altered by the user and databases that are less easy to alter. The easy to change data describes the Station under investigation. In particular, the model users establish what the Station configuration is over time, what operations are being conducted aboard the Station over time, and what overall Space Station program and policy variables are in effect. The internal model databases, that are less easily altered by the model user, supply the detailed technical and cost data.

To produce cost estimates that are sensitive to changes in the Space Station scenario, operations cost estimates are built up from the lowest level of data that it is practical and possible to collect. As a result, operations cost estimates can be affected by changes down to the component level. Building cost estimates from the component level also provides a natural way to assess the costs and benefits of development phase decisions such as commonality in the Station's design.

Cost categories were selected to have specific links to the Unique Project Number (UPN) budgeting system and Space Station Work Breakdown Structure (WBS). They cover a generic set of operations functions and activities and are therefore meaningful across Work Packages and Station systems/elements. Identical functions or activities are costed using the same formulas and equations, even though they may occur in different Work Packages or systems/elements. Costs can be summed to calculate annual operations costs over the Station lifetime for user selected Space Station scenarios. Considerable detail is also available within the 20 cost categories.

MESSOC provides the user with the ability to test the effect of changes in the design, operations, and policies of the Space Station on both estimated operations costs and intermediate Station outputs. These intermediate outputs include crew time available to users, on-line availability of critical Station equipment, and user-dedicated payload mass to orbit. Operations cost estimates alone are not sufficient to address key design and operations issues. These estimates must be tied to useful measures of Station output in order to establish the proper balance between cost and effectiveness.

The heart of MESSOC is a set of integrated algorithms and equations, which for expositional purposes can be divided into nine blocks -- six cost blocks and three intermediate output blocks. Cost blocks pass calculated variables to each other as well as to the output blocks. In this way the operations costs and outputs are linked.

Inputs to the algorithms come from two sources--those variables entered or edited by the model user directly on the screens, and those data contained in the many databases supporting MESSOC. Variables entered from the screens create a Space Station scenario. In constructing a scenario, the model user essentially tells the algorithms what the Station configuration is over time, what operations are being conducted aboard the Station over time, and what overall Space

Station program and policy variables are in effect. Station growth over time is clearly a key determinant of post-IOC operations costs.

From a Space Station scenario, the algorithms and equations in the six cost blocks calculate costs in 20 separate categories. These costs, when summed, give total operations costs in a given year. The calculations are performed for each year of the Station's operational life, taking into account changes in its configuration, on-orbit and ground operations, as well as certain other intertemporal variables. Because of the nature of the algorithms, considerable detail is also available within the 20 cost categories and three intermediate output categories for each year.

In its present version, MESSOC contains algorithms for 17 of the 20 cost categories. In brief, the 17 algorithms cover the planning and execution of tasks associated with sustaining and operating the basic Station elements, while the remaining three algorithms cover customer integration activities, customer logistics, and the operation of the communications and data handling infrastructure. These algorithms are currently being developed.

MESSOC software is written in Turbo Pascal, and is designed to run on an IBM or compatible PC with 640k RAM. The program is user-friendly in so far as minimal training is required to use it, and "help screens" are available at user decision points. The key assumptions are cataloged and can be displayed, but the main quantitative databases are hidden from the casual user so as to retain some consistency across model applications.

Cost Categories in MESSOC

The cost categories in MESSOC were selected to have specific links to the budgeting system and the Space Station Program Work Breakdown Structure (WBS). These categories cover a generic set of operations functions and activities in the WBS, and therefore are meaningful across Work Packages (WPs). In this way, identical functions or activities are costed using the same algorithms and equations, and are displayed together even though they may occur within different WPs (or be non-WP activities). It was further decided early in the development of MESSOC that it would not be practical, or even feasible, to devise an equation for each WBS activity. The MESSOC cost categories contain related WBS operations elements, though these elements may not be costed separately.

Table A-1 shows MESSOC's 20 cost categories.

Table A-1. MESSOC Cost Categories

1. Space Station Control Center (SSCC)/Engineering Support Center (ESC) maintenance and support
2. Training operations
3. Flight design and planning
4. Flight implementation
5. WP sustaining engineering
6. Software Support Environment (SSE), TMIS, and information system support
7. Maintenance documentation, databases, procedures, and analyses
8. Inventory management
9. Ground transportation, handling, and storage
10. Ground Support Equipment (GSE) maintenance and support
11. Intermediate/depot level repair
12. Flight equipment spares
13. Element processing/reprocessing
14. Consumables
15. NSTS/ELV launch services
16. Integration management and institutional support
17. Flight crew pay and allowances
18. Customer integration operations
19. Customer logistics and payload maintenance
20. Communications/data handling infrastructure

To some, the absence of on-orbit functions from these categories may seem to be an oversight, but a moment's thought leads to the realization that no money changes hands on-orbit; all resources are bought and paid for "on the ground." On-orbit time utilization is extremely important for operations effectiveness, however, and this is discussed later when the algorithms for crew time are described.

A "crosswalk" between the 20 cost categories and the WBS is built directly into the MESSOC software. Indeed, all data items required to construct a Space Station scenario, as well as all MESSOC outputs, are defined within the software, and may be displayed on the screen directly.

MESSOC Structure and Databases

As mentioned earlier, the heart of MESSOC is the set of cost and intermediate output algorithms. Alone, these algorithms would be inaccessible to the user, and would be useless without accurate data. The algorithms are therefore supported by an extensive user-interface program and a collection of databases.

The user interface allows the user to construct a Space Station scenario by editing a set of program and crew factors, and two spreadsheets, called the configuration profile and the operations profile. The configuration profile allows the user to describe the Station in terms of hardware elements that physically make up the on-orbit Station over the period of time for which cost estimates are desired. The operations profile allows the user to represent the overall structure of on-orbit and ground operations over the same period. A macro-view of MESSOC's architecture is shown in Figure A-1.

(1) Supporting Databases. The configuration profile is supported by several logistics databases that contain detailed information on each orbital replacement unit (ORU) contained in each hardware element. This information covers on-orbit and ground maintenance characteristics such as mean time between failure (MTBF), how each failed ORU is to be treated, who will maintain it, how long each maintenance task (both scheduled and unscheduled) will take, what parts might be used to effect repair, as well as data on weight and price.

The configuration profile is also supported by a database of physical information on each hardware element such as overall mass and frontal areas. A separate database contains data on sustaining engineering parameters that can be linked to outside models of DDT&E costs.

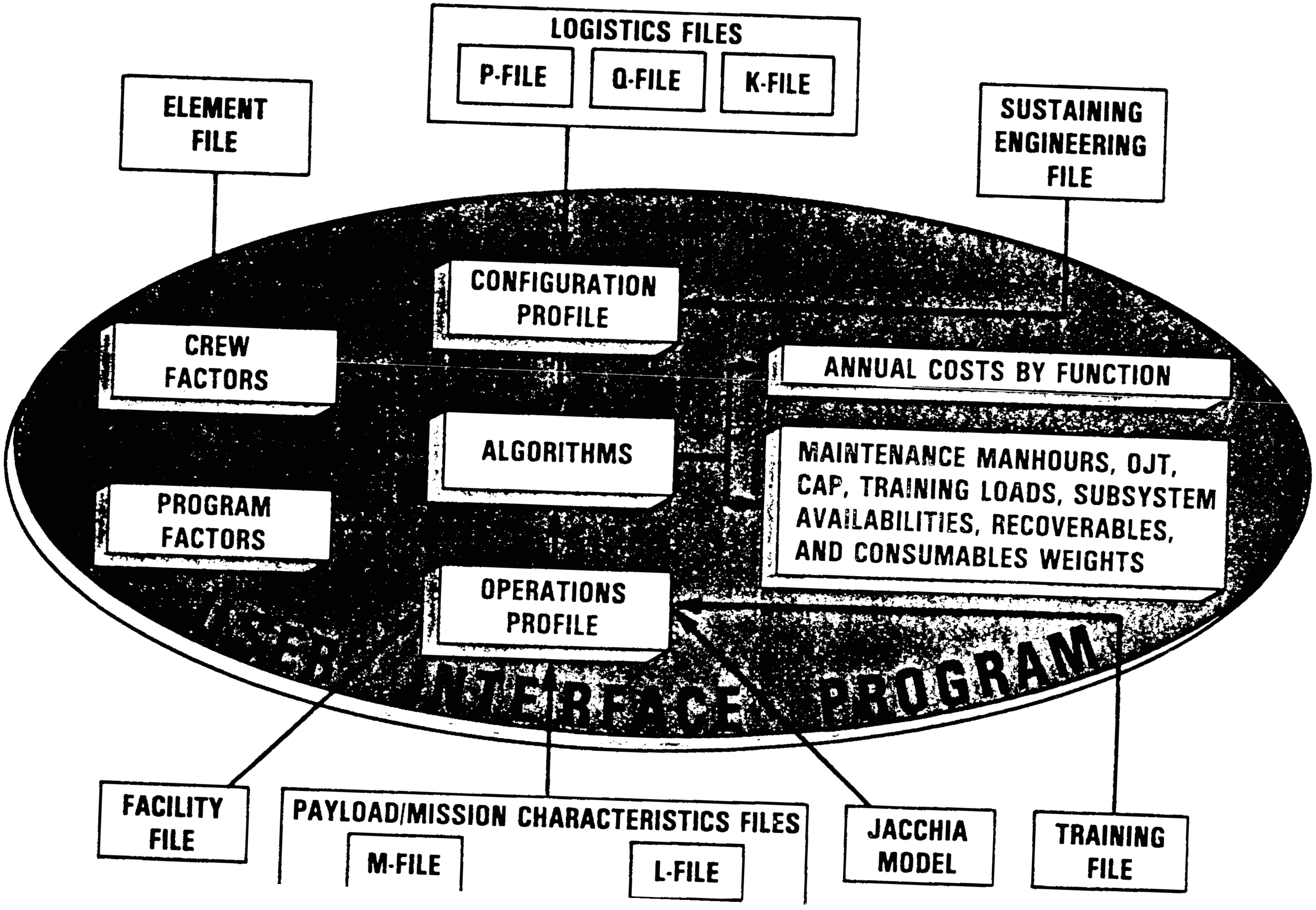
The operations profile is supported by several distinct databases. A training database provides the link between the flight crew, ground personnel, and launch site personnel requirements and training operations. The 1970 Jacchia model is used to represent atmospheric density in calculating drag forces on the Station. A major ground facility database provides detailed information on each such center, and a mission characteristics database provides detail on several sets of potential Station experiments and payloads.

These databases are not intended as replacements for existing engineering, logistics, and training databases, but as copies of them. Consequently, to produce cost estimates that reflect the most current Space Station program, these databases must be maintained in a timely fashion. This is facilitated by the fact that they are stored in the widely-available dBase III+ format.

(2) MESSOC's Algorithms and Equations. MESSOC's algorithms and equations are based on the principle that costs can be causally related to program decisions on Station design, configuration, operations, and logistics policies. It was strongly felt that greater Station complexity, activity rates, and/or Station size should give rise to greater estimated operations costs

Figure A-1

MESSOC ARCHITECTURE



in a systematic way. Further, to the extent that the many options could be anticipated, MESSOC was designed to handle a variety of policies. For example, when properly used, MESSOC ought to be able to recognize the implications of shifting an activity from the Station to a ground facility.

To produce cost estimates that are causally related to program decisions, four qualities were built into MESSOC's algorithms and equations. First, wherever possible, operations costs are built up from the lowest level of data that were practical to obtain. As a result, a change in design of a subsystem that affects the number or characteristics of its ORUs, for example, will result in a different estimate of operations costs. This provides a very natural way of treating the operations cost effects of commonality in the Station's design.

Second, algorithms and equations were linked to each other so that calculations made in one block of equations would be passed to another when needed. For example, an increase in the frequency of logistics resupply flights to the Station acts directly in the processing/reprocessing algorithm to increase those estimated costs, and acts indirectly to increase flight design costs and launch site training costs as well. As another example, MESSOC can be used to determine the effect on training costs of not only design changes that increase the need for EVA, but also of changing operations policies regarding EVA safety. This is possible because of the linked nature of the cost drivers and the detail built into the training and logistics algorithms.

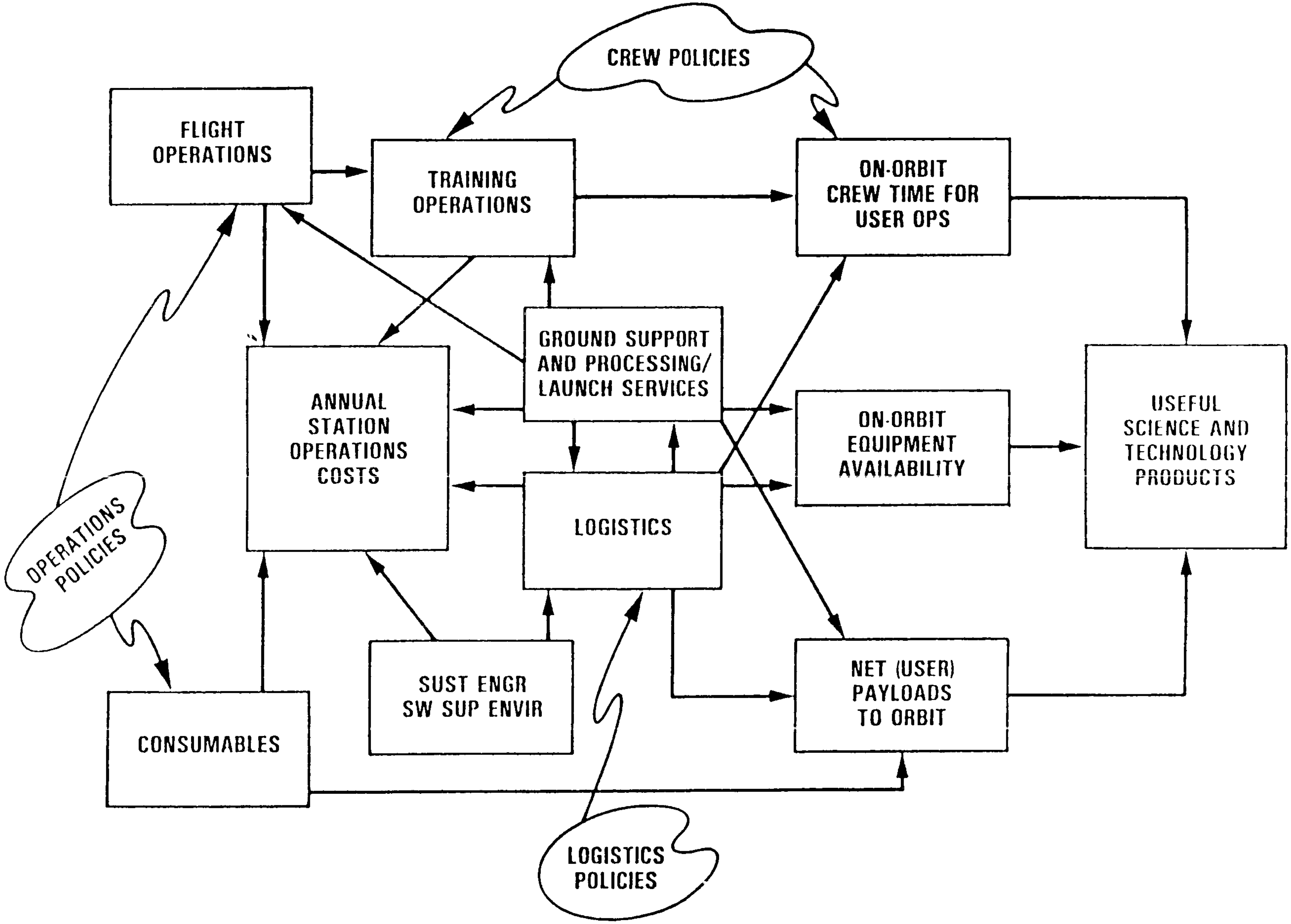
Third, as previously argued, operations cost estimates alone are not sufficient to address key design and operations issues. For example, a change in a subsystem design or operations policy might have very little effect on operations costs, but might significantly increase on-orbit maintenance time. Unless this were known, the wrong decision might be made. Consequently, MESSOC was designed to calculate several measures of intermediate outputs--net crew time available to users, subsystem or component availability, and net user payloads to orbit--at the same time it calculates costs, and to do so by using data passed from the cost algorithms. A conceptual view of how MESSOC's cost and intermediate output blocks are related in shown in Figure A-2.

Last, the MESSOC software incorporates several logical checks to ensure the appropriate timing of costs. For example, it recognizes that training for proximity operations using the Station Orbital Maneuvering Vehicle (OMV) is not needed until the period just before it is placed on-orbit.

MESSOC's algorithms and equations calculate costs deterministically or as expected values. As a result, it is quite likely that actual operations costs will differ from the MESSOC estimate in any year since actual costs tend to be stochastic. It is possible, through the judicious manipulation of the MESSOC databases, to obtain a range of operations cost estimates, should the user desire to do so.

(3) <u>Displayed Outputs</u>. MESSOC computes operations costs in 17 cost categories at present for each year of the scenario created by the user. MESSOC provides color graphics displays of cost outputs, as well as a summary report on costs, key input variables, and intermediate output measures for that scenario. The summary report also displays discounted and undiscounted cost totals. The user can request more detail for each cost category, and can obtain detailed annual breakdowns of how flight crews spend their on-orbit time, availability and stockout probabilities for critical

Figure A-2 Conceptual View of MESSOC Algorithms



subsystems and components, and net user payloads to orbit.

A.2 Interpretation of MESSOC Results

A number of very important points must be made in discussing MESSOC results. It is useful to review some of them at this point.

Mature Operations

First, MESSOC estimates are intended to cover the period of mature Station operations only. The assumption of mature operations carries with it a host of occasionally unrecognized characteristics. For example, all major ground facilities have been built. Their initial outfitting has been completed and checked out; software programs have been verified, and the initial complement of personnel have been trained. The Station's ORUs are performing with the reliability of an operational system, and so on.

MESSOC recognizes, however, that when more sustaining resources are bought in the period before mature operations, operations cost estimates are lower in the first few years of mature operations. For example, if the initial provisioning of spares was greater than required by mature operations, MESSOC's annual spares replacement cost estimates will initially be lower than in the long run. In effect, MESSOC allows the SSP to live off its initial investment for a while. MESSOC can do this because initial amounts of sustaining resources, such as spares and trained crews, are inputs to the model controlled by the user.

Operations Scenarios and Cost Drivers

MESSOC estimates are dependent on the specific operations scenario used. Each run is, in essence, a "what-if" experiment. To obtain useful estimates for the SSP requires the involvement of high-level SSP managers to define what the appropriate operations scenarios are. To the extent that there is no single dominating operations scenario, there is no single "correct" operations cost estimate.

However, in the operations scenarios that have been considered to date, at least 60 percent of the annual Space Station operations cost are attributable to four cost categories. These are (1) launch services, (2) Work Package sustaining engineering, (3) logistics, and (4) program management. MESSOC estimates for some of these costs depend on a few variables, but for others like logistics, the cost estimates depend on several thousand variables. It is possible though to discuss the principal cost drivers for each of these categories in more general terms.

Launch services demanded in a given year depend on the requirements generated by the planned exchange of user payloads, the logistics mass to orbit, and crew turnover policies. The logistics mass to orbit, in turn, depends on the need for spares and consumables, and on the payload capabilities of the launch vehicles when used in conjunction with the Space Station's logistics carriers and pallets. The need for spares and consumables depends ultimately on the Station's design characteristics.

Work Package sustaining engineering covers the correction of any flight hardware and software anomalies identified during mature operations, as well as normal performance enhancements and on-going integration. The cost of this work depends ultimately on the complexity and initial capability of the flight hardware.

Logistics costs depend on the Station's design characteristics, in particular, on the MTBFs at the ORU level. Logistics costs also depend strongly on the logistics policies in effect for the Space Station. These logistics policies include such issues as where ORU repairs are to be done, how much quality assurance and testing are needed, and which, if any, ORUs should be changed out before a failure.

Program management costs are driven by the size and management complexity of the SSP.

International participation adds to this complexity.

Operations Cost Uncertainties

MESSOC estimates represent the expected value cost and performance outcomes. This is particularly important to note for the logistics portions of the model, which are representing highly stochastic cost elements.

Operations cost uncertainties can be divided into two kinds--real uncertainty and statistical uncertainty. Real uncertainty arises when we do not know what value a variable will take and do not understand its underlying probability distribution. Statistical uncertainty--sometimes called simply "risk"--arises when we do not know what value a variable will take, but its underlying probability distribution is well-understood. The SSP must come to grips with both.

The distinction is well-illustrated in the case of Space Station flight hardware spares and repair costs, both of which depend on actual on-orbit failures. The MESSOC expected value estimates of these costs depend directly on the MTBFs for the Station's ORUs. At the present time, these MTBFs are subject to real uncertainty since no actual operations experience or on-orbit testing has been done. If the actual MTBFs were to turn out to be only half of the current predictions, then expected spares and repair costs would about double. Even if the current predictions of MTBFs are correct, actual failures are stochastic. The SSP could have a "bad year" in which failures are much higher than expected, along with spares and repair costs.

Both kinds of uncertainty could affect operations costs in another way. Either MTBF predictions that were in retrospect too high, or a bad year could result in a requirement for additional (above plan) STS launches to resupply the Station. This would be a discontinuous and significant increase in operations costs.

The SSP must be able to perform cost uncertainty assessments. To do this, an independent critical review of the variables and scenarios used in the operations cost model is needed. A cost uncertainty assessment using MESSOC should also examine the associated uncertainties in the intermediate outputs.

Appendix B

APPLICATION OF MESSOC TO THE REPAIR-IN-ORBIT (RIO) ISSUE

by Robert Shishko

Panel Two of the Task Force asked JPL to assist them in determining the efficacy of repairing ORUs in-orbit as part of an overall maintenance strategy. Such an analysis involves asking (1) what ORUs can be repaired in-orbit given human limitations, and (2) given that repair-in-orbit is feasible, under what circumstances does it make sense to do so. The latter question is essentially one of life cycle cost (LCC) since the answer depends on a complex tradeoff of various resources, each of which has value and therefore should not be wasted.

JPL undertook such an analysis for the Station's electrical and electronic ORUs. These ORUs were singled out because they are a significant part of the investment in the Station, they are crucial to the proper functioning of nearly all of the Station's subsystems, and it was felt that repair-in-orbit was feasible a high percentage of the time.

MESSOC was used as the primary "engine of analysis" since it could not only estimate the operations cost implications of repair-in-orbit, but could quantify the crewhour and transportation implications as well. However, the DDT&E cost implications, which are outside of MESSOC, required a one-time effort to quantify. It is important to understand that without data on the DDT&E cost of Station resources, a LCC analysis of this kind is not possible. In other words, a model like the System Design Tradeoff Model (SDTM) is essential.

What Tradeoffs Are Involved?

Adding a repair-in-orbit capability for the Station's electrical and electronic ORUs is not a costless endeavor. Additional generic and specialized test equipment must be bought and installed, maintenance documentation must be expanded, astronauts must be trained to do repair-in-orbit, and additional space allocated to temporary storage. These involve both up-front DDT&E costs as well as annual operations costs.

With a repair-in-orbit capability, astronauts will be doing less remove-and-replace maintenance and more remove, repair-and-replace (or remove, replace-and-repair) maintenance. The total amount of time spent on Station maintenance is very likely to increase, depending on how much longer it takes to actually complete the repair tasks. Crew time spent on maintenance could have been used to operate payloads. If crew time is as restricted as some have argued, then it must be highly valued in any analysis.

Offsetting the additional crew time required is the reduced weight of ORUs and other parts that must be brought down and returned to the Station. Since transportation to orbit is both costly and constrained, any weight savings should be highly valued as well. Indeed, the JPL analysis showed that the optimal amount of repair-in-orbit capability depends almost entirely on the relative "prices", i.e., value per unit, of crew time, transportation to orbit, and pressurized volume. The analysis leading to this conclusion is presented below using as little mathematics as possible. It is a prototype for many possible LCC analyses.

Minimizing the LCC Function

Choosing the optimal amount of repair-in-orbit for electrical and electronic ORUs analytically involves taking the first derivative of the LCC function with respect to the repair-in-orbit probability, RIO, and setting the resulting function equal to zero. Solving for RIO then results in the LCC-minimizing policy, if the appropriate second-order conditions hold. Mathematically, if LCC is the life cycle cost function, then this process can be written as:

$$\mathrm{LCC} = \mathrm{I}\ (\mathrm{X}_{1,0},\mathrm{X}_{2,0},\ldots,\mathrm{X}_{n,0};\mathrm{RIO}) + \sum_{t} \mathrm{C}_t\ (\mathrm{X}_{1,t},\mathrm{X}_{2,t},\ldots,\mathrm{X}_{n,t};\mathrm{RIO})\ (1 + r)^{-t}$$

were $X_{i,t}$ is the ith activity or resource at time t, I is the investment cost function, C_t is the annual operations cost function, t is time measured from the start of Phase E, and r is the annual real discount rate.

$$\frac{d\mathrm{LCC}}{d\mathrm{RIO}} = \sum_{i} \left(\frac{\partial \mathrm{I}}{\partial \mathrm{X}_{i,0}}\right)\left(\frac{\partial \mathrm{X}_{i,o}}{\partial \mathrm{RIO}}\right) + \sum_{t} \sum_{i} \left(\frac{\partial \mathrm{C}_t}{\partial \mathrm{X}_{i,t}}\right)\left(\frac{\partial \mathrm{X}_{i,t}}{\partial \mathrm{RIO}}\right)(1+ r)^{-t} = 0$$

for t = 1, ... ,T.

In the above equation, the product of the related partial derivatives can be considered as a "price" times a "quantity." The first term represents the impact on costs of a change in the ith activity or resource level, i.e., a "price" per unit of change. The second term represents the amount of activity or resource change per unit change in RIO, i.e., a "quantity." These prices and quantities need to be evaluated both for initial investment costs and recurring operations costs.

As mentioned above, MESSOC was used to estimate the partial derivatives with respect to RIO for the operations component of LCC. A one-time effort was necessary to estimate the initial investment implications of increasing the Station's repair-in-orbit capability. These estimates were then converted into the needed partial derivatives with respect to RIO.

For one key resource, pressurized volume, a non-linear function was needed to estimate the changing initial Station requirement when RIO was increased. To perform more repair-in-orbit, certain generic and specialized test equipment would be needed, along with additional work and storage volume. Because pressurized volume is a scarce resource on the Station, the amount needed must be carefully estimated and valued against other resources. The function representing this volumetric requirement had to have several mathematical characteristics, namely:

(1) $V(\mathrm{RIO}) = 0$ when $\mathrm{RIO} = 0$;

(2) $V'(\mathrm{RIO}) > 0$; and

(3) $\lim V(\mathrm{RIO}) = \infty$ as $\mathrm{RIO} \rightarrow 1$.

The function chosen for the analysis was:

$$V(\mathrm{RIO}) = V_0 \tan\left(\left(\tfrac{\pi}{2}\right) \mathrm{RIO}\right)$$

where $V_0 = 17.833$. This function meets the mathematical requirements, and appeared valid for RIO roughly between 0.25 and 0.90. The constant, V_0, was selected to pass the function through a preselected point.

Results with Current Estimates

Tables B-1 and B-2 set out the resulting non-zero partial derivatives necessary to complete the analysis. Both tables work roughly the same way. To the left is a list of activities or resources likely to be affected by doing repair-in-orbit, followed by the column of "prices", a column of estimated "quantity" derivatives, and a column showing the product. Note that some quantities increase and others decrease as RIO is made larger. The total of the "product" column is the net additional initial investment cost per unit of RIO (Table B-1) or the net additional annual operations costs per unit of RIO (Table B-2). Taking the net present value of these costs yields a function of RIO, which is to be set equal to zero and solved for the optimal RIO.

Some clarifying comments on Tables B-1 and B-2 are needed before moving to the solution. A "price" of $1.00/unit in either table means that the "quantity" has been estimated in millions of FY85 dollars. This would naturally be expected using MESSOC. The "prices" of weight-to-orbit, pressurized volume, and IVA have been taken from the System Accounting Model (SAM) as published in the Space Station Cost Management Process Requirements document (JSC 30470--December 30, 1986).

The logistics--cost, weight, and IVA--implications of repairing electrical and electronic ORUs in-orbit were estimated by MESSOC. These ORUs made up 223 of the 1065 ORUs in MESSOC's data base. The MESSOC results are dependent on a host of individual assumptions about these ORUs. For example, if the mean-time-between-failure data were incorrect, then the estimated partial derivatives, on which this analysis depends, would be incorrect as well. There is no substitute for good data.[1]

EVA does not appear in the list of activities in Table B-2 because the way maintenance of EVA ORUs was conducted, no additional EVA was demanded. Those electrical and electronic ORUs requiring EVA were removed and replaced, just as they would be without a repair-in-orbit capability. They might be repaired-in-orbit, but that would be accomplished using IVA. Repaired ORUs were placed in temporary pressurized storage until the next EVA cycle or until external storage was available, whichever came last. An alternative maintenance approach might reduce storage requirements, but increase some other resource. This would have to be evaluated using the same method as this analysis.

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[1] The Operations Task Force would like to thank Mr. Robert Hill (KSC/SS-LSO) for identifying the test equipment and tool requirements, determining which electrical and electronic ORUs could potentially be repaired in-orbit, and estimating the maintenance time required to do so. Without these data, the JPL analysis would not have been possible.

Table B-1. Additional Initial Investment Costs Per Unit of RIO
(In millions of FY85$)

Resource or Activity, $X_{i,o}$	"Price", $\frac{\partial I}{\partial X_{i,0}}$	"Quantity", $\frac{\partial X_{i,0}}{\partial RIO}$	"Product"
Equipment Purchase	$1.00/unit	0.833 units	$0.833
Equipment Launch	3.621/Klb	0.30167 Klbs	1.092
Initial Spare	1.00/unit	-9.70 units	-9.700
Initial Training	1.00/unit	0.15 units	0.150
Maintenance Docum	1.00/unit	1.167 units	1.167
Pressurized Volume	0.056/cuft-yr	$V'(RIO)T$	$0.056 + 0.056V'(RIO)T$
TOTAL			$-6.458 + 0.056\ V'(RIO)T$

Note: $V'(RIO) = 28.012\ (1 + \tan^2(1.57\ RIO))$, and T is the time horizon for operations costs, set in this analysis at 15 years.

Table B-2. Additional Annual Operations Costs Per Unit of RIO
(In millions of FY85$)

Resource or Activity, $X_{i,t}$	"Price", $\frac{\partial C_t}{\partial X_{i,t}}$	"Quantity", $\frac{\partial X_{i,t}}{\partial RIO}$	"Product"
Spares/Reprs/Trans	$1.00/unit	-14.267 units	$-14.267
Spares Launch	3.621/Klb	-6.300 Klbs	-22.810
Training	1.00/unit	1.667 units	1.667
Maintenance Docum	1.00/unit	0.117 units	0.117
IVA	0.0206/crewhr	344.58 crewhrs	7.098
TOTAL			-28.195

Having made these comments, the results can be brought into focus. The optimal RIO probability, designated RIO*, is obtained by solving the following equation:

$$-6.458 + 0.056\ V'(\mathrm{RIO}*)\ T + (-28.195)\ \left(\frac{1 - e^{-rT}}{r}\right) = 0$$

where the term in the large parentheses serves to discount T years of operations cost savings. The equation yields RIO* = 0.79 when T=15 years and the annual discount rate is 10 percent. This value suggests a strong case can be made for providing a repair-in-orbit capability for electrical and electronic ORUs. It is easy to verify that this solution represents at least a local minimum of LCC since $V''(\mathrm{RIO}*)>0$.

Sensitivity of the Results

The SAM prices represent very important decision parameters. They are the long-run marginal cost per unit of their respective activities or resources. Economists sometimes use the terms "shadow price" or "opportunity cost" to express the same idea. Ignoring the implicit price of these resources results in a Station that has less value to its users. Ultimately, the result is a Station with no value to users.

However, the current implicit prices assigned by SAM to activities and resources may not be correct. Some of them may be off by an order of magnitude in fact, because the data used to derived them is woefully out-of-date. The implicit price of weight-to-orbit in SAM is $3621/lb, which is calculated on the basis of STS performance and cost. This implicit price is probably the best of the SAM estimates because it is based on actual experience. It is probably accurate to within 20 percent. But for IVA and pressurized volume, there is considerably more uncertainty.

If the SAM implicit price for IVA were five times higher--not an unreasonable supposition--then the additional annual operations costs would be positive, not negative as shown in Table B-2. In that case, no repair-in-orbit would be optimal. Further, even at lower levels of the IVA implicit price, repair-in-orbit should be sharply curtailed or eliminated. Figure B-1 shows how the optimal RIO varies with the implicit price of IVA. Three different discount rates are shown indicating its effect as well. The higher the discount rate, the less future operations cost savings are valued against current DDT&E costs. At the SAM IVA implicit price of roughly $20,600/crewhour and a discount rate of 10 percent, the optimal RIO is the 0.79 figure calculated above.

Figure B-2 shows how the optimal RIO varies with the implicit price of pressurized volume, holding the IVA implicit price at its SAM value. Again, the discount rate exerts a strong influence. Given the uncertainty in both implicit prices, it is reasonable to ask what combinations of the two implicit prices conspire to make repair-in-orbit uneconomic. That question is answered in Figure B-3, which shows the boundary condition between economic repair-in-orbit and uneconomic repair-in-orbit. Inside the triangle, the optimal RIO is positive; outside, all maintenance on electrical and electronic ORUs should be remove-and-replace.

The triangle covers a wide range of implicit prices, and therefore suggests that even with uncertain SAM prices, some repair-in-orbit looks economic. Note too that the current combination of SAM implicit prices is well inside the boundary.

Concluding Observations on the Analysis

The results of the above analysis confirm the Operation Task Force Panel Two conclusion with regard to repair-in-orbit, namely that a repair-in-orbit capability would be economic for certain classes of ORUs. To make such a capability feasible from an operations point of view, the SSP would have to commit additional resources during the Station's development phase. These resources include additional initial training, maintenance documentation, on-Station test equipment, and pressurized volume to be used as a work and storage place. In return, the LCC of the Station is expected to be lower.

What such an approach requires goes beyond the usual Optimal Repair Level Analysis (ORLA). It requires a systematic identification of the detailed failure modes and probabilities for those ORUs that are candidates for repair-in-orbit. It also suggests that to do the proper analysis on these detailed data, it is important that a few crucial variables be particularly accurate. The calculation of RIO$*$ above was highly dependent on the estimates of required pressurized volume, spares weight-to-orbit, spares and repair requirements, IVA crewhours for maintenance, and the respective implicit prices for these resources. Populating SDTM and MESSOC with accurate data sets so that these crucial quantities can be confidently estimated would yield an extremely high payoff for the SSP.

How much repair-in-orbit should be done has other than economic dimensions. Such repairs would be done by astronauts and they might have strong opinions about spending a couple of hundred additional hours a year repairing circuit boards and the like. Some may view this as an unnecessary diversion from their main task, while others may take a certain amount of enjoyment in keeping the Station in "ship-shape." At the least, some study of this aspect of operations should be made.

The calculation of RIO* above was predicated on a Station with an unchanging configuration and operations scenario. Growth of the Station was not considered. The effect of Station growth would be to alter the partial derivatives in Tables B-1 and B-2. In particular, such growth would likely mean increased maintenance time, spares weight-to-orbit, and pressurized volume requirements per unit of RIO. Furthermore, when such growth occurred would matter since net present values need to be calculated. MESSOC could have handled a growth scenario, and would have produced the necessary partial derivatives for each year of operations, but such a refinement was not done at this time.

Lastly, the LCC function should technically have included decommissioning costs net of any salvage value of the Station. This refinement was also not made. It is unlikely that the optimal RIO was affected by this decision.

Figure B-1

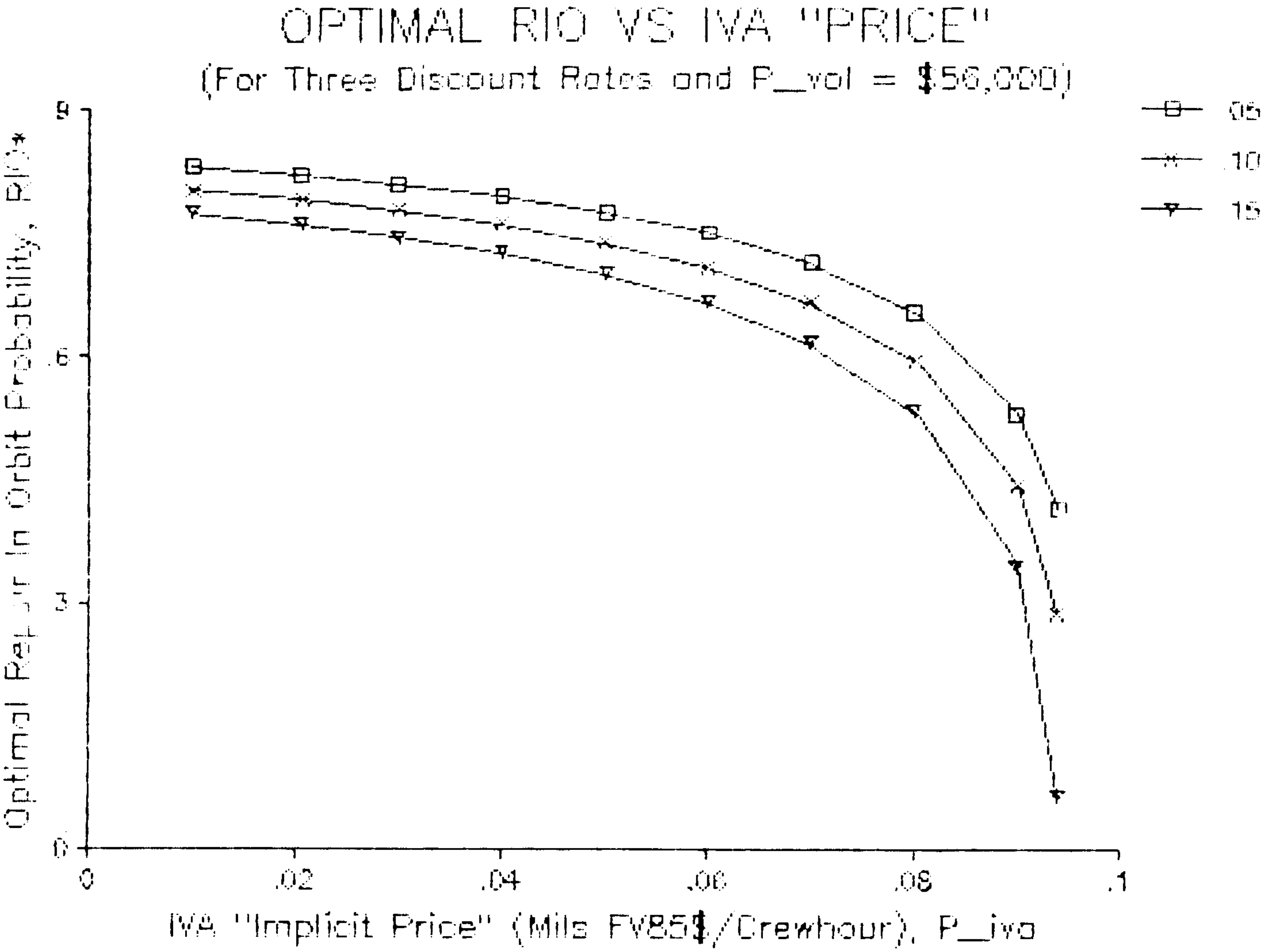
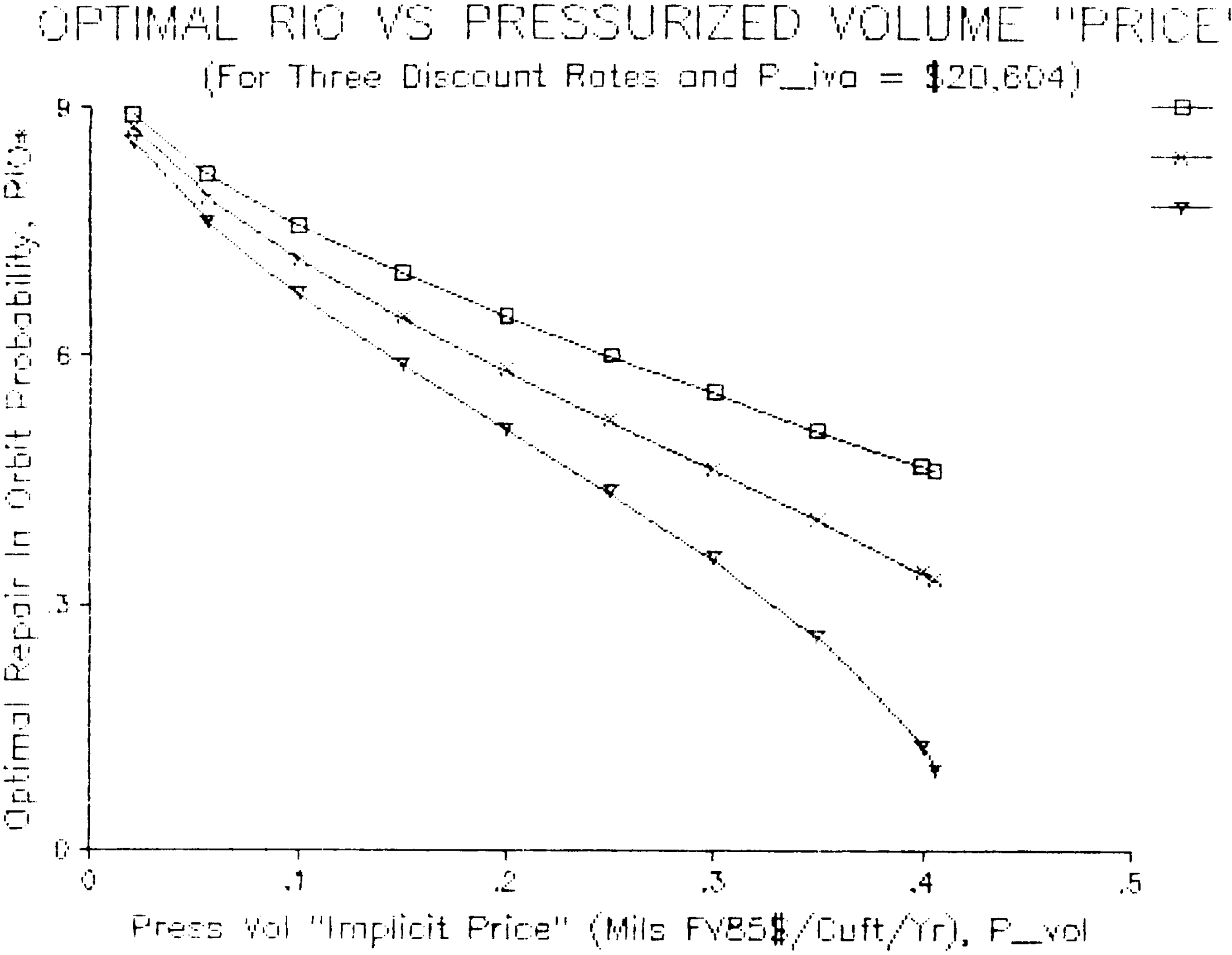
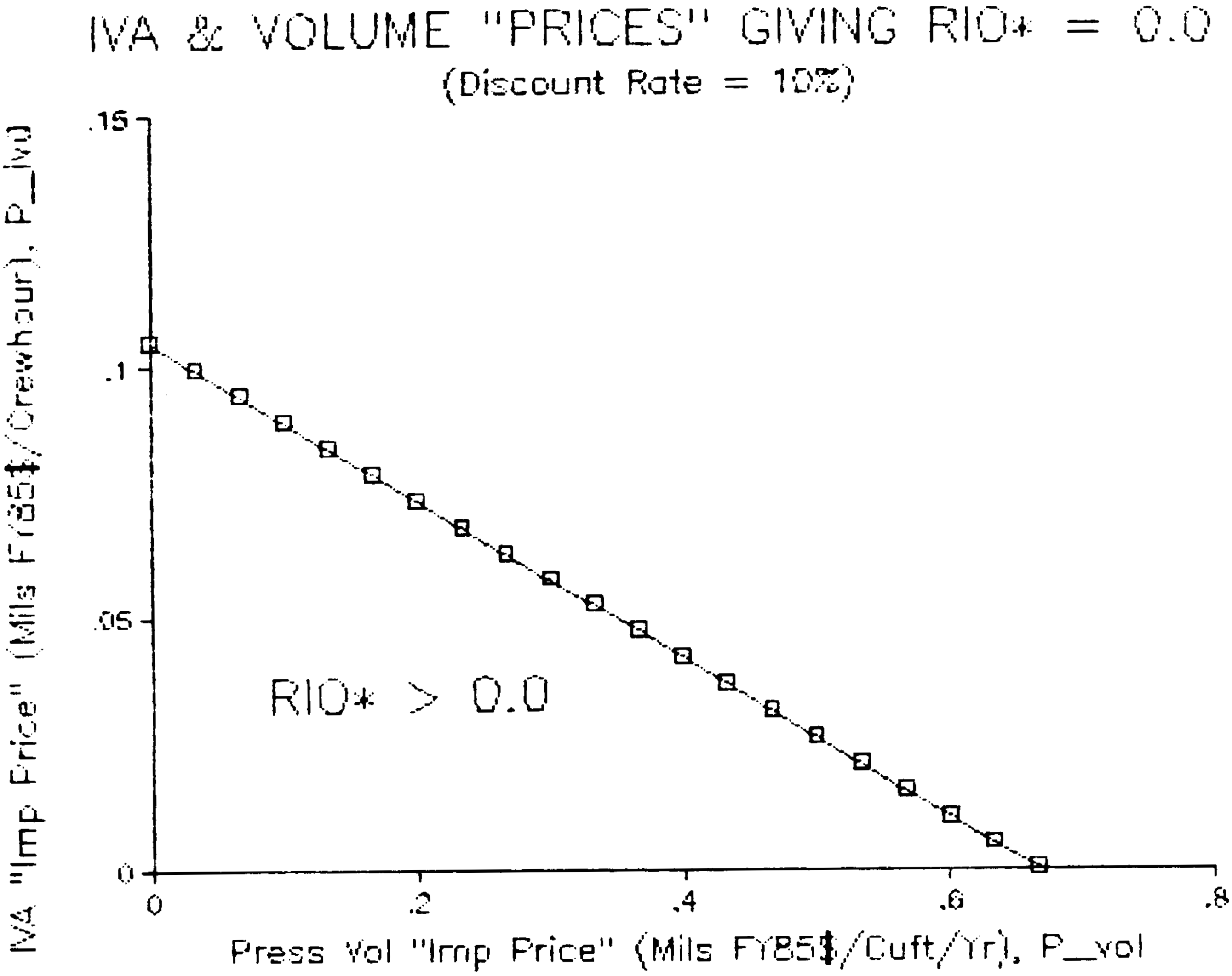

OPTIMAL RIO VS IVA "PRICE"
(For Three Discount Rates and P_vol = $56,000)
Optimal Repair In Orbit Probability, RIO*
.9
.6
.3
0
0
.02
.04
.06
.08
.1
IVA "Implicit Price" (Mils FY85$/Crewhour), P_iva
.05
.10
.15

Figure B-2



OPTIMAL RIO VS PRESSURIZED VOLUME "PRICE
(For Three Discount Rates and P_iva = $20,604)
Optimal Repair In Orbit Probability, RIO*
Press Vol "Implicit Price" (Mils FY85$/Cuft/Yr), P_vol
9
6
3
0
0
.1
.2
.3
.4
.5

Figure B-3


IVA & VOLUME "PRICES" GIVING RIO* = 0.0
(Discount Rate = 10%)
IVA "Imp Price" (Mils FY85$/Crewhour), P_Iva
.15
.1
.05
0
RIO* > 0.0
0
.2
.4
.6
.8
Press Vol "Imp Price" (Mils FY85$/Cuft/Yr), P_vol