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11 MARCH 1983

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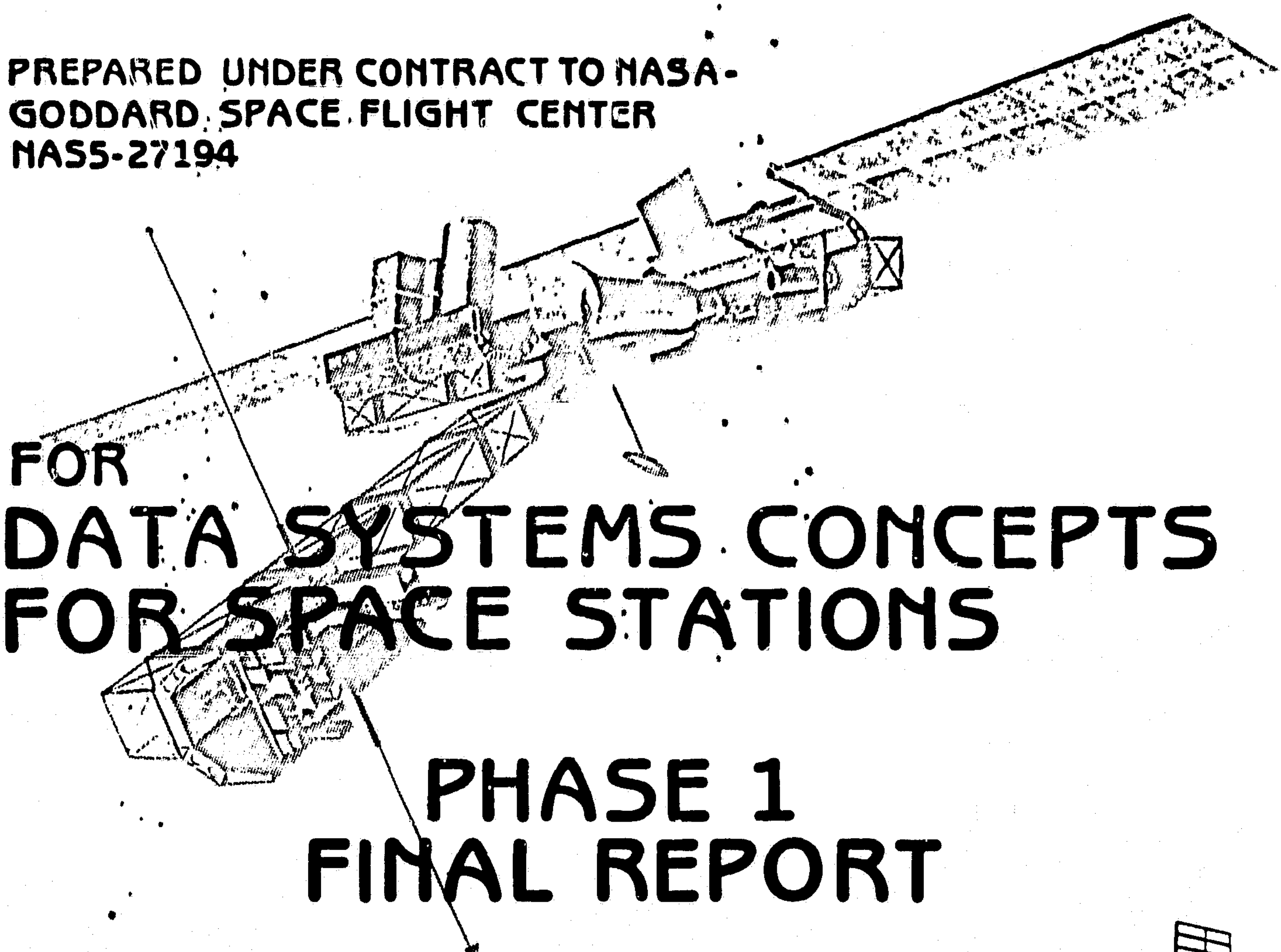
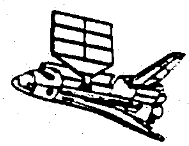
NAS5-27194



FOR

DATA SYSTEMS CONCEPTS FOR SPACE STATIONS

PHASE 1 FINAL REPORT



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THE GENERAL ELECTRIC COMPANY
MILITARY AND DATA SYSTEMS OPERATIONS
HUNTSVILLE OPERATIONS
HUNTSVILLE, ALABAMA

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CODE 502

DATA SYSTEMS CONCEPTS
FOR SPACE STATIONS

PHASE I
FINAL REPORT

PREPARED BY:

S. E. Golden
S. E. Golden

J. W. Neiers
J. W. Neiers
Study Program Manager

PREPARED BY
THE GENERAL ELECTRIC COMPANY
MILITARY AND DATA SYSTEMS OPERATIONS
HUNTSVILLE OPERATIONS
HUNTSVILLE, ALABAMA

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Phase I Final Report
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ACRONYMS AND ABBREVIATIONS

AI	Artificial Intelligence
ARPANET	Advanced Research Programs Agency Network
CMS	Command Management System
CRT	Cathode Ray Tube
DBMS	Data Base Management System
DMS	Data Management System
DOD	Department of Defense
EVA	Extra Vehicular Activity
EXT	External
FAA	Federal Aviation Administration
FP	Functional Programming
GPS	Global Positioning Satellite
I/F	Interface
I/O	Input/Output
IBM	International Business Machine
IJCAI	International Joint Conference on Artificial Intelligence
ILS	Integrated Logistics System
INT	Internal
IR	Infra Red
JPL	Jet Propulsion Laboratory
KW	Kilowatt
LAN	Local Area Network
LRU	Line Replaceable Unit
M	Memory
MEM	Memory
MIT	Massachusetts Institute of Technology
MOCC	Mission Operations Control Center
NASA	National Aeronautics and Space Administration
ODMS	Operations Data Management System
ODMSC	Operations Data Management System Computer
OPNS	Operations
OSSC	Operations Subsystem Computer
PI	Principal Investigator
PROC	Processor
SAR	Synthetic Aperture Radar
SS	Subsystem
SS/TDMA	Satellite Switched/Time Division Multiple Access
TDRSS	Tracking and Data Relay Satellite System
TDM	Time Division Multiplex
TDMA	Time Division Multiple Access
TWT	Traveling Wave Tube
W/R	Write/Read

SECTION 1
INTRODUCTION

"The door to space has been opened. . . And that door leads inevitably to the extension of the human environment into space and eventually to mankind's evolution into a space faring civilization."

James M. Beggs
NASA Administrator

The next step towards this destiny is the establishment of a permanent manned presence on a Space Station in near earth orbit. The shuttle assures a dependable revisit capability. The benefits of space for earth observation, astronomy, scientific experimentation, and high technology manufacturing in the high vacuum, microgravity environment have been demonstrated. Man's ability to function for extended periods in a space environment has been proven with Skylab and the Soviet space program. The next step is to extend the economic applications of space by implementing a Space Station system that will foster an optimum use of available components and technology.

Once a Space Station becomes established with its personnel and support systems, additional applications can be incorporated for relatively small incremental changes. The challenge is to conceive and develop a system with planned modularity and flexibility to permit these easy additions without adversely impacting the overall system optimization.

This role of maturing space technology as a cost effective national resource calls for a new approach to the system concept development. It is no longer a question of what technology is available to put men in space for extended beneficial applications. The important question now is "What technology should be developed and in what sequence so the investment will provide a beneficial return in terms of more applications and lower life cycle costs?" Of special concern is that many of the future requirements are not yet known so any strategy must place a heavy weight on flexibility and modularity.

In addressing this challenge, several groups within NASA and industry are studying particular partitions of the problem (Woodcock 1, CDC 1, Wolbers 1, Runge 1, Priest 1, Bloom 1). This Phase 1 Final Report presents the partial results of a study for deriving Data Systems Concepts for Space Stations. The work is being performed by General Electric Company on contract NAS5-27194 to NASA/GSFC for Code 502. This study was conducted in parallel with other studies (NASA 1, NASA 2, NASA 3, NASA 4, Mann 1, TRW 1, Rockwell 1, White 1) that are identifying the economic justifications and the missions of the Space Station.

The intent of this study was to identify data system technology elements that have a high potential for reducing life cycle costs of Space Stations. To properly assess such potentials, it is necessary to identify data system concepts for the Space Station. Such concepts provide the necessary milieu within which technology alternatives, needs, and benefits can be analyzed. The concept development is dynamic. A Report Update will be delivered in April, 1983, which will document the revised requirements, additional depth of trade studies, and update the concepts.

1.1 STUDY ASSUMPTIONS

The initial Space Station shall have the following characteristics:

- 28.5 degree inclination orbit of approximately 400 kilometer altitude.
- manned base station with colony of unmanned stations within "energy proximity."
- "permanently" manned habitat, with capabilities for docking shuttle and stations, servicing payloads, integrating upper stage, construction and assembly functions.
- some initial time when there is no manned presence in the base station.

1.2 STRAWMAN SCENARIO

The following scenario is envisioned beginning with an initial launch of a shuttle-borne core habitation facility circa 1988. This facility will contain some supporting equipment to provide for minimum essential control and communication as well as additional resources for some manned activity while the shuttle is present, probably in an attached "docked" mode. At the expiration of shuttle time in orbit, all personnel will temporarily leave the facility. On subsequent return visits, additional modules will be added to construct a larger core facility than would be integrally transportable by a single shuttle. These subsequent revisits will occur during a relatively short time period, so the unmanned duration would be measured in days or weeks. During the first year or two, a semi-continuous manned habitation would evolve with the frequency of shuttle visits being such that there would be a docked or nearby shuttle vehicle there continuously. In an evolutionary manner, periods of a few hours or days would occur when a shuttle would be in orbit but not necessarily attached to the manned habitation.

During this time frame, one or more outlying platforms would be deployed to support other experiments and applications. By the early 1990s, a permanent manned presence with some teleoperator and other EVA capability would be established to effect some rudimentary space construction and repair capability. This could evolve toward some on-orbit servicing of structures or vehicles for subsequent transfer to higher energy orbits. This would all occur within the so-called "early time frame."

In later phases, beginning with the late 1990s, on-orbit servicing of space vehicles would be a normal operation. The scenario of interest for the study will primarily be the "early time frame." This scenario is illustrated in Figure 1-1.

1.3 INTEGRATED SYSTEM FUNCTIONS

The functions of the Space Station data system are expected to encompass all those of previous long duration manned spacecraft, particularly Skylab. In addition, they will provide for greater autonomy and efficiency of operations through automation and an increasing role of providing support services for specific missions. In an attempt to enumerate specific functions, a tree structure was developed. In the broad classification, all data system functions were assigned to either "operational" or "mission and applications." This partition was chosen for several reasons. Primarily, operational functions represent the minimum set of requirements for the data system. They must be provided to sustain the Space Station. These are the more critical functions and thus are the ones that justify redundant systems, alternate modes of operation, and high reliability requirements. The missions and

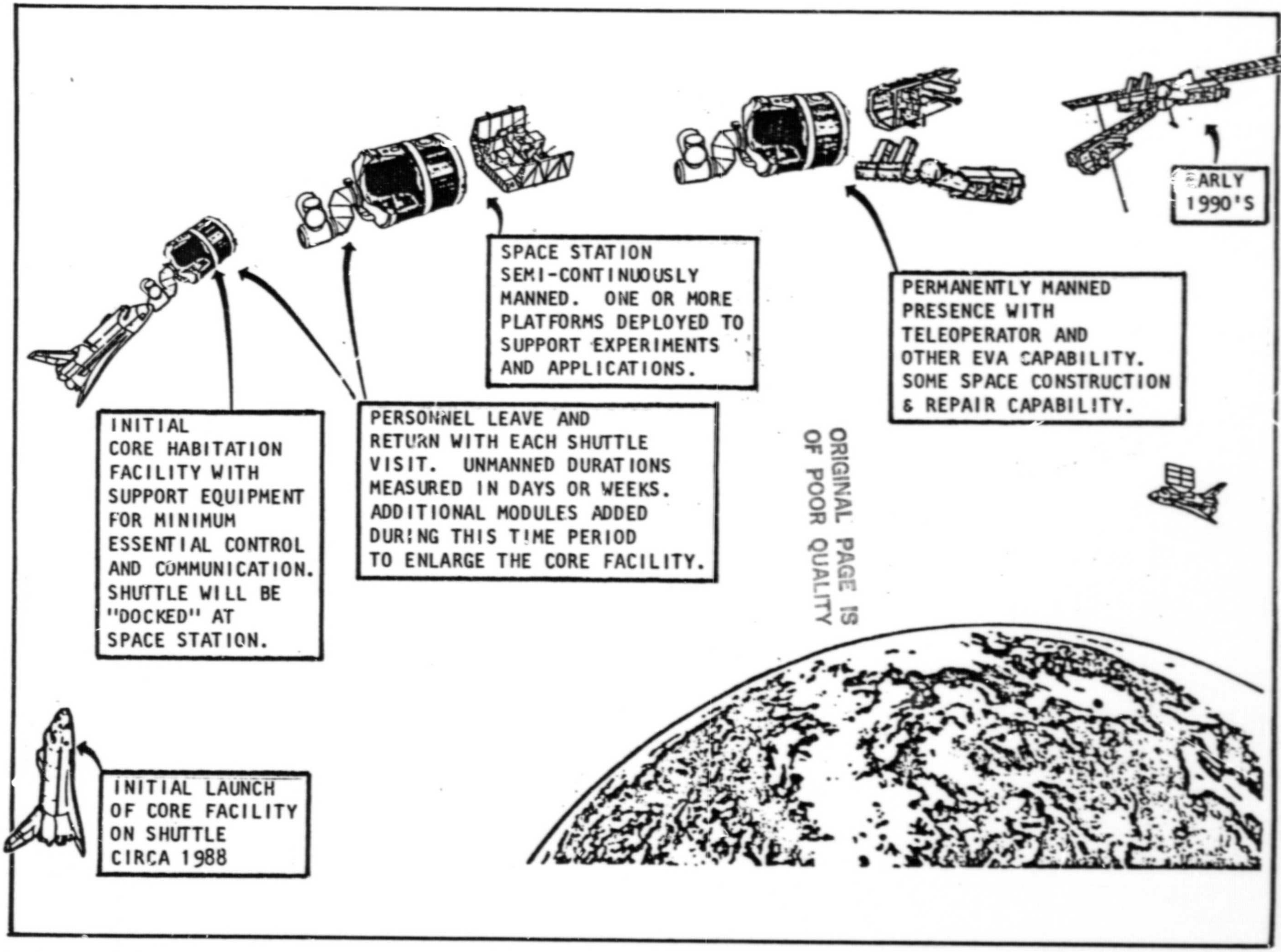


Figure 1-1. Strawman Space Station Scenario for Early Time Frame

application functions are more mission dependent and in some cases may not be required, depending on the specific mission. These are functions that require emphasis on economic justification. Enhancement in their implementation can permit trade-offs of availability, reliability, and degraded performance. Optimization can include mission benefits. These can also be optimized based upon function mix when different mission mixes are considered.

The tree in Figure 1-2 shows the functional breakdown of these two partitions. These functions were adapted from the data system concept OSTA study (GE 1). Especially, the mission functions will be dependent upon a comprehensive consideration of potential applications. As a method to identify those mission specific functions that will be advantageous to consider within the scope of the Space Station data system, Block 2.3, Mission Specific Functions has been expanded and is shown in Figure 1-3. These functions were analyzed against the mission in a matrix as illustrated in Figure 1-4. An outline of all the functions is included in Table 1-1.

Appendix A contains a short description of how each function will impact the system.

1.4 APPROACH

It would be impractical and fruitless to try to develop a complete functional specification, description, or even requirements for the Space Station data system in a study of this magnitude. Consequently, this study has taken the direction of emphasis on the deviations from the traditional spacecraft data systems. The hope is to provide a shopping list of ideas worthy of further development in the belief that if even one finds its way to operational deployment and improved long term cost benefits, the effort will have been well directed. Experts in different areas were convened in a Blue Ribbon Panel to express their ideas and views toward future applicable technologies. The results of that meeting are presented in Appendix B.

Traditional manned spacecraft data system functions must be considered but only to the extent necessary to provide the context for evaluating the things that are new and different. The approach used in this study was to develop the data system architecture from the top down. The overall architecture as reported in Initial Concepts is shown in Figure 1-5. Other concepts reported

- FUNCTIONS
  - 1.0 OPERATIONAL
    - 1.1 OPERATIONS CONTROL
      - 1.1.1 SUBSYSTEM CONTROL
        - .1 LIFE SUPPORT
        - .2 POWER
        - .3 ATTITUDE
        - .4 COLLISION AVOIDANCE
        - .5 ENVIRONMENT CONTROL
      - 1.1.2 SUBSYSTEM PERFORM. ANALYSIS
        - .1 LIFE SUPPORT
        - .2 POWER
        - .3 ATTITUDE
        - .4 MEDICAL
        - .5 ENVIRONMENT CONTROL
        - .6 ENVIRONMENT MONITOR
        - .7 MECHANICAL STRAIN
      - 1.1.3 COMMAND MANAGEMENT
        - .1 ESTABLISH VALIDITY
        - .2 SCHEDULING
        - .3 TRANSFER COMMAND
        - .4 EXECUTE COMMAND
        - .5 MAINTAIN ACCOUNTABILITY
      - 1.1.4 ATTITUDE OPERATIONS
        - .1 DETERMINE DEFINITIVE ATTITUDE
        - .2 EXECUTE CHANGES
        - .3 SPACE STATION MODELS
      - 1.1.5 ORBITAL OPERATIONS
        - .1 EPHEMERIDES PREDICTION & VALIDATION
        - .2 ORBITAL MAINTENANCE
        - .3 DEFINITIVE DETERMINATION
      - 1.1.6 DOCKING MANEUVER
        - .1 LOCATION
        - .2 ASSISTANCE
    - 1.2 COMMUNICATIONS
      - 1.2.1 CHANNEL MANAGEMENT
        - .1 SELECTION
        - .2 SCHEDULING
        - .3 MONITORING
        - .4 INTERFACE CONTROL
      - 1.2.2 CHANNEL SUPPORT
        - .1 ANTENNA POINTING
        - .2 FORMATTING
        - .3 BUFFERING
      - 1.2.3 TRANSMISSION & RECEIPT
    - 1.3 DATA MANAGEMENT
      - 1.3.1 GENERICS
        - .1 ACQUISITION
        - .2 CAPTURE
        - .3 PROCESSING
        - .4 ARCHIVING
        - .5 DELIVERY
      - 1.3.2 OPERATIONS
        - .1 SUBSYSTEM STATUS EQUIPMENT CONFIG.
        - .2 MONITOR & CONTROL
        - .3 COMMAND EXECUTION & VERIFICATION
        - .4 COMPUTER OPERATIONS SUPPORT OF ALL SUBSYSTEMS
      - 1.3.3 CREW
        - .1 HEALTH
        - .2 DUTY SCHEDULES
        - .3 SKILLS
        - .4 ENTERTAINMENT
        - .5 PERSONAL RECREATION
        - .6 LIBRARY STORAGE, CATALOGING
        - .7 TRAINING
      - 1.3.4 LOGISTICS
        - .1 CONSUMABLES
        - .2 SUPPLIES
        - .3 SPARE PARTS
        - .4 RESUPPLY SCHEDULING
        - .5 ENTERTAINMENT/RECREATION SUPPLIES
        - .6 CREW SKILLS
    - 1.4 CONFIGURATION MANAGEMENT
      - 1.4.1 CONFIGURATION IDENTIFICATION
      - 1.4.2 CONFIGURATION CONTROL
      - 1.4.3 CONFIGURATION STATUS ACCOUNTING

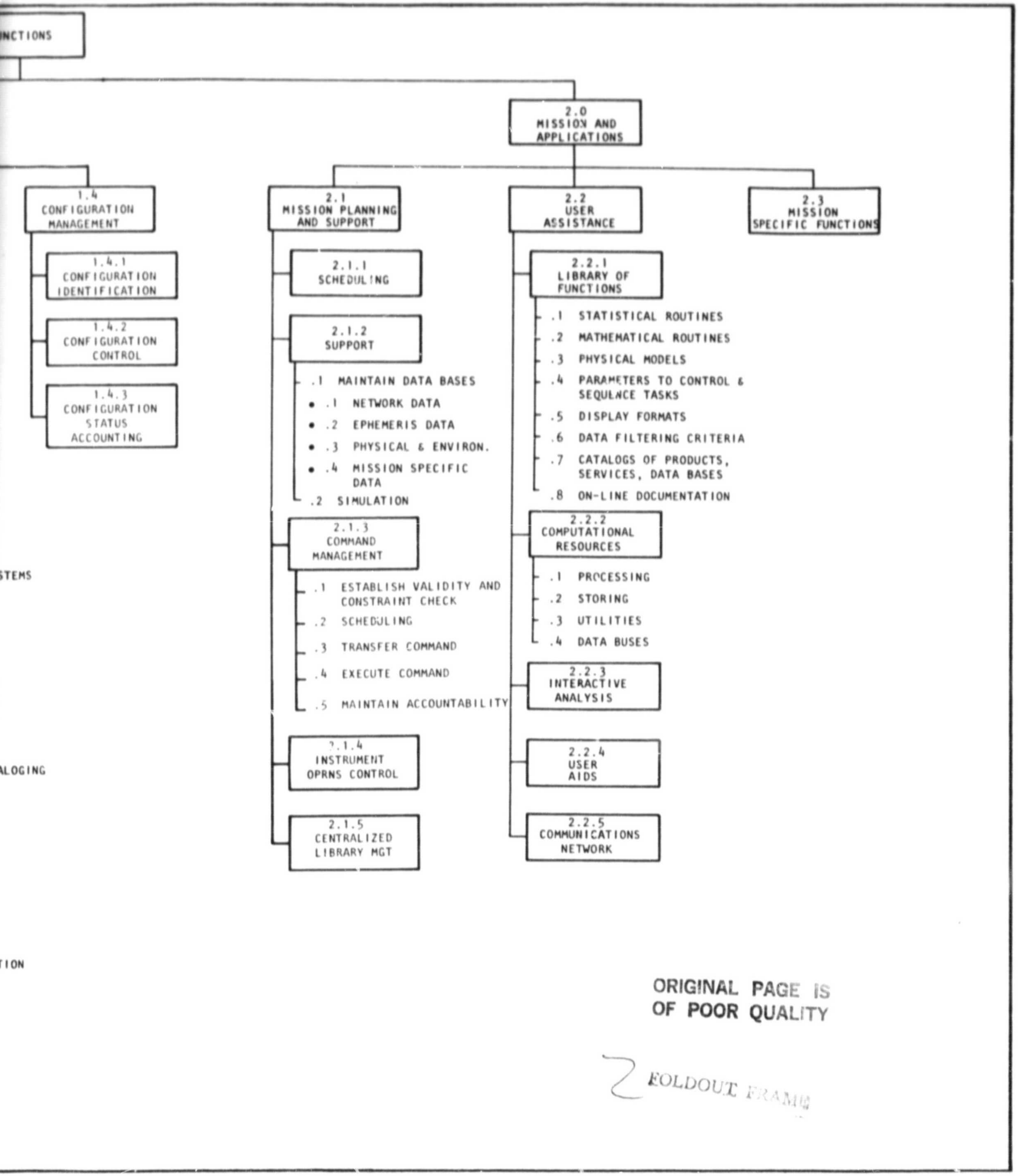
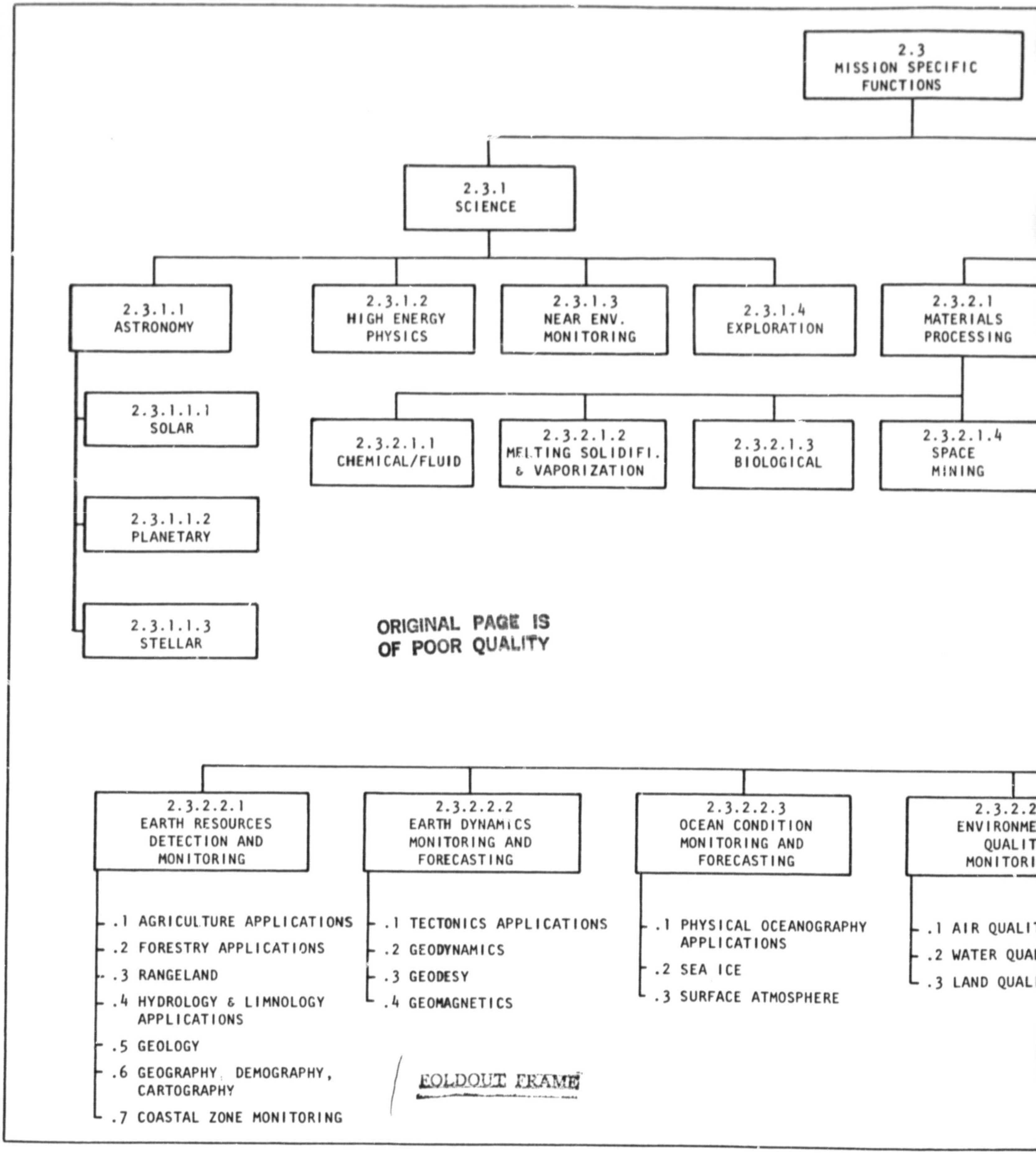


Figure 1-2. Space Station Data System Function Tree


2.3 MISSION SPECIFIC FUNCTIONS
2.3.1 SCIENCE
2.3.1.1 ASTRONOMY
2.3.1.2 HIGH ENERGY PHYSICS
2.3.1.3 NEAR ENV. MONITORING
2.3.1.4 EXPLORATION
2.3.2.1 MATERIALS PROCESSING
2.3.1.1.1 SOLAR
2.3.1.1.2 PLANETARY
2.3.1.1.3 STELLAR
2.3.2.1.1 CHEMICAL/FLUID
2.3.2.1.2 MELTING SOLIDIFI. & VAPORIZATION
2.3.2.1.3 BIOLOGICAL
2.3.2.1.4 SPACE MINING
2.3.2.2.1 EARTH RESOURCES DETECTION AND MONITORING
.1 AGRICULTURE APPLICATIONS
.2 FORESTRY APPLICATIONS
.3 RANGELAND
.4 HYDROLOGY & LIMNOLOGY APPLICATIONS
.5 GEOLOGY
.6 GEOGRAPHY, DEMOGRAPHY, CARTOGRAPHY
.7 COASTAL ZONE MONITORING
2.3.2.2.2 EARTH DYNAMICS MONITORING AND FORECASTING
.1 TECTONICS APPLICATIONS
.2 GEODYNAMICS
.3 GEODESY
.4 GEOMAGNETICS
2.3.2.2.3 OCEAN CONDITION MONITORING AND FORECASTING
.1 PHYSICAL OCEANOGRAPHY APPLICATIONS
.2 SEA ICE
.3 SURFACE ATMOSPHERE
2.3.2.2
ENVIRONME
QUALIT
MONITORI
.1 AIR QUALI
.2 WATER QUA
.3 LAND QUAL

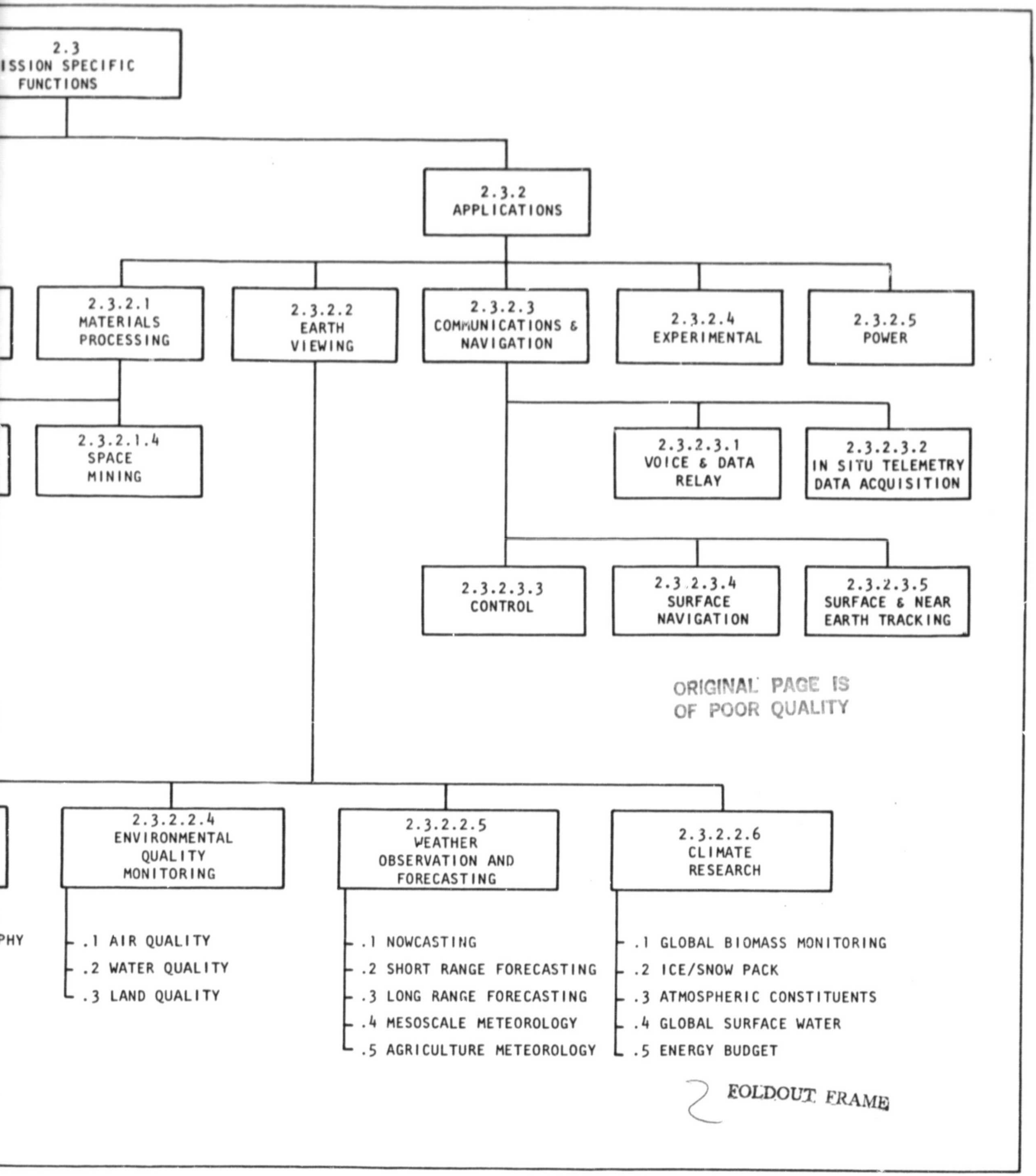


Figure 1-3. Mission Specific Functional Breakdown

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MISSION SPECIFIC FUNCTIONS \ SPACE STATION CAPABILITY	POINTING AT SUN	PRECISION POINTING	TARGET TRACKING	ANTENNAS W/BROAD COVERAGE	COMPLEX POINTING AND CONTROL SYSTEMS	PRECISION LOCATION	ACQUIRE REMOTE TELEMETRY DATA	ACQUIRE DATA FROM SINGLE OR MULTIPLE SIMULTANEOUS SOURCES	UTILIZE FREE-SPACE COMMUNICATION CHANNELS	ACQUIRE LARGE DATA QUANTITIES AT HIGH RATE	UTILIZE LARGE BANDWIDTH COMMUNICATION	CRITICAL ACQUISITION TIMING	CRITICAL PROCESSING RESPONSE TIME	NEAR REAL-TIME UPLINK CONTROL PATHS	EXTRACT INFORMATION FROM COMPLEX MULTIBAND SENSORS			HIGH BANDWIDTH PROCESSING	EXPECT FREQUENT CHANGES IN REQUIREMENTS		MANAGE AND DELIVER SENSOR DATA	DIRECT BROADCAST TO USERS		CRYOGENIC SENSORS	REMOTE CONTROL OTV'S & ROBOTS		MANEUVERABILITY	LONG-TERM STABILITY	PRECISE CONTROL OF SOURCES & ACCELERATION
SOLAR ASTRONOMY	X																		X					X					
PLANETARY ASTRONOMY							X		X																X		X		
STELLAR ASTRONOMY		X				X													X					X			X	X	
HIGH ENERGY PHYSICS		X																							X			X	X
NEAR ENVIRONMENT MONITORING								X																	X				
EXPLORATION							X																		X				
CHEMICAL/FLUID PROCESSING									X				X						X										X
MELTING, SOLIDIFICATION & VAPORIZATION																			X									X	X
BIOLOGICAL PROCESSING																			X										X
SPACE MINING																			X						X				
AGRICULTURE APPLICATIONS								X		X	X	X	X	X	X			X			X	X							
FORESTRY APPLICATIONS								X		X	X		X	X	X			X			X	X							
RANGELAND								X		X	X		X	X	X			X			X	X							
HYDROLOGY & LIMNOLOGY APPLICATIONS							X	X		X			X	X	X			X			X	X							
GEOLOGY										X	X			X	X			X			X	X							
GEOGRAPHY, DEMOGRAPHY, CARTOGRAPHY										X	X							X			X								
COASTAL ZONE MONITORING							X	X		X	X		X		X			X			X	X							
TECTONICS APPLICATIONS						X															X								
GEODYNAMICS							X						X		X			X			X								
GEODESY						X												X			X								

FOLDOUT FRAME

MANAGE AND DELIVER SENSOR DATA	DIRECT BROADCAST TO USERS		CRYOGENIC SENSORS	REMOTE CONTROL OTV'S & ROBOTS		MANEUVERABILITY	LONG-TERM STABILITY	PRECISE CONTROL OF SOURCES & ACCELERATION		SCHEDULING COMMUNICATION RELAYING	SCHEDULING SPECIFIC OPNS, ASSY & CHECKOUT REQUIREMENTS	SUPPORT REMOTELY PLACED EXPERIMENTS	REAL-TIME SCHEDULING & WORK PLANNING	MANAGE COMMANDS & PROCESS DATA W/CRITICAL TIMELINES		PLANETARY MODELS	PHYSICAL MODELS WITH EXTENSIVE COMPUTATION REQMTS	EXTENSIVE ORBIT MODELING	MAINTAIN MODELS		LOGISTICS MGT OF SAMPLES & RESOURCES	PROCESSING OF MATERIALS		MANAGE USER COMMANDS		DATA BASE MANAGEMENT	COLLATERAL DATA STORAGE AND MANIPULATION	UNIQUE DATA BASES WITH ASSOCIATED STORAGE	ON-BOARD INTERACTIONS	MAINTAIN DATA BASES	PROVIDE ACCESS TO DATA BASES	PROVIDE INTERROGATION ACCESS	PROVIDE ACCESS TO REMOTE DATA BASES
			X										X											X					X				
				X		X				X	X	X				X		X						X		X		X	X				X
			X			X	X						X											X		X			X				
				X			X	X					X																X				X
				X													X												X	X	X		
				X																									X				X
								X													X								X				X
							X	X													X	X							X				X
								X													X	X							X				X
				X							X										X	X							X				X
X	X									X			X				X		X					X		X	X		X	X	X	X	X
X	X									X			X	X										X		X			X	X	X	X	X
X	X									X			X											X		X	X		X	X	X	X	X
X	X									X			X	X			X		X					X		X	X		X	X	X	X	X
X	X									X									X					X		X	X		X	X	X		X
X																	X		X							X	X			X	X		X
X	X									X			X	X			X		X					X		X	X		X	X	X	X	X
X																			X							X				X	X		X
X													X	X					X					X		X	X		X	X	X	X	X
X																	X	X	X							X				X	X		X

Figure 1-4. Matrix of Mission Specific Functions

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MISSION SPECIFIC FUNCTIONS / SPACE STATION CAPABILITY	POINTING AT SUN	PRECISION POINTING	TARGET TRACKING	ANTENNAS W/BROAD COVERAGE	COMPLEX POINTING AND CONTROL SYSTEMS	PRECISION LOCATION	ACQUIRE REMOTE TELEMETRY DATA	ACQUIRE DATA FROM SINGLE OR MULTIPLE SIMULTANEOUS SOURCES	UTILIZE FREE-SPACE COMMUNICATION CHANNELS	ACQUIRE LARGE DATA QUANTITIES AT HIGH RATE	UTILIZE LARGE BANDWIDTH COMMUNICATION	CRITICAL ACQUISITION TIMING	CRITICAL PROCESSING RESPONSE TIME	NEAR REAL-TIME UPLINK CONTROL PATHS	EXTRACT INFORMATION FROM COMPLEX MULTIBAND SENSORS			HIGH BANDWIDTH PROCESSING	EXPECT FREQUENT CHANGES IN REQUIREMENTS		MANAGE AND DELIVER SENSOR DATA	DIRECT BROADCAST TO USERS		CRYOGENIC SENSORS	REMOTE CONTROL OTV'S & ROBOTS		MANEUVERABILITY	LONG-TERM STABILITY	PRECISE CONTROL OF SOURCES & ACCELERATION
GEOMAGNETICS																					X								
PHYSICAL OCEANOGRAPHY APPLICATIONS							X	X		X				X	X			X			X	X							
SEA ICE			X				X			X	X			X	X			X			X	X							
SURFACE MONITORING								X		X					X			X			X	X							
AIR QUALITY	X							X						X	X						X	X							
WATER QUALITY							X							X							X	X							
LAND QUALITY										X				X							X	X							
NOWCASTING		X	X	X				X		X	X	X	X	X	X						X	X							
SHORT RANGE FORECASTING								X						X	X						X	X							
LONG RANGE FORECASTING	X							X							X						X	X							
MESOSCALE METEOROLOGY								X		X				X	X						X	X							
AGRICULTURE METEOROLOGY				X			X	X					X	X	X						X	X							
GLOBAL BIOMASS MONITORING								X		X					X			X			X								
ICE/SNOW PACK						X		X		X					X			X			X								
ATMOSPHERIC CONSTITUENTS	X							X							X						X								
GLOBAL SURFACE WATER							X	X							X						X								
ENERGY BUDGET	X																				X								
VOICE & DATA RELAY									X													X							
IN SITU TELEMETRY DATA ACQUISITION				X			X		X												X								
CONTROL REMOTE SYSTEMS				X					X				X	X								X							

FOLDOUT FRAME

MANAGE AND DELIVER SENSOR DATA	DIRECT BROADCAST TO USERS		CRYOGENIC SENSORS	REMOTE CONTROL OTV'S & ROBOTS		MANEUVERABILITY	LONG-TERM STABILITY	PRECISE CONTROL OF SOURCES & ACCELERATION		SCHEDULING COMMUNICATION RELAYING	SCHEDULING SPECIFIC OPNS, ASSY & CHECKOUT REQUIREMENTS	SUPPORT REMOTELY PLACED EXPERIMENTS	REAL-TIME SCHEDULING & WORK PLANNING	MANAGE COMMANDS & PROCESS DATA W/CRITICAL TIMELINES		PLANETARY MODELS	PHYSICAL MODELS WITH EXTENSIVE COMPUTATION REQMTS	EXTENSIVE ORBIT MODELING	MAINTAIN MODELS		LOGISTICS MGT OF SAMPLES & RESOURCES	PROCESSING OF MATERIAL		MANAGE USER COMMANDS		DATA BASE MANAGEMENT	COLLATERAL DATA STORAGE AND MANIPULATION	UNIQUE DATA BASES WITH ASSOCIATED STORAGE	ON-BOARD INTERACTIONS	MAINTAIN DATA BASES	PROVIDE ACCESS TO DATA BASES	PROVIDE INTERROGATION ACCESS	PROVIDE ACCESS TO REMOTE DATA BASES
X																	X		X							X	X	X		X	X		X
X	X									X				X			X		X					X		X	X	X	X	X	X	X	X
X	X									X			X	X					X					X		X		X	X	X		X	X
X	X									X			X	X			X		X					X		X				X	X		X
X	X									X			X	X			X		X					X		X	X	X	X	X		X	X
X	X									X			X	X					X					X		X	X	X	X	X		X	X
X	X									X			X						X					X		X	X	X	X	X		X	X
X	X									X			X	X			X		X					X		X	X	X	X	X		X	X
X	X									X							X		X							X				X	X	X	X
X	X									X							X		X							X				X	X	X	X
X	X									X							X		X					X		X	X			X	X	X	X
X	X									X							X		X					X		X	X			X	X		X
X																			X							X	X		X	X	X		X
X																			X							X				X	X		X
X																	X		X							X			X	X	X		X
X																			X							X	X		X	X	X		X
X																			X											X	X		
	X									X																							
X										X									X							X				X		X	
	X									X			X	X					X					X		X				X	X	X	

Figure 1-4. Matrix of Mission Specific Functions (Continued)

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MISSION SPECIFIC FUNCTIONS \ SPACE STATION CAPABILITY	POINTING AT SUN	PRECISION POINTING	TARGET TRACKING	ANTENNAS W/BROAD COVERAGE	COMPLEX POINTING AND CONTROL SYSTEMS	PRECISION LOCATION	ACQUIRE REMOTE TELEMETRY DATA	ACQUIRE DATA FROM SINGLE OR MULTIPLE SIMULTANEOUS SOURCES	UTILIZE FREE-SPACE COMMUNICATION CHANNELS	ACQUIRE LARGE DATA QUANTITIES AT HIGH RATE	UTILIZE LARGE BANDWIDTH COMMUNICATION	CRITICAL ACQUISITION TIMING	CRITICAL PROCESSING RESPONSE TIME	NEAR REAL-TIME UPLINK CONTROL PATHS	EXTRACT INFORMATION FROM COMPLEX MULTIBAND SENSORS			HIGH BANDWIDTH PROCESSING	EXPECT FREQUENT CHANGES IN REQUIREMENTS		MANAGE AND DELIVER SENSOR DATA	DIRECT BROADCAST TO USERS		CRYOGENIC SENSORS	REMOTE CONTROL OTV'S & ROBOTS		MANEUVERABILITY	LONG-TERM STABILITY	PRECISE CONTROL OF SOURCES & ACCELERATION
SURFACE NAVIGATION			X	X					X					X								X							
SURFACE & NEAR EARTH TRACKING			X	X	X	X	X		X				X	X								X							
EXPERIMENTAL APPLICATIONS	X	X	X	X	X	X	X	X	X	X	X	X		X	X				X		X			X	X		X	X	X
POWER APPLICATIONS	X				X																								

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DIRECT BROADCAST TO USERS		CRYOGENIC SENSORS	REMOTE CONTROL OTV'S & ROBOTS		MANEUVERABILITY	LONG-TERM STABILITY	PRECISE CONTROL OF SOURCES & ACCELERATION		SCHEDULING COMMUNICATION RELAYING	SCHEDULING SPECIFIC OPNS, ASSY & CHECKOUT REQUIREMENTS	SUPPORT REMOTELY PLACED EXPERIMENTS	REAL-TIME SCHEDULING & WORK PLANNING	MANAGE COMMANDS & PROCESS DATA W/CRITICAL TIMELINES		PLANETARY MODELS	PHYSICAL MODELS WITH EXTENSIVE COMPUTATION REQMTS	EXTENSIVE ORBIT MODELING	MAINTAIN MODELS		LOGISTICS MGT OF SAMPLES & RESOURCES	PROCESSING OF MATERIALS		MANAGE USER COMMANDS	'	DATA BASE MANAGEMENT	COLLATERAL DATA STORAGE AND MANIPULATION	UNIQUE DATA BASES WITH ASSOCIATED STORAGE	ON-BOARD INTERACTIONS	MAINTAIN DATA BASES	PROVIDE ACCESS TO DATA BASES	PROVIDE INTERROGATION ACCESS	PROVIDE ACCESS TO REMOTE DATA BASES
X									X																							
X									X				X																			
		X	X		X	X	X		X			X	X					X					X		X	X	X	X	X		X	X

Figure 1-4. Matrix of Mission Specific Functions (Continued)

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Table 1-1. Outline of Space Station Data System Functions

1.0 OPERATIONAL

1.1 OPERATIONS CONTROL

1.1.1 Subsystem Control
- 1.1.1.1 Life Support
- 1.1.1.2 Power
- 1.1.1.3 Attitude
- 1.1.1.4 Collision Avoidance
- 1.1.1.5 Environment Control

1.1.2 Subsystem Performance Analysis
- 1.1.2.1 Life Support
- 1.1.2.2 Power
- 1.1.2.3 Attitude
- 1.1.2.4 Medical
- 1.1.2.5 Environment Control
- 1.1.2.6 Environment Monitor
- 1.1.2.7 Mechanical Strain

1.1.3 Command Management
- 1.1.3.1 Establish Validity
- 1.1.3.2 Scheduling
- 1.1.3.3 Transfer Command
- 1.1.3.4 Execute Command
- 1.1.3.5 Maintain Accountability

1.1.4 Attitude Operations
- 1.1.4.1 Determine Definitive Attitude
- 1.1.4.2 Execute Changes
- 1.1.4.3 Space Station Models

1.1.5 Orbital Operations
- 1.1.5.1 Ephemerides Prediction and Validation
- 1.1.5.2 Orbital Maintenance
- 1.1.5.3 Definitive Determination

1.1.6 Docking Maneuver
- 1.1.6.1 Location
- 1.1.6.2 Assistance

1.2 COMMUNICATIONS

1.2.1 Channel Management
- 1.2.1.1 Selection
- 1.2.1.2 Scheduling
- 1.2.1.3 Monitoring
- 1.2.1.4 Interface Control

1.2.2 Channel Support
- 1.2.2.1 Antenna Pointing
- 1.2.2.2 Formatting
- 1.2.2.3 Buffering

1.2.3 Transmission and Receipt

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Table 1-1. Outline of Space Station Data System Functions (Continued)

1.3 DATA MANAGEMENT

1.3.1 Generics
- 1.3.1.1 Acquisition
- 1.3.1.2 Capture
- 1.3.1.3 Processing
- 1.3.1.4 Archiving
- 1.3.1.5 Data Delivery

1.3.2 Operations
- 1.3.2.1 Subsystem Status
- 1.3.2.2 Equipment Configuration Monitor and Control
- 1.3.2.3 Command Execution and Verification
- 1.3.2.4 Computer Operations Support of all Subsystems

1.3.3 Crew
- 1.3.3.1 Health
- 1.3.3.2 Duty Schedules
- 1.3.3.3 Skills
- 1.3.3.4 Entertainment
- 1.3.3.5 Personal Recreation
- 1.3.3.6 Library Storage, Cataloging
- 1.3.3.7 Training

1.3.4 Logistics
- 1.3.4.1 Consumables
- 1.3.4.2 Supplies
- 1.3.4.3 Spare Parts
- 1.3.4.4 Resupply Scheduling
- 1.3.4.5 Entertainment/Recreation Supplies
- 1.3.4.6 Crew Skills

1.4 CONFIGURATION MANAGEMENT

1.4.1 Configuration Identification

1.4.2 Configuration Control

1.4.3 Configuration Status Accounting

2.0 MISSION AND APPLICATIONS

2.1 MISSION PLANNING AND SUPPORT

2.1.1 Scheduling

2.1.2 Support
- 2.1.2.1 Maintain Data Bases
  - 2.1.2.1.1 Maintain Data Base of Network Data
  - 2.1.2.1.2 Maintain Data Base of Ephemeris Data
  - 2.1.2.1.3 Maintain Data Base of Physical and Environmental Constants
  - 2.1.2.1.4 Maintain Data Base of Mission Specific Data
- 2.1.2.2 Simulation

Table 1-1. Outline of Space Station Data System Functions (Continued)

2.1.3 Command Management
- 2.1.3.1 Establish Validity and Constraint Check
- 2.1.3.2 Scheduling
- 2.1.3.3 Transfer Command
- 2.1.3.4 Execute Command
- 2.1.3.5 Maintain Accountability

2.1.4 Instrument Operations Control

2.1.5 Centralized Library Management

2.2 USER ASSISTANCE

2.2.1 Library of Functions
- 2.2.1.1 Maintain Library of Statistical Routines
- 2.2.1.2 Maintain Library of Mathematical Routines
- 2.2.1.3 Maintain Library of Physical Models
- 2.2.1.4 Maintain Library of Parameters
- 2.2.1.5 Maintain Libraries of Display Formats
- 2.2.1.6 Maintain Libraries of Data Filtering Criteria
- 2.2.1.7 Maintain Library of Catalogs of On-Line Products, Services and Data Bases
- 2.2.1.8 Maintain a Library of On-Line Documentation

2.2.2 Computational Resources
- 2.2.2.1 Processing
- 2.2.2.2 Storing
- 2.2.2.3 Utilities
- 2.2.2.4 Data Bases

2.2.3 Interactive Analysis

2.2.4 User Aids

2.2.5 Communications Network

2.3 MISSION SPECIFIC FUNCTIONS

2.3.1 Science Missions
- 2.3.1.1 Astronomy
  - 2.3.1.1.1 Solar Astronomy
  - 2.3.1.1.2 Planetary Astronomy
  - 2.3.1.1.3 Stellar Astronomy
- 2.3.1.2 High Energy Physics
- 2.3.1.3 Near Environment Monitoring
- 2.3.1.4 Exploration

2.3.2 Applications
- 2.3.2.1 Materials Processing
  - 2.3.2.1.1 Chemical and Fluid Processing
  - 2.3.2.1.2 Melting, Solidification, and Vaporization
  - 2.3.2.1.3 Biological Processing
  - 2.3.2.1.4 Space Mining
- 2.3.2.2 Earth Viewing Applications

Table 1-1. Outline of Space Station Data System Functions (Continued)

2.3.2.2.1 Earth Resources Detection and Monitoring
- 2.3.2.2.1.1 Agriculture Applications
- 2.3.2.2.1.2 Forestry Applications
- 2.3.2.2.1.3 Rangeland Applications
- 2.3.2.2.1.4 Hydrology and Limnology Applications
- 2.3.2.2.1.5 Geology
- 2.3.2.2.1.6 Geography, Demography, and Cartography
- 2.3.2.2.1.7 Coastal Zone Monitoring

2.3.2.2.2 Earth Dynamics Monitoring and Forecasting
- 2.3.2.2.2.1 Tectonics Applications
- 2.3.2.2.2.2 Geodynamics Applications
- 2.3.2.2.2.3 Geodesy
- 2.3.2.2.2.4 Geomagnetics

2.3.2.2.3 Ocean Condition Monitoring and Forecasting
- 2.3.2.2.3.1 Physical Oceanography Applications
- 2.3.2.2.3.2 Sea Ice
- 2.3.2.2.3.3 Surface Atmosphere

2.3.2.2.4 Environmental Quality Monitoring
- 2.3.2.2.4.1 Air Quality Monitoring
- 2.3.2.2.4.2 Water Quality Monitoring
- 2.3.2.2.4.3 Land Quality Monitoring

2.3.2.2.5 Weather Observation and Forecasting
- 2.3.2.2.5.1 Nowcasting Applications
- 2.3.2.2.5.2 Short Range Forecasting
- 2.3.2.2.5.3 Long Range Forecasting
- 2.3.2.2.5.4 Mesoscale Meteorology
- 2.3.2.2.5.5 Agriculture Meteorology

2.3.2.2.6 Climate Research
- 2.3.2.2.6.1 Global Biomass Monitoring
- 2.3.2.2.6.2 Ice and Snow Pack
- 2.3.2.2.6.3 Atmospheric Constituents
- 2.3.2.2.6.4 Global Surface Water
- 2.3.2.2.6.5 Energy Budget

2.3.2.3 Communication and Navigation
- 2.3.2.3.1 Voice and Data Relay Applications
- 2.3.2.3.2 In Situ Telemetry Data Acquisition
- 2.3.2.3.3 Control Applications
- 2.3.2.3.4 Surface Navigation
- 2.3.2.3.5 Surface and Near Earth Tracking

2.3.2.4 Experimental Applications

2.3.2.5 Power Applications

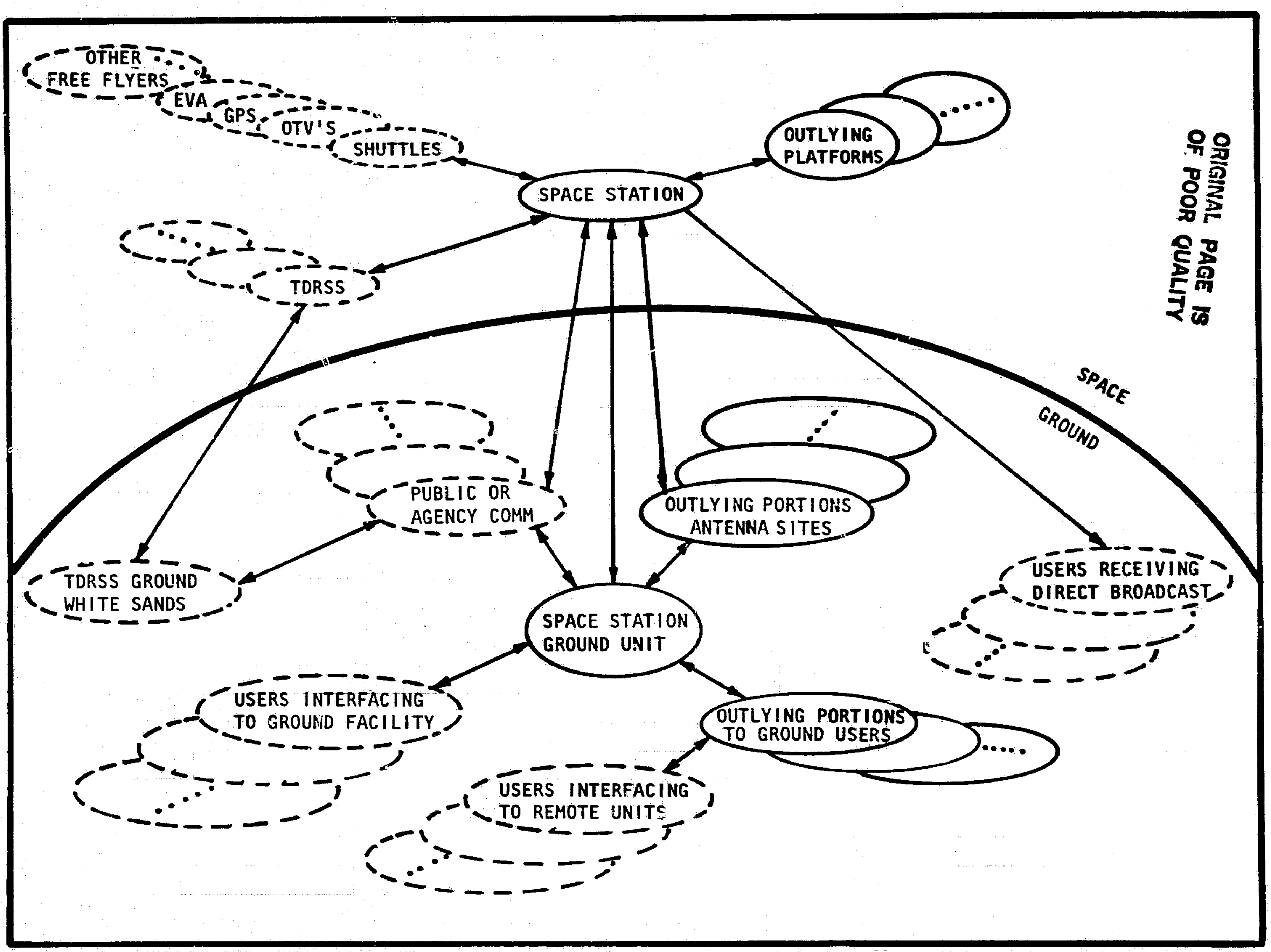

Figure 1-5. Conceptual Relationship of Space Station Data System Components

in that same document provide the framework for specific implementations. As a background to the discussion of things new and different, some major deviations from the traditional data systems are introduced.

1.5 DEVIATIONS FROM THE TRADITIONAL

The indefinite lifetime, manned presence, maturing applications, increasing technology performance, relaxation of power, size, and weight constraints, and a realistic consciousness of operating costs all drive considerations of deviations from traditional ground-base controlled data systems to future space-based systems. Some of these potential deviations are:

- The space-based system is the controlling element and the ground portion of the system is a slave component to the space-based portion.
- Data base management becomes primarily an on-board rather than a ground function.
- Command management becomes primarily an on-board function.
- Definitive orbit determination is either performed or made available on-board.
- On-board collision damage avoidance becomes necessary.
- A shift in emphasis from reliability to availability is required.
- On-board software changes will be permitted.
- There will be some on-board quick-look data analysis.
- Data will be directly broadcast to users.

Conceptual alternatives for implementing these deviations in varying degrees are addressed in this report. Even though some functions are distributed between the space and ground, the mere capability to perform them at all on-board the spacecraft, even if for a limited time in a contingency mode, is a significant departure from tradition worthy of examination.

1.5.1 SLAVE THE GROUND TO THE SPACECRAFT

This represents a change in philosophy from the traditional ground controlled data system hierarchy. It follows from a desire and necessity to provide autonomous operation of the manned Space Station with minimum dependency on

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the ground functions. This desire, when tempered with the reality that it is cheaper to perform some functions on the ground, results in providing the Space Station with the capability to remotely control some of the ground resources. This is particularly true of some data bases, their manipulation and data retrieval, and support functions. Several trade-off candidates result from the partitioning of data storage between the ground and the Space Station.

1.5.2 ON-BOARD DATA MANAGEMENT AND ACCOUNTING

This concept places the major responsibility and the need for knowledge of the data base on-board the Space Station. This applies to both the data needed for operations (e.g., predictive ephemerides for communication scheduling) and the applications data (e.g., acquisition status of earth images). In this concept, the Station would be given the responsibility for generating specific data such as location, bands, quality, and time constraints. It would be the responsibility of the Station to plan the acquisition, select the instruments, process the data, assess data quality, and to optimize the use of its resources to obtain the desired data quality. Cloud conditions, demands of other users, and on-board resource limitations would enter into the work planning strategy.

Some physical data storage in this concept could be located off the Station since ancillary data might be better suited to acquisition and storage on the ground. Yet, in both concepts, the bulk of the data management would reside on-board. The Station should have the capability to access the remote data bases for needed data and to initiate requests or commands for additional ground data acquisition.

1.5.3 ON-BOARD COMMAND MANAGEMENT

This refers to command management in the broadest sense of the word and is intended to include such functions as safety and preservation of the Station. Consequently, the coordination of commands from users, interactive analysts, crew members, and various automatic systems would be vested on-board. In the traditional concept, the coordination is preplanned by teams of personnel. The expected complexity of the Space Station prohibits the preplanning of all contingency conditions and necessitates autonomy and smart computer assistance. In the interest of autonomy, the responsibility must reside on-board. Off-station assistance may be most effective within the concept of slaving the ground to the Station.

1.5.4 ON-BOARD DEFINITIVE ORBIT DETERMINATION

The complexity of data acquisition sources and the need to streamline applications data management is a strong driver toward self-documenting data sets. The Global Positioning Satellite (GPS) system (GE 3) is based upon on-board navigation. To completely realize the advantages of these approaches, it is essential to determine the precise location of the Space Station and other satellites or platforms. Some of the problems and approaches to determining definitive orbit and making it available on-board have been documented in previous studies (Graf 1, Graf 2). To be autonomous, these functions must either be on-board or be performed as slave functions to the on-board system.

1.5.5 ON-BOARD COLLISION DAMAGE AVOIDANCE

The large cross sectional area and the indefinite lifetime of the Space Station will greatly increase the potential of damage from collision with satellites, meteorites, and particularly space debris (IEEE 2). The nature of the Space Station may make it more cost effective, and certainly safer for its inhabitants, to employ sophisticated subsystems to reduce the probability of collision and to avoid ensuing damage. The primary concern is to avoid collision with the small, out of orbital plane debris which are not tracked by NORAD or other such tracking systems and whose data is not available in existing bases. The techniques employed to sense collision courses, maneuver the station to change orbital plane to avoid collision, to change attitude to minimize damage and protect critical subsystems, or the countermeasures required to destroy with lasers or to sweep up the debris with remote vehicles, do not fall under the auspices of the data system. However, the data system should have the capability to receive pertinent collision data, process the data to determine course of action, (to maneuver, shut down critical operations, et cetera) and provide warning and safing information to the crew and subsystems.

1.5.6 SHIFT IN EMPHASIS FROM RELIABILITY TO AVAILABILITY

The long term, manned presence in space calls for a change in the data system operational philosophy. It is no longer necessary, practical or cost effective to operate for years without a failure being evident to the crew. With a shift from real time fault tolerance toward availability, the operational functions need to be classified according to criticality properties. Those are 1) the length of time the functions can be suspended, 2) which functions must fail operational, and 3) which functions may fail safe. Then, fault detection, isolation, and repair assistance become important. In this environment, it may be better to have controlled failures and a well planned maintenance program than to burden the system with multiple redundancies that mask failures and automatically replace failed units in a real time mode such that the exact system state cannot be determined.

1.5.7 ON-BOARD SOFTWARE UPDATE

The long term, manned presence and changing mission mix will require changes in system configuration, both hardware and software. The mode of operation during these changes must still be determined. It is expected that they generally will be accomplished while the remainder of the system continues to function. This represents a marked change in spacecraft philosophy and requires special planning during the early design phases.

1.5.8 ON-BOARD DATA ANALYSIS

The Space Station with its complement of sensors and personnel will be an information acquisition facility. Implicit with the near real time work planning and processing selection is the need to obtain feedback about the information being acquired. This dictates the requirement for on-board data analysis in a quick-look mode. This would require an emphasis on flexibility and data base access. Performance requirements will be driven by overall response time. The sizing of the system to provide this on-board analysis capability need not be so large as to replace the ground system for normal operational processing. However, this is an option for future trade-off analysis should the resulting data reduction and communication requirements significantly reduce life cycle cost.

1.5.9 DIRECT BROADCAST TO USERS

The characteristics of the Space Station acquired data and the acquisition process favor direct communication to users under certain conditions. The Space Station will effectively remove some of the constraints such as power and weight that are currently limiting data acquisition volumes. Thus, orders-of-magnitude increases in data volume and concomitant communication bandwidth requirements may be expected. Additional investment in system complexity to achieve this added bandwidth will be justifiable on a case-by-case basis. In this environment, overall system optimization tends toward not upgrading the total communication system (relay satellite, communication ground acquisition station, et cetera) but only for the link segments required. The Space Station will also be a more heterogeneous source of data products with its capability to have in-place, although not necessarily operating simultaneously, a large variety of experiments and sensors. Again overall system optimization favors a restricted case-by-case approach to the driving communication requirements. Direct communication to users is a viable approach because in many cases the acquired data is of interest only to users in the coverage area where direct communication is possible. This eliminates the need for relay satellites for those high bandwidth communication applications.

SECTION 2
CONCEPTS

The notion of a data system concept carries a multitude of connotations. The person expecting a concept to be complete from end-to-end with all incompatibilities resolved can be disappointed when the concept involves only a single aspect of implementation. On the other hand, most trade-off analyses involve pieces of the whole. Within the context of this study both extremes of concept definition were used. The abstract concepts include the end-to-end system but only at a high level. From these abstractions came the more defined data system concepts. Both the concepts of abstraction and instantiation will be expanded upon in this section.

2.1 DATA DEPENDENCY DIAGRAMS

As a means of functionally partitioning the data system, the data products of each function were identified and described. The description included their structure, size and make-up, their source, and their use. From these descriptions, data dependency diagrams such as Figure 2-1 were devised. These diagrams in turn indicate which functions can be performed in parallel, which functions should logically be co-located, and the data transfer capability required between functions.

2.2 CONCEPTS OF ABSTRACTION

Just as issues arise over the practicality and implementation of data system concepts, other concepts arise because of issues. Figure 2-2 illustrates the first level of concepts and how they were driven by the issues.

2.2.1 HIERARCHICAL CONTROL

The concept of hierarchical control is fundamental to addressing the issue of autonomy. It can also be supportive of the architectural issues. This concept is illustrated in Figure 2-3.

The significance of this concept is that commands across boundaries provide a description of what is needed to be accomplished and the return information is a verification of accomplishment. Theoretically, once a command is received, the interface could be severed and the objective would still be accomplished.

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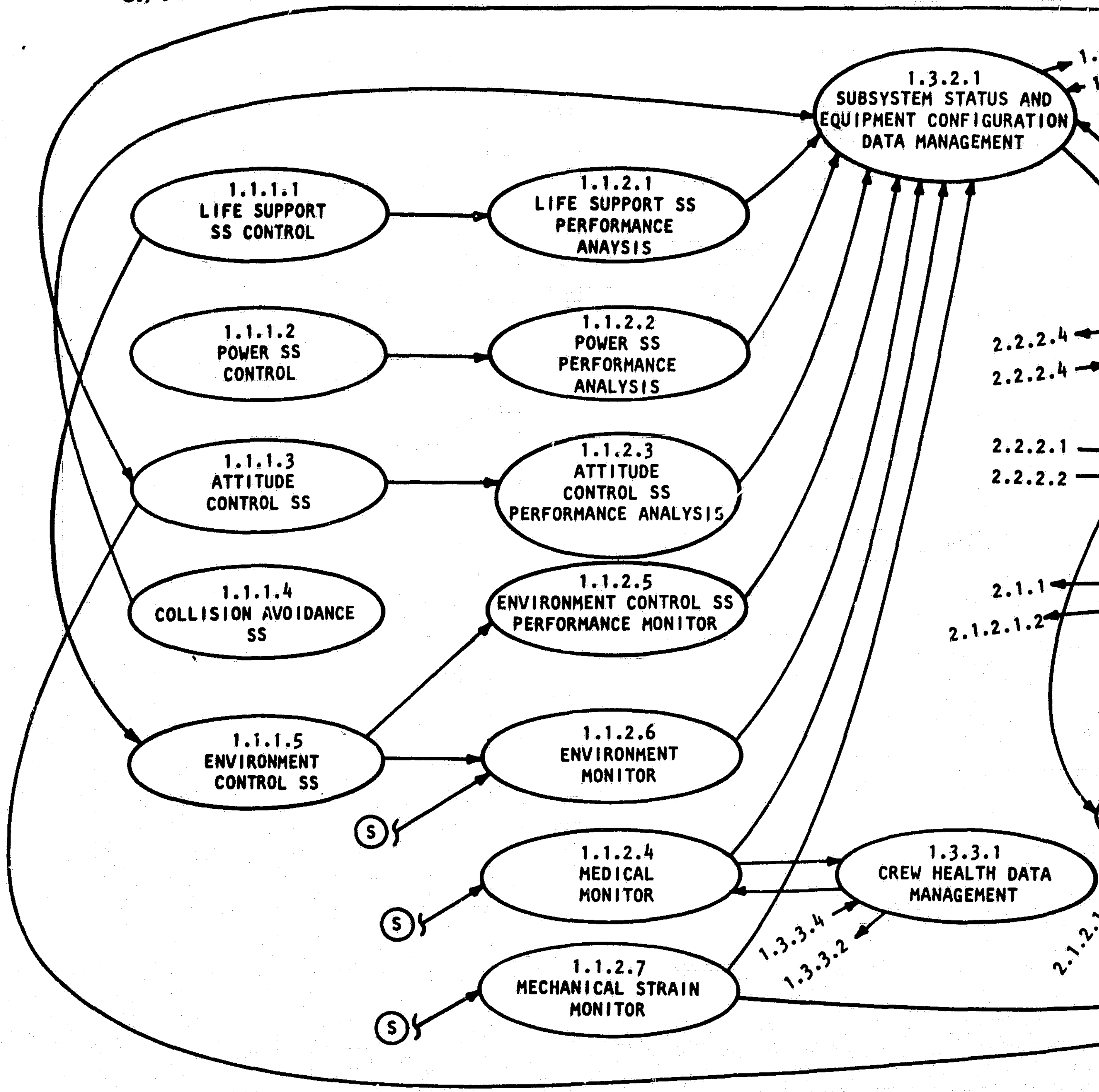

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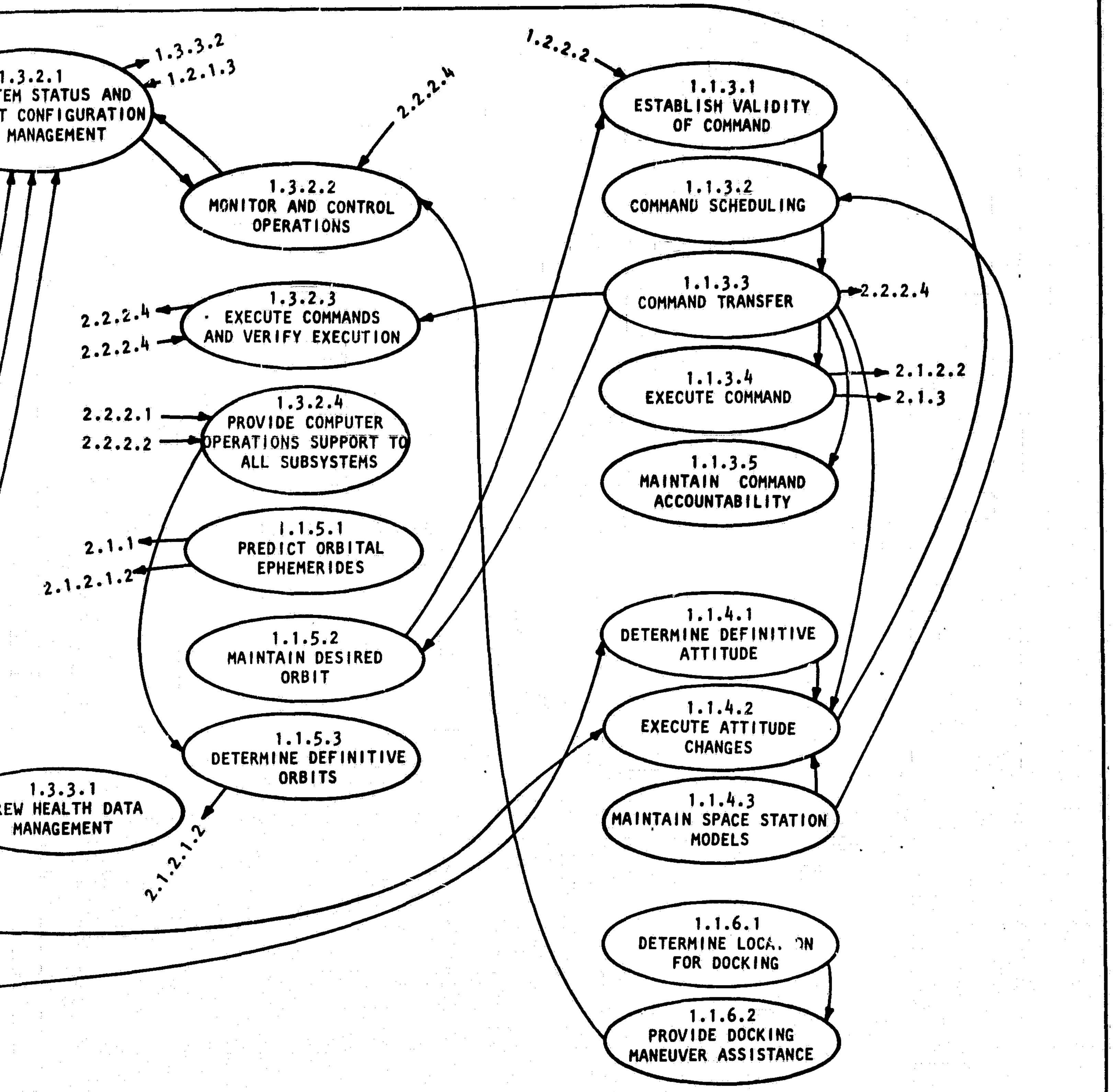

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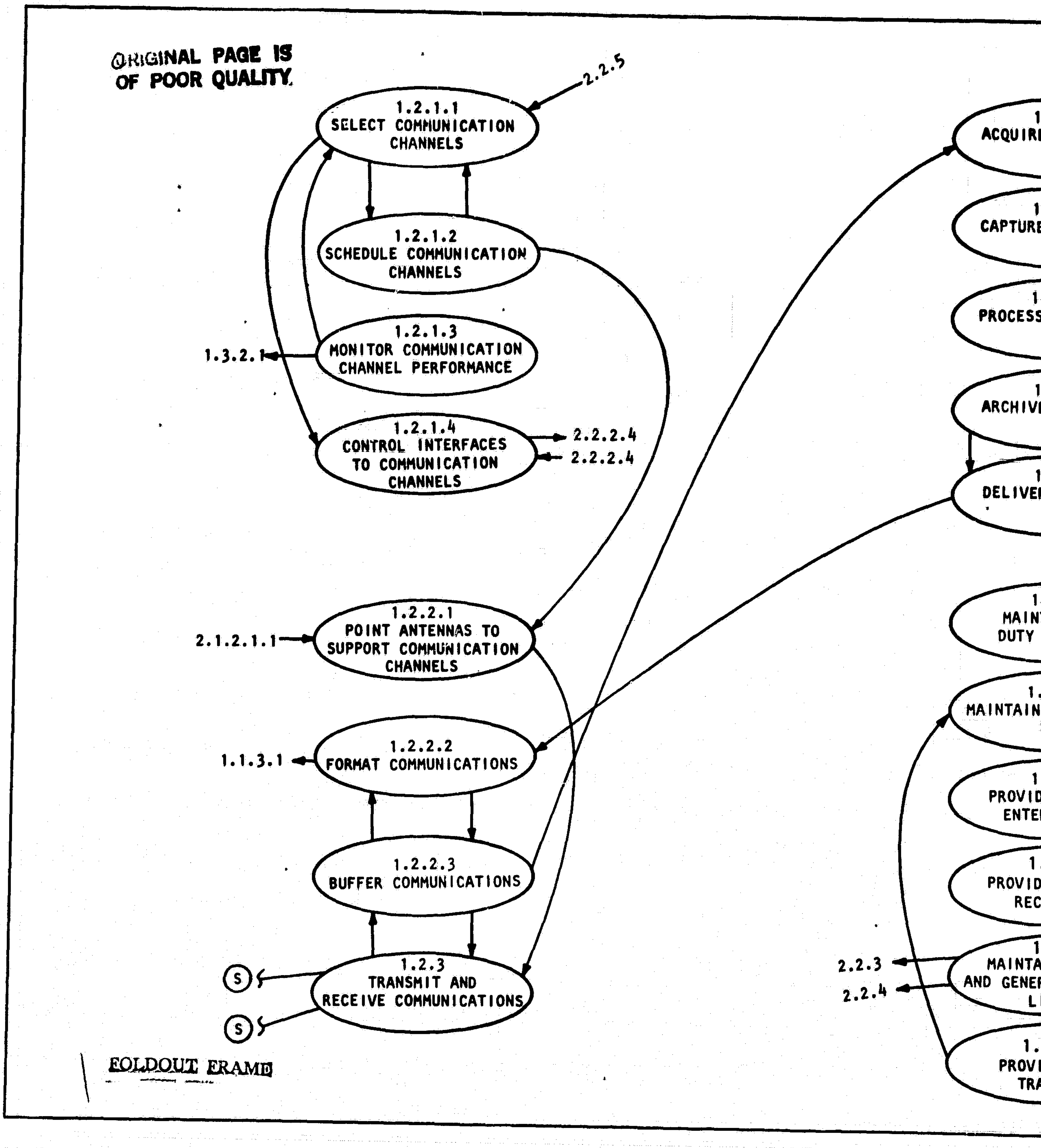
Figure 2-1. Data Dependency Diagram


2.2.5
1.2.1.1
SELECT COMMUNICATION
CHANNELS
1.2.1.2
SCHEDULE COMMUNICATION
CHANNELS
1.2.1.3
MONITOR COMMUNICATION
CHANNEL PERFORMANCE
1.3.2.1
1.2.1.4
CONTROL INTERFACES
TO COMMUNICATION
CHANNELS
2.2.2.4
2.2.2.4
1.2.2.1
POINT ANTENNAS TO
SUPPORT COMMUNICATION
CHANNELS
2.1.2.1.1
1.2.2.2
FORMAT COMMUNICATIONS
1.1.3.1
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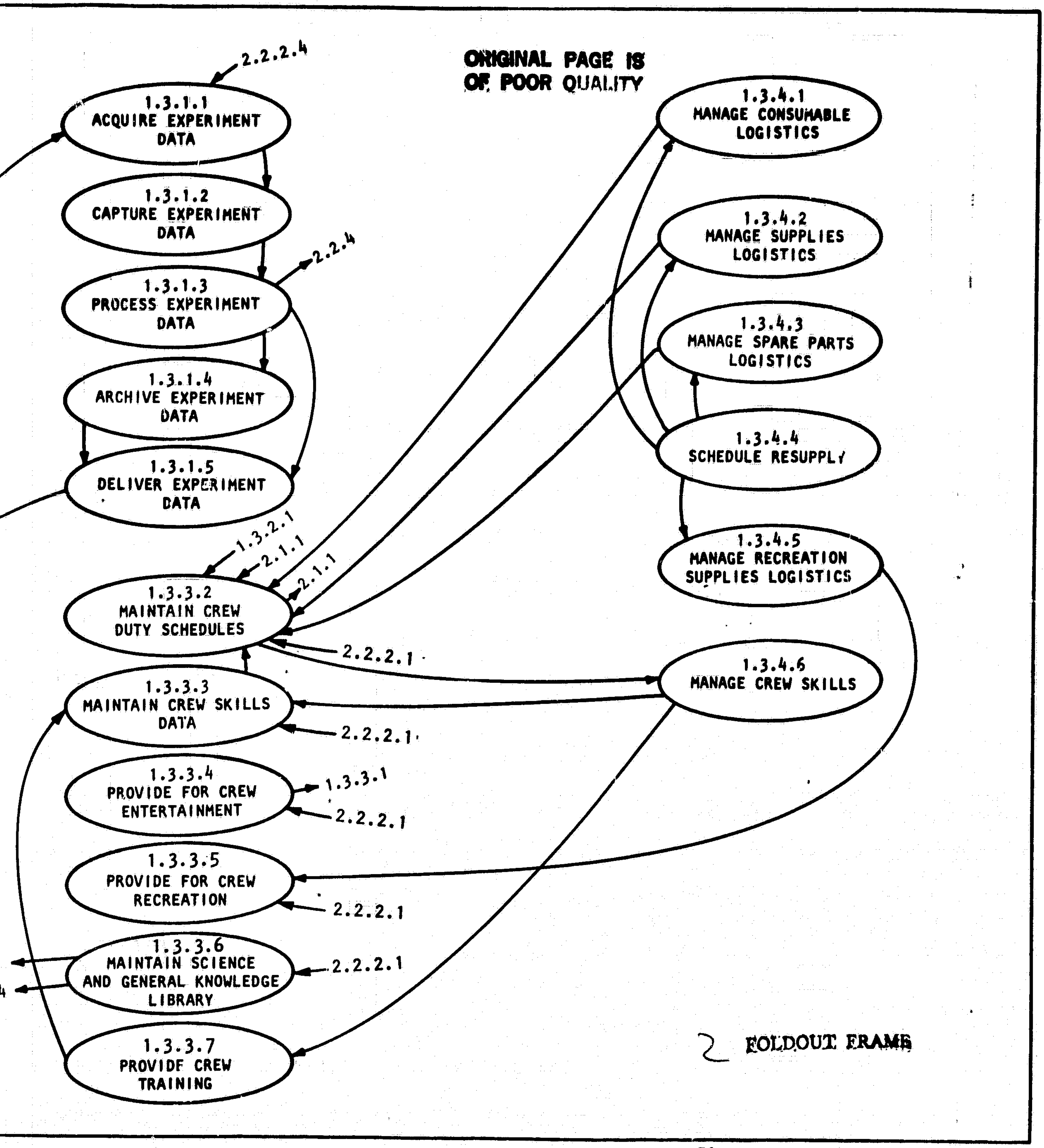

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Figure 2-1. Data Dependency Diagram (Continued)

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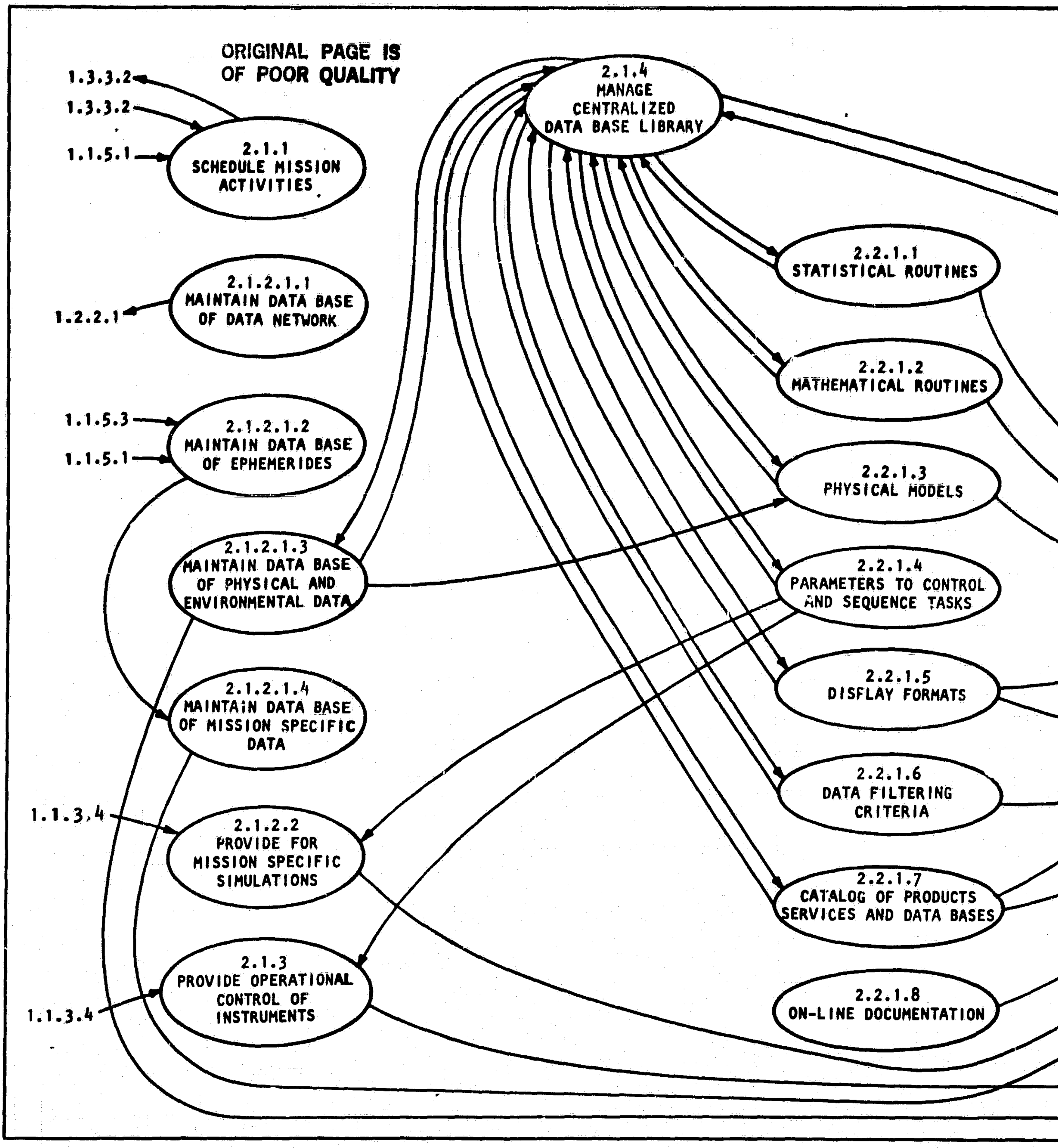

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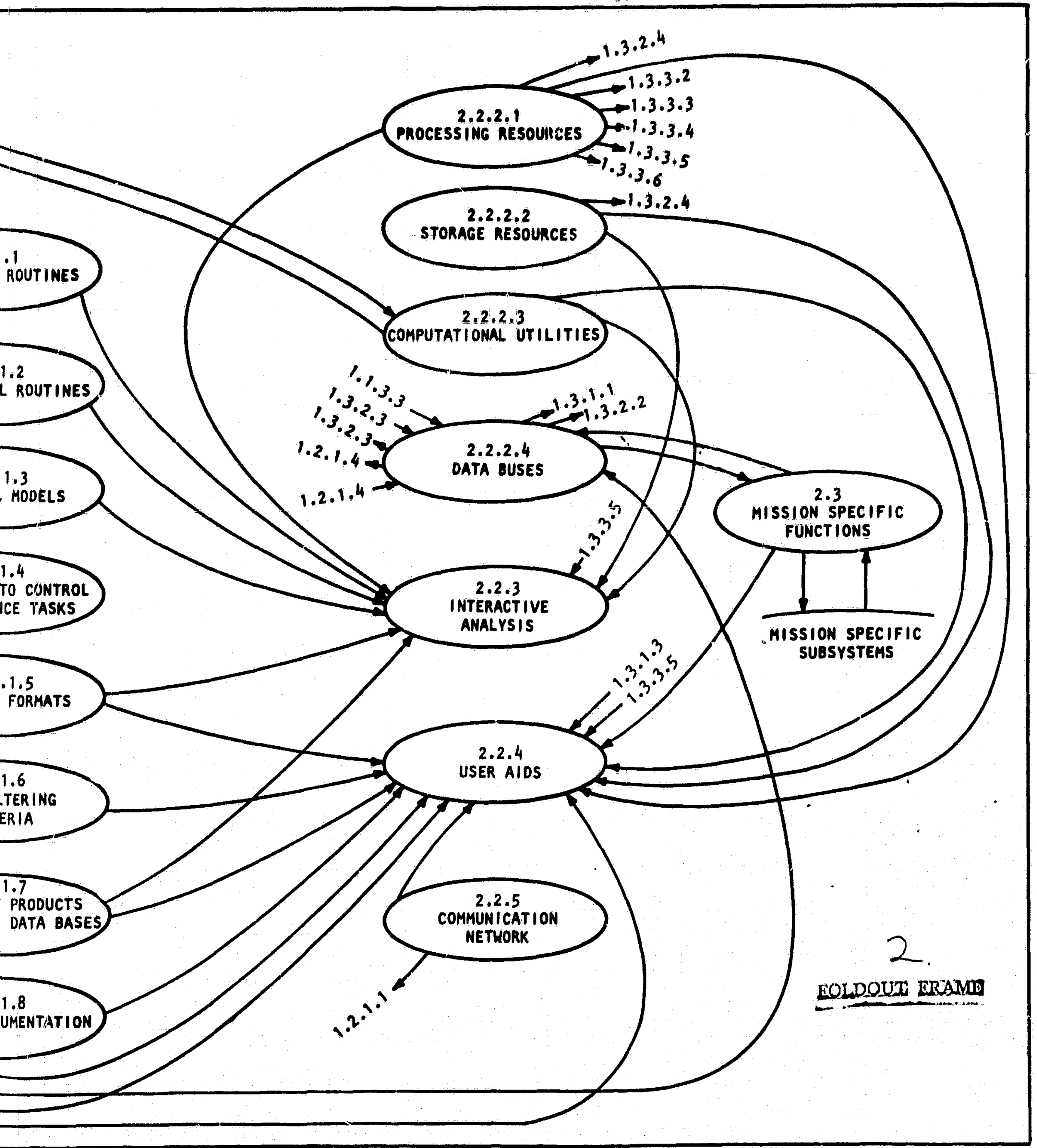

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Figure 2-1. Data Dependency Diagram (Continued)

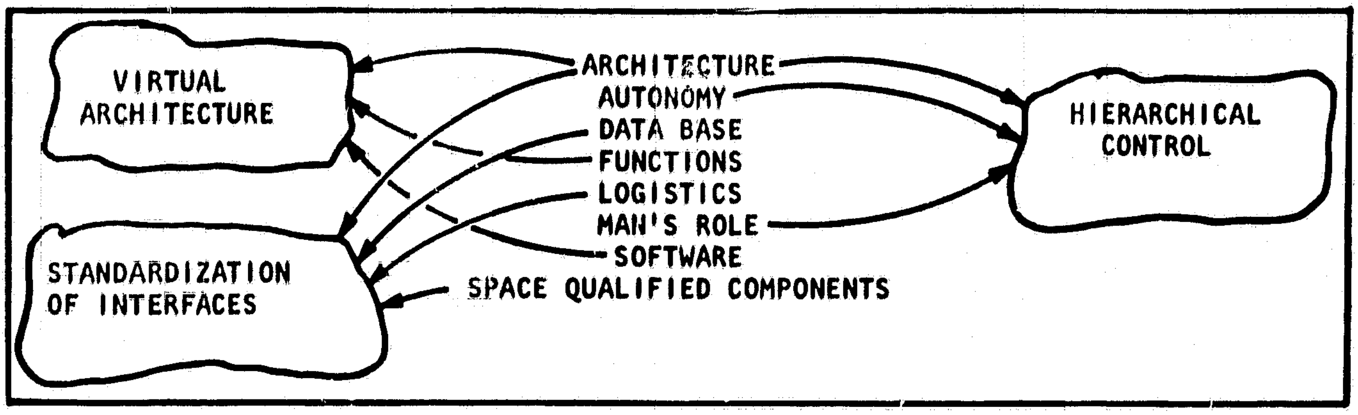


Figure 2-2. First Level of Concepts Driven by Topics

Intelligence, which implies computational resources and data sets, is distributed at the lower levels. This will allow incremental growth with minimum system level impact. It improves survivability by incorporating a degree of internal reconfiguration at the intermediate levels. The failure of a verification signal can be used to trigger the reassignment of the functional command to another unit.

The role of man in this concept can vary according to the approach to autonomy. For some completely automated functions that can continue without manned intervention, man will be interjected at a subsystem level. In this role, man is an information source. The information is combined with other information for the automatic operation of the system. For some functions, the system could operate even when the inputs from man were lacking.

2.2.2 VIRTUAL ARCHITECTURE

The concept of virtual architecture is illustrated in Figure 2-4. This concept incorporates layering. Each layer of integration, when successfully performed, is the gateway to the next layer. With such a protection scheme the impact of a design flaw in the new capability, or a flaw resulting from its interaction with the on-line system will be minimized. The "layering" from an integration viewpoint should cause a "staged activation" of the new function. Intermodule communications and data flows will be across specific boundaries.

A clear partitioning between operational functions and mission functions is indicated. This is justified on the presumed greater availability and fail operational requirements for operational functions. Redundancy and cautious

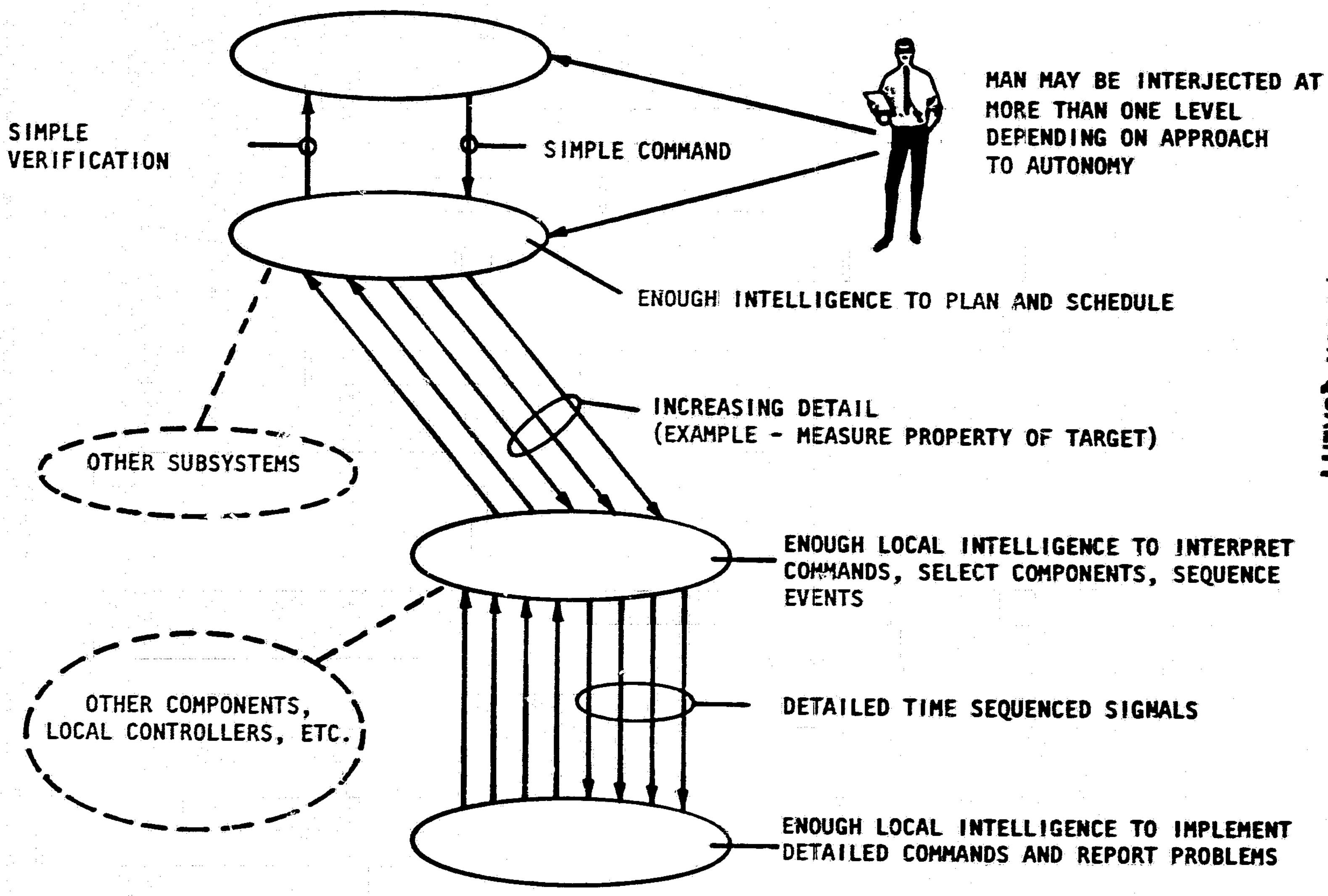


Figure 2-5. Concept of Hierarchical Control

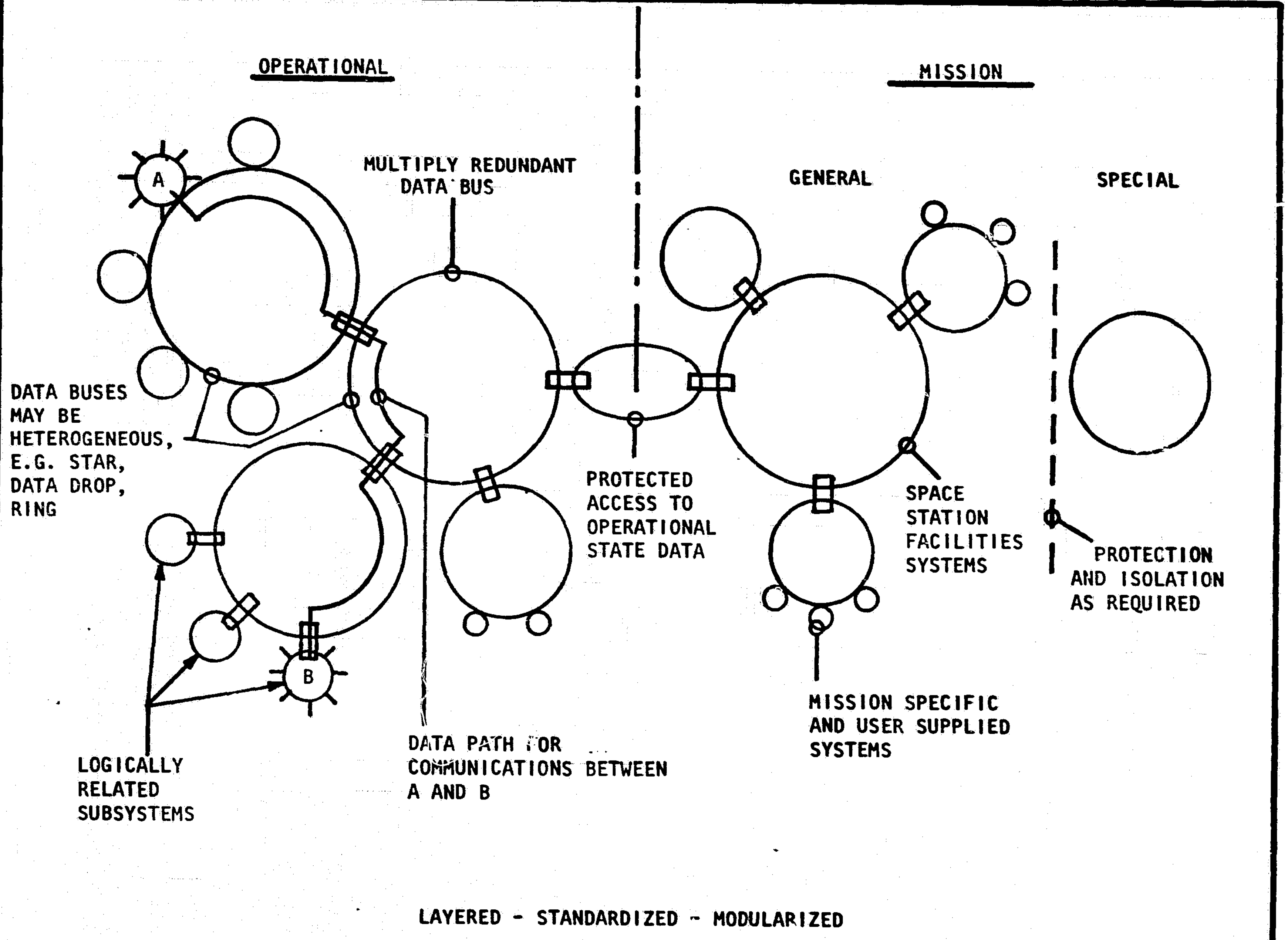


Figure 2-4. Concept of Virtual Architecture

implementation of modifications will be drivers for the operational systems. The mission systems will be more subject to change and trade-offs of fail operational to fail safe modes against an environment of cost and functionality considerations.

A significant assumption in this concept is that the mission applications systems and their users will have total access to all data defining the operational state of the Space Station. This can be accomplished with a layered architecture and yet maintain absolute isolation of effects in the mission systems from adversely impacting the integrity of the operational systems.

The mission systems are shown with a common communication path although that is not inherent in the concept. As systems would be remotely deployed (e.g., on outlying platforms) separate interconnecting layers would be implemented.

Those mission functions that have a high degree of commonality across missions would be included as part of the Space Station data system facility. Processors, storage, human interfaces, and general use data sets are in this category.

If some missions require complete isolation, as do some of the military missions, completely separate components could be accommodated. These would be the responsibility of the mission users.

2.2.3 STANDARD INTERFACE

The concept of standardization of interfaces follows as an adjunct to implementing the layered, virtual architecture. This concept is illustrated in Figure 2-5. Implicit in this concept is standardized formats. If this can be carried through the entire data system implementation, future flexibility will be enhanced.

A set of standard interfaces will permit a selection of data paths tailored to the functional needs. Parallel and serial interfaces of a number of data rates and bus width categories are desired. The definition of standards will

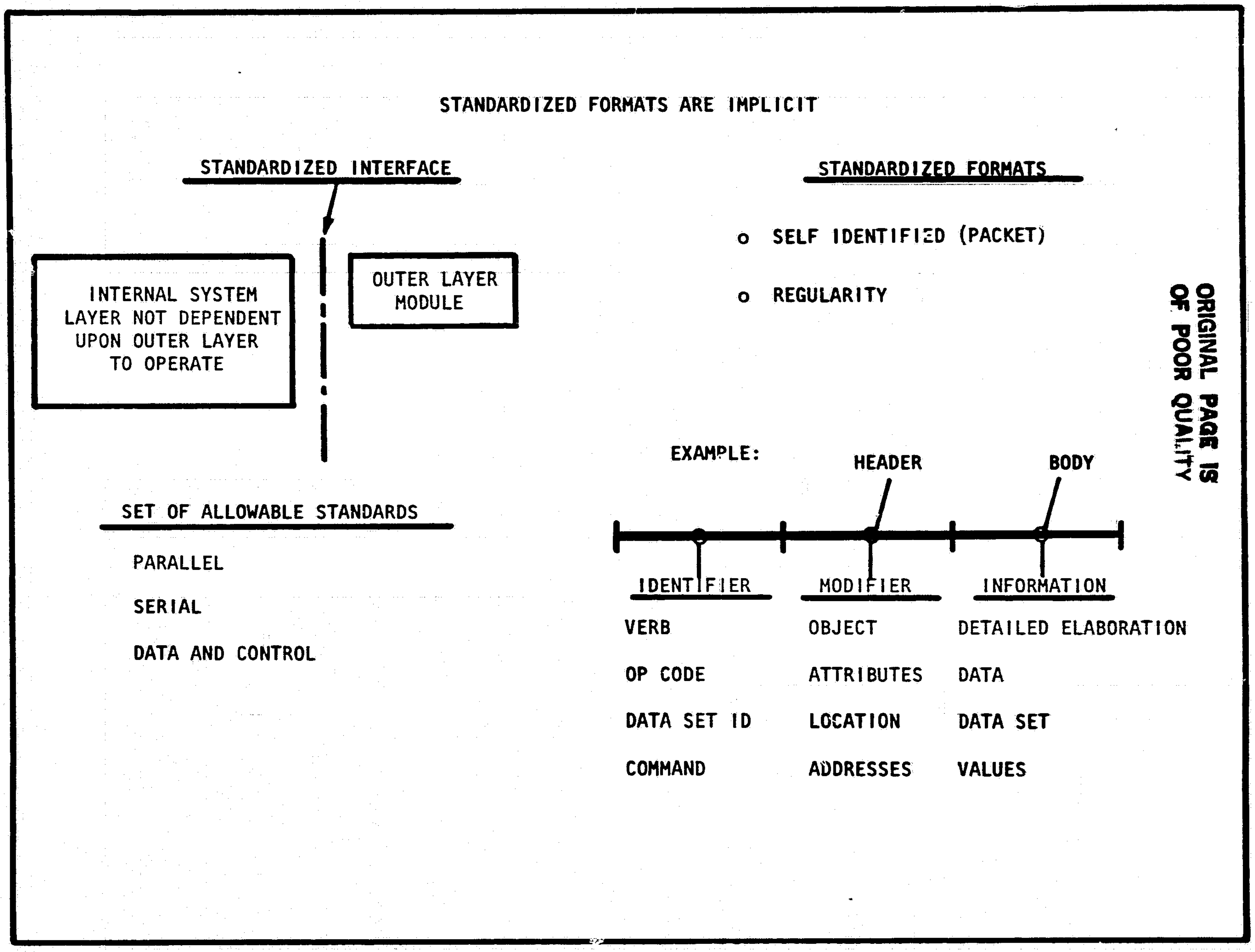


Figure 2-5. Concept of Standardization of Interfaces

allow parallel subsystem development and future improvement without impacting the overall system.

The standardized formats will apply to signals and data. Some precedents are being established in the communications field with packetized messages, whether data or commands. This concept is consistent with the notion of self documented data sets. In a parallel control interface environment, the identifiers would be the control code lines. The length of the messages or data width can be variable according to the established rules or as identified in the header.

The underlying objective of this concept is to assure that every interface is adequately defined so that the correct function of the system is independent of a system module having predetermined information about the presence of specific modules.

2.2.4 ALTERNATE CONCEPTS OF AUTONOMY

Two concepts of autonomy that have major differences in the placement of burden are illustrated in Figure 2-6. Autonomous operation can include the Space Station ground facilities. In the one concept, complete capability for mission operations exists in space. The obvious penalty is the need for additional functions, equipment, and personnel on the Space Station. The corollary benefit is a reduced space to ground communication channel requirement.

The alternate concept has an implicit interaction with the ground facility. Computed values would be uplinked and intermediate data products would flow in both directions.

2.3 CONCEPTS OF INSTANTIATION

A basic overall system configuration and concept which can be used to implement the two categories of functions is depicted in Figure 2-7. It consists of separate data buses and computational systems for each class function with some shared memory storage. It is envisioned that the operations computer system would have full control over the shared storage, i.e., both read and write capability; while the mission computational system

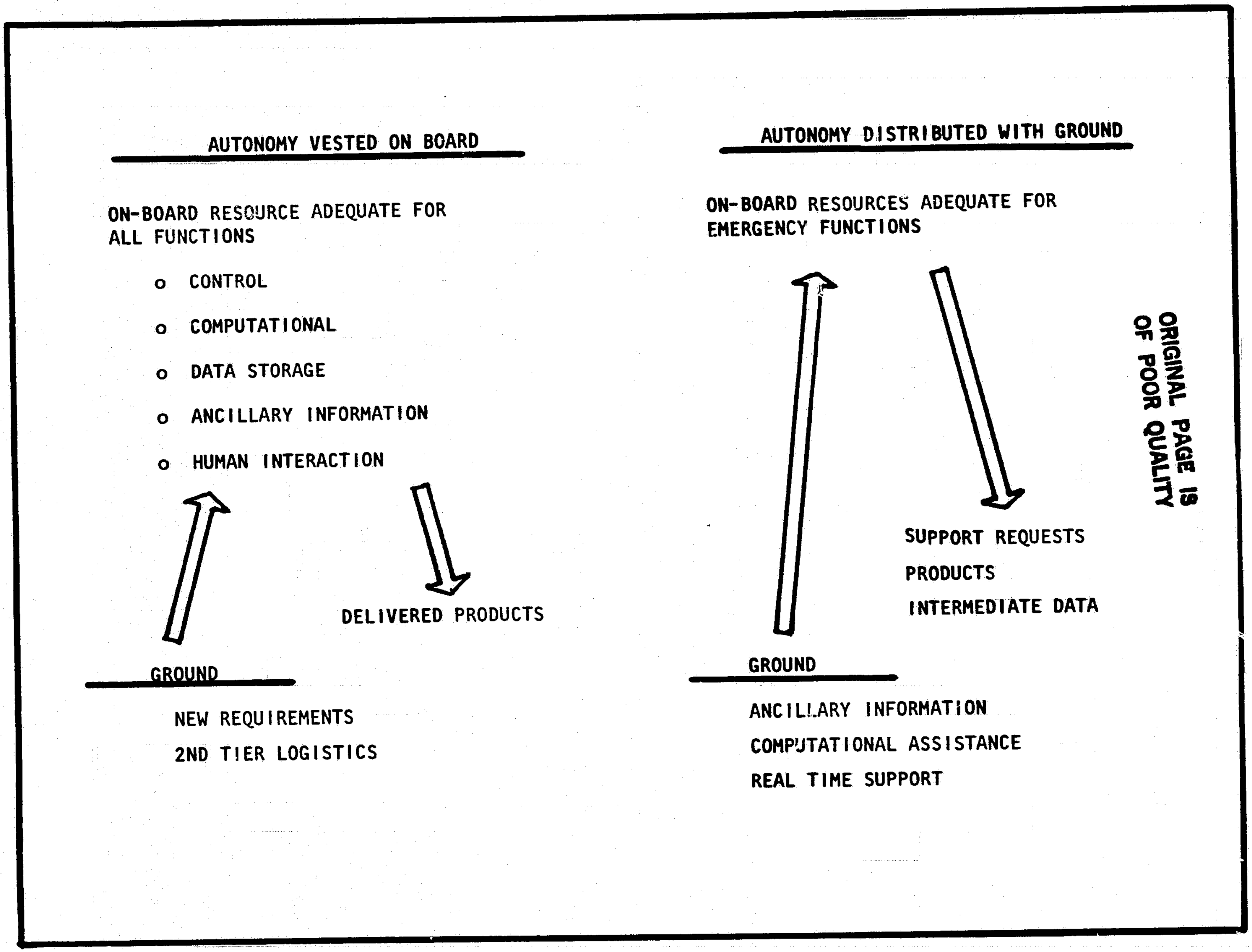
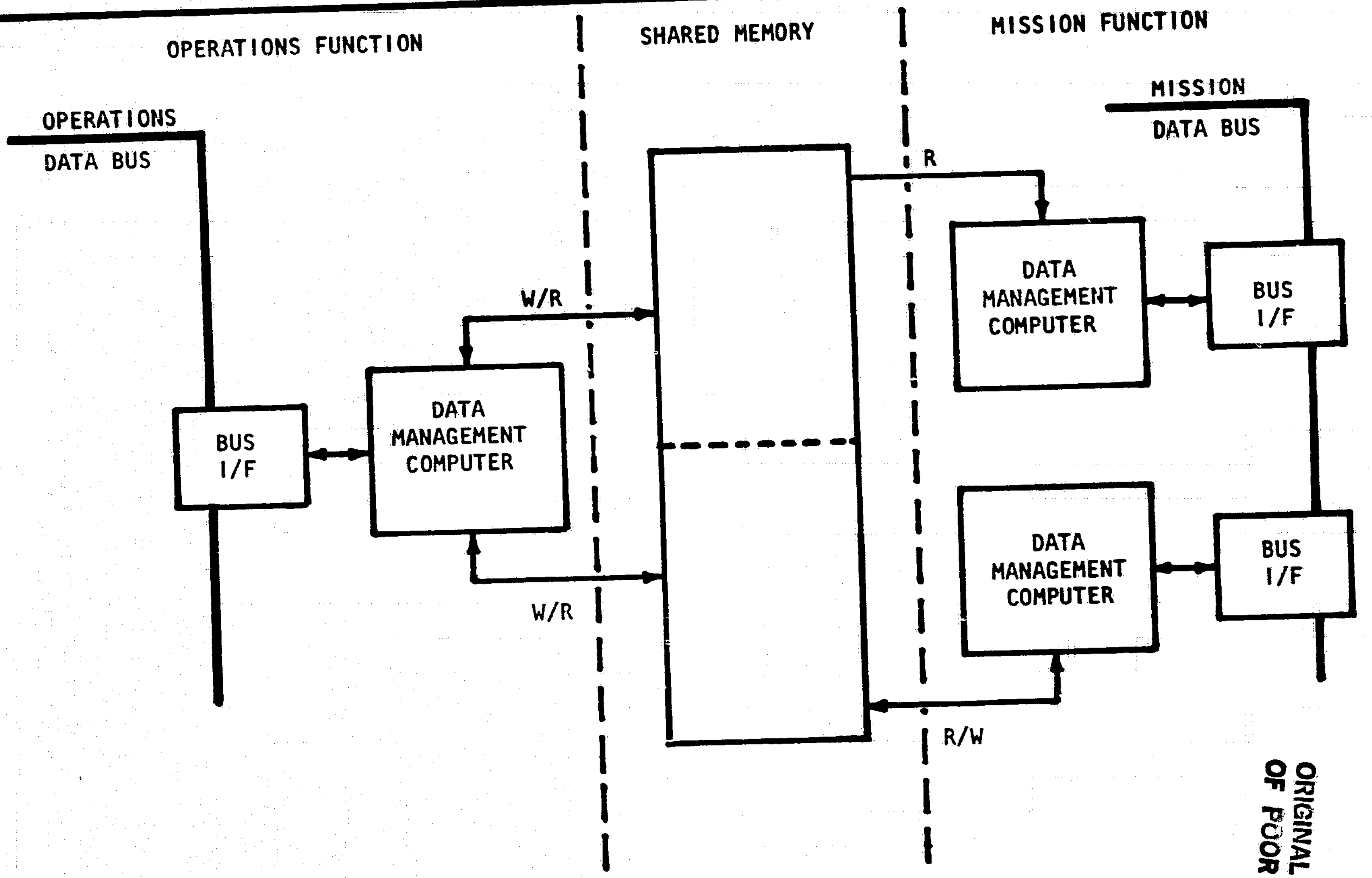


Figure 2-6. Major Alternate Concepts



NOTE:
- o DATA BUSES & I/F UNITS ARE MULTIPLY REDUNDANT.
- o COMPUTERS CONSIST OF MULTIPLE PROCESSOR, MEMORY, I/O, AND I/F FUNCTIONS IN FAULT TOLERANT ARCHITECTURE.

Figure 2-7. Space Station Data Management System would have read/write freedom in only a portion of common memory with read only capability in the remaining portion. Some common shared storage is desirable to facilitate communications between the two basic categories of functions and also to allow the two systems to operate on common data bases. However, storage protection of data and information in the read only portion to the missions computer is necessary for data/information generated by and peculiar to the operations system. It must be available for the mission systems to assist in minor operational functions.

The shared memory hierarchy (i.e., cache, primary working storage, bulk store, et cetera), memory system redundancy schemes, rebooting techniques, et cetera, and memory technologies to implement the select hierarchy are subject to more detailed trade studies.

For economical and operational reasons such as design, development, logistics, and training, the data management computers shown in Figure 2-7 will utilize identical architectural and detailed design philosophies although the specific composition of a particular computer may differ from the others. This approach can be better understood with the aid of Figure 2-8 which shows an architectural concept that can be used in the computer. An overall computer system would consist of a variable number of processors, memories, memory switches, and internal memory buses. The system is highly modular to provide high reliability throughput (both variable) depending upon its specific application. The internal buses must be fast to enhance the flow of information between processors and memories. They would be parallel buses. Data buses external to the computer system which interface the various operation functions such as power, life support, environmental control, and monitoring would be serial for practical reasons. The number necessary will depend on the number and possible type functional mixtures, bus speed, and bus loading. Error coding techniques and redundancy schemes would be utilized in each of these buses as required to satisfy criticality and reliability objectives.

Two concepts utilizing this basic system will be discussed in the following paragraphs. The first is a system design where the subsystems operate asynchronously with the command management subsystem "in charge" and the data

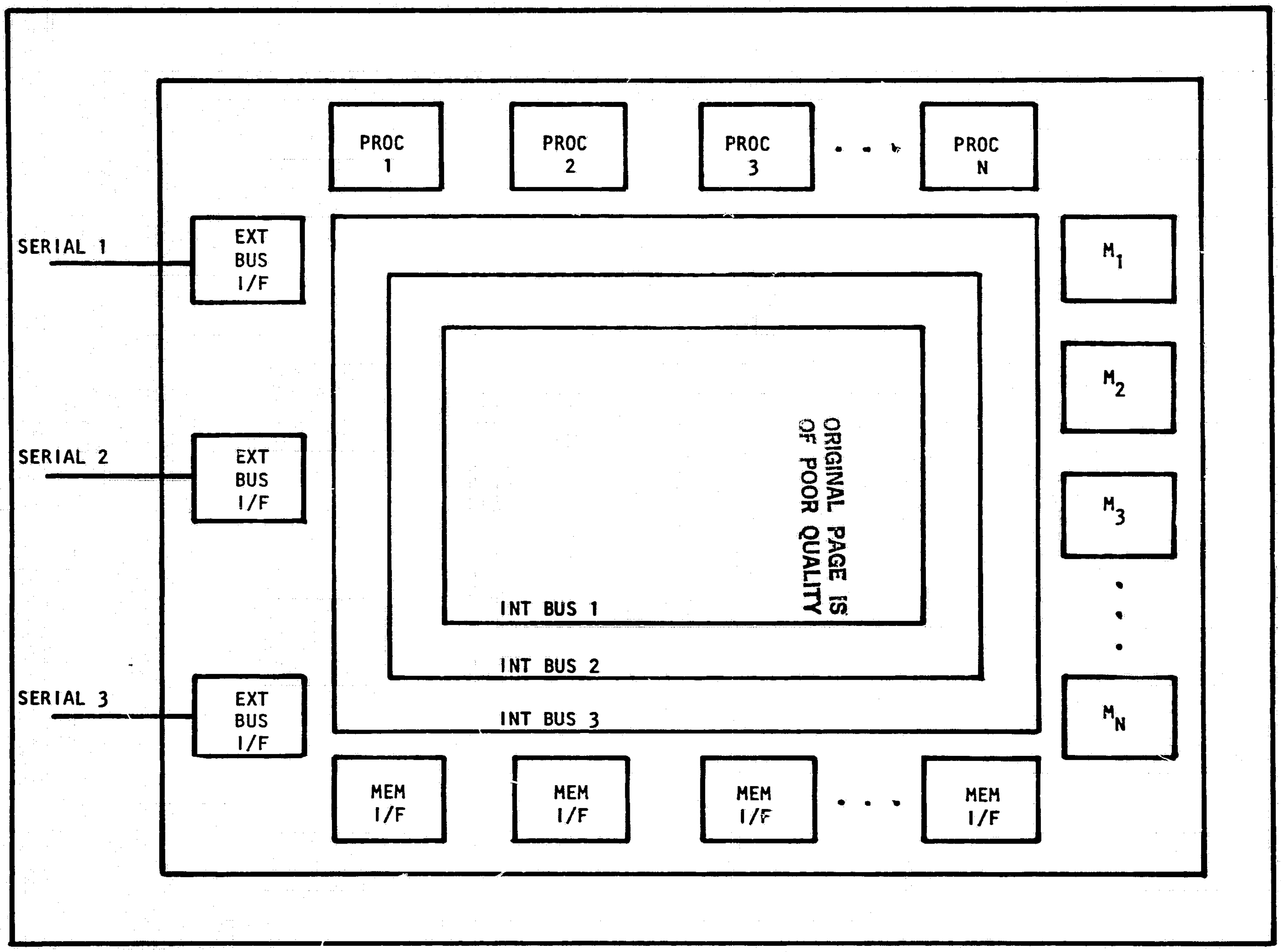


Figure 2-8. Data Management System Computer

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management computer merely a data supplier. In the second system design, the data management computer is responsible for more of the overall system control functions including data system management, subsystem state control, status monitoring, and configuration management.

2.3.1 CONCEPT 1

Concept 1 consists of subsystem functions which are essentially autonomous, i.e., no single element within the system provides overall control. However, the Command Management System (CMS) will provide a certain degree of control in that it:

- o arbitrates conflicts between subsystems,
- o checks constraints before issuing commands to make sure there are no conflicts, and
- o generates lower level commands to the subsystems.

Except for these control functions of the CMS and the passing of information between them, the subsystems are functionally independent of one another. The system is stochastic and asynchronous in that the operation of each subsystem cannot be predicted with certainty at any given time.

Figure 2-9 provides an overview of Concept 1 and Figure 2-10 provides a more detailed description. It shows the various inputs to the system; the internal and external communications, the commander, and chief operations officer.

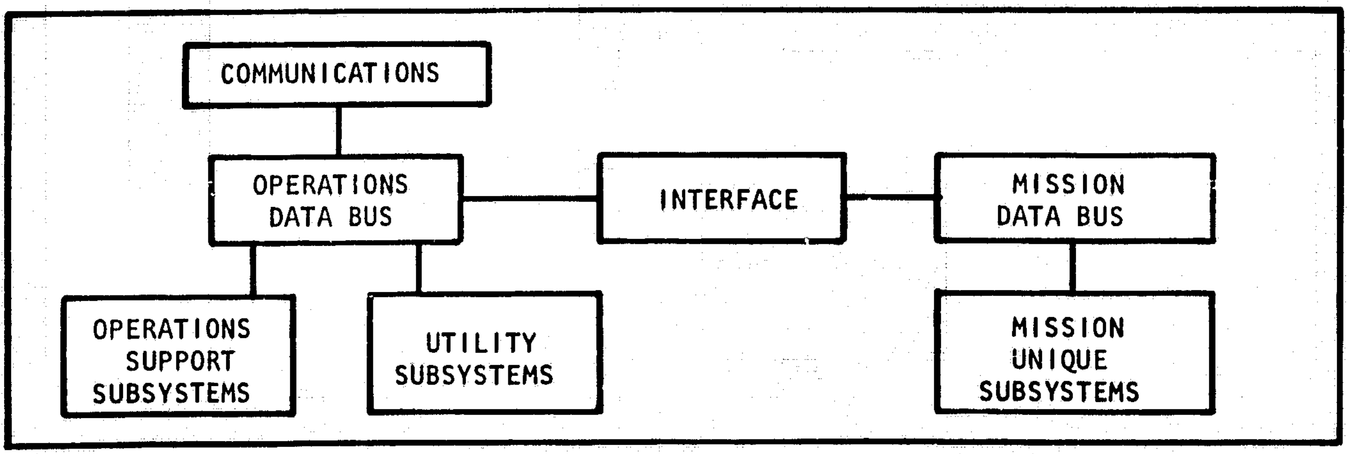

Figure 2-9. Overview of Concept 1

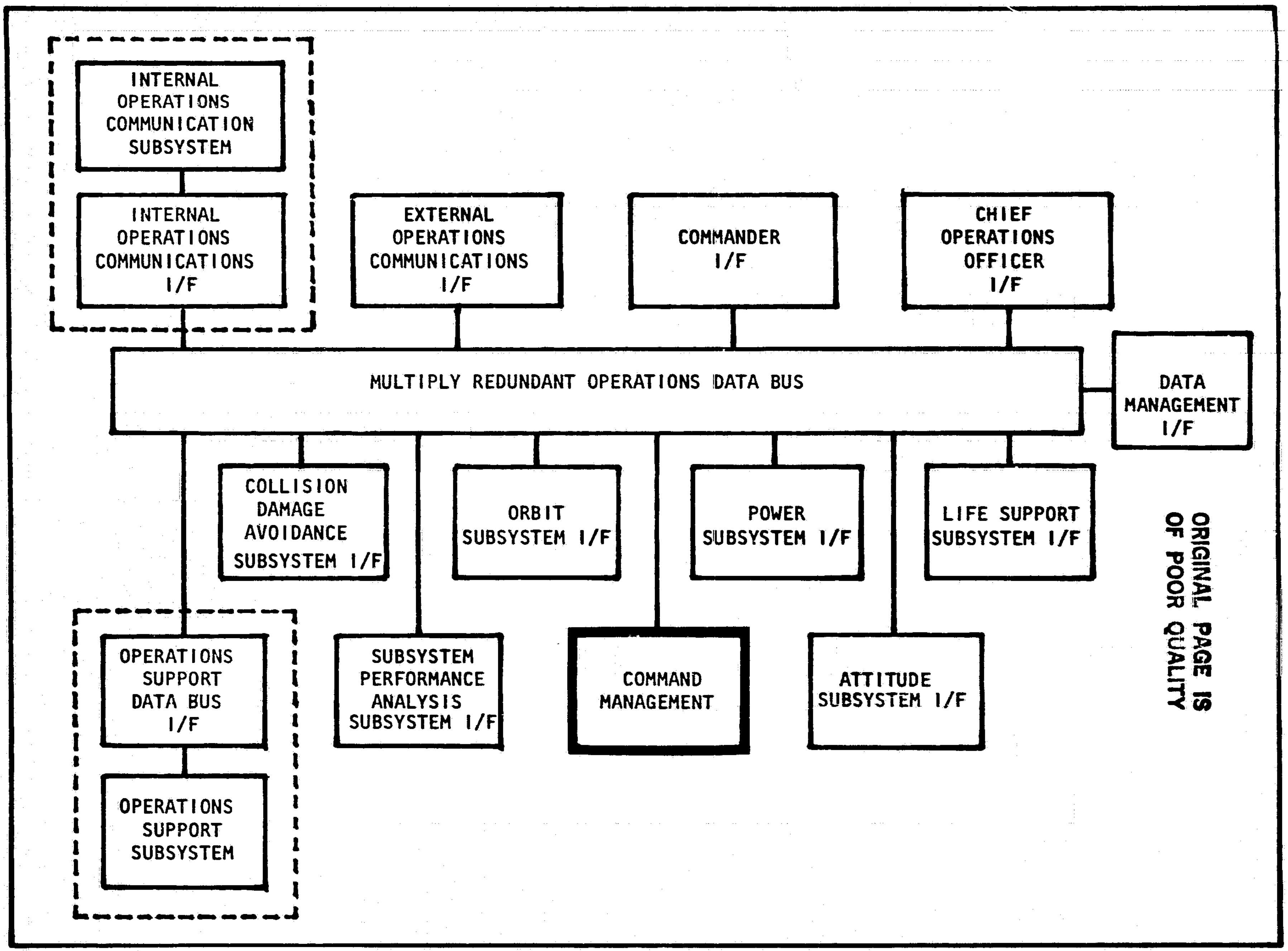

Figure 2-10. Operations Data Management System

These inputs will be interfaced to the subsystems through a multiply redundant data bus. The subsystems will perform their functions asynchronously, with the command management subsystem having responsibility for orchestrating the other systems. The data management computer will serve mainly as a data supplier providing the subsystems with the common operational data.

A scenario illustrating this concept might be as follows. An experiment informs CMS that a change in attitude is necessary. The CMS checks all other subsystems to assure there are no conflicts and then generates the necessary descriptors to relay to the attitude subsystem. The attitude subsystem, in turn, takes the descriptors to the level of actually executing the maneuver.

In a hierarchical partitioning of functions according to response time criticality, some were allocated to a support subsystem. Figure 2-11 shows the operations support subsystem. This subsystem contains its own dedicated computer and data buses as required. This subsystem interfaces directly to the serial buses of the operations data management computer system.

A scheme for reducing the burden on the operational and mission primary computational and data systems is shown in Figure 2-12. The flow of auxiliary or utility data between the major subsystems within the overall system, both operational and mission function, is accommodated. It allows direct communication from subsystem to subsystem without involving the various other components within the overall system hierarchy. The number and type of utility buses which should be made available are subject to trade studies and the specific definition of the Space Station data management system configuration selected. It has been included in this concept because it provides the system with a great deal of flexibility and utility and is expected to lead to ease of system operation.

Similar to Figure 2-10 on the operations side, Figure 2-13 shows the mission functions of subsystems interfaced to the mission function data management computer system through a multiplicity of serial data buses. From a conceptual point of view and technical design considerations, the two functions (operational and mission) are identical; they differ only in the types of functions, bus loading, function consolidation, et cetera.

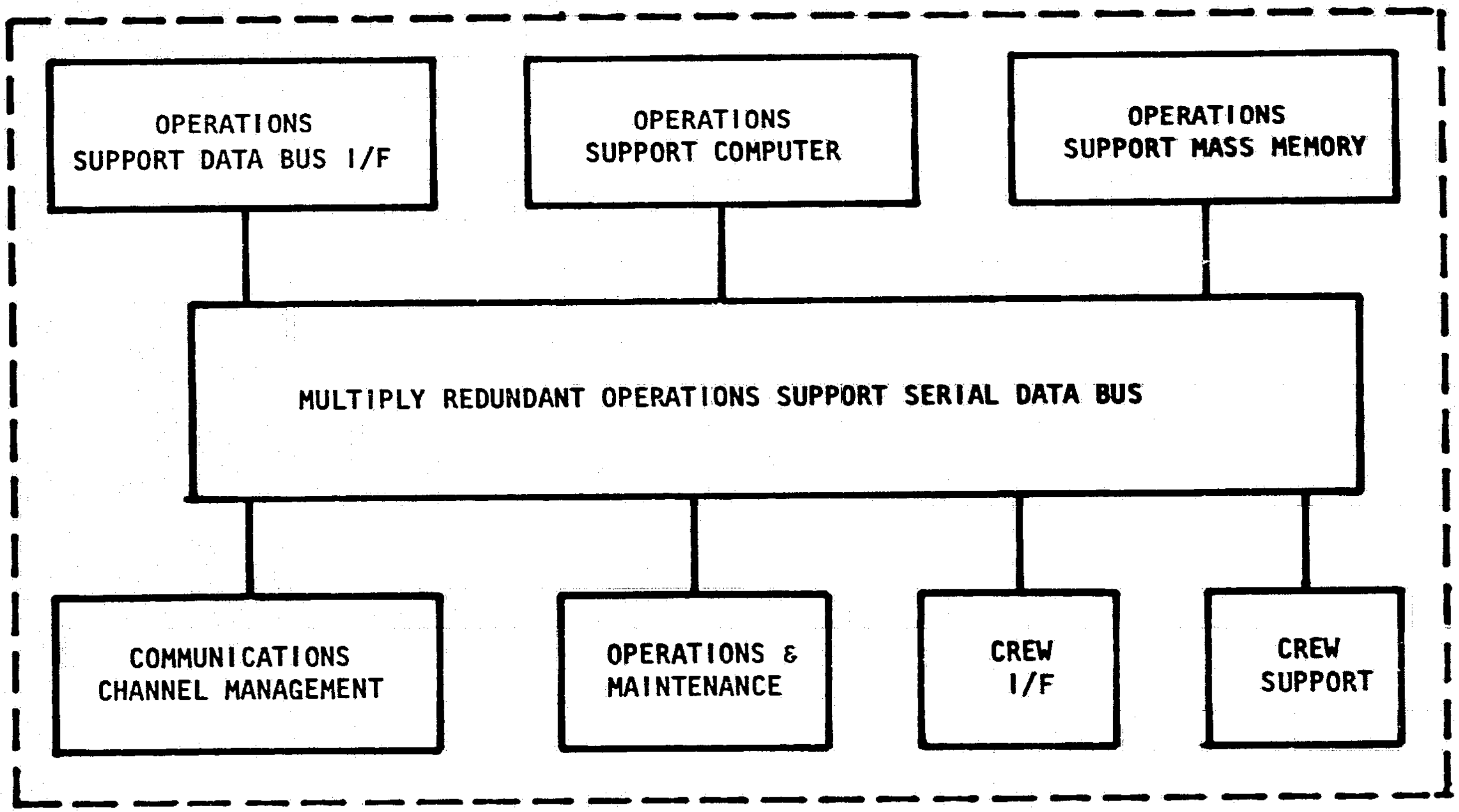

Figure 2-11. Operations Support Function Subsystem

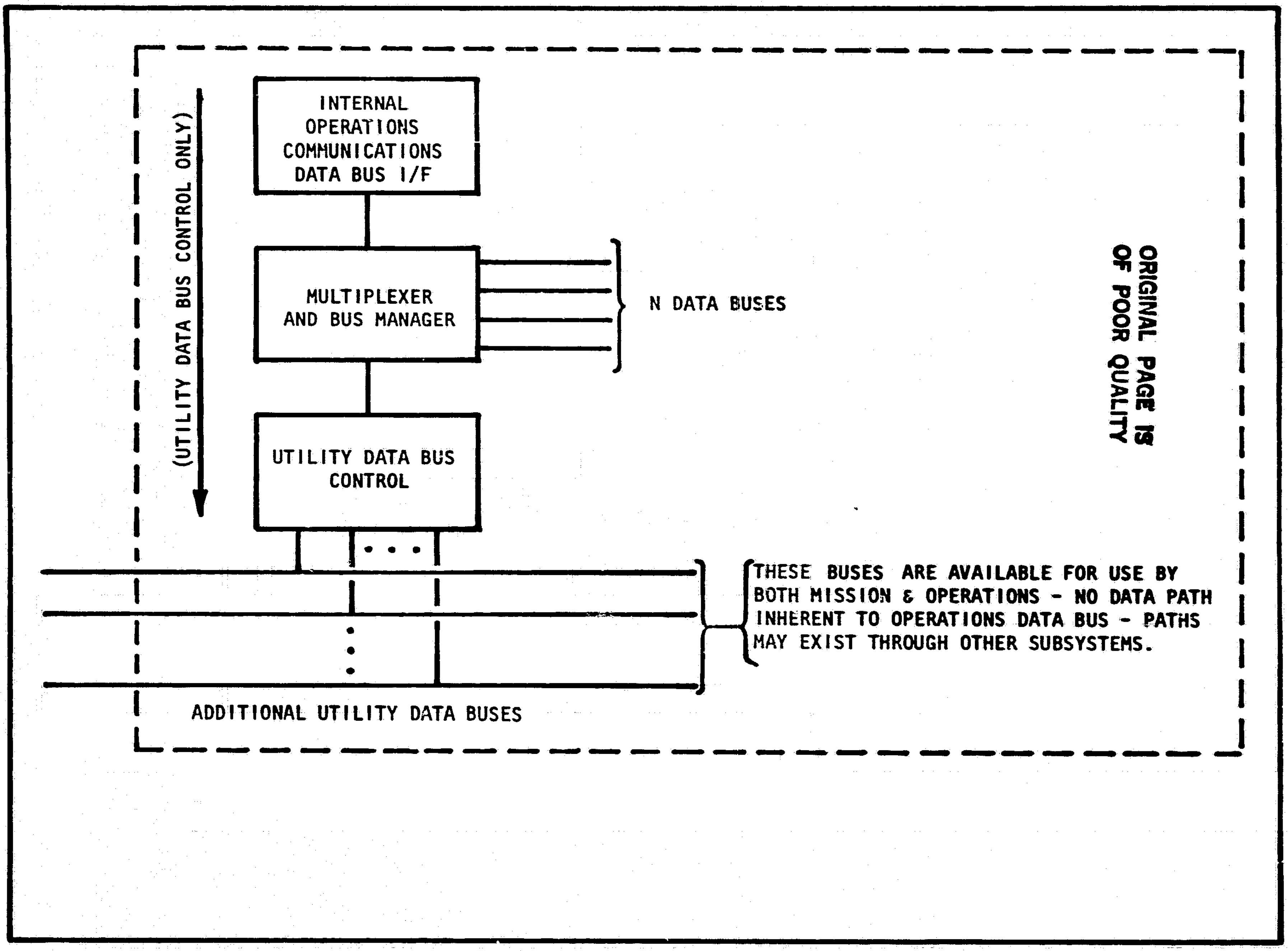

Figure 2-12. Internal Operations Communications Subsystem

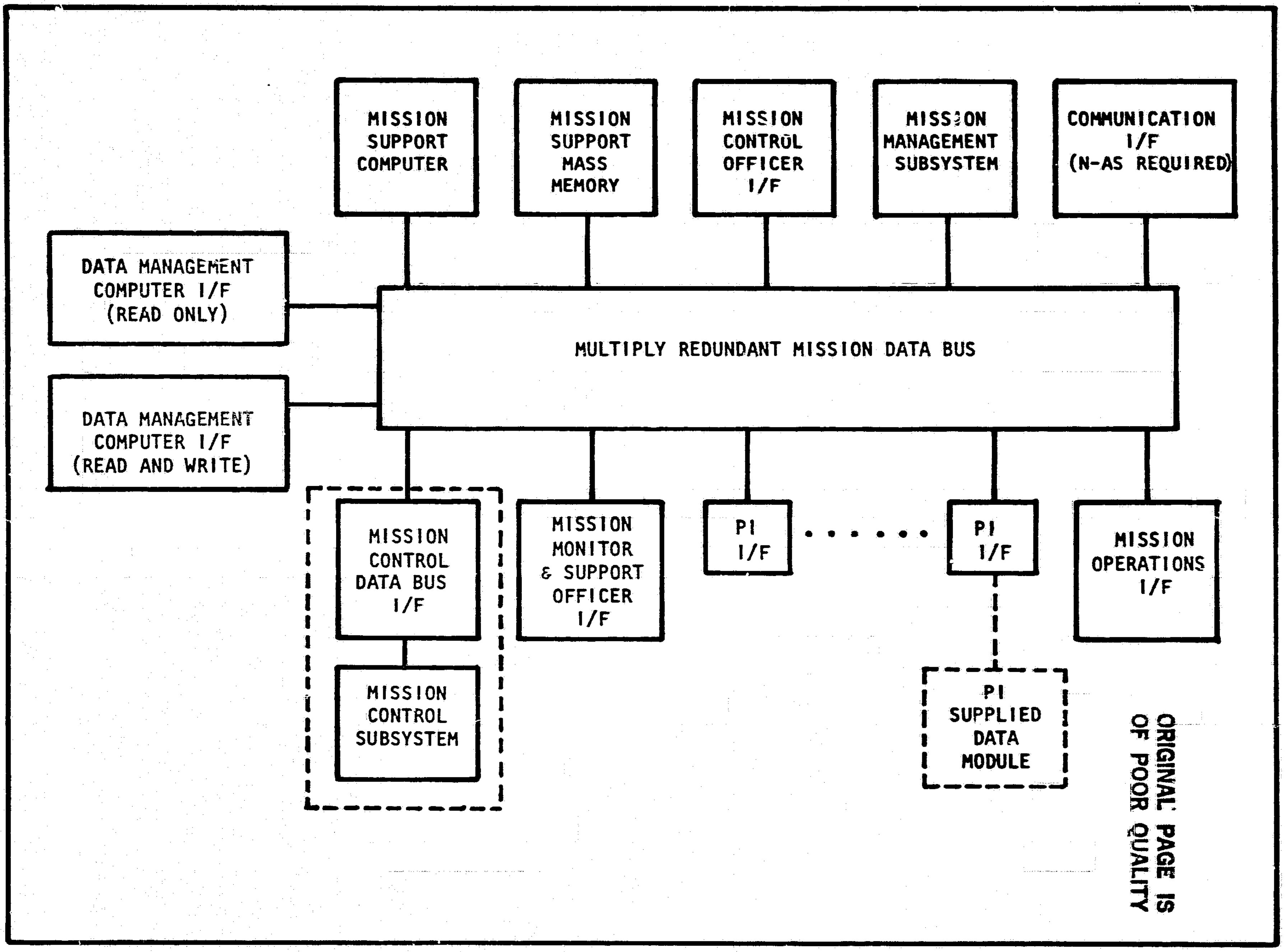

Figure 2-13. Mission Data Management System

Figure 2-14 shows a typical mission specific subsystem and gives more details of what may be required in the mission control subsystem.

2.3.2 CONCEPT 2

Concept 2 considers a different approach to the Space Station data management. The major variations of Concept 2 from the first concept are:

- Reallocates functions for simplification and economy
- Illustrates implementation for operations data management system (ODMS)

A block diagram of the system is shown in Figure 2-15. The figure shows several of the Station's subsystems and suggests ways in which the operations function may be broken down or combined. For example, the navigation, collision avoidance, and orbit determination and maintenance function have been combined into a single subsystem because of interdependence in functions and physical components. Maintaining or changing trajectory entails inputs from navigational sensors to determine orbital ephemerides. The collision avoidance function likely will use information from both the navigation sensors and special collision avoidance sensors to solve the orbital mechanics problem and ascertain if an impact with Space Station is probable.

Figure 2-16 shows a simplified block diagram of the navigation, collision avoidance, and orbit subsystem. The subsystem consists of an interface to the primary station operations data bus, an internal redundant subsystems bus, interfaces to the navigation and collision avoidance components and a subsystem computer. External inputs flowing into the subsystem consist of data from navigation and collision avoidance radars, lasers, and other sensors. The independent subsystem computer is used to determine the orbital parameters of both the station and incoming targets and to control the slewing of the navigation and collision sensors as required. To effect orbital change, this subsystem must communicate with the attitude and control and the propulsion subsystems through the Station's operation bus. In addition, considerable information will flow between this subsystem and the display and control and the data base operations subsystem.

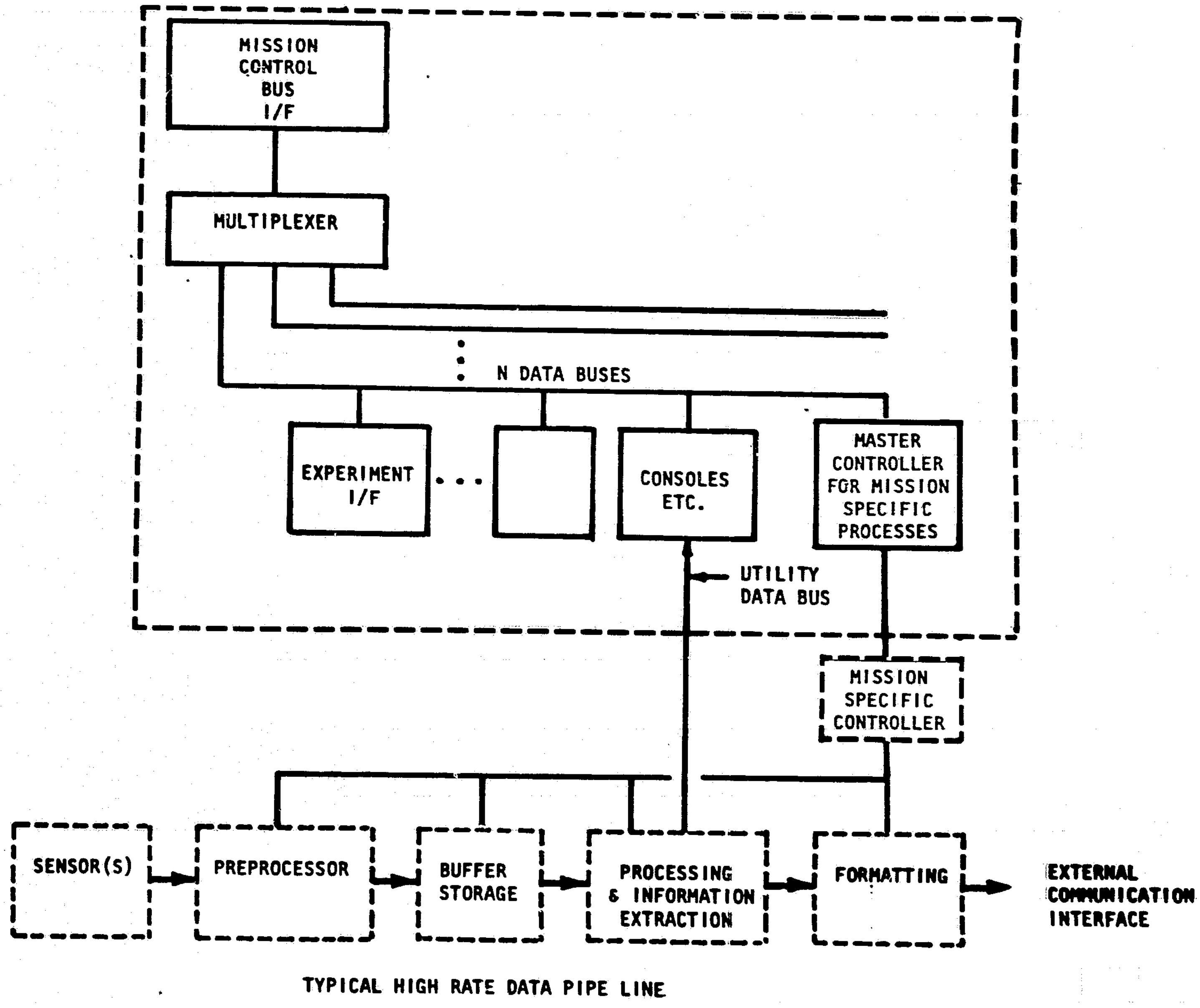

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Figure 2-14. Mission Control Subsystem

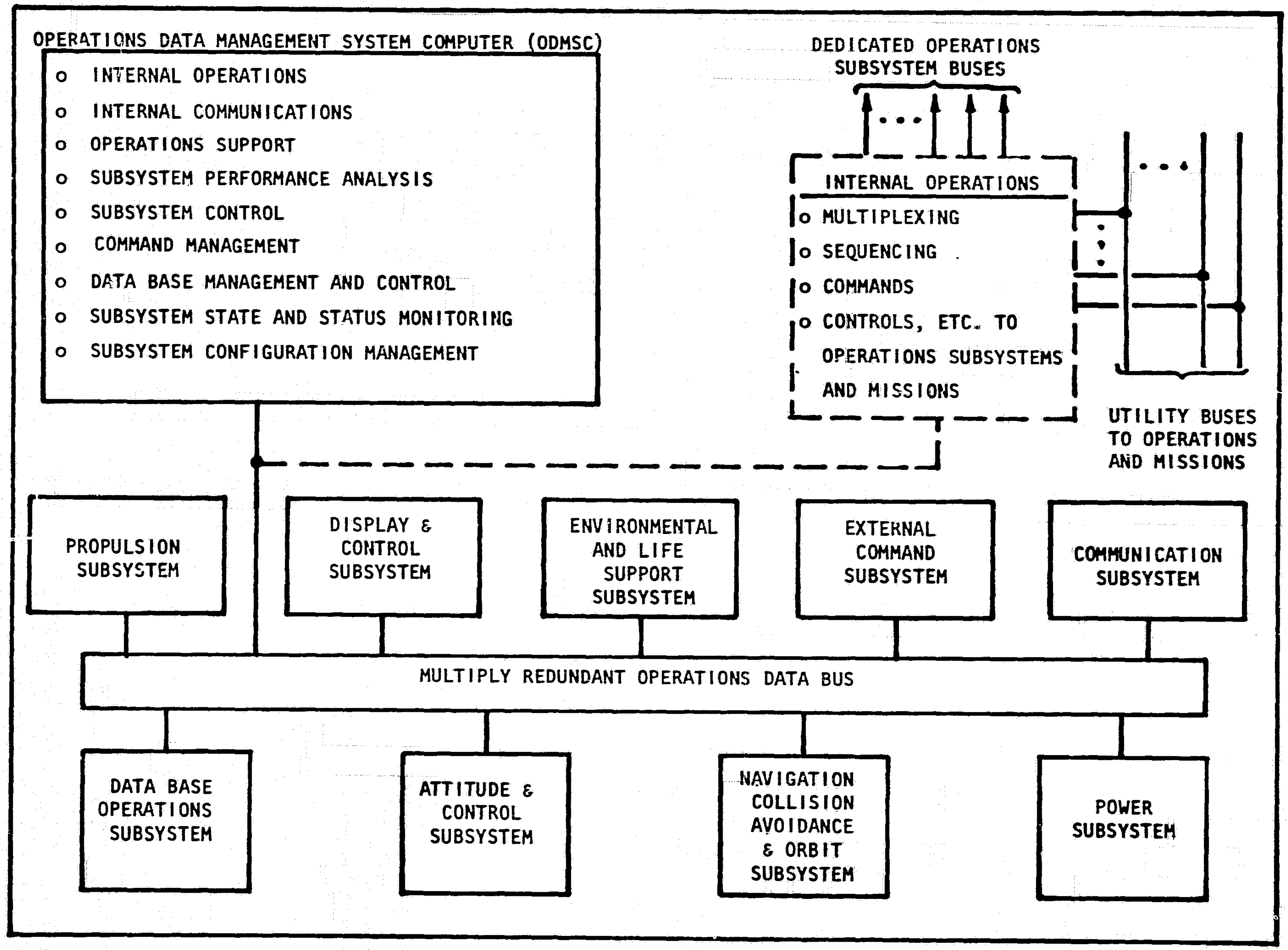

Figure 2-15. Operations Data Management System

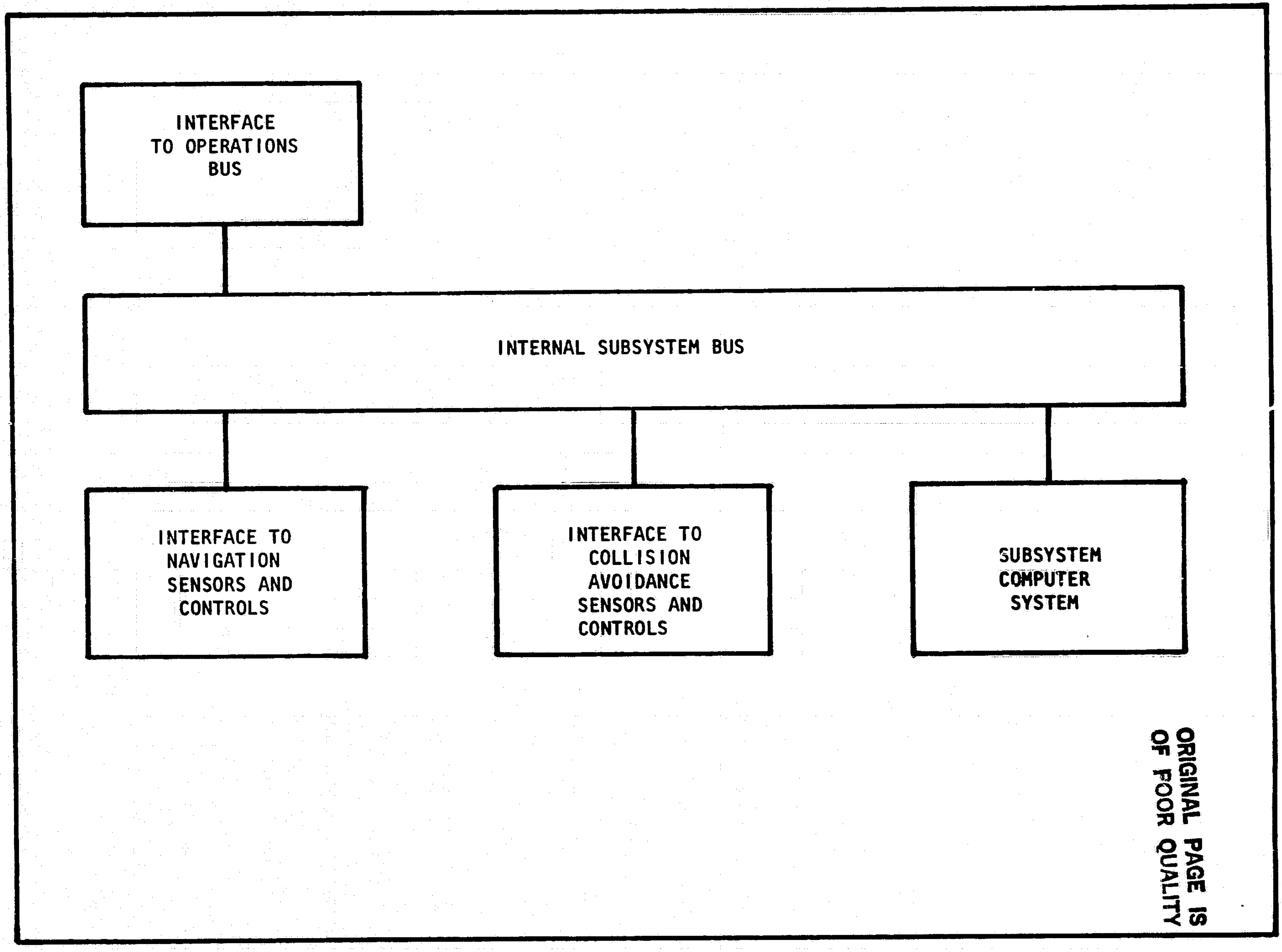

Figure 2-16. Navigation, Collision Avoidance, Orbit Subsystem

Unlike Concept 1, Concept 2 provides a display and control subsystem. This subsystem provides the link between any station inhabitant, the subsystems and the operations data management computer. It is the "man-machine" interface. The commander, chief operations officer, and crew functional interfaces are provided in this subsystem. Figure 2-15 does not imply that displays, panels, control switches, keyboards, printers, audio inputs and outputs, or other input/output devices and components are centrally located. It is assumed they are distributed throughout the Space Station core module and communicate through internal buses.

The environmental and life support functions have been combined in Concept 2 because of the similarity which exists in these operations.

Although in Concept 2, operational functions have been considered and grouped differently than in Concept 1, the major difference lies in the operational control of the data management and in the functions performed by the operations data management system computer (ODMSC). It should be noted that the operational functions of the Space Station have been distributed as much as possible to the subsystems. Each subsystem contains its own computational unit and functions as independently as possible of the other subsystems. Unlike Concept 1 however, the ODMSC schedules, directs, assigns, coordinates, integrates, monitors, and orchestrates the activities of the subsystems (and missions as required). Although the concept cannot in any reasonable sense be considered as "centralized control" since so many functions (as many as possible) have been relegated to the subsystems, it provides for coordination and orchestration within the operations data management system. Figure 2-15 shows some of the functions which may be accomplished in the ODMSC. Unlike Concept 1, which contained separate subsystems for operations support, internal communications, and subsystem performance analysis, these functions are accomplished in the ODMSC in Concept 2. Although Figure 2-15 provides a data base operations subsystem for the bulk of the data base functions, it is possible that some (limited) functions can be most efficiently handled in the ODMSC. It also appears that subsystem status, performance analysis, configuration management, et cetera, should reside in a central common source. While control of the data management system in Concept 1 may be considered a stochastic process, that of Concept 2 is of a more deterministic nature.

However, neither concept employs control techniques which can be categorized entirely in one of these pure forms. It is really a matter of degree and the two concepts are considered to lie at different ends of the spectrum.

As in Concept 1, it may be desirable to break the internal operations function, which provides multiplexing, sequencing, command, and controls directly to the operations subsystems and mission data management, into a separate subsystem. This option is indicated by the dotted lines in Figure 2-15 which show the internal operations function as a separate subsystem. The details and approach which could be employed are very similar to that shown in Figure 2-12.

2.3.3 COMPARISON OF CONCEPTS 1 AND 2

A brief summary of the characteristics and attributes of the two concepts is provided in Table 2-1.

Table 2-1. Summary Comparison of ODMS Concepts

CHARACTERISTIC	ODMS CONCEPT 1	ODMS CONCEPT 2
CONTROL PHILOSOPHY	STOCHASTIC DISTRIBUTED ASYNCHRONOUS	DETERMINISTIC CENTRALIZED SYNCHRONOUS
RELATIVE NUMBER BUS CONNECTIONS	MODERATE TO HEAVY	LIGHT TO MODERATE
RELATIVE BUS LOADING	MODERATE TO HEAVY RATES	LIGHT TO MODERATE RATES
ODMSC RELATIVE COMPUTATIONAL CAPABILITY	LOW TO MEDIUM THROUGHPUT	MEDIUM TO HIGH THROUGHPUT
ODMSC FUNCTIONS	1. DATA MANAGEMENT 2. CONTROL INTERACTIONS BETWEEN OPNS & MISSION FUNCTIONS	1. DATA MANAGEMENT 2. INTERNAL OPNS 3. OPERATIONS SUPPORT 4. SUBSYSTEM PERFORMANCE 5. COMMAND MANAGEMENT 6. STATE AND STATUS MONITORING 7. SUBSYSTEM CONFIGURATION CONTROL

SECTION 3
ANALYSIS

The analysis of the alternate concepts will of necessity be at a high level pending more detailed development. Since the purpose of this study is to concentrate on innovative approaches that may uncover technology needs, the effort in this section will be directed toward those concepts that have not been previously applied to spacecraft. An interactive relationship exists between the conceptual development and the analysis. At each succeeding level, alternatives of implementation arise and are subjects for trade studies. At some point, an option is selected for further refinement of the concept. In this section, a high level qualitative assessment of the alternate concepts is presented.

3.1 RELATIVE COMPARISON OF CONCEPTS

Each concept presented in Section 2 has some inherent advantages that will be addressed in a summary manner as a beginning of the analysis. A list is presented in Table 3-1.

Table 3-1. Relative Advantages of Alternate Concepts

	Advantages for Concept 1
o	Major Partitioning by Criticality of Functions
o	Modularized to Extent Non-Traditional Functions are Separate Modules
o	More Hierarchically Connected
	Advantages for Concept 2
o	Fewer Subsystems to Connect on Bus
o	More Reserved Processing Capability Available for Critical Functions by Implementing Priority Load Shedding
o	Operations Data Bus Less Burdened with Data Flow

3.1.1 CONCEPT 1 PARTITIONING

The major partitioning of functions by criticality offers some advantage for Concept 1. This permits a concentration of attention to reliability, redundancy, and fault identification for those functions requiring it. The relaxation of requirements for other segments of the data system may permit an overall simplification.

3.1.2 CONCEPT 1 MODULARIZATION

The high degree of modularization of Concept 1 allows the non-traditional data system functions to reside in nearly autonomous modules. This should facilitate the development of a system initially along more traditional approaches and then grow to greater functionality by adding modules. In this concept, command management, subsystem performance analysis, collision damage avoidance, the various support functions, communications channel management, and maintenance assistance are each separate modules. These functions are presently ground activities.

3.1.3 CONCEPT 1 HIERARCHICAL CONNECTIVITY

Concept 1 is hierarchically connected. This offers advantage for fault isolation and correction. It also has some advantages for distributing control among smart system elements.

3.1.4 CONCEPT 2 BUS CONNECTIONS

Concept 2 has fewer components connected on the bus. This has inherent savings in component count and inherently better reliability. With fewer devices, greater attention can be devoted to redundancy and fault tolerance.

3.1.5 CONCEPT 2 PROCESSING RESERVE

By concentrating more functions in the data management computer in Concept 2, a greater reserve computing power is available for critical functions. This follows from the assumption that the same number of processors is required in both concepts. Then some of the support functions could be temporarily suspended to make processors available in a contingency mode.

3.1.6 CONCEPT 2 DATA BUS LOADING

The concentration of functions in the data management computer in Concept 2 reduces the need for data movement on the data bus. This will reduce the bus bandwidth requirement and permit resources to be allocated for greater redundancy.

3.2 ARCHITECTURE ANALYSIS

The basic approach and concept employed in the Space Station data management system is that there is a hierarchy of bus and computer structures so that the overall objectives and tasks can be defined and broken down into succeedingly smaller tasks. The lowest level which is concerned with and dedicated to accomplishing a specific task is relegated to a subsystem or possibly even a component (e.g., in determining the desired attitude of the station or by accepting a desired orientation from another internal or external source, the subsystem (or component) can issue a command or a sequence of commands to effect the desired change).

In order to be cost effective, a standard approach and architecture must be developed and utilized at the various levels within the Station's data management hierarchy such that common elements can be mixed to achieve the objectives of that particular level. Principal variables at each level are throughput and criticality/reliability, and a method has to be developed so the overall system and specific subsystems can be readily configured to meet these objectives. A paramount requirement in both the overall system and subsystem design is that faults and failures be detected and isolated. Defective elements can then be either automatically or manually replaced. The discussion which follows deals primarily with the problems of achieving variable throughput, reliability, and trade-offs thereof, and in fault detection and isolation in a computer architecture which can be employed at any level within the hierarchy. However, the same principles and concepts apply to the networks or buses which are used to interconnect the levels within the hierarchy.

Figure 2-8 showed a standard computer architecture which employs a variable number of processors, memories, input/output units, buses, et cetera. The number of processors used, for example, does not have to equal the number of input/output units. The objective is that the number of processors, memory units, and input/output units can be tailored for a particular level to meet the throughput and criticality/reliability objectives of that particular subsystem. The basic problem is to develop an architectural concept which can be designed to satisfy these objectives.

The crux of the problem lies in determining when a malfunction has occurred, in planning strategies and taking corrective actions, and in providing and scheduling resources to meet the overall objectives. Hardware, software or a combination of techniques can be utilized. The choice depends upon the objectives and constraints such as the necessity to mask faults (in real time), system response and timing specifications, the physical attributes of power, weight and volume, et cetera. One method which employs a combination of hardware and software techniques is illustrated in Figures 3-1 and 3-2. In this approach, there is a kernal (prime) activity which is running and a monitor (essentially a replica or a condensed version of the prime) activity which is performed concurrently. Signals ("heart beats") pass back and forth between the kernal and monitor indicating that the two processes are obtaining similar results or that they are synchronized. In the simplest form, the monitor may be a watchdog timer which expects to receive specific signals from the kernal within prescribed time frames. Should either the kernal or the monitor fail to receive a "heart beat," then decision logic must be initiated to determine wherein the problem lies. Decision strategies and logic are shown in Figure 3-2. A basic question is that if this approach is taken, at what level in the hierarchy should it be applied?

It is also possible to rely heavily upon hardware to detect and isolate failures as well as mask faults within a system. This technique is usually employed for real time operations where false outputs or any down time cannot be tolerated.

The primary concern in the Space Station data management system architecture is to define the objectives of the system and to devise a concept which meets these objectives within the known constraints. A major goal of the Space Station is developing a basic architectural approach that exhibits the following characteristics:

- o can be used at the various levels in the station's data management hierarchy,
- o provides variable throughput,
- o allows ready fault detection and isolation to optimize system availability, and
- o standardizes elements to minimize life cycle costs.

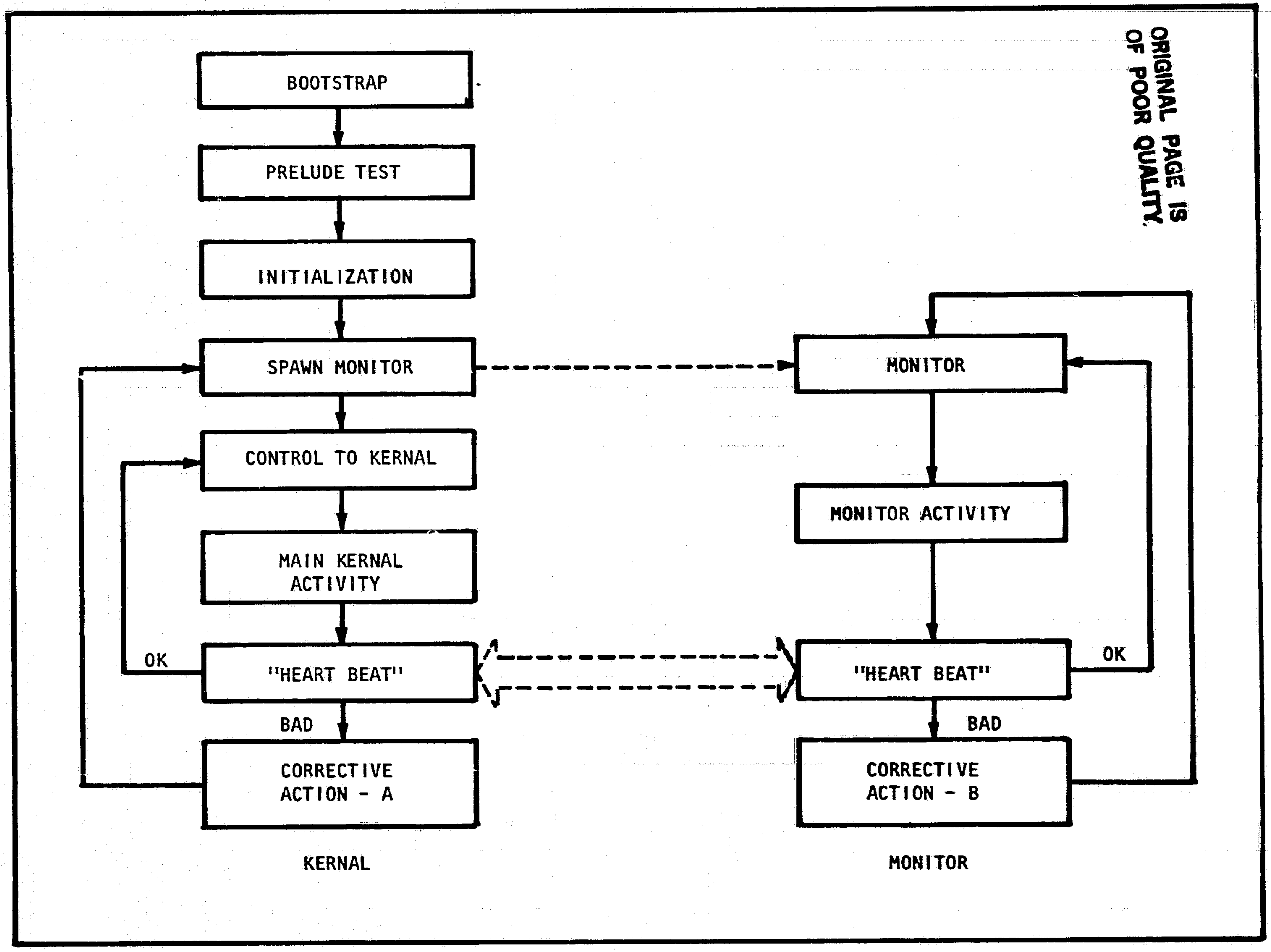

Figure 3-1. The Concept of Independent Kernal and Monitor Tasks

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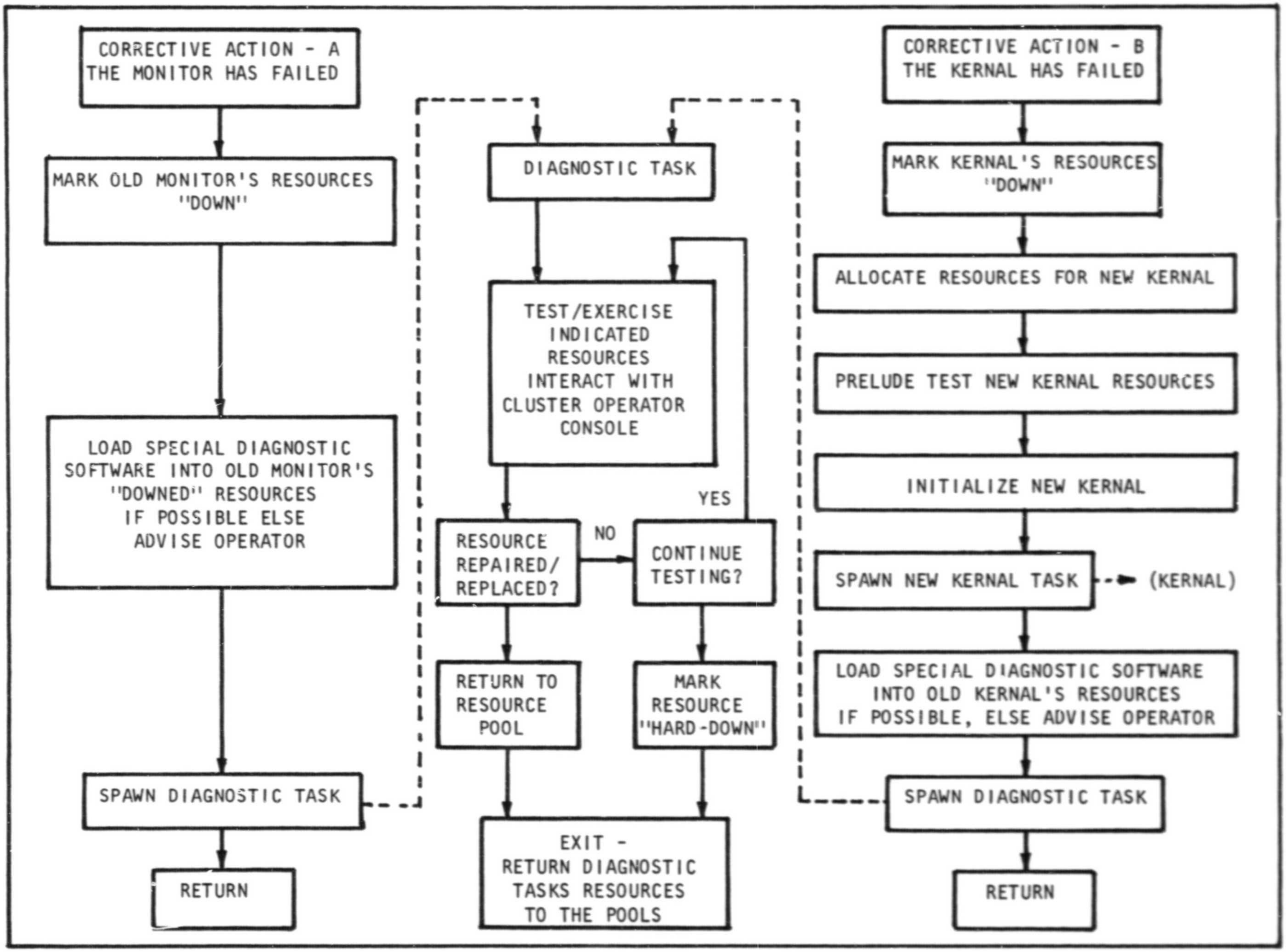

Figure 3-2. A Fault Tolerant Operating System

3.3 AUTONOMY ANALYSIS

Since the Space Station will be a long term national asset, serious consideration should be given to the various modes of operation involving the interplay between the ground, the crew, remote stations, freeflyers or satellites, and the operational systems on-board the Station. Due to the indefinite lifetime of the Station which emphasizes the need to minimize operational costs and the fact that there will be times when the Station is unattended, some degree of autonomy is required. In fact, a major objective and driving function in the design of the data management system is autonomous operations. There are several degrees or definitions of autonomy which are applicable to the Space Station. These are:

- The Space Station and personnel can operate for extended periods without benefit of ground support or other non Space Station systems.
- The Space Station system, including the ground segment, can operate for extended time without support from other non Space Station systems.
- The Space Station in orbit can operate without human intervention, continuing automatically to acquire data and perform its function.
- The Space Station system, including both the in-orbit and ground segments, can operate automatically without human intervention.

There are many motivations for autonomy such as peak performance, greater flexibility, and lower life cycle costs. Methods of achieving these goals include:

- Reducing the number of operational personnel required. In space the number must be limited. On the ground, the indefinite lifetime multiplies the effect of operational personnel on lifetime costs so significant investment in an autonomous (not requiring humans in the loop) system can be justified.
- Increasing mission success probabilities by reducing reliance on ground support. This is especially pertinent for military missions.
- Freeing Space Station inhabitants from the operational aspects of the Station so that they may devote maximum time to scientific observations and experiments.

Trade-offs and definitions in the varying degrees of autonomy are necessary and are expected to be used to establish groundrules and guidelines for the eventual design of the Space Station's data management system.

3.4 DATA BASE ANALYSIS

Providing the data where and when it is needed is the prime objective of the data base system. This system includes the storage medium and the update and access facilities.

The following assumptions have been made concerning the data base:

- o Separate data base partitions will be provided for the operations-oriented and mission-oriented functions.
- o Processed data will be stored in the data base by function. The raw data will serve as backup.
- o Data storage and file management will be provided to support both real time operations requiring immediate data access and for storage of archival data requiring occasional access.
- o The DBMS will provide parallel redundant storage for data that cannot be regenerated.
- o The DBMS will provide staging capabilities such as ground/space, operation/ mission, and function/function (e.g. collecting data for docking from orbit and attitude data bases).
- o Security of the data will be effected by access privileges, encryption, non-disclosure agreements and policy regulations. Military security will be effected by separation of subsystem components and black boxes. Military security will not encompass data necessary to the operation of the Space Station. This operational data will be available to all users.

There is a need to provide multiple access to a distributed, heterogeneous data base. This may be accomplished by having a portion of the data base on the ground and staging it to the Space Station as required. Staging involves loading necessary data bases into readily accessible memory prior to when it is needed. Access methods, natural language query, and other technological advances must be considered.

The idea of a self-organizing data base is discussed in more detail in Section 4.5. This is an artificial intelligence approach to access data from a large, distributed data base over a computer network.

3.5 LOGISTICS ANALYSIS

The data system will perform a major role in logistics and logistics management. Because of the indefinite lifetime and manned presence, the entire operational philosophy will be different from previous spacecraft. Built-in fault detection, isolation, and manned repair will be normal. Spare parts management will be a significant role for the data system. The whole reliability requirement will also change with an emphasis on availability. The need for man to effect repairs has been emphasized.

3.5.1 DATA SYSTEM COMPONENTS

As an aid to analysis of the data system involvement in logistics, selected components from Concept 1 are shown in Figure 3-3. Each of these will have some involvement in the operations or manipulation of logistics data. The basic question is whether logistics should be managed from the ground or the space segment. With either approach, a significant function of the ground facility will be to assist in performing the logistics function.

Logistics will involve the supply and maintenance of every element on the Space Station. These elements include consumables, supplies, spares, and mission products. Depending upon the maintenance philosophy, line replaceable units (LRU) may be returned to the ground for repair. For space processing missions, the transportation and tracking of those products will impose a significant load on the ground support system.

Because of the design philosophy imposed on the concepts, the spaceborne data system will exhibit sufficient autonomy that no part of the ground system is deemed critical. Therefore, integration of mission driven logistics with operation logistics is acceptable.

3.5.2 FLOW OF LOGISTICS DATA

Logistics data may originate from many components of the data system. On the mission side, the mission management subsystem will have interfaces to update data files of logistics information. The files will physically reside on the mission mass memory. The maintenance of these files will be performed by the mission support computer.

Logistics data may also originate from the operation components. The preparation of logistics data files for transmission to the ground will be performed by the operations support computer. It will maintain the up-to-date

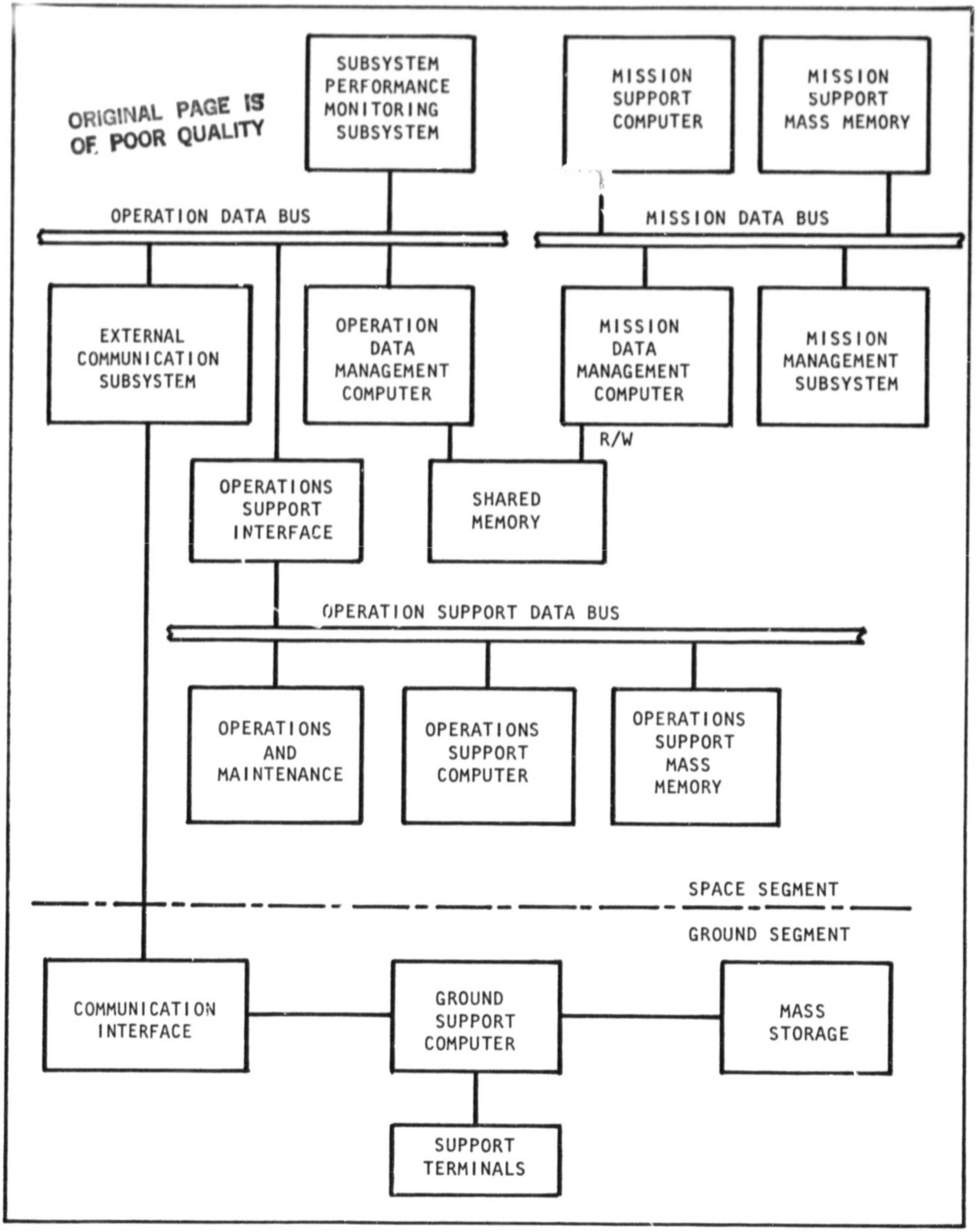

Figure 3-3. Selected Data System Components Involvement in Logistics

files on the mass memory. These files will include mission data. That data would be passed to the operations support computer via data requests to the operation data management computer. That computer would direct the mission data management computer via the shared memory to provide the data to the shared memory. The mission data management computer would obtain the data from the mission support mass memory in a read only access authority.

Other logistics requirements would be determined by the operations support computer from data provided by the operations and maintenance subsystem and the subsystem performance monitoring subsystem.

The operations support computer will keep up with logistic data on the consumables such as fuel, oxidizers, gases, and other resources that are automatically consumed during the normal function of the subsystem. Included is data on supplies, such as food, and experiment expendable items that have a scheduled consumption and replacement cycle. Other data includes the nature and quantity of the spare parts. It includes those on-board the Space Station, in ready supply locations, on other vehicles such as shuttles, and available for cannibalization from other subsystems. As part of logistics management performed by the operations support computer, supply levels are monitored and resupply is scheduled when a predetermined level is reached.

3.5.3 LOGISTICS ALTERNATIVES

As indicated, some of the logistics management, especially the scheduling of resupply, may be performed on the ground. The principal argument for performing the function on-board the Station is that the Space Station is responsible for its own mission scheduling. Therefore, any logistics impact as well as any anticipated mission impact on logistics requirements can be more accurately forecast.

Other functions frequently included in logistics under the terminology "Integrated Logistics System" or ILS include training, maintenance, and configuration control. These functions will be incorporated into the Space Station data system. Many, such as crew training, crew skills inventory, on-board maintenance assistance, and configuration are needed interactively on-board. Should it be determined to perform the management and analysis on the ground, the data would need to be accessible in near real time by the on-board systems. For some of the more sophisticated training and maintenance concepts, such as using interactive color video displays, a significant reduction in communication requirements can be achieved by performing the functions on-board.

3.6 COLLISION AVOIDANCE

There is a high probability that the Space Station will be impacted by an object at some point in time because of its large cross sectional area and long duration. Satellites, either active or dead, meteorites, and space debris or junk are examples of the type of objects likely to be encountered by the Station. Satellite ephemerides may exist in ground based data systems and be available to the Station. However, sporadic meteors and meteorites by definition are unpredictable; little or no effort has been made to keep track of the numerous small to medium sized objects comprising space debris. Objects approaching the Station from an out-of-orbital plane position are of most concern. These may be approaching the Station from above, the sides, or the front. The earth shields the Station from below and the relative velocity of an object approaching from the rear would probably be small.

The destruction potential of an object to the Station depends upon its momentum relative to the Space Station; i.e., its mass and relative velocity. Depending on the Station's structural materials, design, and construction, the Station may be able to withstand impacts from very small objects. Collision with objects which can result in severe structural damage or the loss of critical components must be avoided.

Given a sufficiently long period of observation of an object, it is possible to avoid collision with only minor changes in either station velocity (fore or aft) or direction (lateral or vertical). The distance, P, through which the Station can be moved in time, t, when given an acceleration, A, is $P=\frac{1}{2}At^2$. (Morrell 1). Thus, the longer the observation time, the lesser the acceleration or energy required to move the Station out of the object's path.

Figure 3-4 shows the miss-distance in meters at time intervals of five seconds using $A=1/100$ meter/sec^2. This figure shows that the best solution is to make small changes early. A change in fore or aft acceleration of the Space Station would be difficult to achieve; therefore, the lateral or vertical acceleration maneuver would be the best approach. To ensure that minimum maneuvering energy is used, two factors are of importance; that the miss-distance is small and that imminent collision be known early. The challenge is to detect those objects at sufficient distance to allow time to avoid them.

3.6.1 OBJECT DETECTION

The larger objects in space are tracked by ground radar and their trajectory can be provided to the Space Station. It is the small objects that are of interest to on-board detectors. Because of the narrow beam width used in most tracking radars, a small unknown object is difficult to acquire. (Berkowitz 1) lists the characteristics of the AN/FPQ-6 and AN/TPQ-18 radars. Using this information, Figure 3-5 shows the object size in meters^2 as the radar maximum detection capabilities. These radar sets have range accuracy capabilities of less than one meter on a well defined object. But the angle accuracy is between 0.1 and 0.05 meter radians. This would be an error of 20 to 50 meters. It is possible to improve these figures using special smoothing techniques. Reaching the goal of two to five meters is questionable because of random errors. A range of 65 to 70 miles as a requirement would allow the Space Station personnel time to make the necessary calculations to determine whether a collision was imminent and take collision avoidance action if necessary. This short range radar would allow tracking of objects with a closing rate of 140 meters per second.

3.6.2 SOME RADAR PARAMETERS

There are approaches to developing a system to meet the Space Station requirements for detecting objects at a range of 65 to 70 miles. The system may use radars or lasers. A typical pulse radar system will be developed here since radar is more mature. However, the resolution may be marginal. The selection of a frequency or band is a problem because of the many pros and cons to be evaluated in making the selection. To ensure the availability of hardware and test equipment, an X-band system would probably best meet the Space Station requirements. A transmitter frequency of 1200 MHz was selected. A noise budget figure of 8 db would be achievable. Using the 1200

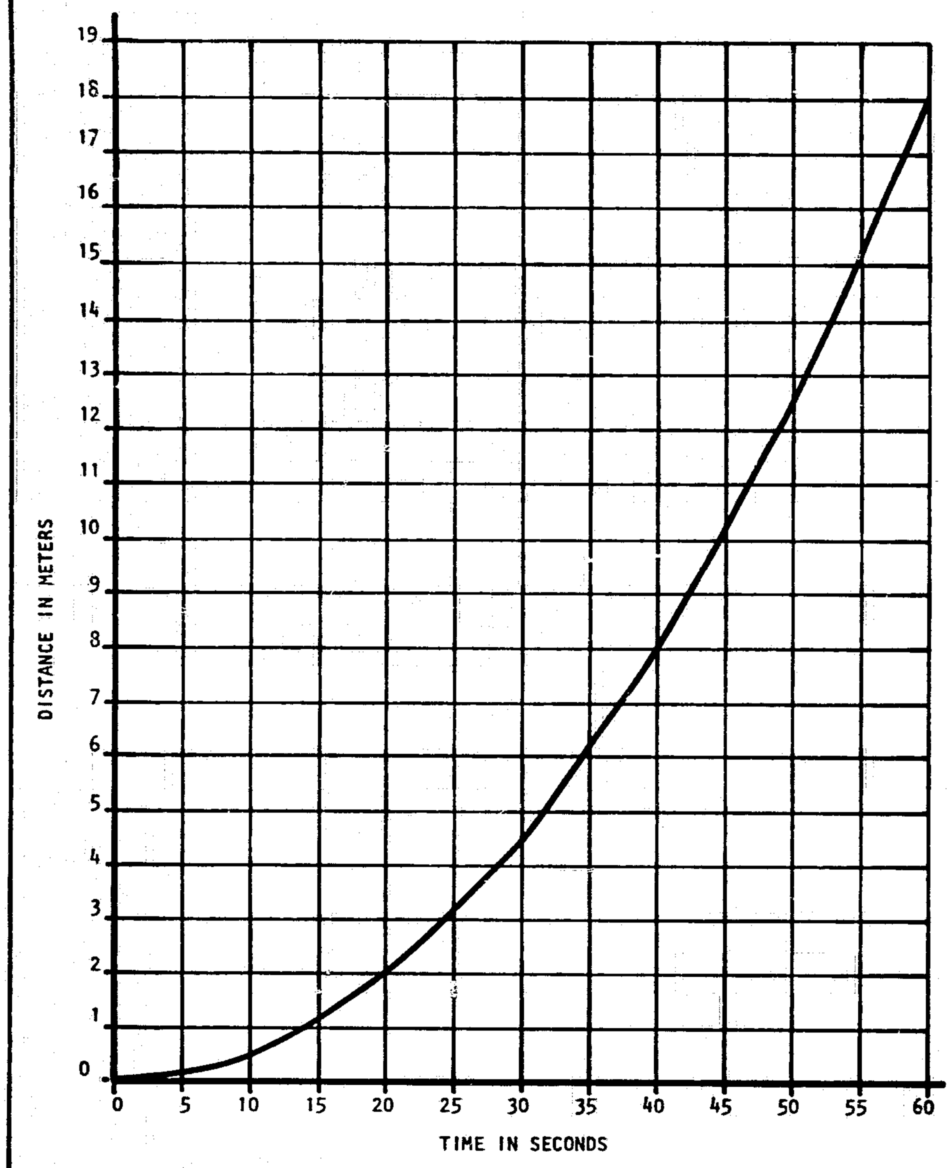

Figure 3-4. Observation Time vs. Miss-Distance

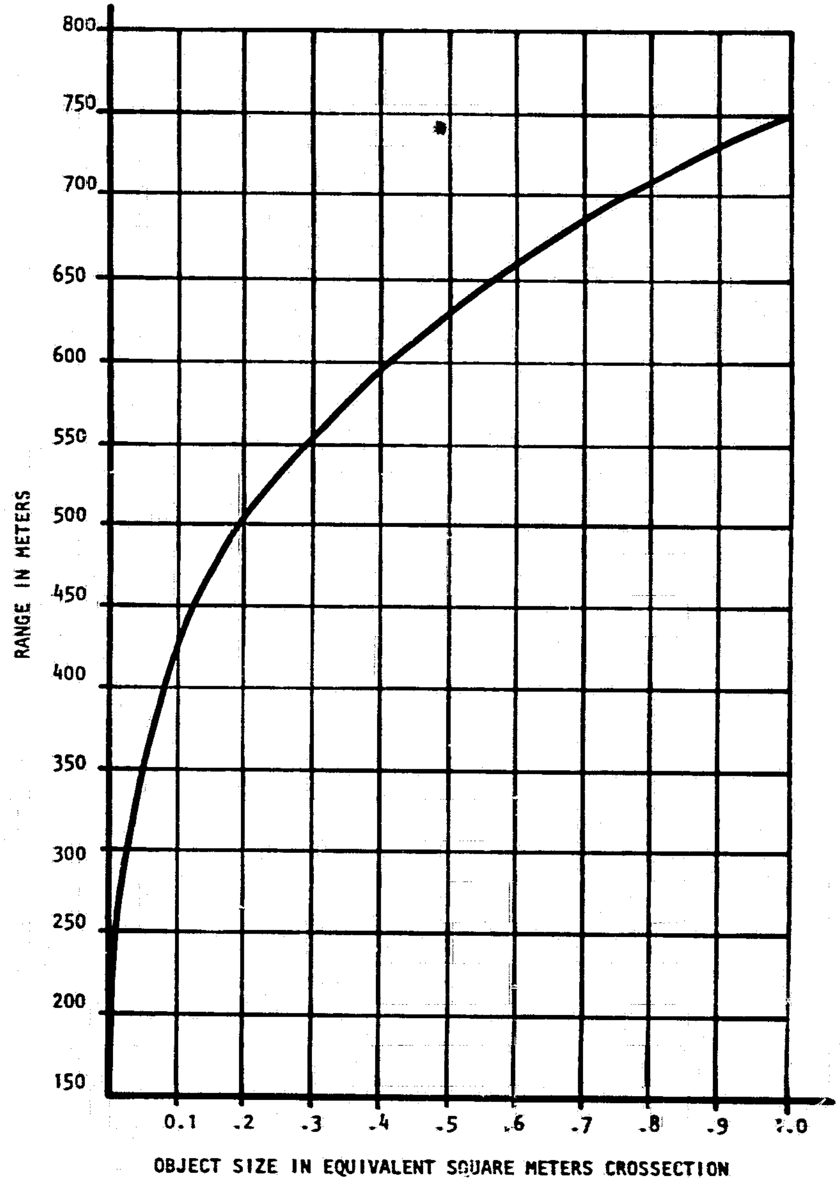

Figure 3-5. Object Size vs. Observation Range

MHz frequency and a two meter parabolic antenna, the antenna gain would be 45 db. A pulse duration of two microseconds was assumed. Another assumption is that the transmitter would have a peak power of 50 KW.

Using the above parameters, the radar system would be capable of detecting and tracking a one square meter target at a range of 154.5 kilometers and a 0.5 square meter target at 125.5 kilometers. Table 3-2 shows the relationship between the target sizes and distances at which the object may first be detected.

Table 3-2. Collision Avoidance Radar

TARGET SIZE (METERS^2)	RANGE (KILOMETERS)	+6db. (KILOMETERS)
1.0	154.5	212.4
0.5	125.5	180.2
0.2	99.8	135.2
0.1	85.3	117.5
0.05	70.8	117.5
0.02	56.3	80.5
0.01	46.7	67.6

A number of changes could be made to this radar system to improve performance. The receiver performance could be improved by the use of a matched filter system, analog or digital integration, or a form of correlation detection. These approaches could be used to increase the radar system's range or reduce the transmitter power requirements. A trade study would be to optimize the radar system as to system weight, antenna size, frequency, and tracking range.

3.6.3 COLLISION AVOIDANCE SUBSYSTEM

A data management scheme for accomplishing the collision avoidance function is described briefly here and is shown in Figure 3-6 along with the other operations data systems and functions which are associated with the detection and collision avoidance subsystem. It is anticipated that special sensors such as radars and lasers would be required for target detection and tracking.

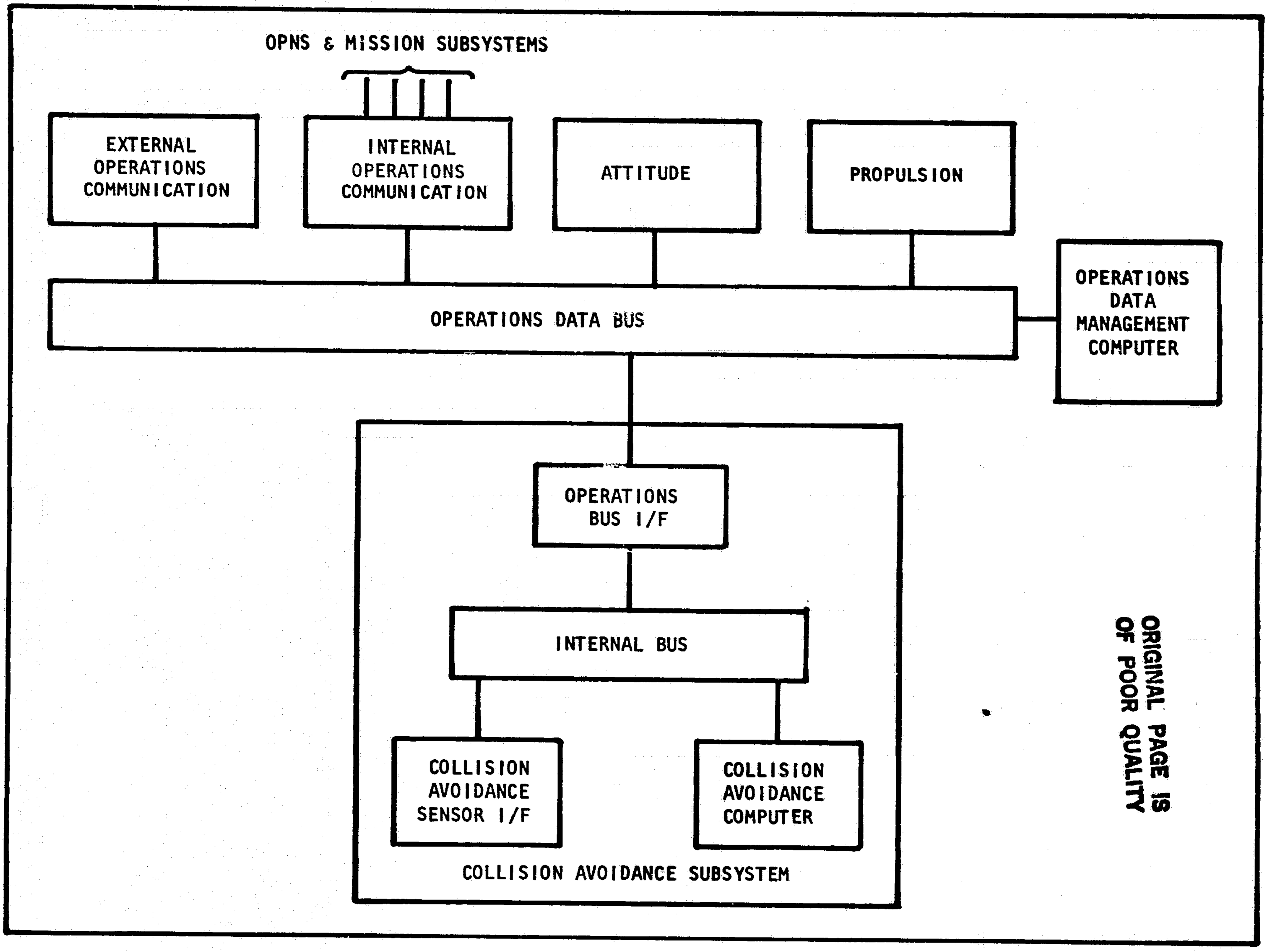

Figure 3-6. Collision Avoidance Subsystem and Interactions

They would be located in positions to provide detection of objects approaching the Station from the top, front, and each side; protection from behind (trailing edge) or below (facing earth) the Station probably will not be required. The sensors may be of the scanning type requiring slewing which would be accomplished by the collision avoidance subsystem. The collision avoidance sensors may be used either separately or in conjunction with those employed elsewhere, e.g. in rendezvous and docking. For larger objects which are tracked from ground based stations, ephemeris information enters the system through external communication channels and is routed to the collision avoidance subsystem computer. With inputs from special collision sensors on-board, rendezvous and docking or other on-board radars, ephemeris data from the ground or other external sources, and from data base or catalog information residing in its memory, the collision avoidance computer determines if a collision is imminent. If it is, the computer essentially takes control of the Station by putting the various operations and mission subsystems in the desired state, either through individual buses emanating from the internal operations subsystem or through normal communications on the operations data bus. The operations data management computer, if not a part of the collision avoidance function, is at least made aware of the situation. Communication with the attitude control subsystem is necessary to orient the Station and with the propulsion system to change the Station's trajectory. Should other actions be required, such as the destruction of the approaching object, the collision avoidance subsystem would serve to close the loop between the sensor inputs and the impending action.

3.7 SOFTWARE ANALYSIS

The potential impact of software, especially software maintenance, on the operating Space Station is enormous. Software has been estimated (or accused) of accounting for 80 percent of the life cycle cost of large systems with embedded computers. The concern for software, both cost and errors, is emphasized by the U.S. Department of Defense (DoD). About 1974, DoD realized that it was spending too much on software. It carried out a detailed analysis of how costs were distributed over the various application areas and discovered that over half of them were directly attributed to embedded systems. This led to the development of Ada, which is a DoD language that has many features desirable in Space Station. However, before any discussion of language and its analysis can be undertaken, the broader issue of software must be addressed.

3.7.1 BASIC CONCEPTS

In the most basic sense, computer software permits a real time modification to a digital output vector. This output vector may be representative of a numeric value or data, it may control some electronic functions, or it may be converted to some analog representation. The sequence by which the transfer function from input vector to output vector is altered is the software program. The way this software program is put together is a language. The sequence of steps is a procedure.

Although software and hardware can in theory be separated from the hardware implementation, and there are strong arguments in favor of so doing, there is a defined relationship, or binding, sometime during the process. The method of establishing the procedure of a language is strongly associated with its implementation.

3.7.1.1 Control Concepts

Most language control is based upon the use of a program counter to determine the next executable action. This is commonly referred to as a Von Neumann architecture. This Von Neumann model is sometimes classed as the notion of sequential execution. Within this model, several concepts of transferring control across module boundaries have been implemented. From the simplest structure of the single procedure with all control effected by branch instruction, layered systems have evolved with well defined protocols for control transfer. The problem of conceptual management of complex control schemes was recognized and attempts to modify the conditions led to a movement to banish GOTOs. Some concepts for implementing logical control implicit in algorithms are implemented with such statements as "IF THEN" and "WHILE." With the transfer of control across module boundaries, new environments are encountered, each with possibly its own binding. The establishment of a hierarchy of call procedure formally assures compatible environments, even if initialization is required. This is sometimes termed context switching.

Another variation among languages in implementing control concepts is the notion of iterative and recursive. Generally, an action-oriented language like FORTRAN that may use the same algorithm over and over again will be iterative. DO loops are iterative. Other languages such as LISP are recursive and permit modules to call themselves or other modules that may later call them.

As control is passed among modules, there is a need to transfer data across module boundaries. This is sometimes referred to as imported values, such as parameters, or exported values. Two approaches are implemented, one is to provide a copy of the data and the other is for modules to share the same data. An object is said to be accessible from an identifier if there is a chain of references, called an access path, from the identifier to the object. Two identifiers which can access the same object are said to be sharing that object. If an object shared by two identifiers is modified by an access path through one of the identifiers, it affects the value seen by the other identifier. This is called a side effect. The management of side effects is one goal of choosing a language that aids program verification.

As hardware becomes less expensive and greater concurrency of processing is effected, the problem of controlling side effects will increase. Models other than Von Neumann are thought to be more suitable for distributed computing. John Backus, a software consultant at the IBM Research Laboratory in San Jose, California, and one of the creators of the programming language FORTRAN, says the first step is to design non-Von Neumann languages; then computer designers will see how to build non-Von Neumann machines. Alternatives to Von Neumann languages include functional programming and models termed data flow systems.

3.7.1.2 <u>Non-Von Neumann Models</u>

Functional programming (FP), to oversimplify the concept, uses two strategies: 1) The elimination of the heart of the bottleneck in Von Neumann programs--the "assignment" statement, which refers to arithmetic expressions and to storing data in memory and fetching it back; and 2) The introduction of mathematical functions, which are functions of functions and do not refer to specific variables. Therefore, FP programs are not limited to operating only on data in memory cells named by variables.

Data flow models of computation are based on a model of objects and control structure that is fundamentally different from that of conventional (Von Neumann) computers. The notion of "memory-cell-objects" with destructive assignment and accessing by copying is replaced by the notion of "object streams" which flow from one site of computation to another, and from which objects can be entered and removed in a first-in-first-out order. The notion of sequential execution is replaced by the notion of distributed execution of operators whenever there are operands on which the operators may act. Since the only effect of executing an operator is to remove operands from input streams and place results into output streams, side effects are eliminated.

The data flow model is appealing both because it eliminates side effects and because it provides a more direct model for many real-world applications than the Von Neumann model. However, progress in developing computers and languages which directly support data flow computations has been slow. It is not at present clear whether there are inherent problems in the data flow model or whether further research could result in acceptably efficient side-effect-free general purpose data flow computers.

When the sites of a data flow system are substantial computational devices, a data flow system becomes a distributed computing system. The data objects flowing between sites of a distributed computing system are called messages. Distributed computing systems introduce a new set of "communication" research issues, including trade-offs between computing on data objects at the point where they reside or at the point where they are to be used, and issues concerning the updating of multiple copies of data objects in a distributed data base. These issues are not language design issues but must be addressed in the development of mechanisms and languages for data flow computation.

3.7.2 SOFTWARE ISSUES

Within the Space Station there are going to be many needs for software. The operations system concerned with the housekeeping functions have a need. The experimenters and mission users have a need. The on-board principal investigators have another need, often to develop software programs in real time to assist in their experiments. Within this framework several issues must be addressed. Some are:

- o Commonality of software from ground to different configurations of computers on-board.

- o Commonality of software as computer configurations change due to maintenance or failures.

- o Consistency of computational results as comparable software executes on different hardware configurations.

- o Readability - it is recognized that professional programs are read much more often than they are written. It is important therefore to avoid an overly terse notation such as in APL which, although allowing a program to be written down quickly, makes it almost impossible to be read except perhaps by the original author soon after it was written.

- o Programming in the large - mechanism for encapsulation, separate compilation and library management are necessary for the writing of portable and maintainable programs of any size.

- o Exception handling - it is a fact of life that programs of consequence are rarely correct. It is necessary to provide a means whereby a program can be constructed in a layered and partitioned way so that the consequences of errors in one part can be contained.

- o Data abstraction - extra portability and maintainability can be obtained if the details of the representation of data can be kept separate from the specifications of the logical operations on the data.

- o Tasking - for many applications it is important that the program be conceived as a series of parallel activities rather than just as a single sequence of actions. Building appropriate facilities into a language rather than adding them via calls to an operating system gives better portability and reliability.

- o Generic units - in many cases the logic of part of a program is independent of the types of the values being manipulated. A mechanism is therefore necessary for the creation of related pieces of program from a single template. This is particularly useful for the creation of libraries.

- o Configuration control - as the system changes the total software system will also change. Absolute control and traceability must be maintained.

- o Software management responsibility - is this too big and too complex a problem to be assigned to the Space Station? If so, a dedicated ground facility may be required. This facility may include simulation and various code generating support tools.

- o Software requirements - does each major system partition (e.g., operation, mission, mission specific, support) have needs for different kinds of software and language or can a common approach satisfy all?

- Programmer productivity - how important is productivity? Does the need for accurate software overshadow productivity? Can the two requirements be satisfied by the same approaches?

The above list contains a few of the issues that require investigation. Others will certainly surface during the Space Station system design.

3.7.3 OTHER CONCEPTS

The recognition of a link between higher level languages and increased programmer productivity is fostering research into more complex implementations. This is aided by the increasing performance of the hardware to implement the languages. Some concepts from automata theory and artificial intelligence will ultimately influence future high level languages.

The notion of binding time can be viewed from the position of automata theory. An object may carry a type identifier explicitly, or the type could be bound at compile time. In the latter case, one dimension of the information vector, in this case type, was replaced by information in memory. The language remembered the type that was assigned at compile time. Taking this concept one step further introduces context in which information is obtained from the surrounding constructs, usually those preceding, but not essentially so.

Early languages were necessarily quite restrictive in both vocabulary and allowable structure. Hardware was expensive and it was incumbent upon the programmer to conform. Now hardware is cheap and the cost of programming is high. Programming languages must adapt to the needs of the programmer. But there is still a broad gap between the richness of the language in which the programmer thinks and available programming languages. The natural language, being open and allowing for infinite differences in meaning, does not easily translate to the programming language. The natural language uses context to resolve ambiguities. Few programming languages have such capabilities.

3.7.4 SOME SYSTEM CONCEPTS

The total data system concepts must inexorably include software. These include the executable on-board software, the tools to perform the translations from readable code with the ability to convey information to the programmers, and the development tools to generate and verify the code. A significant ground segment to support the software element of the Space Station is envisioned.

3.8 DIRECT BROADCAST

The concept of direct broadcast or at least direct transmission of data from the Space Station to consumers on the ground must be considered. There are precedents with some of the earth observation satellites and ground stations in developing countries which have many rural earth stations. While broadcast communication in the sense of wide area coverage may be neither practical nor desirable for many situations involving the Space Station, there are many compelling reasons why direct communications makes sense. The implementation of such capability will shape the data system requirements. Once the larger need for direct communications is argued and the impact on data system requirements is quantified, additional alternatives of implementation require analysis.

3.8.1. DRIVERS FOR DIRECT COMMUNICATION

There has been a well justified force in the design of low earth orbiting spacecraft communications systems towards a concentrated relay approach using dedicated communications satellites at synchronous altitudes. This approach effectively solved the problem of maintaining nearly continuous communications for satellites in world coverage orbits. Satellite design could be simplified by reducing data buffering. Because of the bandwidths required for those satellites with predominantly imaging sensors, the higher frequency bands and complex ground receivers have been used. Thus the Tracking and Data Relaying Satellite System (TDRSS) with the receiving site at White Sands, NM, has evolved. While the TDRSS and subsequent systems are expected to serve a significant portion of the Space Station communication requirements, other factors require consideration. These factors are:

- o Channel bandwidth requirements may be one to two orders of magnitude greater than planned centralized communications capability
- o As a data generator, the Space Station will be a more heterogeneous source than previous satellites
- o Acquired data will have a significant local interest characteristic

3.8.1.1 Increased Channel Bandwidth Requirement

The Space Station will effectively reduce several constraints that limited total communications bandwidth requirements of earlier satellites, specifically weight and power. Thus there will be a capability for a greater number of sensors and their data taking time will not be subjected to such severe power restrictions. The classic example of a power restriction was the SAR on SEASAT. Conceivably, several active directional sensors could be simultaneously operating on the Space Station. With very large communication requirements, it is desirable to reduce or eliminate all unnecessary links which includes relaying through synchronous satellites and their dedicated ground stations.

3.8.1.2 Heterogeneous Data Source

The Space Station will have a heterogeneous complement of sensors. It will act as a national resource whereby the sensors will be deployed on an as-needed basis. This contrasts to previous satellites with detailed pre-planning for the entire mission. The result is a wide variance in communication channel requirements that would require either a) an undesirable and avoidable restriction on scheduling option, or b) an excessive cost for communication relay channel bandwidth that would be unused much of the time.

3.8.1.3 Parochial Data

Direct communication to the data consumer on the ground over the higher frequency channels is feasible only when a receiver is in sight. Fortunately, in the context of the Space Station as a national resource, the user on the ground with a particular need is likely to be interested in a surface area near his present location. This presupposes that the global information will be supplied in the conventionally evolving way with established processing and data reduction. The data of interest to the parochial user will be the detailed, high information content, unprocessed, near real time data. It may be surrounding ocean and atmosphere measurements or localized topography and weather data intended for special user processing. The data would be acquired only when the Space Station was in the particular location which coincides with the time when direct communication with the ground consumer is feasible. The required high bandwidth communication channels would be very directional and would permit communication with several users without interference.

3.8.2 DATA SYSTEM REQUIREMENTS IMPACT

The obvious requirement additions to serve the direct communications needs are additional antennas, scheduling, and control functions. In satellite communications, wide-area coverage and high antenna gain are generally mutually exclusive. Fortunately, for the Space Station high gain and directivity (with adequate pointing) are desirable. For wide-area coverage, the emerging technology of time division multiple access (TDMA) utilizes a satellite's resources very efficiently, but at a cost of straining today's satellite technology to improve signal gain. High antenna gain is possible using another emerging technology, spot-beam antennas, but their coverage is limited to smaller geographic areas. Now a technique has been found that uses TDMA to provide high antenna gain over a wide area of coverage. This technique is called scanning spot-beam antennas.

Spot beams offer significant advantages in satellite system design. They provide high gain and thus high effective radiated power. Using large-aperture antennas that might be employed in the Space Station, antenna gains as high as 50 db can be realized at 12 GHz. In the United States, particularly on the East Coast and in the South, rain attenuation is particularly severe, and link margins of 15 db or more might be required to ensure that signals exceed the system threshold for all but an hour or two per year. Another advantage of antenna beams is that the same frequency band can be reused several times within the desired coverage region. Offset Cassegrain antenna designs make it possible to form several essentially independent beams with only one large main reflector.

Spot-beam antennas are not without problems, however. It is impossible to reuse the frequency band in contiguous zones, even if orthogonal polarization is employed. Antenna patterns cannot fit together precisely, since they do not have well-defined edges. As a result, more than four independent signal sets may be required, depending upon the degree of interference. To get complete area coverage with spot beams, several sacrifices must be made in terms of available bandwidth or antenna efficiency. Another complication associated with spot beams is that most satellite system designs require redundancy of the power amplifier to build a multibeam of the same capacity.

A scanning spot beam can give total coverage to the entire service area, while still providing the high antenna gain of a spot-beam satellite, by sweeping its beam in synchronism with a time-division format. The advantages are clear: the high gain of a spot beam is combined with the organizational efficiency of TDMA.

For complex sweep patterns involving stochastic transmission time the planning, scheduling, and control requirements will be significant. In addition, the use will basically be asynchronous and consumer initiated, which will require new session access protocols of a type not previously encountered.

3.8.3 ASYNCHRONOUS SESSION ACCESS PROTOCOL

The session access protocol must accommodate spatially dispersed, stochasticly queued channels with heterogeneous bandwidth and error requirements. To be acceptable to the consumer community, the ground stations must be inexpensive. A rudimentary protocol and the system topology is suggested below.

3.8.3.1 Direct Broadcast System Topology

The burden of access and interference control would reside in the Space Station data system. In addition to the necessary work planning, scheduling, pointing, and control system, the Space Station will have multiple antennas. There will be a nondirectional, low bandwidth system for initiating access. Session initiation may originate from both the Space Station and any ground station. The possibility of over-the-horizon session initation has merit for additional investigation. At least two low frequency carrier frequencies for full duplex session initiation operation are recommended. Thus the Space Station and every ground station with a requirement for Space Station initated sessions would continually monitor for session initiation. Each of the ground stations would have a fixed, highly directional antenna suitable for the frequency and bandwidth appropriate to the application. The number of frequencies deployed is subject to additional analysis. Some of the ground stations will have high bandwidth uplink capability also. Generally, half duplex operation of the high rate channels is adequate. Each ground station will have a unique access code.

3.8.3.2 Space Station Initiated Session

For a Space Station initiated session, whether it be for uplink data such as obtaining in situ measurements, or for downlinking predetermined data, the unique access code would be broadcast to all the ground receivers that are in the standby listen mode. Those specifically addressed would respond with an acknowledgement. This low rate communication would use the nondirectional lower frequency channels. The Space Station would have the burden of locating the ground station. Subject to additional trade study, it may be via an on-board table look up of ground station coordinates or by use of a radiated homing signal initiated over the low rate channel. The cone of coverage of the ground station will necessarily be restricted. The parameters require additional analysis to trade-off directivity, error rates, power and total communication interval. The elapsed time for high rate communication will be relatively short. As much as possible, the selection of frequencies and channel coding should precede the high rate communication time window; thus the necessary handshaking should occur over the low rate channel. There will be additional trade-offs in establishing the optimal protocol for error encoding, data acknowledge, and error recovery. On-the-fly error correction will require more bandwidth, but may drastically improve overall system bandwidth because shorter transmission times may be scheduled. Tight scheduling would not allow room for retransmissions. The optimal protocol requires analysis for this peculiar environment.

3.8.3.3 Ground Station Initiated Session

The initiation of communications from the ground stations will have different drivers than the Space Station initiated sessions. There will be two distinct conditions. In the first, the session will be a request for data acquisition which then must be planned, scheduled, and executed. The execution would involve a Space Station initiated session requiring a high rate channel for data delivery. The predecessor session would involve relatively small quantities of data and would use the low rate channel. Only in a relatively few circumstances, would large volumes of data be uplinked from the ground in a ground initiated session. Such conditions should be allowed for but not be permitted to drive the protocol determination. The remainder of this discussion will focus on use of the low rate channel.

Each ground station will have a unique identification code. The Space Station will monitor the uplink frequency for session requests. Some clashes may occur between two adjacent ground stations initiating simultaneous session requests. However, this will be an unlikely and inconsequential condition because of the short message length and unique identification codes. Receipt of a valid code by the Space Station will initiate a full duplex handshake condition. The predetermined protocol for ground station initiation can require a specified monitoring period prior to transmissions. This is analogous to the interrecord gap on a base band data bus. The selection of this and other wait periods must be analyzed to fully utilize the system bandwidth. This protocol determination is beyond the analysis reported in the document.

3.8.4 DIRECT BROADCAST IMPLEMENTATION ALTERNATIVE

Several alternatives were indicated in the previous paragraphs. They are summarized below:

- Optimization of number of SS antenna vs. frequency bands and directionality
- Selection of ground station directionality
- Sizing of session initiation messages and content
- Relationship of error correction coding versus retransmission to scheduling flexibility
- Table look up positioning vs. beacon homing
- Ground station pointing and protocol determination studies

3.9 ON-BOARD DATA ANALYSIS

A function of the Space Station data system that will significantly impact its complexity and operational philosophy is on-board data analysis. This has not been an appreciable function on previous spacecraft although it has its analog in the quick look data system of some ground systems. The justification for on-board data analysis is to permit real time adaptations of experiments, sensors, data acquisition elements, and operational processing to maximize the information acquisition of ephemeral phenomena. A specific instance that illustrates the benefit of on-board analysis would be the acquisition of multispectral images involving both active and passive sensors. For this example, there will be some limited opportunity for acquisition over the designated target area as dictated by the orbital dynamics of the spacecraft. Some sensors may be nadir viewing while others may be the forward or side viewing. Some, such as the visible band sensors, would require relatively cloud free conditions and daylight illumination. The passive microwave sensors could not operate simultaneously with the active microwave sensors. The planning and scheduling of this data acquisition requirement is dependent upon the atmospheric conditions and the segments of the total task that have been already accomplished. On-board quick look assessment will aid the decision to abort or alter data acquisition efforts that are not producing data products of acceptable quality.

3.9.1 QUICK LOOK ANALYSIS SYSTEM CONCEPT

The system concept for implementing quick look on-board analysis is illustrated in Figure 3-7. It should be noted that the system is not sized to accommodate all acquired data. Only a sampling of the data would be duplicated and subjected to quality analysis. This methodology has its analogy in high volume raw material industrial processes where quality control samples are subjected to detailed analysis as an aid to controlling the process. The significant elements in the quick look system are the analysis, human interface and the collateral data components. These components interact to achieve a system performance characterized by the following attributes:

- o Flexible
- o Easy to use
- o High performance

Flexibility is essential because the main purpose of this quick look feature is to provide experimental ability to alter processing algorithms for optimized information capture of the resulting data products. To determine the results of the altered process, the quick look system must be capable of performing it, albeit on a limited data volume.

Easy to use is consistent with the theme for the overall Space Station data system. The on-board crew and users will not be efficiently utilized if their training must be overly concerned with how to manipulate their tools.

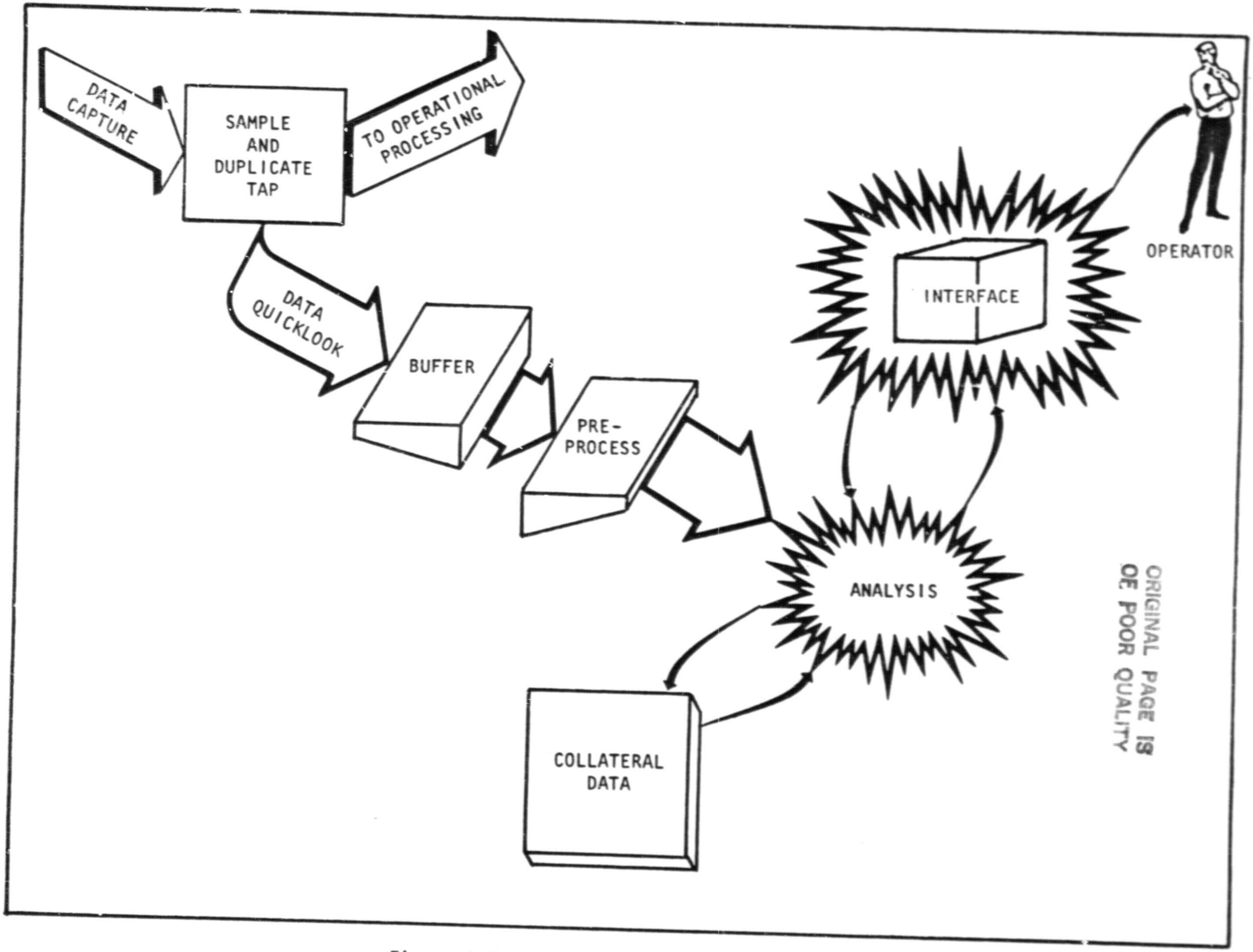

Figure 3-7. On-Board Analysis System

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The value of the human in the Space Station will be to recognize and interpret acquired data. The expected tours of duty are sufficiently short that only a short training period can be tolerated before full performance is achieved. When a system of considerable sophistication and complexity is considered, the human interface must be easy to use.

High performance, within the constraints of limited data volume, is a necessary attribute because of the near real time processing requirement. The value of the function is in its ability to provide the user with useful information with which he may better optimize the acquisition and information extraction process. Thus the information is needed in a timely manner.

To achieve these qualities, automation of functions that have traditionally been performed by humans will be required. These functions will require accessing diverse collateral data bases, making judgmental decisions and inferencing results without having predetermined procedures identified. These disciplines are within the technology of artificial intelligence (AI). Also within AI are techniques for making systems easy to use. Generally these approaches tend toward natural emulation of human functions. Natural language is predominant for these functions.

3.9.2 ARTIFICIAL INTELLIGENCE PARTITIONING

Having introduced notions that have counterparts in AI research, additional applications will be explored. The needed access to collateral data can draw upon techniques of knowledge organization. This is discussed under the heading of self-organizing data bases. There have been several experimental applications involving AI that have potential application to on-board data analysis. These systems have been applied to automated work planning which would aid in sensor selection and scheduling and to data fusion and perception which applies to automating the analysis function directly. Other AI systems in various application domains offer interface features that are applicable. These systems are presently exhibiting natural language processing capabilities or have been applied to explanation and training. Several systems that have been implemented to reason and automatically perform work planning are listed in Table 3-3. There have been several systems developed for so called data fusion or multispectral analysis and feature vector

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Table 3-3. AI Systems for Work Planning

SYSTEM	DEVELOPER	CHARACTERIZING FEATURES
ABSTRIPS	E. Sacerdoti at SRI International	Robot planning using hierarchical search Outlines solution and then develops details
ETHER	MIT	Language suitable for parallel execution Employs pattern directed invocation
GPS	R.M. Kaplan	Parses and generates strings in natural language
IMPLY		Natural deduction theorem prover
INTERPLAN	A. Tate at University of Edinburgh	Planning and problem solving system
KNOBS	MITRE Corporation	Uses knowledge bases stored as frames Deductively backward chains using production rules
NOAH	E. Sacerdoti at SRI International	Robot planning using backward chaining to assign time ordering
NUDGE	I. Goldstein & R. Roberts at MIT	Office scheduling, accommodates incomplete and inconsistent requirements using frame based sematics
PLANNER	C. Hewitt at MIT	Goal directed reasoning and problem solving language Designed but only partially implemented
SNIFFER	R. Fikes & G. Hendrix	Theorem prover and deductive system for planning data base searches
SODA	SRI International	Intelligent data access system that plans access paths
STRIPS	R. Fikes & N. Nilson at SRI International	Theorem proving problem solver for planning robot tasks that searches world space for achievable goals
WARPLAN	D. Warren at University of Edinburgh	Plan generating system
WHISPER	B. Funt at University of British Columbia	Reasoning system using analog diagrams

extraction. Some are directed toward extraction of spatial information to identify objects. Some have particular capabilities to learn what is significant in scenes to extract classification information. Others automatically apply classification techniques to a variety of data inputs. The systems have been directed towards easy use and manipulation of the data. These systems are listed in Table 3-4.

Table 3-4. AI Systems for Perception and Data Fusion

Perception	Learning	Interpreting	Interactive Aids
ACORN	AQ11	BETA	AIPS
AQVAL	CLS	Dipmeter Advisor	HAWKEYE
INTERPRET	CRAPS	MSIS	
POLY	ID3	MSYS	
VISIONS	INDUCE	SLAP	
		SU/X (HASP)	
		TATR	

3.10 GROUND SUPPORT

Ground support for the Space Station will take on a much broader role than with previous spacecraft. Due to the indefinite lifetime with regular resupply, the ground support facility will be a regularly functioning node in the total system, managing, storing and processing products ranging from raw material to logistic supplies to data. The development of these details is a normal function of system definition which is not addressed in this report. These functions are identified in Appendix A.

Of major concern is the ability to streamline and accommodate the requirements analysis, system engineering, and software development activities as continuing elements in the entire operating process of the Space Station system. These activities have been discrete planning and engineering functions in the life of previous satellite programs. The concept considered here is to relegate these functions to operating elements in a continuous process "pipeline." By planning these functions as an integral part of the total system, knowledge acquired during the early design phases will assure ready transfer to subsequently evolving systems. This concept is depicted in Figure 3-8.

3.10.1 SPACE STATION SYSTEM ELEMENT LIFE CYCLE

In the most general sense, the Space Station will comprise a collection of system elements. Each element may be represented as a black box with interfaces and the capability to exert influences on those interfaces. In reality, the boxes may be hardware, software, or combinations. The significance is that each of these elements has a definite life cycle through which certain metamorphosis may take place. Each element has at least a seminal genesis in the perceived need to do something. These perceived needs are usually called user requirements. They are also usually vague, incomplete and, when considered in total, conflicting. The process of resolving conflicts, completing the definition, and maintaining traceability is called requirements analysis. It is a labor intensive process utilizing highly skilled personnel. The resulting requirements comprise a system specification which is subjected to extensive engineering analysis to produce system design, functional partitioning, hardware and software partitions, and detailed specifications. Again, this is labor intensive utilizing skilled resources. By systematizing the process with compatible centralized data management, each of the system elements can be consistently analyzed and the benefits of modern analysis tools can be made available to everyone working on the system. At any given instant, system elements will exist in various stages of the process. New or altered requirements will be generated during the engineering process and later during on-board operations. Ultimately, the resulting optimized partitions will find their way into implementable hardware and software. Along the way, test, verification and operating procedures will be developed. The result will be a factory for supporting the present flight portion of the Space Station system.

3.10.2 CRITICAL ELEMENTS

The support system outlined in Figure 3-8 has some critical elements that are not restricted to a particular segment of the process. They are primarily concerned with the management of large heterogeneous data bases and the

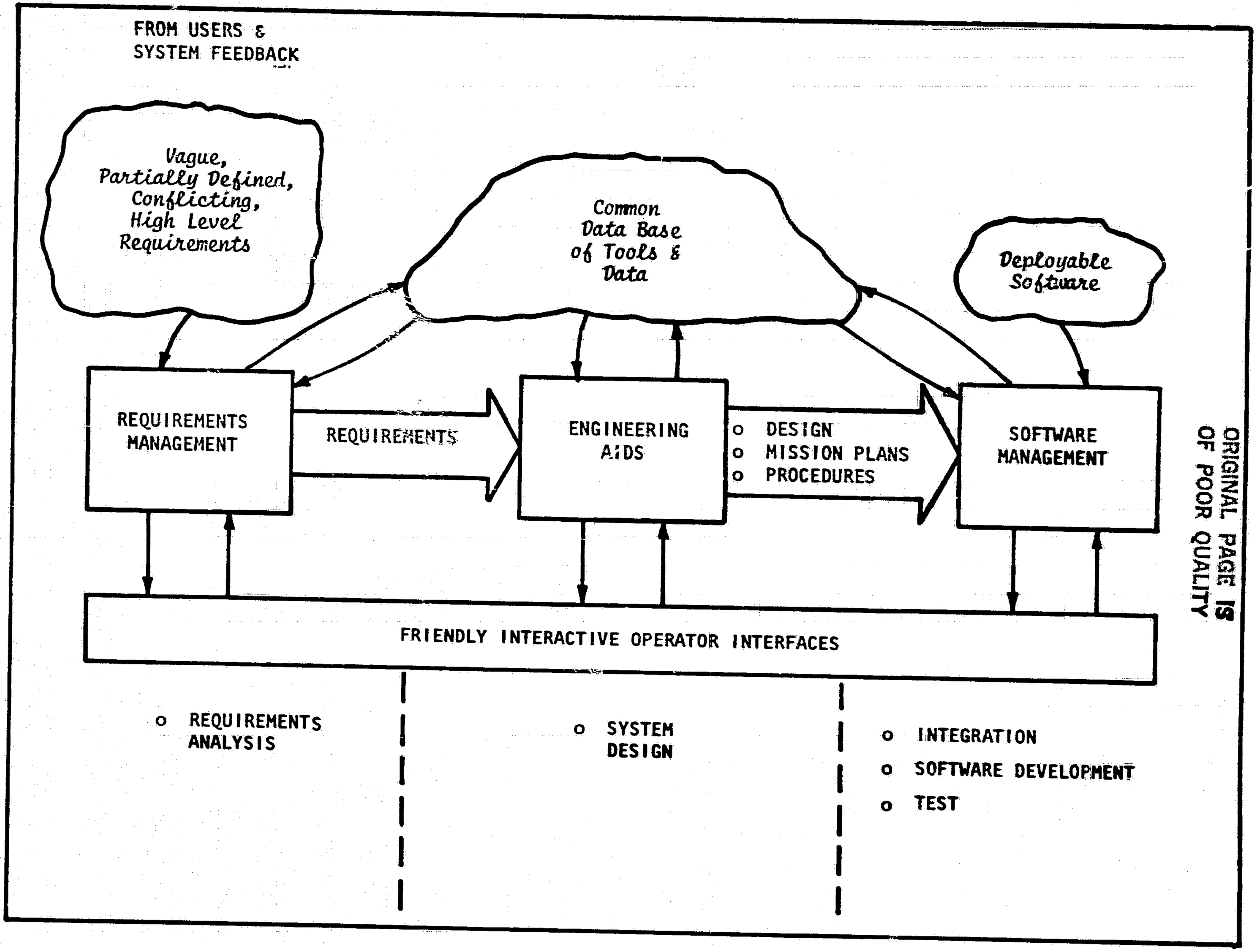

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Figure 3-8. Integrated Ground Support System friendly interface with the operators. Both of these concepts are discussed elsewhere.

3.10.3 REQUIREMENTS MANAGEMENT SUPPORT

The key feature of the requirements management elements is the recognition that the initial requirements will be vague, partially defined, and conflicting. The system should be capable of accepting such requirements and transforming them into complete requirements. This transformation will require a series of separate but cooperating subsystem specialists. Such concepts have been successfully employed in expert systems such as ETHER, HEARSAY III, PSI, and SAFE. ETHER and HEARSAY III are both general purpose and might be directly applicable. PSI and SAFE are both systems in the domain of automatic programming, but exhibit concepts that are applicable in the requirements management domain. These systems are further identified in Table 3-5. A rudimentary concept of the requirements management system is sketched in Figure 3-9. Natural language processing, interaction with the operators, and the many knowledge-bases are implicit. Only major components are identified.

3.10.3.1 Requirement Recognition

The first component of a requirement management system is the recognition of a requirement. The input format should be easy and natural. Many of the human friendly natural language interfaces addressed elsewhere are appropriate. Beyond that, there is the need to accept anaphoric reference and the vast amount of information implied by context. The conceived systems are rich in contextual information because the environment is the Space Station and references to the particular experiment or subsystem involved. Systems such as COOP, GUS, JETS, NUDGE, and QUIST provide good prototypes and models for inferring meaning. These systems are further identified in Table 3-6. Many of these systems were developed for the domain of data retrieval. Nevertheless, they have features applicable to recognizing requirements. COOP is capable of detecting violations between a user's presumption and a present state and then formulating correct, indirect, and more informative responses. This is a desirable feature to rapidly resolve ambiguities interactively, over and above the friendly interface components. GUS uses knowledge frames, much like scripts, to infer missing information based on what is expected for usual

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Table 3-5. Systems Utilizing Independent but Cooperating Subsystem Specialists

SYSTEM	DEVELOPER	CHARACTERIZING FEATURES	ADDITIONAL INFORMATION
ETHER	W.A. Kornfeld at MIT	A language for constructing problem solving systems for parallel execution. It employs "pattern directed invocation" which means procedures are called by what they do rather than by name. Other concepts are "sprites," "activities," and "stifles." A sprite consists of a pattern and a body. When a sprite is created, it watches for assertions that match its pattern and when that occurs, executes the body. The body may also create sprites and broadcast assertions. Activities may be considered as a package of subgoals and when a goal is achieved by some sprite, a sprite within the activity recognizes that the goal was achieved and broadcasts a stifle which stops the execution of the other sprites.	W.A. Kornfeld "ETHER - A Parallel Problem Solving System," 6 IJCAI, 1979, pp. 490-492 and masters thesis at MIT - Using Parallel Processing for Problem Solving, May 1979.
HEARSAY-III	USC/Information Science Institute based on earlier HEARSAY projects at CMU	A generalized domain independent extension of HEARSAY II. It includes a "context" mechanism and an elaborate "blackboard" and scheduler to permit increased cooperation among the separate knowledge sources. The major design ideas of HEARSAY are: separate, independent, anonymous, knowledge sources that allow efficient modification; self activating, asynchronous, parallel processes; globally accessed data base; i.e. the "blackboard;" and data directed knowledge invocation.	Barr 1, Vol. 1, pp. 343-348, L. Erman et al. "The HEARSAY II Speech Understanding System; Integrating Knowledge to Resolve Uncertainty". Computing Surveys, Vol. 12, 1980, pp. 213-253.
PSI	Cordell Green and colleagues at Stanford University	An automatic programming system that integrates several more specialized knowledge-based systems, each an expert module. A program is specified by means of an interactive, mixed initiative dialogue, which may include partial specifications by examples of input/output pairs or by traces. A PARSER/INTERPRETER, EXPLAINER, DIALOGUE MODERATOR, AND EXAMPLE/TRACE INFERENCE cooperate with the user to construct a program net that describes the desired program. Then the PROGRAM-MODEL BUILDER module converts the net into a complete, consistent description of the program, called the program model. Next, the CODING and EFFICIENCY modules, through repeated transformations, convert the program model into an efficient implementation in the target language.	C. Green, "A Summary of the PSI Program Synthesis System," 5 IJCAI, 1977, pp. 380-381. Barr 1, Vol. 2, pp. 326-331.
SAFE	Robert Balzer, Neil Goldman, David Wile, and Charles Williams at USC/Information Science Institute	An automatic programming system that accepts incomplete specifications in constrained preparsed English and using knowledge-base of constraints, problem domain knowledge, and some user interaction, resolves ambiguities, generates missing information, and produces a high level complete program specification in the language AP2.	Barr 1, Vol. 2, pp. 336-342 Balzer et al. "Principles of Good Software Sepcifications and Their Implications for Sepcification Languages," Proc IEEE Specification of Reliable Software Conf., Cambridge, MA, 1979.

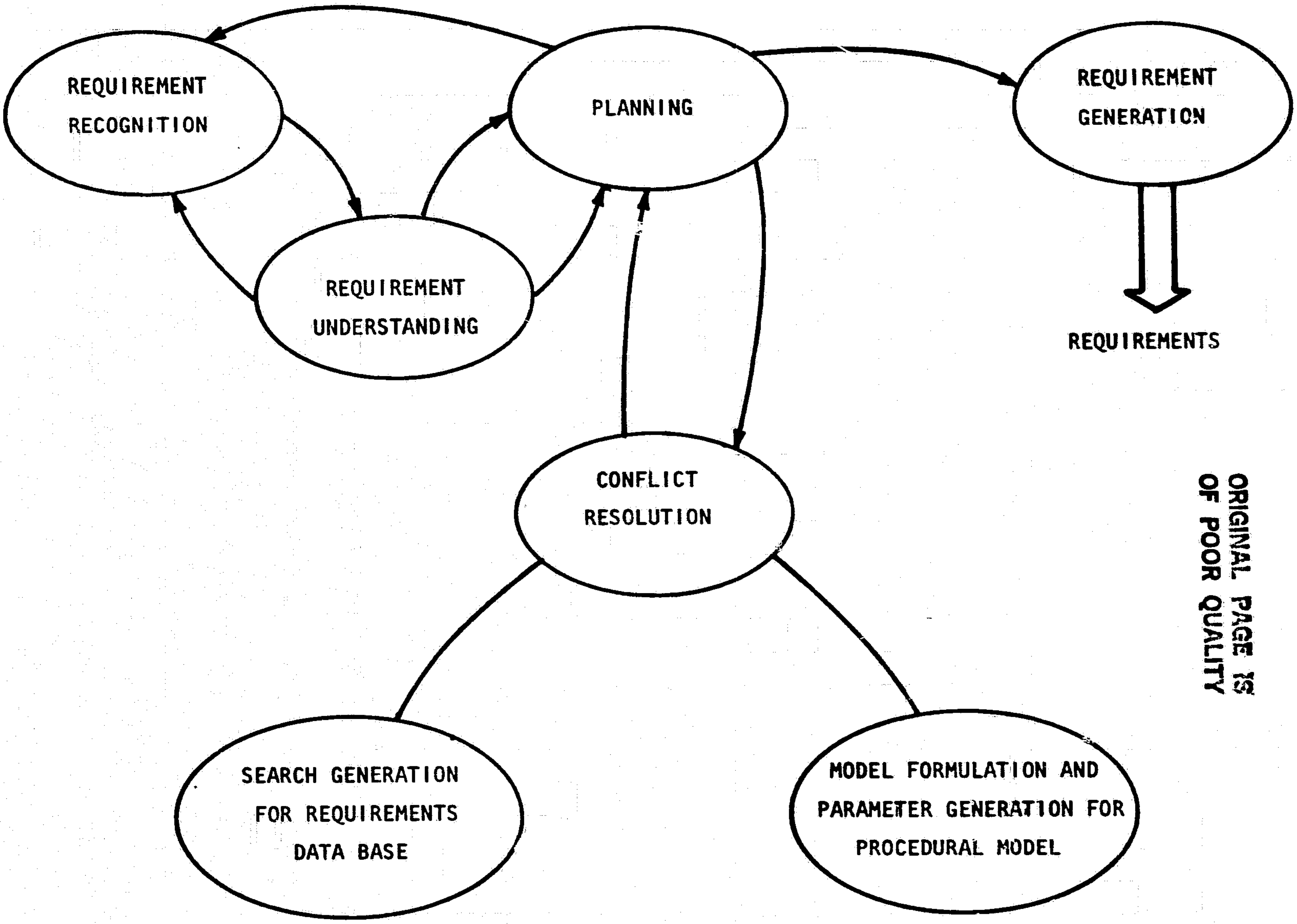

Figure 3-9. Sketch of Requirement Management System

Table 3-6. Systems that are Models for Requirement Recognition

SYSTEM	DEVELOPER	REFERENCE
COOP	S. J. Kaplan University of Pennsylvania	Kaplan, Cooperative Responses from a Portable Natural Language Data Base Query System
GUS	D. G. Bobrow R. M. Kaplan M. Kay D. A. Norman H. Thompson T. Winograd	Bobrow et al. "GUS, A frame driven dialog system," Artificial Intelligence 8, 1977, pp. 155-173
JETS	Tim Finin Bradley Goodman Harry Tennt at U of IL	Finin et al. "JETS: Achieving Completeness through Coverage and Closure," 6 IJCAI, 1979, pp. 275-281
NUDGE	Ira Goldstein Bruce Roberts at at MIT	Goldstein et al. "NUDGE, A knowledge-based scheduling program," 5 IJCAI, 1977, pp. 257-264
QUIST	J. J. King at Stanford University	J. J. King, Query Optimization by Semantic Reasoning, Doctoral dissertation, Report No. CS-81-857, Stanford University, 1981

properties of known concepts and what typically happens in familiar situations. JETS specifically addresses difficulties of anaphoric references, ellipses, and other context dependent deletions. NUDGE is a front end for conventional scheduling programs that accepts and understands incomplete and inconsistent requests. It also uses frame-based semantics to resolve anaphoric requests. QUIST is directed toward data base accesses and improves the execution by using semantic constraint information available from the data base schema.

3.10.3.2 Requirement Understanding

The marked deviation of the conceived system from more conventional requirements management systems is that this system understands the requirements rather than merely manipulating and keeping track of them. Every requirement will be referenced and translated into an internal representation. This is conceptual dependency. This idea was advocated by R.C. Schank (Schank 5). Meaning is encoded by decomposition into a small set of primitive actors with actions and objects. This concept is used in several of the knowledge representation systems and languages such as FRL, KLONE, KRL, KRS, NETL, RLL, SYSP and UNITS. These are discussed under the data management topics. Knowledge in the understanding portion of the system would aid the requirement recognition process. The recognition portion would be activated for clarification when the understanding portion failed. The objective of the understanding portion is to identify unambiguous requirements. They may still be incomplete and conflicting. A system that offers an applicable model for this portion is SAM. SAM (Script Applier Mechanism) is a program developed by Roger Schank, Robert Abelson, and their students at Yale University to demonstrate the use of scripts in understanding stories. Conceptual dependency representations are manipulated using scripts to establish the context of events. Scripts are frame-like data structures that provide stereotyped sequences of events that may be considered usual behavior in a particular context. SAM comprises three parts: PARSER that accepts English input and transforms it to conceptual dependency representation, MEMTOK that makes inferences, and APPLY that applies the script. For additional reference, see (Barr 1) and (Schank 4).

3.10.3.3 Requirements Planning

The next portion of the system has the goal of developing complete, detailed requirements. There are combinations of approaches to performing these tasks that have precedence in several systems. These are planning systems, particularly in the robotic domain. Examples are INTERPLAN, MICROPLANNER, NOAH, PLANNER, and WARPLAN. Other systems hypothesize a solution and then prove it. Given an overall requirement, based upon knowledge in the knowledge-base or inferred knowledge, additional subgoals will be generated or discovered by search. In some cases the subgoals will not complete the goal path but will advance the present state closer to the goal leaving the complete solution to other attempts. Some systems using theorem proving approaches are GPS, IMPLY, and QA. The generation of a complete chain of subgoals is analogous to the generation of complete requirements. Consequently, the indicated systems offer models for the planning portion of the system. A further identification of planning, problem-solving, and theorem proving systems is provided on Table 3-7.

3.10.3.4 Conflict Resolution

Having complete unambiguous requirements is not the end of requirements management. These will originate from many sources and have different times during which they will remain valid. Individually, there will be conflicts which the next portion of the system will attempt to resolve. In effect, there will be many sets of requirements for the Space Station according to an associated time line. The result of the good and complete requirements will be a large data base. The only concern in the discussion is the need for tools or a system to formulate searches within that data base. The conflict resolution portions will involve search mechanisms for needed data. It will also involve an interface to more conventional, yet still not commonplace, requirement management tools such as SREM (TRW 2, GE 4). The conflict resolution portion of the system will itself be an expert system. Production systems constructed using languages and system structures such as EMYCIN, MOLGEN, OPS and OWL are appropriate for this portion of the system. For additional information on these systems, see Table 3-8.

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Table 3-7. Planning, Problem Solving, and Theorem Proving Systems

SYSTEM	DEVELOPER	REFERENCE
GPS	A. Newell, J. Shaw, H. Simon	Barr 1, Vol 1, pp. 113-118 G. Ernst and A. Newell, GPS; A Case Study in Generality and Problem Solving, New York, 1969, Academic Press
IMPLY	W. Bledsoe and M. Tyson of University of Texas	Cohen 1, pp. 94-101 Bledsoe
INTERPLAN	A. Tate at University of Edinburgh	A. Tate,"Interacting Goals and Their Use", 4 IJCAI, 1975, pp. 215-218
MICROPLANNER	G. Sussman, T. Winograd, E. Charniak at MIT	G. Sussman et al., MICROPLANNER Reference Manual, MIT AI Memo No. 203A, 1971
NOAH	C. Sacerdoti at SRI International	Cohen 1, pp. 541-550
PLANNER	C. Hewitt at MIT	C. Hewitt, "PLANNER: A Language for Proving Theorems in Robots" Proc 1 IJCAI, 1969, pp. 295-301
QA	C. Green and Colleagues	J. Rulifson, J. Waldinger, and J. Perkson "A Language for Writing Problem Solving Programs", Proc of AFIPS Congress 1971, Ljubljana, Yugoslavia
WARPLAN	D. Warren at University of Edinburgh	D. Warren, WARPLAN: A System for Generating Plans, Department of Computational Logic, Memo No. 76, University of Edinburgh, June 1979

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Table 3-8. Some Basis Systems for the Conflict Resolution Subsystem

SYSTEM	DEVELOPER	CHARACTERIZING FEATURES	REFERENCE
EMYCIN	Stanford University	A goal directed backward chaining production system framework with extensive explanation and knowledge acquisition capability.	W. VanMelle, "A domain independent production rule system for consultation programs", 6 IJCAI, 1979, pp. 923-925
MOLGEN	M. Stefik, J. Lederberg, Nancy Martin, Peter Friedland at Stanford University	A frame and semantic network based system in the genetics domain that utilizes interactive knowledge bases.	M. Stefik "An examination of a frame structured representation system", 6 IJCAI, 1979 pp. 845-852
OPS	C.L. Forgy and J. McCarthy at CMU	A production system with features for capturing self augmentation (learning) and achieving performance efficiency by limiting size of current memory.	Forgy and McDermott, "OPS - A domain independent production system language" 5 IJCAI, 1977, pp. 933-939
OWL	William Martin at MIT	A knowledge representation language and structure closely aligned with English. Primarily applied in medical domain but applicable to others.	W. Martin, An Overview of OWL, A Language for Knowledge Representation, Technical Report MIT/LCS/TM-86, MIT Jun 1977

3.10.3.5 Requirement Generation

The final step in requirement production is the generation of the requirements in the consistent compatible format with the other portions of the overall system. Some of the production system features applicable to conflict resolution may also be applicable to this portion of the system. Implicit in the total process is a management of the many sets of requirements, each with a different time value. This requirement generation portion has the objective of pr·viding the requirements in the proper format. Throughout the process, human interaction and changes are anticipated. Traceability and ease of verification are overall goals.

3.10.4 ENGINEERING AIDS

Once requirements are defined, the system engineering process begins. The concept illustrated in Figure 3-8 has the effect of integrating the many data products and tools into a consistent format for easy repetitive flow through the system with a minimum of human translation. Many of the tools such as the various structured analysis programs, loading and scheduling programs, and simulators are large and cumbersome. Aids to the use of these tools would be incorporated. An example of a successful application of intelligent aids is SACON. SACON is an expert system in the engineering domain developed by James S. Bennett and Robert S. Englemore at the Heuristic Programming Project, Stanford University. It was built using EMYCIN as its framework. SACON provides automatic consultation to engineers in the use of a structural analysis program, MARC. MARC uses finite-element analysis techniques to simulate the mechanical behavior of objects. The user of MARC knows what is desired but does not know how to set up the program. A year of experience is typical of the time required to learn how to use all of MARC's options proficiently. SACON recommends an analysis strategy to guide the MARC user in the choice of specific input data, numerical methods, and material properties. The system contains some 160 rules and 50 attributes, half of which are concluded by the rules. SACON is described by Bennett and Englemore in the <u>6 IJCAI</u>, pages 47 to 49, "SACON": A knowledge-based consultant for structural analysis."

The list of engineering aids can be quite extensive and is not developed in this report. However, mathematical tools, physical knowledge assistance, and simulators are all candidates. A general purpose simulation system such as Data System Dynamic Simulation (DSDS) (Geer 1, Golden 1), will provide the next step in the system design process. System functions can be simulated without forcing the hardware/software partition. Mission timelines can be developed and when necessary, requirements can be altered for an additional pass through the system.

The output of this portion of the overall system will be the Space Station system design, mission plan, procedures, and all the accompanying documentation. Some data formats will be directly compatible with computer aided design, manufacture, and test. For software, the specifications will be sufficient for direct implementation by the software management system.

3.10.5 SOFTWARE MANAGEMENT

The software management system has the management of all the specified software elements of the Space Station system as its objective. There will be many sets of software as the system evolves. An exact duplicate simulation, or model of the current system, along with the necessary simulation of the hardware environment will be included in this portion of the ground support. Capability to re-enact historical configurations will be required for some post event analyses. Many versions of future configurations will be required to assure that problems will not be introduced when computer software is changed while the Space Station is operational. As a goal toward the consistent generation of reliable computer software, automatic programming systems have future potential.

Automatic programming has taken on a variety of definitions as attempts have been made to relieve the programmer of some of the burden in order to improve productivity. The first FORTRAN compiler was regarded as "automatic programming" in 1954. Today, when most programming is done in high level languages, automatic programming implies an even more advanced programming environment. Since programmers are usually considered to exhibit intelligent features in the performance of their work, it is rational that attempts to automate more of this work involve AI research. An entire chapter in Volume 2 of the <u>Handbook of Artificial Intelligence</u> is devoted to automatic programming (Barr 1).

Early automatic programming systems were predominently based on theorem proving. Others concentrated on program transformation which is not too different from compiler optimizers in the traditional sense. The introduction of knowledge engineering, especially knowledge about programming and the domain, has greatly improved the potential for automatic programming.

Another conceptual approach is automatic data structure selection. It allows the selection of efficient, low-level data structure implementation without incurring the penalty of the abstract data types that are default implemented by most compilers as a compromise between efficient implementation and likely users. Other approaches are traditional problem-solving using heuristics and induction methods for inference, program from examples, input/output pairs, or incomplete specifications used in conjunction with the domain knowledge-base. Some automatic programming systems that implement concepts with potential application to the software management system are indicated in the following paragraphs.

3.10.5.1 PSI and CHI

PSI and CHI are automatic programming systems that are presently considered to have achieved the greatest degree of success and generality. PSI is a knowledge-based system that integrates several concepts. It was developed by Cordell Green and his colleagues at Stanford University. A program is specified by means of an interactive, mixed initiative dialogue, which may include partial specifications by examples of input/output pairs or by traces. A PARSER/INTERPRETER, EXPLAINER, DIALOGUE MODERATOR, and EXAMPLE/TRACE INFERENCE cooperate with the user to construct a program net that describes the desired program. Then the PROGRAM-MODEL BUILDER module converts the net into a complete, consistent description of the program, called the program model. Next, the CODING and EFFICIENCY modules, through repeated transformations, convert the program model into an efficient implementation in the target language. (Ginsparg, Steinberg, Phillips, McCune, Barstow 4, Green 1). This approach of integrating cooperating specialists is appealing for the Space Station environment because many of the knowledge domains can be predetermined and segmented along lines of space system discipline, applications, and Space Station subsystems.

CHI (Green 2, Kedzierski) is of interest to the Space Station software management system because it is an extension of PSI with an emphasis on the environment. It uses the very high level, wide spectrum language "V" for specifying both programs and programming knowledge. The CHI project would also serve as a convenient paradigm for the extension and application of a complex system like PSI to a different environment (i.e. Space Station).

3.10.5.2 PECOS

PECOS (Barstow 1,2,3) is of special interest because it is the automatic coding expert in PSI at Stanford University. PECOS is a dynamic transformation system that has a knowledge-base of transformation rules. It begins with a complete specification and, through repeated selection and application of the rules, a gradual refinement process results in an implementation in a target language. PECOS works on symbolic programming, originally LISP. It is of special interest because it operates in a stand-alone mode and Schlumberger Ltd. has ported it for applications of generating and maintaining FORTRAN programs.

3.10.5.3 SAFE

The fourth system of special interest to Space Station automatic programming is SAFE (Balzer 1,2,3,4) because it is an extensive system that treats the problem as two subproblems. The first part is the development of detailed specifications in a high level program specification languages, AP2. The second part is the optimization of that program specification. The unaddressed part is code generation which can be similar to the final stage of conventional compilers.

The SAFE system views automatic programming as a production of a program from a description of the desired behavior of that program. The system accepts a program specification comprising preparsed English, including terms from the problem domain. They can be incomplete and ambiguous. It is not necessary to describe the algorithm of how a transformation is to be accomplished, only what is to be accomplished. The system has internal mechanisms to account for efficiency and other concerns for data representation protocol, resource utilization, et cetera.

3.10.5.4 Other Automatic Programming Systems

Other systems with specific interest for this application are PHENARETE, Programmer's Apprentice, AURA, ACE, and HACKER. Each has some concepts of particular merit. PHENARETE (Wertz) is a program debugging aid. It accepts incompletely defined LISP programs, evaluates them, and using a library of rules and specialist modules, fixes them. It uses a specialist module for each function and it also provides explanations of what it did and why. The system is also applicable to PASCAL and ALPHARD.

Programmer's Apprentice (Rich) is an interactive system for helping programmers with the task of programming. The system may be conceived as midway between an aid to improved programming methodology and an automatic programming system. A programmer and the apprentice work together through all phases of the development and maintenance of a program. The programmer does the difficult parts of design and implementation, while the apprentice acts as junior partner and critic, keeping track of details, and assisting in documentation, debugging, and modifications. The emphasis is on the ability of the programmer's apprentice to understand the program.

AURA is an AUtomated Reasoning Assistant and automatic programming aid developed at Argonne National Laboratory and Northern Illinois University.

ACE, Application Coding Expert, is a program initiated in 1982 by Pierro P. Bonissone and John W. Lewis of General Electric Corporate Research and Development Laboratory at Schenectady, NY. This program has an objective to develop an implementable conceptual model which will enable the average programmer to approach expert programmer performance in particular applications domains. The system accepts natural language requirements which are parsed and built into a partial conceptual model. Interactively, missing components are requested and checked for completeness. The resulting requirements specifications are then matched with implementation frames from a knowledge-base. The system constructs plans for the software program from the knowledge-base and interactive "customs" which do not yet have a counterpart in the knowledge-base. The resulting plans are subjected to additional analysis using other rules to diagnose errors and suggest optimization.

HACKER is a system built by G. J. Sussman in an attempt at automatic programming. It is based upon the heuristic compiler of H. A. Simon which regards the task of writing a computer program as a problem-solving process. HACKER generates "buggy" code without detailed planning, detects and generalizes the bugs, and then defines appropriate operators to resolve them. Some features incorporated in HACKER are: learning through practice how to write and debug programs; modular, pattern-invoked expert procedures, i.e. chunks of procedural knowledge; and hypothetical world models for subgoal analysis.

SECTION 4
TECHNOLOGY NEEDS

The distribution of data system functions and the corresponding control in varying degrees of autonomous operations will require development and evaluation of key concepts prior to commitment in the system architecture. The desirability of those concepts will be subjected to continuing analysis as the Space Station program evolves. The effort and risk of using them will be a factor in assessing that desirability. This section provides an initial précis of the presently perceived technology needs should the subsequent analysis of the concepts indicate that the concept is desirable.

Based on the early analysis, the driving factor for technology needs appears to be automation, in particular, the automation of data management functions. This is not too surprising since automation of other functions has been pursued for some time. It is only recently that serious attempts were made to employ automation techniques, because the data management problem was perceived as unmanageable using traditional labor intensive techniques.

Those candidate technologies and their characteristics are listed in Table 4-1 and are briefly described in the remainder of this section.

4.1 AUTOMATED WORK PLANNING AND SCHEDULING

In present day usage, "command management" is restricted to the transformation of general requests for spacecraft operations into minutely detailed operational plans. Within the context of today's spacecraft, these plans contain an enormous amount of information including complete and, at times, minutely detailed spacecraft position attitude descriptions, and communications contact description. Spacecraft configuration information including all the specific spacecraft commands with specific command execution conditions, instructions to ground system personnel, time lines, histories, various verification products (e.g., computer images), and measures of spacecraft performance, health, safety and efficiency is also contained in the operational plans. This planning is accomplished by using a formal Command Management System (CMS) which provides the Mission Operational Control Center (MOCC) with sequences of spacecraft commands. These spacecraft command

Table 4-1. Candidate Technology Developments Required

Title	Anticipated Need or Benefit
Automated Work Planning and Scheduling	Needed to perform command management.
Requirement Management System	Needed to reduce manpower and assure completeness of changing requirements and pseudo-real time implementation.
Engineering Aids	Needed to reduce time to verify and implement changing configurations as missions and requirements change.
Software Management System	Needed to reduce risk and cost of implementing software changes in operational system.
System of Self-Organizing Data Base	Needed to support changing mix of operational and applications data and requirements.
Human to Data System Intelligent Interface	Expected complexity of data system requires a simplified interface to free humans for their primary roles.
Automatic Configuring Computer Bus and Operating System	Inherently required in architecture identified. Facilitates upgrades and flexibility without impacting software.
Space Qualified Large Screen Display	Multiple sensor data will have utility for several crew members. Desirable not to restrict their physical movement.
Qualification System for Data System Components	Multiple users will benefit by being able to bring along modules. Safety and costs are prime drivers.
Direct Broadcast	High bandwidth communications. Data of parochial interest.

sequences are derived from general requests for specific operations made by experimenters, mission operations personnel or mission support personnel. The CMS performs all of the functions necessary to transform these general requests into detailed operational plans including all of the general and special output products. This assures safe, efficient, and coordinated spacecraft operations.

In the present system with a large number of free flyers, each directed toward single or relatively few missions, there are a large number of specialized CMSs. The size, nature, complexity, and operational characteristics of each CMS are determined by a large number of highly variable spacecraft, mission, and operational characteristics; consequently, each CMS is highly tailored to the individual mission.

Within the context of free flyer systems, ORI has classified CMSs and the categories of functions performed. These are reported in (Rogers 1). The functions are listed in Table 4-2. Within this same report, four types of CMSs were identified with type 4 having the greatest complexity. The classification system is repeated as Table 4-3.

Table 4-2. Major Categories of Functions Performed by CMS

1.	User Interactive Communications Functions (User Oriented Language)
2.	Edit Functions
3.	Maneuver Related Functions
4.	Command Sequence Generation
5.	Constraints Consideration
6.	Command Memory Management
7.	Simulation and Training Functions

For the Space Station, the challenge becomes one of implementing a CMS with all the attributes of type 4 but in a far greater degree. There will be a multiplicity of users and missions not necessarily related in any commonality other than the ability to share the same orbital position in space. The sustained operations have a related indefinite lifetime. There will be many more constraints. The systems will be more autonomous and will have greater functionality. There will be a near real time requirement. The culminating

Table 4-3. Attributes which Determine the Type of CMS

Type 1	o	A single on-board memory
	o	Nearly all commands result from explicit user requests
	o	Only five basic functions: a) input editing, b) merging, c) assembling, d) fabrication, and e) output interfacing
	o	Prescribed contact stations
Type 2	o	Modeling of command sequencing logic required
	o	Some modeling required to determine commands
	o	Dynamic management of on-board memory regions provided
Type 3	o	Coordination of several experiments
	o	Spacecraft controlled by separate on-board computer
	o	Experiments contain microcomputers or command memories
	o	Coordinate functions for many experiments
	o	Limited 3-axis pointing by command
	o	Some constraints checking
Type 4	o	High-fidelity modeling of spacecraft subsystems
	o	Sustained spacecraft operations
	o	Extensive constraints modeling
	o	Continuous 3-axis pointing by command
	o	Interfacing and coordinating with several users

difficulty is the desire to provide on-board autonomy, which means a significant portion of the CMS must be on-board the Space Station.

4.1.1 ISSUES OF AUTOMATED COMMAND MANAGEMENT

Some of the issues associated with automating command management for near real time on-board command acceptance, generation, and execution are listed in Table 4-4.

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Table 4-4. Issues of Command Management

o	What partitioning and priority of requests for commands should be implemented?
o	How much autonomy can be vested in individual subsystems to off-load the burden on the CMS?
o	To what extent can the on-board CMS be dependent upon ground support?
o	Is it really impossible to implement CMS in the traditional algorithmic approach?

4.1.1.1 Partitioning and Priority

Some of the partitioning and prioritizing categories of command origination are: the commander and other humans responsible for the well being of the Space Station and its missions, ground personnel with similar responsibilities, automatically operating subsystems on the Space Station or in ground segments, on-board mission specialists and crew members, on-board principal investigators, official ground-based Space Station personnel, and other individual ground investigators. Each of these sources of command initiation and constraints must be considered. Within each source, differing criticality and timeliness requirements are expected. The concept of direct experimenter interaction with the space-borne sensors has been identified but merely from the viewpoint of the user and not the implementor of the CMS. A scenario whereby artificial intelligence is incorporated in a direct user interaction CMS is illustrated in Figure 4-1.

4.1.1.2 Hierarchical Distribution

The off-loading of detailed microcommand generation to individual subsystems is in keeping with the hierarchical control concept which is successful for complex systems, whether army, government, business, or biological organisms. The hierarchical control concept is workable when the system has a high degree of capability or "intelligence," which is the condition being approached for the autonomous Space Station data system. The command and control structure for such systems is invariably a hierarchy wherein goals or tasks selected at the highest level are decomposed into sequences of subtasks which are passed to the next lower level in the hierarchy. This same procedure is repeated at each level until, at the bottom of the hierarchy, a sequence of primitive tasks

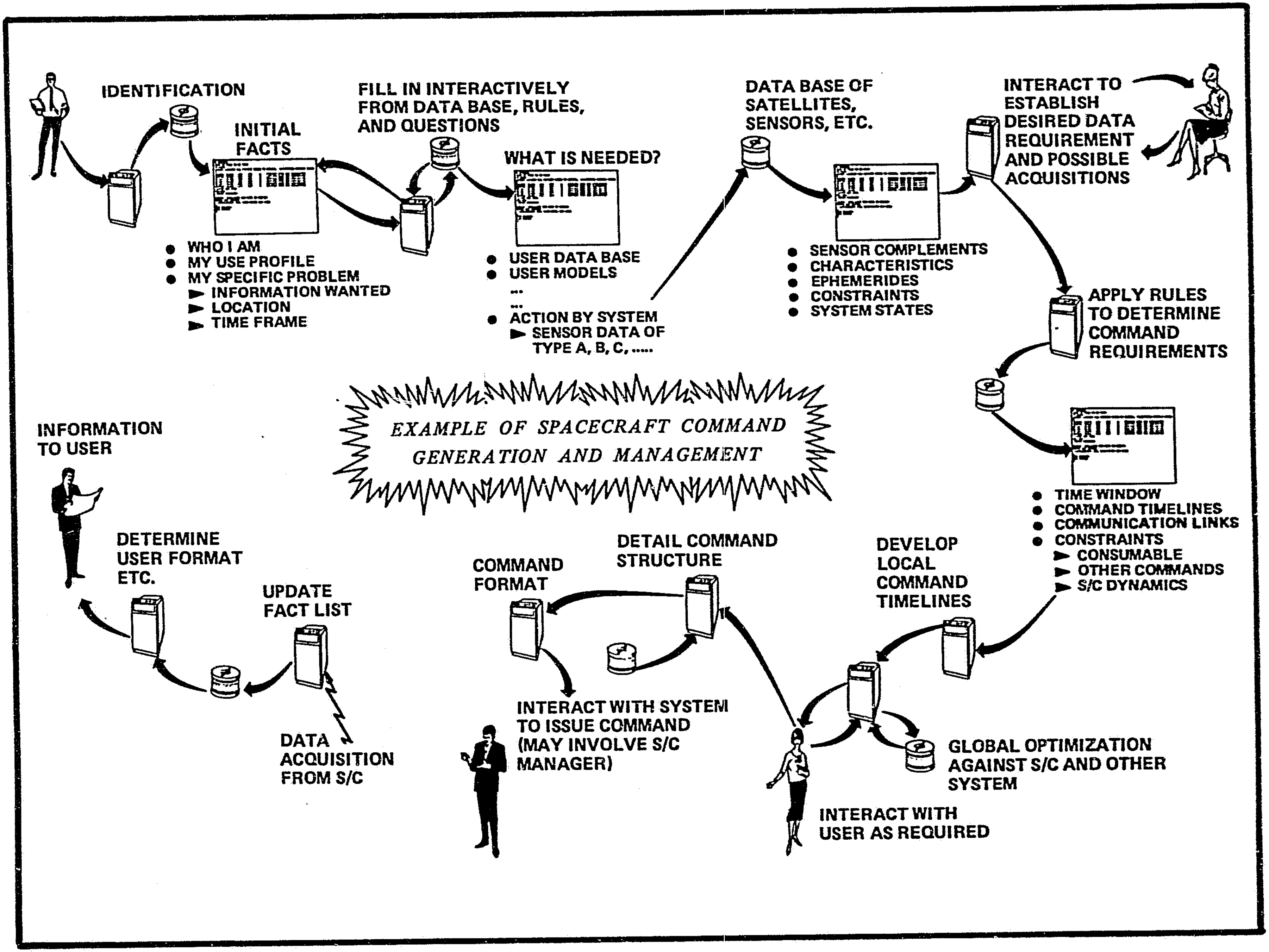

Figure 4-1. An Application of AI to Advanced Systems

which can be executed with single actions is generated. Sensory feedback enters the hierarchy at many different levels to alter the task decomposition to accomplish the highest level goal in spite of uncertainties or unexpected conditions in the environment.

For a further description of hierarchical control see (Albus 1) which describes the National Bureau of Standards applications to factory automation. A theory of hierarchical control is presented in this report incorporating three parallel interconnected hierarchies. The first is a behavior-generating hierarchy which decomposes tasks into subtasks in the context of sensory information. The second is a sensory-processing hierarchy which extracts the information needed for goal seeking behavior. The third is a world-model hierarchy which generates expectations and predictions for the sensory-processing modules at each level. A robot control and vision system is described that implements the triple hierarchy model in a microcomputer network. A possible application of the theory to an automatic factory control system is outlined in (Albus 1).

4.1.1.3 Ground Dependency for CMS

The extent to which the on-board CMS can be dependent upon ground support is an additional aspect of that same question with regard to autonomy for the entire Space Station. Reliability, communication channel requirements, mission criticalities, and the performance of the various components required for implementation must be considered interactively. The resolution of this issue will necessarily involve the Space Station system as a whole.

4.1.1.4 Algorithmic Implementation of CMS

Algorithmic implementation of automatic command management is probably the current most controversial issue. It has been implemented in rather restrictive domains. The generation and verification of the necessary algorithms and supporting software is extremely expensive. It is doubtful that such an approach is practical in the context of the Space Station. Interesting alternatives that have some history of success within NASA at JPL involve AI approaches.

In most realistic environments, it will be impossible to completely build a detailed plan and execute it in an unmodified form to obtain the desired result. A further complication arises when the plan must meet real time constraints--that is, definite short-term requirements for actions where failure to meet the timing requirements carries significant undesirable consequences. Because of this, it is important that complex autonomous systems have plan formation capabilities well in excess of current state-of-the-art.

In 1980, AI was advocated as an essential technology for implementing autonomous command management (Long 1). At that time there was a growing awareness among AI researchers that the time had come to produce limited capability in a useful working system. The following is from Long's report.

> "Theoretical research in AI problem-solving and planning techniques will be an active area for several decades to come. If NASA is to become effective in directing this research toward its own goals, then early experience is necessary with elementary state-of-the-art techniques--although substantial advantages can even be obtained by relatively unsophisticated, near-term AI planning and monitoring techniques."

That the assessment of the maturing nature of AI was correct is further evidenced by the spurt of interest in the technical literature. (Gevarter 1, Hayes 1, Duda 1, IJCAI 1, Barr 1) and even the popular literature (Business 1, Webster 1, Yasakil 1, and Business 2). Industry interest is also apparent as evidenced by the major corporate programs involving AI. The rapid maturity of AI is probably most succinctly stated by Peter Hart of Fairchild Camera and Instruments Corporation when he said "It has taken AI twenty-five years to become an overnight success."

The exploration of the issue of applying AI techniques versus the traditional algorithmic approach for automatic command management is a major effort. It is compounded by the relative newness of the AI field.

4.1.2 APPROACH TO AUTOMATED COMMAND MANAGEMENT

Further analyses of this technology will be based upon some of the traditional approaches as documented in recent study reports (Rogers 2, Rogers 3).

4.2 REQUIREMENT MANAGEMENT SYSTEM

The system engineering process of assimilating requirements, synthesizing solutions, accommodating constraints, resolving conflicts and transforming the entire concept into a smoothly functioning system with well conceived plans, schedules and supporting paraphernalia has developed with the space program. With the advent of the Space Shuttle, concerns were expressed that somehow the lengthy, labor intensive process had to be streamlined to effect timely turnaround of diverse missions in a more cost-effective manner. An analogous problem must be faced and planned for with the Space Station. All concerns for the operational complexity and cost of an indefinite life, manned Space Station with changing multiple concurrent missions are embodied in the need for an efficient and effective Requirement Management System. Efficient implies a system capable of performing the necessary activities with a minimum involvement of human resources. Effective means that all items will be accommodated and no critical problems will remain unresolved. All this has to be accomplished while the Space Station remains operational!

The development of automation tools and interactive computer assistance systems to improve the productivity of the mission planners, the system designers, and the software generation is deemed a critical technology for the progression of the Space Station to the fully operational state envisioned. The development of an integrated concept for identifying and managing the requirements is a critical first step.

4.2.1 ISSUES OF REQUIREMENTS MANAGEMENT

Some of the issues of requirements management involve the capture of the implicit processes that are now performed during the requirements analysis phase of system engineering. Most of the implemented systems are applied to more restrictive domains than are expected for the Space Station. This study serves as a model of the range of involvement. Requirements originate from both operational and mission needs. The missions can be widely varied and often conflicting. Several parallel studies will provide background for the data acquisition process leading up to mission requirements generation. For operating support and orbital computational requirements, see (Graf 1, Graf 2, CSS 1 and MITRE 1). A recent investigation at JSC identified the current practices and future approaches for acquiring and utilizing Shuttle Flight operations data (Shepperd 1). In this report, a concept of developing an integrated flight operations data management system is identified. The data management system would be amenable to eventually incorporating AI technology. Presently, there is no singular source of potential mission requirements. Earlier studies provide partial and unofficial sources (des Jardins 1,GE 1).

4.2.2 APPROACH TO REQUIREMENTS MANAGEMENT SYSTEM

The development of an integrated concept for requirements management is the first step in an end-to-end system that will include a significant amount of automation in the generation and production of hardware and software components. Software in this sense includes documentation, test plans, and operating procedures as well as computer programs. Such concepts are currently considered and are being implemented by major system integration companies in limited scope. They are frequently termed the environment for requirements development. These environments have some characterizing features:

- o Provision for easy interactive iteration between system requirements, development personnel, and mission requirements.
- o Software simulations of system implementation without regard for hardware or software partitioning.
- o Traceability of requirements and impact of configuration changes.

The development of a requirements environment concept will require three major activities:

1. The research of related effort which, at present, is quite limited. Parallel activities in the area of software development environments will provide some guidance.
2. The development of the functional catalog of what role this system would perform.
3. A synthesis of a possible implementation.

4.3 ENGINEERING AIDS

The development of automation techniques to improve productivity of system engineering for Space Station operations and minimum planning is the second step in automating the end-to-end requirement to implementation support activity. Systems have been implemented to provide computer-aided design in the mechanical and VLSI engineering fields. It is plausible that such systems can be implemented in specific system engineering fields when requirements are committed to an on-line automated system. The intention is to provide templates and engineering aids for developing lower level specifications, simulating system performance, and generating component performance specifications and test data.

Consideration of incorporating various engineering aids at the time of implementation of the requirements system will be useful. Again, in the field of AI, several concepts in data management are promising. Each of the functions of a data system can be considered a node in a frame structured representation system. Such a data structure was described by Minsky as follows:

> "We can think of a frame as a network of nodes and relations. The "top levels" of a frame are fixed, and represent things that are always true about the supposed situations. The lower levels have many terminals --"slots" that must be filled by specific instances of data. Each terminal can specify conditions its assignments must meet." (Minsky 1)

The use of frames as a technique for classifying information on the basis of its properties is described in Chapter 11, "Simple Discrimination Nets" (Charniak 1). Such discrimination nets are sometimes called discrimination trees or semantic networks. Links are identified between nodes and can be structured with explicit definitional roles, types of inheritance, defaults, and data formats. For a Space Station data system, the links could be data flows and dependency relationships could be established. Processing times, data bus bandwidth requirements, data dependency, and a multitude of performance parameters could be rapidly and consistently determined and checked for conflicts. Complex algorithms can be implemented as attached procedures that are treated as other data properties.

The development of such a concept for system engineering assistance has a background of several AI systems available (Stefik 1, Friedland 1, Stefik 2, Roberts 1, Bell 1, Rychener 1). The domain described by Rychener is particularly appropriate as it is the symbolic description and manipulation of computer structures at the PMS (processor-memory-switch) level. The system is intended for computer-aided design activities.

4.4 SOFTWARE MANAGEMENT SYSTEM

The realization that software maintenance will of necessity be performed on a live operational manned spacecraft is terrifying to everyone that has ever been involved with software systems or spacecraft. Yet, it is a condition that must be faced and planned for. The development of the necessary technology to implement and install software changes that will work immediately as intended is a significant challenge for Space Station data system planners. The implementation of modern programming practices which stress readability, data declaration, encapsulation, and generic units will help improve productivity of software generation and maintenance, but it will not provide assurance of correctness to the degree required.

One opinion is that only by using automatic code generation can the required consistency and assurance of correctness be obtained. There are projects for generating software automatically, but they are just getting started. The most popular initial approach seems to be through the interactive use of templates and still involves human activity to a large extent. This is the approach employed in the Programmer's Apprentice system being developed at MIT (Rich 1). This system is conceived as being midway between an aid to improved programming methodology and an automatic programming system. A programmer and the apprentice work together throughout all phases of the development and maintenance of a program. The programmer does the difficult parts of design and implementation. The apprentice acts as a junior partner and critic, keeping track of details and assisting the programmer wherever possible. A key feature of the apprentice is its ability to understand the logical structure of a program so that it can interact with the programmer in a meaningful way.

Work on automatic programming systems was pioneered by Barstow and Green in the late 1970s (Barstow 1-4, Green 1). The classic program for developing automatic programming is PSI which is summarized in (Green 2). Other references pertinent to the PSI program are (McCune 1) and (Steinberg 1). The use of natural language processing in automatic programming is described in (Ginsparg 1). For a general discussion see (Biermann 1).

Other related activity to improve productivity is directed toward methods of measuring the output of automatic programming systems such as PSI. A system called LIBRA uses knowledge-based rules and algebraic cost estimates to compare potential program implementations. This system measures "efficiency" of the resulting programs (Kant 1). Another system, PECOS, uses expert system technology to update FORTRAN programs. This system was developed by Barstow at Schlumberger. A system called PHENARETE (Wertz 1) improves incompletely defined LISP programs. It takes as input the program without any additional information. In order to understand the program, the system meta-evaluates, using a library of pragmatic rules describing the construction and correction of general program constructs, and a set of specialists describing the syntax and semantics of the standard LISP functions. The system can use its understanding of the program to detect errors, to debug them and eventually, to justify its proposed modifications.

The assessment of the feasibility of automatic software generation for the Space Station is premature at this time. An attempt will be made to outline the initial effort required to investigate this technology further. Should it become operationally reliable, it is likely that some aspects would even be deployed on-board, perhaps initially as an aid for mission analysts and principal investigators. It is expected that a system of phased implementation will be desired. Initial effort would likely concentrate on more traditional software engineering approaches. Such a system or facility would be incorporated into the Space Station ground facility. It would contain a dynamic model of the Space Station and provide some degree of emulation of software incorporation prior to installation on the live system. An integrated system of requirements management, engineering assistance, interactive software development center, and verification tools seems appropriate.

4.5 SELF ORGANIZING DATA BASE SYSTEM

The anticipated diversity of undefined missions and other sensor and data requirements provides an indication that the data management problem will be horrendous. In anticipation of this need, a desirable condition would be one in which data structure could be added or removed independently of the remainder of the data base.

Approaches for developing this technology are still being explored. The AI researchers are leading in the theory development for methods of knowledge representation. Development in self-documenting data sets and even the acceptance of packetization schemes that include extensive header descriptions should aid this technology. Applications of the semantic network structures and frames as discussed under Engineering Aids will provide a basis for such a data base. AI systems such as those illustrated in Table 4-5 may be used. This concept can also benefit from some of the learning systems that can enrich the interconnectiveness, i.e. fill some slots, as the data base is maintained and accessed. Significant accomplishments in intelligent data management and retrieval concepts have been achieved in selected applications.

Figure 4-2 illustrates LADDER, a system currently being used by the Navy. It is an application of artificial intelligence to access data from a large, distributed data base over a computer network. A running system provides real time access over an ARPANET to a data base distributed over several machines. The system accepts a rather wide range of natural language questions about the data, plans a sequence of appropriate queries to the data base management system to answer the question, determines on which machine(s) to carry out the queries, establishes links to those machines over the ARPANET, monitors the prosecution of the queries and recovers from certain errors in execution, and prepares a relevant answer.

The LADDER system (Sacerdoti 1) consists of three major functional components, as displayed in Figure 4-2, that provide levels of buffering of the user from a data base management system (DBMS). It employs the DBMS to retrieve specific field values from specific files just as a programmer might, so that the user need not be aware of the names of specific files, how they are formatted, how they are structured into files, or even where the files are physically located. Thus, the user can think he is retrieving information from a "general information base" rather than retrieving specific items of data from a highly formatted traditional data base.

Table 4-5. Some Knowledge Representation Systems

SYSTEM	DEVELOPER	CHARACTERIZING FEATURE	REFERENCE
FRL	R. Bruce Roberts and Ira P. Goldstein at MIT	Frame-based system language which allows procedures in network notations.	The FRL Manual, MIT AI Memo No. 409, 1977
KLONE (KL1)	R. J. Brachman, at Bolt, Beranek and Newman, inc. (BBN)	Current research in the theory and design of frame-based systems.	R. J. Brachman, A Structural Paradigm for Representing Knowledge, Report No. 3605, BBN, Cambridge, MA, 1978
KRL	D. G. Bobrow and T. Winograd at Xerox PARC	Frame-based programming and representation language developed to explore frame-based processing. It allows procedures in network notation.	D. G. Bobrow and T. Winograd, "An overview of KRL, a knowledge representation language," Technical Report, Xerox PARC, 1976 and Winograd, "KRL, another perspective," Cognitive Science 3, 1979, pages 29 to 42; Bobrow and Winograd, "Experience with KRL-0, one cycle of a knowledge representation language," 5 IJCAI, 1977, pages 213 to 223; and W. Lennert and Y. Wilks, "A critical perspective on KRL," Cognitive Science 3, 1979, pages 1 to 28.
KRS	Brian Smith at MIT	Formal representation of knowledge using meta-level structures in which various layers share the same syntax and interpreting process.	Smith, Brian, Levels, Layers, and Planes: The Framework of a System of Knowledge Representation Semantics. Unpublished Draft, MIT, Cambridge, February 1978.
NETL	Scott E. Fahlman	Makers use of real-world knowledge.	Scott E. Fahlman, NETL: A System for Representing and Using Real-World Knowledge, MIT Press, Cambridge, MA, 1977.
RLL	R. Greiner and D. B. Lenat at Stanford Univ.	Tool for building expert systems whose expertise is knowledge representation. Allows a program to define new representations dynamically.	Greiner, R., 1980, "RLL-1: A representation language language", Rep. No. HPP-80-9, Heuristic Programming Project, Computer Science Dept., Stanford University. Greiner, R., and Lenat, D. B., 1980, "A representation language", AAAI 1, pages 165-169.
SYSP	Toshio Yokoi Shooichi Yokoyama Taisuke Satoo Fumio Motoyoshi Kazuhiro Fuchi	A highly structured symbol manipulation system. A general purpose computation system.	6 IJCAI-79, pages 998-1000, "SYSP: A new programming language to the next generation."
UNITS	M. Stefik at Stanford University	A knowledge representation language and an interactive knowledge acquisition system. The language provides both for frame structures and production rules. It is a transportable package that has been used to build working AI systems for scientific applications.	M. Stefik, Planning with Constraints, Report No. 784, Stanford University, 1980.

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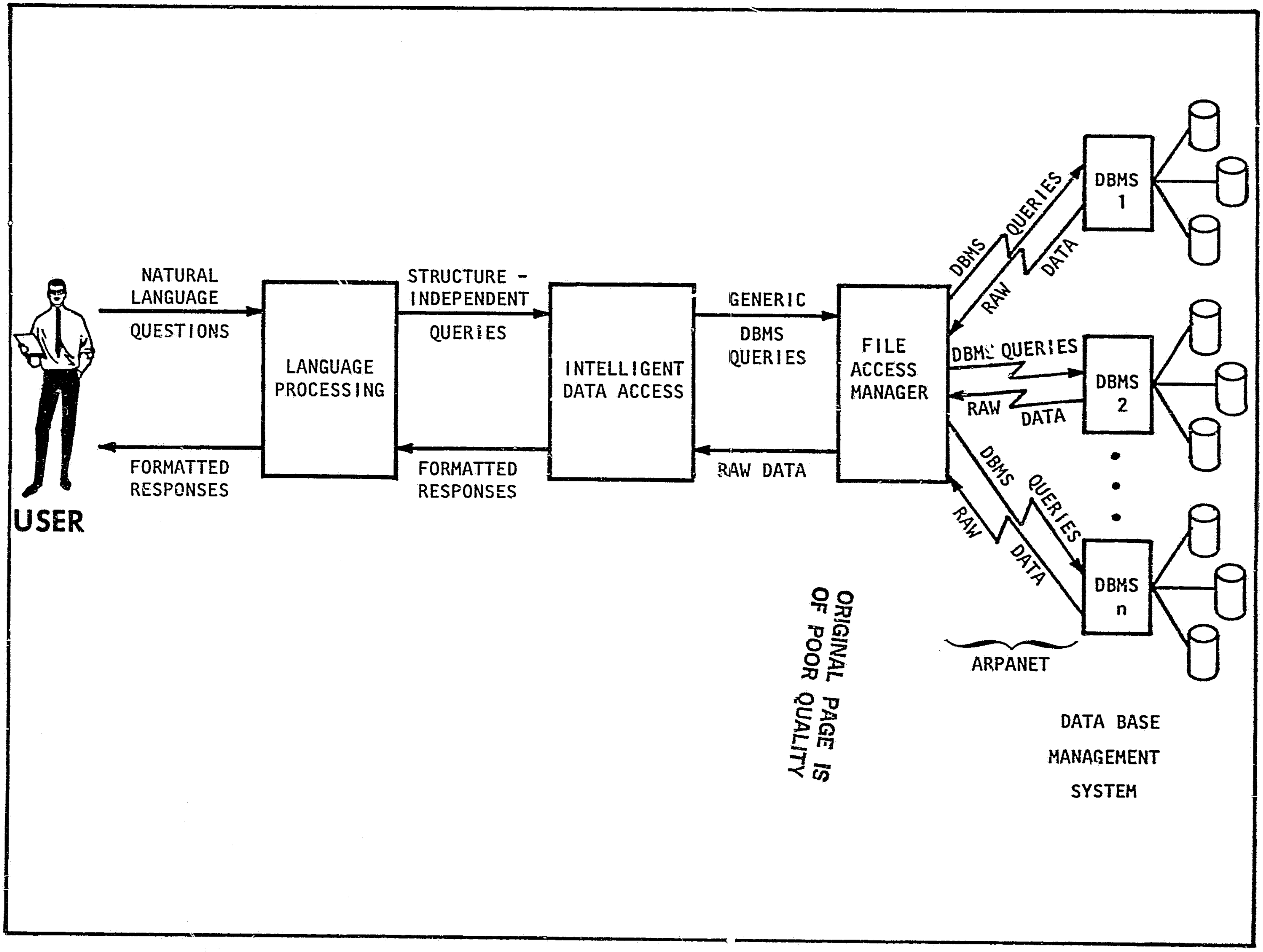

Figure 4-2. Overview of LADDER System

The first component accepts queries in a restricted subset of natural language. This language processing component produces a query or queries to the data base as a whole. The queries to the data base refer to specific fields but make no mention of how the information in the data base is broken down into files.

The second functional component called IDA (for Intelligent Data Access) breaks down the query against the entire data base into a sequence of queries against various files. IDA employs a model of the structure of the data base to perform this operation, preserving the linkages among the records retrieved so that an appropriate answer to the overall query may be returned to the user.

In addition to planning the correct sequence of file queries, IDA must actually compose those queries in the language of the DBMS. The current system accesses, on a number of different machines, a DBMS called the Datacomputer whose input language is called Datalanguage. IDA creates the relevant Datalanguage by inserting field and file names into pre-stored templates. However, since the data base in question is distributed over several different machines, the Datalanguage that IDA produces does not refer to specific files in specific directories on specific machines. It refers instead to <u>generic files</u>, files containing a specific kind of record. It is the function of the third major component to find the location of the generic files and manage the access to them.

To carry out this function, the third component, called FAM (for File Access Manager) relies on a locally stored model showing where files are located throughout the distributed data base. When it receives a query expressed in generic Datalanguage, it searches its model for the primary location of the file (or files) to which it refers. It then establishes connections over the ARPANET to the appropriate computers, logs in, opens the files, and transmits the Datalanguage query, amended to refer to the specific files that are being accessed. If at any time, the remote computer crashes, the file becomes inaccessible, or the network connection fails, FAM can recover and, if a backup file is mentioned in FAM's model of file locations, it can establish a connection to a backup site and retransmit the query.

A system such as LADDER could be developed and tailored toward use on the Space Station. Some other natural language systems are shown in Table 4-6. Further investigation into this area would be extremely worthwhile.

4.6 HUMAN TO DATA SYSTEM INTELLIGENT INTERFACE

An important function of the data system is to provide a friendly interface with the personnel on the Space Station. The top down approach to developing concepts of this interface starts with the identification of the personnel functions and their need to interact with the data system. Some assumptions as to the makeup of personnel were made, recognizing that this discipline is being extensively investigated by other working groups. The assumptions continue with the sharp distinction between operations and mission activity. A minimum of five personnel is assumed with provisions for as many as twelve in the early time frame. These assumed categories, according to their needs for data system interfaces or work stations, are listed in Table 4-7.

There was no attempt to address personnel functions such as "medical officer," or others that may be required. These functions, could probably be accommodated by any of the categories identified. The categories are: commander, chief operations officer, mission monitor and support officer, crew member, mission operations, principal investigator, and construction. The officers, crew members, and mission operations personnel are considered as professional Space Station personnel. Principal Investigators and construction personnel are considered temporary visitors and would have different data system interface requirements. The initial complement would include the officers and one or more crew members or either mission operations or a principal investigator.

4.6.1 MAJOR COMPONENTS OF HUMAN INTERFACE

Several components such as displays and work stations are envisioned for the different personnel categories of Table 4-7. Some devices, such as a large screen display and electronic mimic board would provide information for more than one category of personnel. The relationship of these components in the system is illustrated in Figure 4-3.

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Table 4-6. Some Natural Language Systems

SYSTEM	NATURAL DM & DM LANGUAGE	LANGUAGE INTERFACE	SPEECH RECOGNITION	TEXT GENERATION	ADDITIONAL REFERENCES
ATNG			X		Kobayashi 1
BABEL				X	Schank 1&2
CONVERSE		X			Kellogg 1
COOP		X			Kaplan 2
DADM	X				Klahr 1
DEACON		X			Thompson 1
DIAMOND		X			*
DONAU		X			Guida 1
EPISTLE				X	**
ELIZA		X			Weizenbaum 1&2
FOUL-UP		X			Granger 1
GSP		X			Barr 1, Kaplan 1
GUS					Bobrow 1
HAM-RPM				X	Wahlstor 1
HARPY			X		Barr 1, Lowerre 1
HEARSAY			X		Barr 1, Erman 1
HWIM	X				Barr 1, Wolf 1
INTELLECT		X			***
JETS		X			Finin 1
LADDER		X			Sacerdoti 1
LIFER		X			Barr 1, Hendrix 1,2,3
MARGIE				X	Barr 1, Schank 1,2,
MIND		X			Kay 1
PAM				X	Barr 1, Wilensky 1
PARRY				X	Colby 1
PHLIQA1		X			Landsberger 1
PLANES		X			Waltz 1
PROTOSYNTHEX		X			Simmons 1
QUIST	X				King 1
REL		X			Rubinoff 1, Thompson 2
RENDEZVOUS		X			Codd 1
RITA		X			GWU 1
ROBOT		X			Harris 1,2,3
SAM				X	Barr 1, Schank 3&4
SDM	X				Hammer 1
SHRDLU		X			Barr 1, Winograd 1
SIR		X			Minsky 1
SNIFFER	X				Fikes 1
SODA	X				*
SPEECHLIS			X		Woods 1
STUDENT		X			Bobrow 2
TAXIS	X				Mylopolous
TEAM		X			*
TED		X			Hendrix 4
TQA		X			Damerau 1

*SRI International Proprietary
**IBM Proprietary
***AI Corp Proprietary

Table 4-7. Personnel Categories

CATEGORY	QTY	INITIAL	LATER	PRINCIPAL FUNCTIONS	DATA SYSTEM REQUIREMENTS
COMMANDER	1	1	1	o MAINTAIN WELL-BEING OF SPACE STATION AND PERSONNEL	o COMMUNICATIONS o INFORMATION ACCESS o HIGH LEVEL CONTROL & BACKUP
CHIEF OPERATIONS OFFICER	1	1	1	o MAINTAIN ORDERLY OPERATIONS	o SIMILAR TO COMMANDER o MORE DETAILED PLANNING o INTERACTIONS AND STATUS ASSESSMENT o HIGH LEVEL CONTROLS
MISSION MONITOR AND SUPPORT OFFICER	1	1	1	o MAINTAIN ORDERLY MISSION ACTIVITY o PLAN AND SCHEDULE MISSION TASK o ASSIST MISSION PERSONNEL	o ACCESS TO SUBSET OF INFORMATION COMMUNICATIONS o INTERACTIVE PLANNING & STATUS ASSESSMENT
CREW MEMBER	1-3	1-2	2-3	o MAINTAIN STATION o ASSIST EVA AND OTHER OPERATIONS ACTIVITY o MATERIAL HANDLING	o CONTROL AND ACCESS TO SUBSYSTEM o TEST & MAINTENANCE AIDS
MISSION OPERATIONS	0-5	0-1	2-5	o ROUTINE MISSION ACTIVITY o DOCKING, ASSEMBLY, CHECKOUT o SPACE MANUFACTURING o TELEOPERATOR o EARTH OBSERVATIONS	o SPECIAL PURPOSE FUNCTIONS EG. CHECKOUT, OTV, MANUFACTURING
PRINCIPAL INVESTIGATOR	0-5	0-1	0-5	o SCIENTIFIC INVESTIGATION ACCORDING TO SPECIALTIES	o SPECIAL PURPOSE FUNCTIONS o MODULAR I/F
CONSTRUCTION PERSONNEL	0-6	0	0-6	o OFF STATION ACTIVITY o STATION HABITAT ONLY	o PERSONAL ONLY

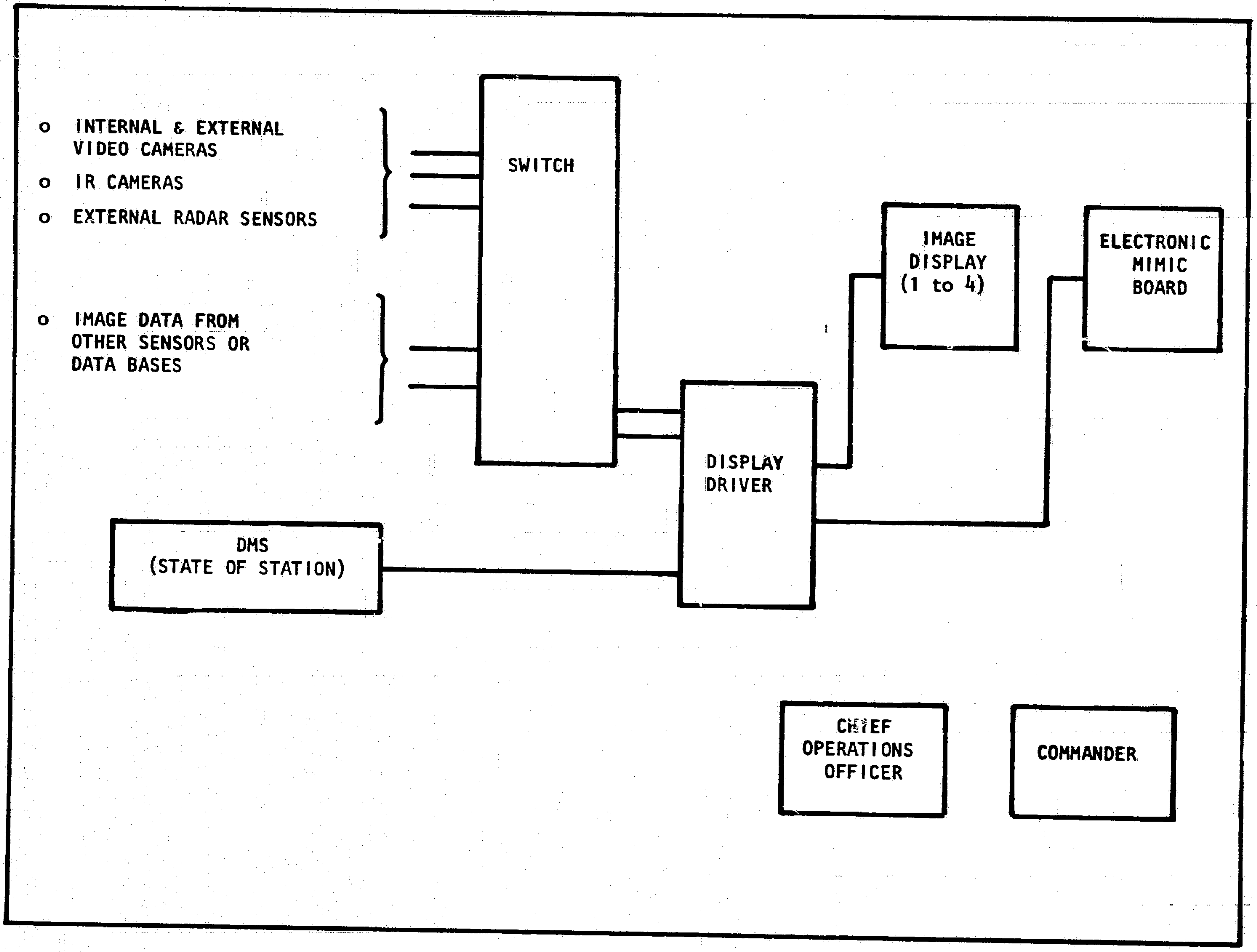

Figure 4-3. Some Displays for Human Interface

4.6.1.1 Electronic Mimic Board

The electronic mimic board will have video raster format output which will be displayed to a large screen. It will generate digital images mimicking the configuration of the Station and detailing the current status of subsystem and critical components. This data will be obtained from the performance monitoring subsystem and the shared data base. The purpose of the electronic mimic board will be to provide warning indications in case of a malfunction or failure.

4.6.1.2 Large Screen Display

The large screen will provide a display of raster scan video format data visible from (5 meters) and (color TBD). Size will be as large as practical in the space environment since some of the techniques for large screen display (light valves) may not provide adequate lifetime and others such as the direct projection may not provide adequate brightness. An assumed enclosed tube type of 24 inches may be adequate.

The purpose of the large screen will be to display radar, IR, and visible TV camera images and digital images plus to serve as electronic mimic board. The screen will be visible by both the commander and chief operations officer. It could also serve for docking and checkout mission operations.

4.6.1.3 Crew Member Console

The crew member console will be at a work station with tools for analysis and testing of Space Station subsystems and components. The work stations will be distributed throughout the Space Station as required. They will provide a miniature display of the electronic mimic board and the detailed insets. They will simulate mode switching, reaction, et cetera as an aid to maintenance and contingency operations. Also, they will provide automatic mode interlocks during maintenance operations.

These consoles will provide detailed troubleshooting assistance and augmentation of built-in test aids to assist in designating corrective actions for the crew members in case of malfunctions or failures. They will provide an interface for portable media supplement, such as optical or floppy discs, with specialized maintenance or procedural information.

4.6.1.4 Mission Operations

Mission operations will be conducted from a work station for routine scheduled activities. Configuration of the work station will be modular and will vary according to the operation being supported. The three types of operations to be supported are:

- Materials manufacturing
- Earth viewing image data acquisition
- Assembly, checkout, and control of OTV or teleoperator

Each of these would require different options. For example, OTV or teleoperator would require some control and maneuver devices. All will likely have some types of displays. The intent is to standardize the work stations and minimize hardwired, special purpose interfaces.

4.6.2 GATEWAY REQUIREMENT DEDUCTION

Future data systems for elaborate spacecraft such as the Space Station will necessarily be extremely sophisticated. These data systems will be so complex that it would be a major undertaking for any single individual to fully understand its internal workings. The complexity is expected to exceed that of major earth-located automated factories, power plants and such. Such earth installations frequently are only understood by long service employees who participated in the system evolution. This will not be the situation on the Space Station where a frequent change of personnel can be expected.

Another trend in the future space data systems is autonomy. The systems will be more capable and much less dependent upon the human operators. Thus, there will be a lessened requirement to bring information to the human on the internal status of the system. The design goal will be to free him to perform his primary goal and not to burden him with having to adapt to the needs of the system. With more capable data systems, the burden of adapting can be shifted to the hardware and software system. This is precisely what AI researchers are attempting when they are developing systems with humanlike qualities.

A separate human gateway subsystem, or possibly a separate one for each category of personnel, is suggested. If more than one is employed, there would be a high degree of commonality of functions, hardware, and software. Each human gateway subsystem would have the basic functions of interpreter. It would understand the human need for information and obtain it. It would interact and "carry on a conversation," requesting additional clarification if it did not "understand" what was expected. The system may evolve from the basic concept with increasing functionality, voice synthesis and recognition added and modularly expanded as the system matures.

For purpose of discussion, eight functions of the human interface subsystem are identified. These eight will be required of each subsystem deployed, although the degree of functionality and the method of implementation may vary for different personnel and the system nature. The eight functions are: Input, Recognition, Understanding, Reasoning, Translation, Explanation, Tolerance, and Output. Each will be discussed along with some ramifications of different implementation techniques.

4.6.2.1 Input

The input function can be as pedestrian as a keyboard or as sophisticated as an imaging scanner. Should vision capability be desired, it would be another form of input. A requirement for voice input is a distinct possibility. Trade studies are required to determine the needed degree of sophistication for voice input. The acceptance of a small vocabulary of trained, single word, carefully selected, voice commands is within current technology. Such a restricted input would still have many advantages. The reliable functioning of a system accepting untrained joined sentences would require extensive computational power. While it may be technically feasible in the time frame of interest, additional analysis is required to determine if it is a worthwhile feature.

4.6.2.2 Recognition

The next function of the human interface subsystem is recognition. This is similar to interpretation. A natural language input capability is understood. Consequently, the recognition function would involve parsing and semantic interpretation. Access to a reasonable sized data base is necessary to provide the grammatical rules and the necessary semantic information to accept natural language input. For the assumed multiple input formats, multiple processing procedures would be required. Some scanner or digitizer inputs would have special needs.

4.6.2.3 Understanding

The next important function of the human interface subsystem is the understanding of what was input. In the simplest of situations, this would require the differentiation between a command and a data input. Understanding requires some kind of generic internal representation so subsequent actions can be determined. In many cases, the understanding function will be a direction to a particular routine for the generation of a sequence of machine code data.

4.6.2.4 Reasoning

Some degree of reasoning will be required for the gateway to accomplish its functions. It will be impractical to explicitly incorporate all the information required. The human will be making inferences on his side of the interface. Reasoning appears to be a practical way to match the human communication mode while limiting the volume of internal information that must be processed.

4.6.2.5 Translation

This function is bidirectional and employs as many formats as required by the data system. Commands from the human, once understood by the interface subsystem, get translated according to where they are directed. The translation function includes the generation of the proper syntax or protocol. For information directed to the human, a natural language format or a display format is employed.

4.6.2.6 Explanation

This function includes an interactive dialog. When the reasoning function is employed to decide what should be done, an explanation may be provided for verification prior to execution. Likewise, when cryptic data is obtained from the system, additional explanatory information and displays may be accessed as part of the explanation function. This could be implemented with mimic boards and illustrative material such as might be available from video disc storage. Some of the maintenance aids might employ extensive explanation functions of the human interface subsystem.

4.6.2.7 Tolerance

The tolerance function is the built-in provision to avoid having to reject inputs for syntax errors and spelling variations. It may employ the reasoning and explanation function to make assumptions and carry on a dialog to obtain needed additional input information.

4.6.2.8 Output

This is the function that drives the output devices. They may be displays or voice synthesis or more conventional hard copy devices. Whatever their format, the output function will accommodate it with the suitable translation function.

4.6.3 SUMMARY OF HUMAN GATEWAY

The envisioned human gateway will exhibit five attributes:

- o Understanding
- o Forgiving
- o Easy to Use
- o Multiple Senses
- o Knowledgeable About the System

A system that exhibits more than human being qualities is suggested. Such a system would exhibit the qualities of the perfect human personality. It would be the perfect assistant, always trying to understand the needs and intent of the human and never blaming the human when it fails. It will forgive the human's errors, and will not require difficult feats of memory, mental agility, or physical dexterity. It will be exceedingly "sharp" in that there will be many senses available such as vision and voice input and output. In addition, this perfect assistant will be brilliant when it comes to knowing details about the underlying system, its state, and the likely consequences of alternate courses of action.

4.7 AUTOMATIC CONFIGURING COMPUTER BUS AND OPERATING SYSTEM

The overall operations data management system architecture is depicted in Figure 4-4. It is a hierarchical structure consisting at the highest level of an operations data management system computer (ODMSC), a high speed computer network or busing system which interconnects the ODMSC to the lower level functional elements or subsystems, and the operations subsystem computers (OSSC). The OSSCs are completely self-contained and self-sufficient with their own control and operating system. The status of each subsystem can be monitored and managed by the ODMSC. The local area network (LAN) interconnecting the subsystems and the ODMSC is redundant. The LAN is of the Ethernet or Hyperchannel class.

4.7.1 GENERIC ARCHITECTURE FEATURES

To be cost effective, it is imperative that the overall system architecture encompass approaches and techniques which can be applied throughout the system; i.e. the problem must be considered from a general point of view and the use of special purpose concepts or devices within a given computation system must be avoided. The computation systems shown in Figure 4-4 are identical except for the number or amount of resources employed at a given level or subsystem. To accomplish these generalized objectives, the data management and computer systems must possess the following salient features:

- o Be capable of adapting to various throughput demands. This implies that each computer contain varying resources, i.e., processors (P), memories (M), and input/output (I/O) units as indicated in Figure 4-4.
- o In each local computer, resources must be configured either to achieve high reliability or to provide automatic fault detection and isolation to minimize system down time.
- o With the resources available to accomplish the goals of items 1 and 2 above, reconfigure the system to provide trade-offs in throughput and reliability; i.e., the system should be able to degrade in a graceful manner as opposed to an abrupt outage.
- o To minimize life cycle costs (developmental, operational, maintenance, logistics, training, et cetera) a common set of rudimental elements, such as processors, memories and input/output units must be provided which can be used in all Space Station computational systems.
- o The basic architecture must be capable of accepting the latest technological innovations.

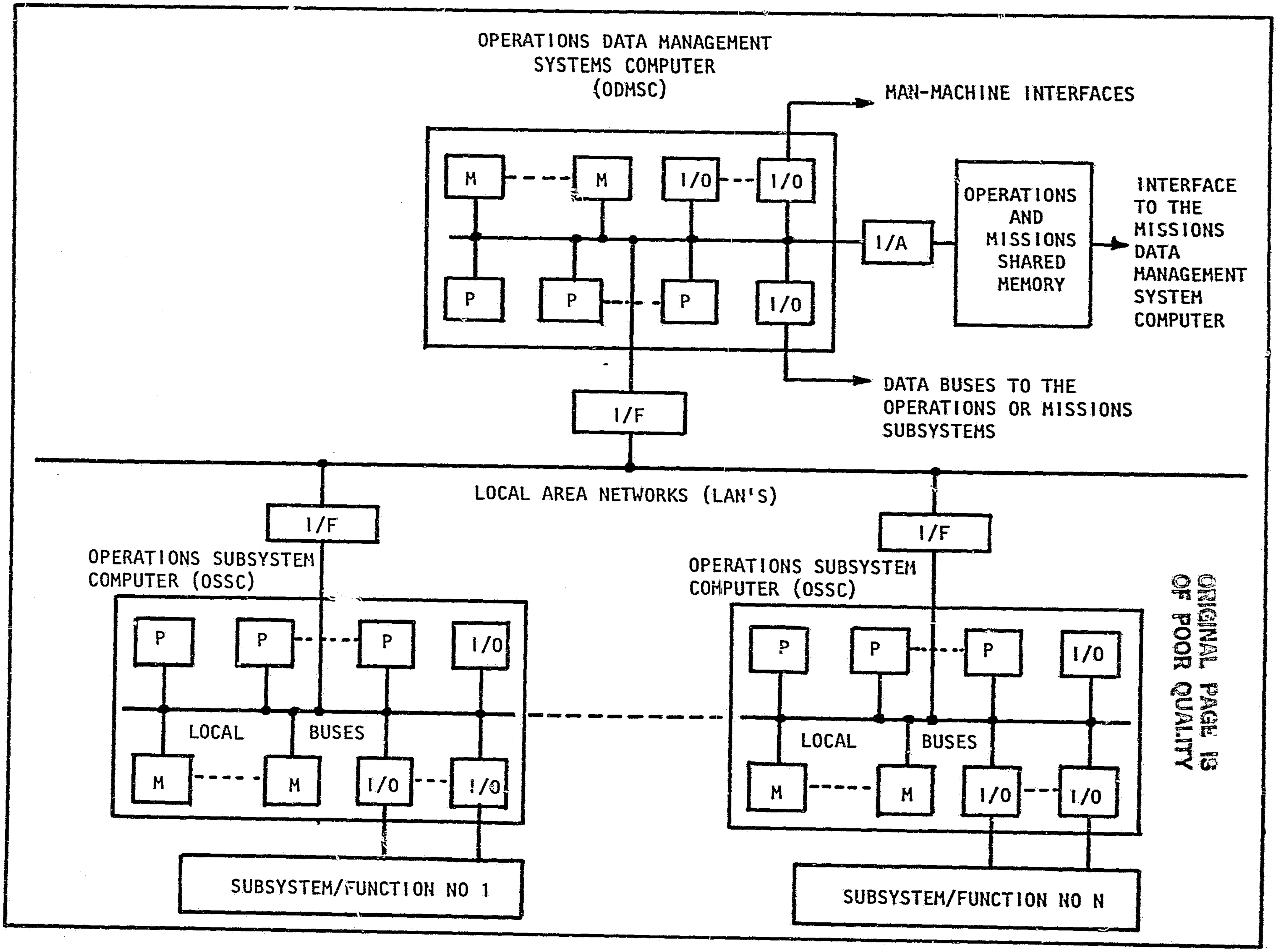

Figure 4-4. Overall ODMS Architecture

- A generalized architecture and common computing devices imply standard software and software development tools; i.e., higher order languages, compilers, translators, assemblers, operating systems, et cetera.

4.7.2 RELIABILITY, COMPUTATIONAL CAPACITY AND DEGRADATION

To gain an understanding of the trade-offs which can be made in reliability, computational capacity, and degradation (items 1 through 3 above), a specific example will be helpful.

Consider an idealized model, as shown in Figure 4-5, which contains three stages: memory, processor, and input/output. As shown, each of these stages has been replicated N times. For this illustration, it is assumed that an element in any stage can be interfaced and used with any element in the succeeding stage. No consideration in the model is given either to how this might be accomplished or to the effect it might have on the parameters of the model. In other words, a perfect interface or switching device is assumed.

Figure 4-6 shows the parameters reliability, computational capability, and degradation plotted as a function of operating time. Operating time has been normalized to the mean time to failure of a simplex system. Computational capability is expressed in terms of the throughput relative to a simplex system. In the figure shown, each stage has been replicated six times (a six processor system) and five failures are allowed in any one or all stages, i.e., only one processor is required to be functional to have an operational system. A further simplifying assumption is that the reliability of each element in the three stages is equal.

4.7.3 MODULAR ORGANIZATION

Figure 4-7 indicates the effect of modularity in a six processor system on reliability, computational capability, and graceful degradation. For m=1 through 3, the total computational capabilities are 5.5, 8.0, and 10.25 respectively times that of a single processor; the operating times when the last system can be expected to have failed are 2.45, 3.6, and 4.6 times that of a single processor. The total computational capability of an idealized system is dependent on the time the system is expected to be operational.

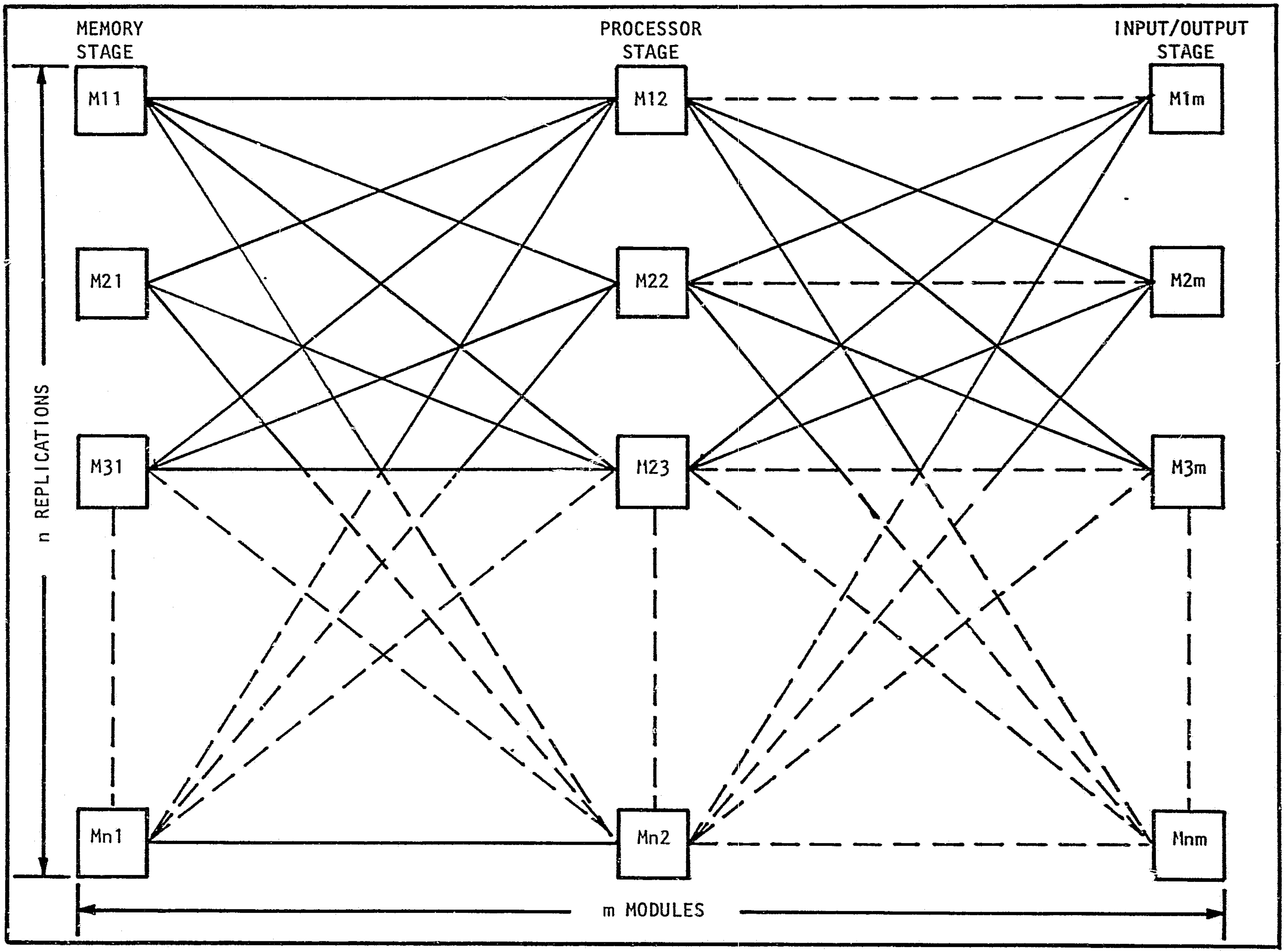

Figure 4-5. Idealized Modular System with n Replications and m Modules

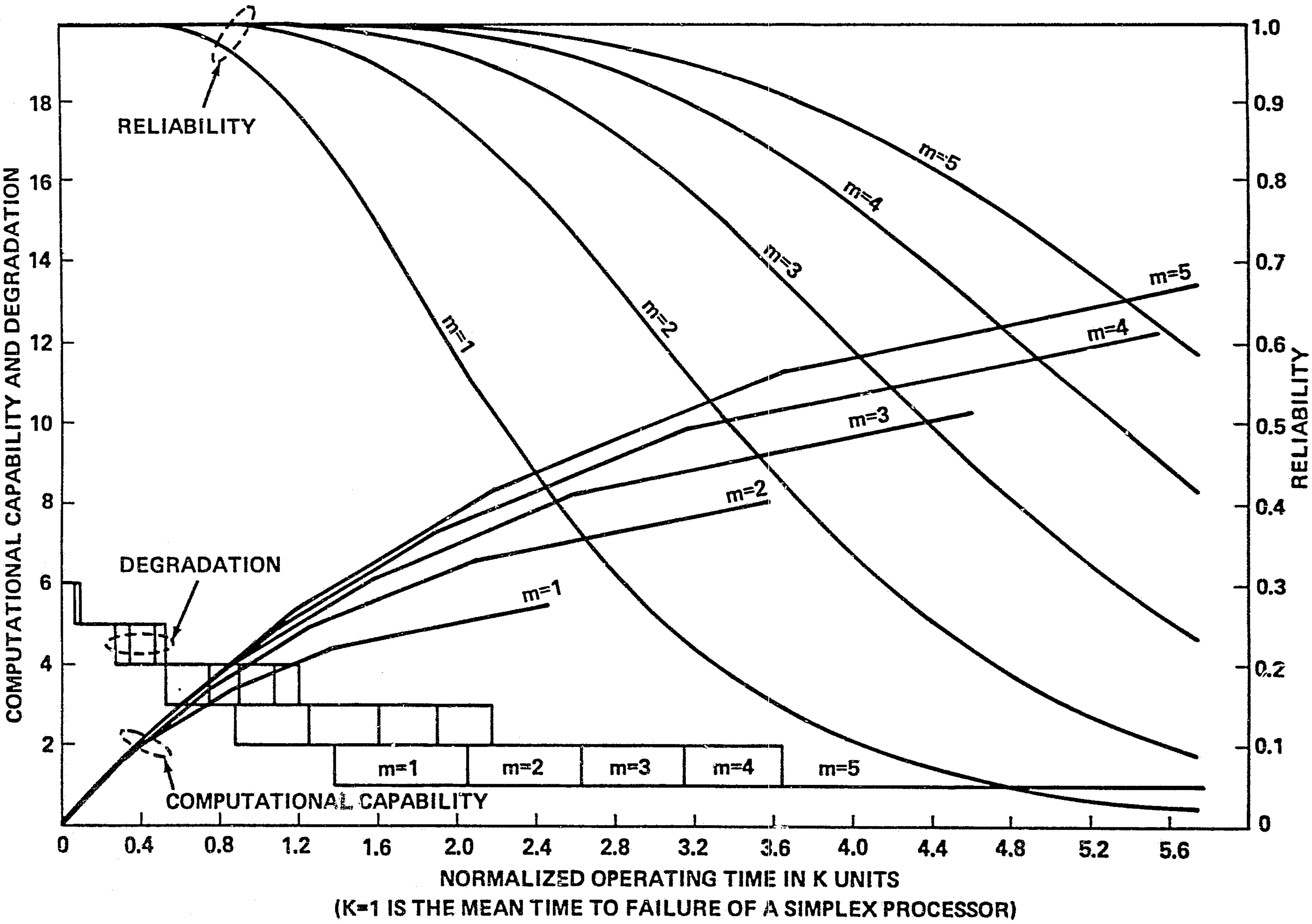

Figure 4-6. Plot of Six Processor System with r=5

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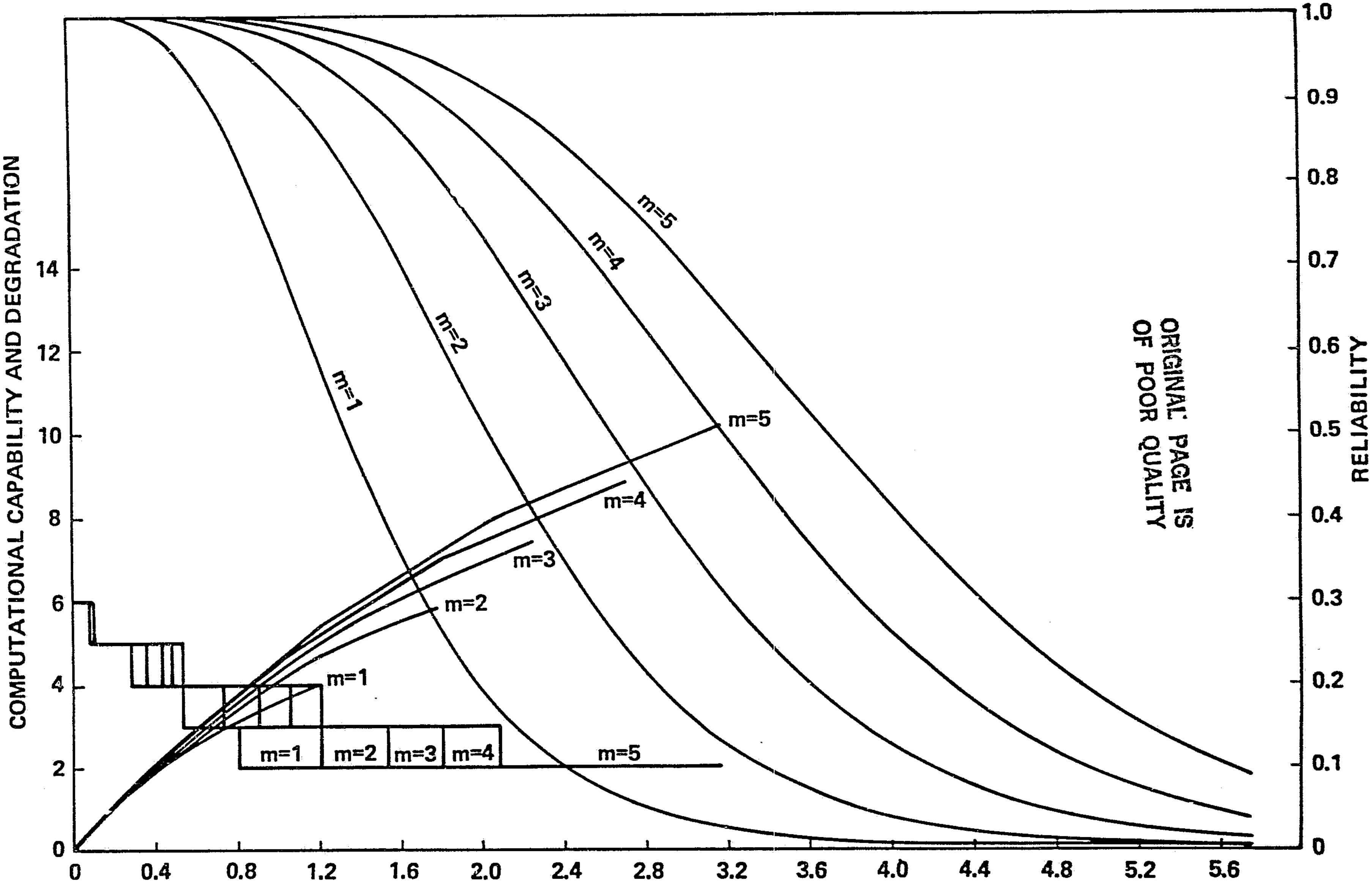

NORMALIZED OPERATING TIME IN K UNITS
(K=1 IS THE MEAN TIME TO FAILURE OF A SIMPLEX PROCESSOR)

Figure 4-7. Plot of Six Processor System with r=4

This follows directly from definition and is clearly indicated in the figure. The effect of modularity on degradation, computational capability, and reliability is clearly indicated by the sets of curves: A six processor system with m=3 yields more than 1.7 times the computational capacity obtained from six parallel processors (m=1) and it is expected to be functional more than 2.1 times as long. The upper set of curves indicates the effect of modularity on reliability. (Appendix C gives a more detailed treatment, derivation, and discussion of the effects of modularity on throughput, degradation, and reliability.)

4.7.4 MULTIPROCESSOR TOPOLOGIES

From the above discussion, it is clear that modular organizations can improve throughput and allow a system to gradually degrade in contrast to an all up or all down situation. A so-called multiprocessor organization can provide the attributes of optimum computing capacity and gradual degradation. A multiprocessor is defined herein as follows: (This definition, as well as much of the basic material can be found in (Enslow 1)).

- o It must contain two or more central processing units. In the general sense, these may or may not be identical or have approximately the same capabilities, but for logistic reasons, the basic processing elements in the Space Station will be assumed to be identical.
- o Some portion of main processor memory must be shared and accessible by all processors. All memory may be common, but some private memory may be highly advantageous. Sharing total memory may complicate some of the system problems.
- o Input/output access, including channels, control units, and devices must be shared as appropriate.
- o There must be a single well integrated operating system in overall control of all hardware and software.
- o There must be intimate interaction at both the hardware and software operating system levels: At the system software level in the execution of systems tasks; at the program level for the execution of portions of the same programs by several processors in turn and the execution of an independent task of a program on a processor other than the one executing the main task (the ability to move a job); at the data set level; and at the hardware interrupt level.

Hardware and software interactions depend both on the systems software and operating procedures and the physical configuration and interaction between the various elements.

For an operating system controlling the complete system to be effective and reliable, several hardware features should be present. These include:

- o There should be a hardware "lock" that can be set to prevent entry by another to ensure the integrity of tables or data sets while being accessed by one processor.
- o There must be a capability for variable logical addresses or names of processor channels, memories, and devices rather than fixed physical addresses.
- o A processor must have the capability to signal or interrupt another to request that it perform a certain function or to determine if the other processor is still functioning. This may be accomplished with an interrupt or a mailbox and polling message passing procedure; i.e., a "soft-interrupt".
- o If a processor has failed, another processor detecting this and wishing to reschedule the work in progress on the down machine must be able to access all the information necessary to do this even if some of that data is within the processor itself.
- o It may be necessary to have the ability for one processor to start or restart another no matter what state the latter may be in as long as it is still operational.

In the past, systems have been defined and developed with varying topologies of the interconnecting networks between the various functional elements. There must be several groups of multiple paths, either paths present physically at all times, or logical paths created by the connection network on an "as needed basis." These paths must provide the following capabilities:

- o Any processor can control and transfer data to and from any location in memory. (It may be convenient for each processor to have a small amount of private memory.)
- o Any processor can pass control commands to any I/O channel controller.
- o Any I/O channel can access any location in memory.
- o Any I/O channel can control and transfer data between the central memory and any of its appropriate I/O devices.

These interconnections must provide for total resource sharing.

Typical examples of various types of interconnecting schemes between processors, memories, I/O channels, and devices are shown in Figures 4-8 through 4-13. Figure 4-8 shows a single bus arrangement which is time shared between the elements. Figure 4-9 illustrates a multiple time shared common busing system. Figures 4-10 and 4-11 illustrate another scheme for connecting

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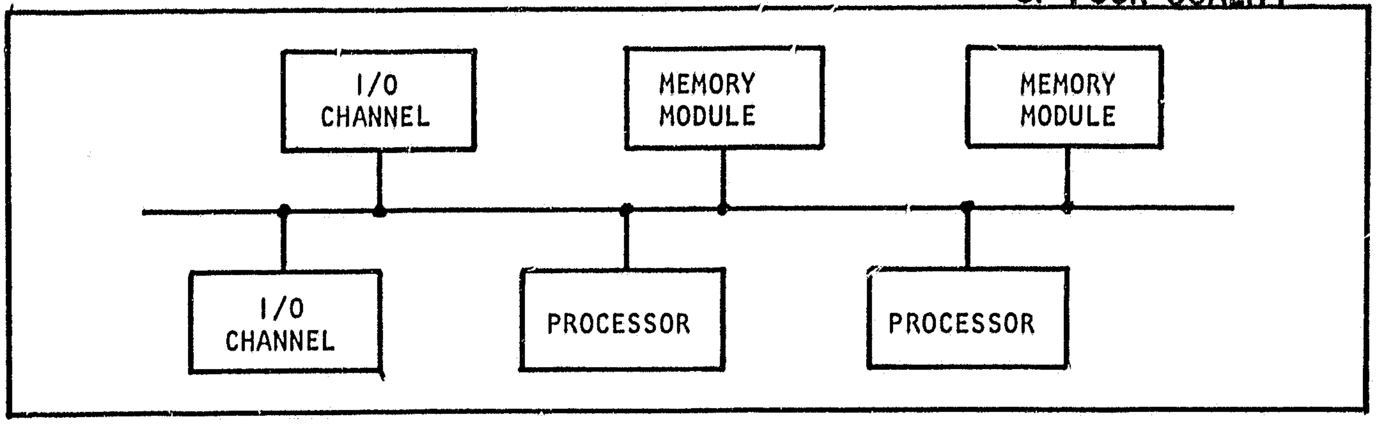

Figure 4-8. Time-Shared/Common-Bus System Organization-Single Bus

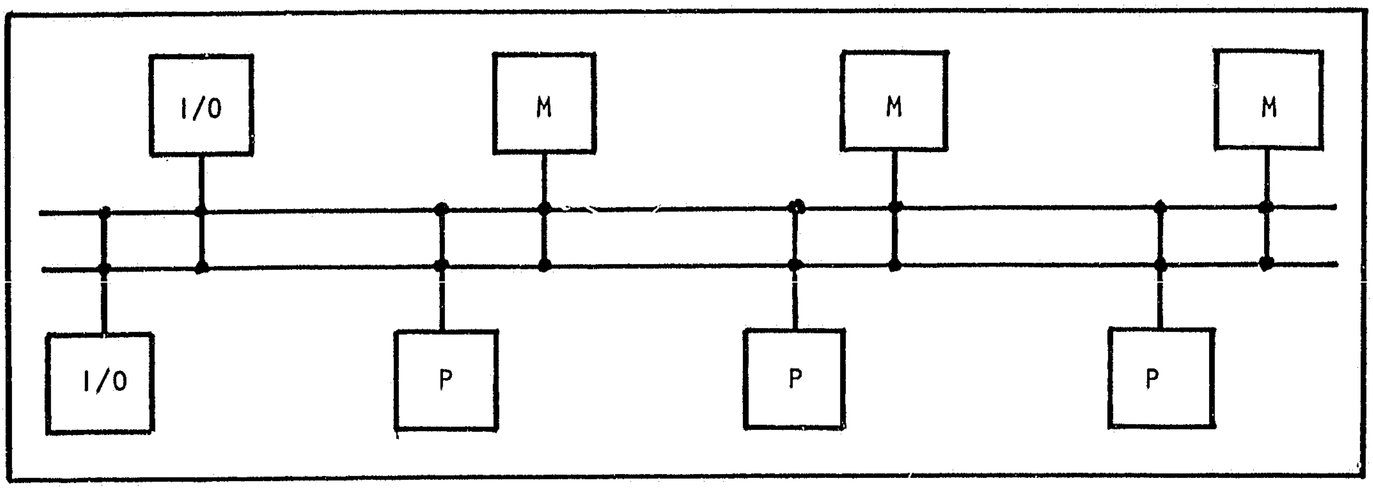

Figure 4-9. Multiple Time-Shared/Common-Bus System Organization

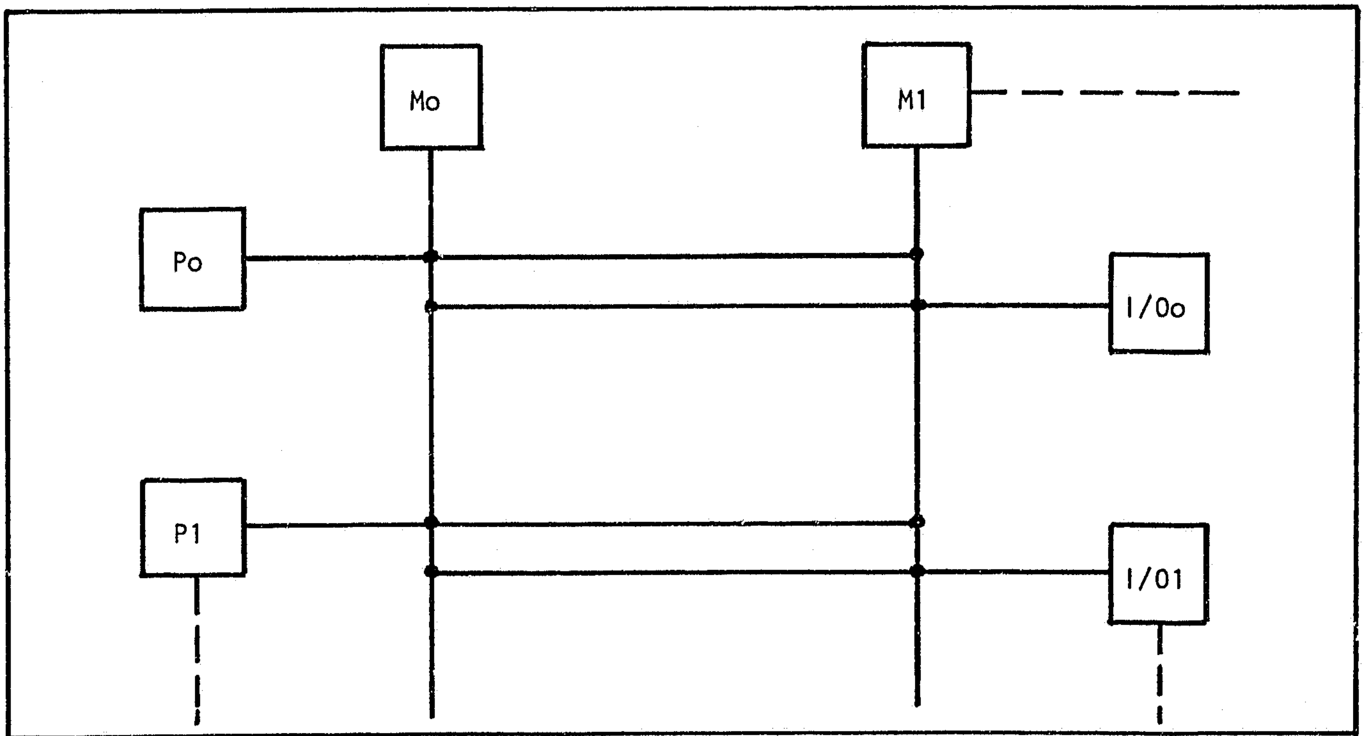

Figure 4-10. Crossbar Switch System Organization

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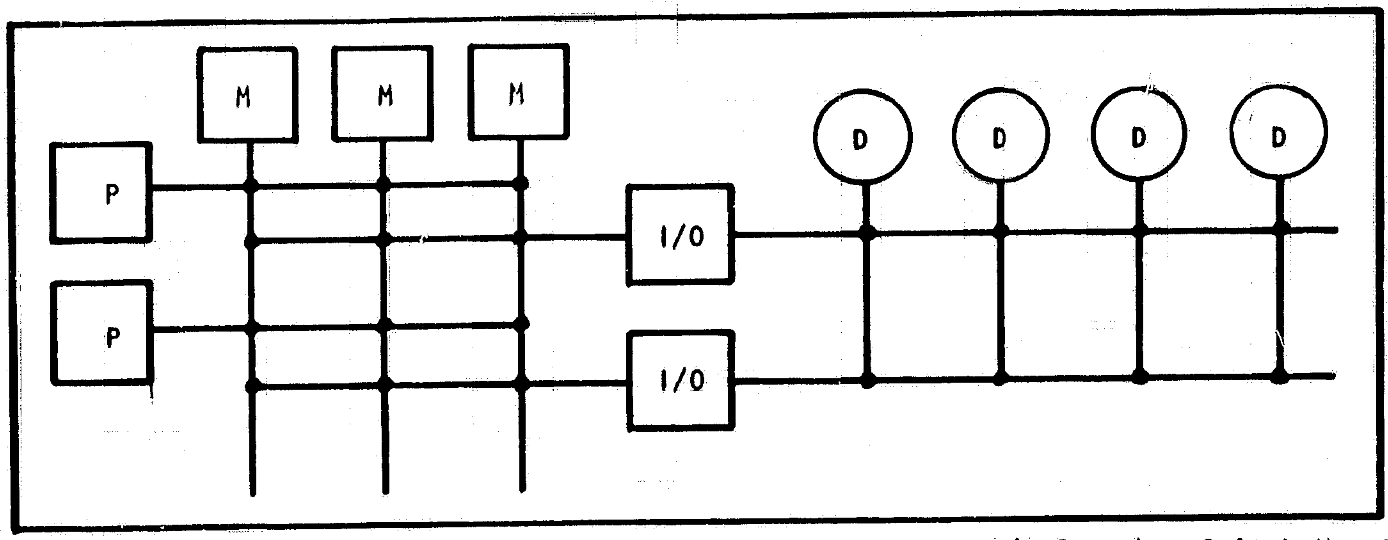

Figure 4-11. Crossbar Switch System Organization with Separate I/O Crossbar Switch Matrix

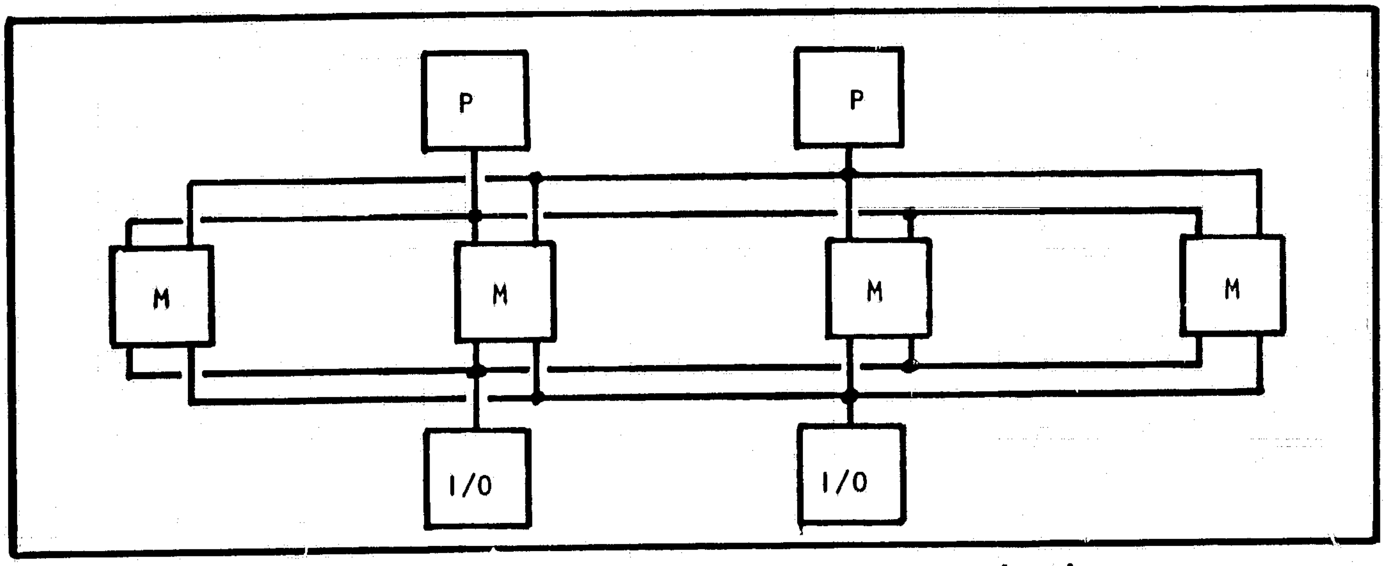

Figure 4-12. Multiport-Memory/Multibus System Organization

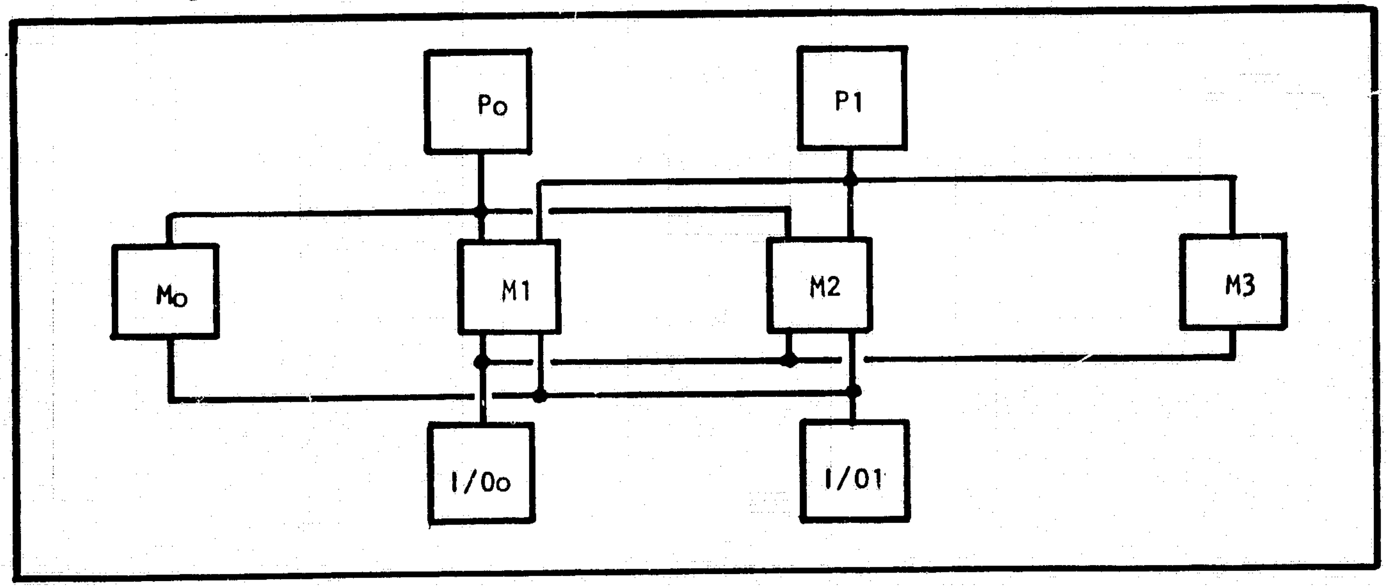

Figure 4-13. Multiport System with Private Memory

any element on the bus to any other element. Such a scheme is known as a crossbar and has been used in such systems as Burroughs D825 (AN/GYK-3). Figure 4-10 shows a single crossbar switch between processors, memories, and I/Os, while Figure 4-11 shows a secondary crossbar switch between the I/O controllers and the I/O devices themselves. Figure 4-12 illustrates a multiport, multibus memory system organization where each processor and I/O element can access any memory module through alternate buses. In Figure 4-13 the multiport, multibus concept has been combined to obtain common shared storage (M_0 and M_3). The above illustrations and discussion serve to indicate that many different interconnecting schemes are possible and have been considered; each has its advantages and disadvantages and the one which should be selected for use with a particular system depends on the overall goals and objectives of that particular system.

There are three basic organizations and modes of the operating system executive of a multiprocessor:

- Master-slave
- Separate executive for each processor
- Symmetric or anonymous treatment of each processor

(Enslow 1) gives a very good treatment of these types. A summary of his account follows.

4.7.4.1 Master-Slave

The master-slave mode may be dictated by the different characteristics of processors in the system and may have one processor designed especially for supervisory control and dedicated to that function. The primary characteristics of the master-slave mode of operation are summarized below:

- The supervisor always runs in only one of the processors that is selected. This processor may be of special design configured just to run the supervisor or it may be similar to all of the others in the system. If this approach were selected for Space Station, the supervisory processor would be identical to the other processors in the system.
- It is not necessary that all of the supervisory routines be written in reentrant code, since only one processor will be executing them. Reentrant coding will still be necessary for some of the common routines that are used recursively or are subject to multiple activations.

- o There is no problem of conflict or lock-out of executive tables, since only one processor will be accessing them.
- o The system is subject to catastrophic failure if the master fails. Restart can occur using another processor as the master. Also, special designs utilizing fault tolerant techniques are possible.
- o The system is inflexible in that it has one main processor and one or more satellite processors.
- o The master must execute its supervisory and executive functions fast enough to stay ahead of the demand; otherwise, inefficiency results.
- o Generally, the master-slave approach contains simpler hardware and software structures but does not have as much flexibility as the other schemes.

4.7.4.2 Separate Executive

In the separate executive for each processor mode, memory is shared and there is no need for completely separate copies of the coding for the operating system for each processor. Each processor operates autonomously and executes all of its own executive, supervisory, and support functions just as if it were a stand-alone processor. Each task is assigned to a particular processor and runs to completion on that unit. The characteristics of this type of operating system organization and operation may be summarized as follows:

- o Supervisory functions are executed by each processor as required to service its own needs and those of the program assigned to it.
- o Because several processors are executing it, the code for the supervisor must be reentrant, or private copies will have to be loaded for each processor.
- o There will be less conflict on system table lock-outs, since each processor will have its own private set. There will not be as many common executive tables.
- o The total system is not subject to catastrophic failure due to the failure of any one processor; however, recovery and restart of the work in progress on the failed unit will usually be very difficult.
- o All I/O operations for a given task are executed by the processor to which it is assigned.
- o I/O interrupts are directed to the processor initiating the I/O operation.
- o Each processor has its own private set of I/O equipment, files, et cetera.
- o Sharing of auxiliary storage is not possible without special coding.

- o Efficiency can be low if one processor has several long jobs in progress while others sit idle.
- o Reconfiguration of I/O may require manual switching.

4.7.4.3. Symmetric or Anonymous Processors

The most "pure" hardware configuration for a multiprocessor is an ensemble of identical processing units containing identical processors, shared common memory, I/O channels, and I/O devices which can be treated symmetrically. Every processor can be equally effective in executing the supervisor and, for efficiency, this is what is done. The executive "floats" from one processor to another. There are certain executive functions that are inextricably associated with a task and are best executed by the same processor that is executing the task; however, there are many others such as the handling of interrupts for asynchronous I/O operations that can be handled by any processor. The primary motivation for this mode of operation is the overall system efficiency achieved in spite of the difficulties to be considered later. Perhaps the most interest and attention has been given to this mode of operation.

The basic characteristics of symmetric operation are as follows:

- o Each processor executes those supervisory functions inextricably connected with the task that it is currently executing and those functions necessary to get a new task when the current one is interrupted or completed. Any processor can perform all or most of the general purpose functions.
- o Because of the anonymity of processors and the symmetry of their treatment, a task may be executed on various units during its progress through the system. On successive executions, a different set of processors can be utilized.
- o Overall system control "floats" between the processors.
  - The one in control of system tables and functions such as scheduling is called the executive processor.
  - Only one at a time can be the executive to prevent conflicts.
  - Each processor may be assigned a priority.

Although only one processor is the executive in overall control, several processors may be executing the same supervisory code simultaneously and the coding must be reentrant to provide for separate copies for each activation.

There are very real problems of conflict which must be dealt with in the access of tables and data sets. These include:

- o Excessive lockouts of system control tables can greatly affect overall efficiency.
- o Lockouts on each data set are essential and the time delays have to be accepted since one processor might try to access a record being modified by another.

There are several advantages of symmetric or anonymous executive control of multiprocessor systems. Some of these are:

- o It can provide graceful degradation.
- o Better uptime potential than separate backup system, provided that system is designed properly.
- o Only way to achieve real redundancy.
- o Most efficient use of resources.

Although this organization is the most aesthetically appealing concept, it is the most difficult to realize and most systems utilizing it have had to back down when they have become operational; e.g., IBM's 9020 system for the FAA.

4.7.4.4 Factors in Topology Selection

Some of the basic functional capabilities which must be considered and provided for in a multiprocessor system are:

- o Resource Allocation and Management
  - Memory Allocation and Control
  - Scheduling and Dispatching
- o Processor Intercommunications
- o Abnormal Termination
- o Processor Load Balancing
- o Table and Data Set Protection
- o Input/Output Load Balancing
- o Reconfiguration
- o System Deadlock

The attributes, alternate approaches, and factors which must be decided in the design of a multiprocessor system have been discussed above. A very fertile area for future research is studying and evaluating the various trade-offs to arrive at an efficient computer system for Space Station. In the past, considerable effort and cost were devoted to developing individual elements for the multiprocessor system; i.e., processors, memories, and input/output units, etc. With today's technologies, these devices are readily available at a very reasonable cost, and the majority of effort and monies can be devoted to system approaches, configurations, and software control techniques.

4.7.5 DESIRABLE CONCEPTS FOR SPACE STATION

Although considerable investigation and research are required (and highly recommended) within the framework of the previous discussion, the characteristics desirable in the Space Station computer can be defined and an approach broadly considered.

Each computer in the Space Station operations, ODMSC, OSSC, and missions applications functions is a multiprocessor. Each processor is a fully capable stand-alone computer with its own operating system. Each processor has the single minded goal of working a set of jobs that it will obtain from an external stack in a designated memory module. Each processor will have a multitask operating system and interrupt capability so anytime there is a need to await some external event, such as an I/O completion, the processor can get another task. Tasks are placed in the memory queue for execution by whichever processor is available next. This has inherent reliability advantages without a sacrifice in throughput. Should a processor fail for any reason, or simply be removed, the software awaiting execution does not realize any change in configuration. By employing the concept of process objects that has received recent attention with the Intel Corporation's IAPX-432, a complete identification of the required I/O, data files, and state can be included in each "task." By storing the state data when an interrupt occurs, it is not even necessary that interrupted processing be resumed by the same processor. This concept was first demonstrated on the Navy's AN/GYK-3(V) D825 ARCH multiprocessor in 1962 (Thompson 1). Advances in microprocessor technology make this concept attractive for the highly functional, redundant, repairable, and modular expandable computer desired for Space Station.

4.7.5.1 Critical Tasks

With the concept of fully describing each process object in terms of its needed resources, critical tasks can be flagged for multiple execution. In such situations, an accepting processor would leave a copy on the stack and identify that it was being executed. As other processors became available, process objects could be executed the required number of times and eventually removed. Results would be placed in the designated location, probably distributed among several memory modules. Thus redundant, voting logic execution could be selectively executed without a commitment to excess resources when not required. A failure of a processor would be so reported to the subsystem performance monitoring subsystem for annunciating and subsequent corrective action, which would likely be the scheduling of maintenance at the next available shift. Some computational capability would be lost, but reliability would not.

With the advances in microcircuitry, many sophisticated built-in test concepts are evolving. In many instances, the triple redundant voting logic is not necessary. The only requirement is that faults be detected in time to perform the computations over again on a different processor. For an overview of design for testability, see (Williams 1).

4.7.5.2 Analytic Redundancy

An interesting concept for Space Station fault detection is the notion of analytic redundancy, discussed in (Deyst 1). An example of how this concept might be employed by the subsystem performance monitoring subsystem would proceed as follows:

> The performance monitoring function could obtain positional information from both the navigation subsystem and from the mission data. It is assumed that in the mission partition, some image processing and registration capability exists. It is also assumed that the image processing system has access to some ground control points. In order to assemble completely documented data sets, there is a correlation of position and the acquired images. The on-board data base could correlate the ground control points to a specific position and time and this could be compared with the data from the navigational system. While this might be too process intensive for normal navigation, it provides a means to monitor the performance of the navigation system using analytic redundancy.

4.7.5.3 Fault Tolerant Memory

An additional point of interest for further development of the computer system is fault-tolerant memory. Soft memory errors are induced by alpha particles, cosmic radiation, and other random sources. Characteristics of a fault tolerant memory are presented in a paper by (White 1). The effectiveness of this approach is illustrated with numerical examples and the use of a mathematical model. This same memory architecture is incorporated in the NASA NSSC-II.

4.7.6 COMPUTER ARCHITECTURE DEVELOPMENT NEEDS

In summary, it is highly recommended that a research and development task be instigated to perform trade-offs in the various network configurations, executive control schemes, resource assignment and allocation, reconfiguration, et cetera, to arrive at an efficient multiprocessor configuration which satisfies Space Station requirements. With today's technology and available equipment, such a study could readily treat the heart of the problem; i.e., configuration and control techniques, rather than in having to design and fabricate specific elements such as processors, memories and I/Os to demonstrate an architecture.

4.8 SPACE QUALIFIED LARGE SCREEN DISPLAY

The degree of automation envisioned for the Space Station tends to reduce the need for personnel to be located at stationary positions. It is likely that some fair degree of mobility will be the norm for Space Station personnel. Yet, with the large number of imaging sensors available, a means of displaying the images that will provide good resolution at a distance is required. Large displays have been effectively used for ground-based launch control and payload operations centers. They will likely be needed in the Space Station.

Space Station space will be much larger than historical spacecraft. Before Space Station, there was no need to develop space qualified large screen displays. Consequently, there is little experience available. At this point, no single technology is favored. The oil film does not seem suitable for the microgravity of space. Experience with electrophoretic and light valves in space is almost nil. Plasma has always been limited by lack of grey scale and approaches at color have not been very successful. Large folded CRTs have not been implemented for various reasons.

4.9 QUALIFICATION SYSTEM FOR DATA SYSTEM COMPONENTS

The correct consideration of space qualified components will have a major impact on life cycle cost. The changing role of manned presence and indefinite life call for new considerations of reliability and maintainability. Technological advances of commercial components should not be forfeited because of excessive space qualification processes. Yet, because of safety concerns, especially outgassing of materials, commercial products cannot be used carte blanche.

One alternative is to include a space equipment test facility as part of the research program. The best method of determining if a commercial part may be space qualified is to simply take it out into space and test it. This method not only eliminates the excessive space qualification processes, but may also reduce the life cycle cost of the Space Station.

A facility as described would be incorporated into the Space Station and would be highly instrumented for EMI, outgassing, and any other contaminants that are likely. The technology required would be the development of a complete concept for 1) handling such testing, 2) the generation of guidelines and standards for use by experimenters and users that had to build components for use on the Space Station, and 3) the initiation of an education and information dissemination process to acquaint potential users with the critical factors.

4.10 DIRECT BROADCAST

Trends in satellite communications technology can be predicted with reasonable certainty over the next five years.

Body-stabilized platforms allow complex antennas to be directed toward the earth and larger solar-cell arrays to be oriented toward the sun. Energy conversion and storage will become more efficient and sophisticated, and more power will thereby become available. Higher frequency bands will greatly increase capacity. Multibeam antennas and improved interconnectivity of antennas and transponders will allow flexibility in assigning capacity to different geographic areas. Reusable manned launch vehicles --the Space Shuttle-- should reduce launch costs, permit controlled tests of new technology, and eventually make possible the repair of satellites in orbit.

To increase capacity any significant amount, future satellites will employ several simultaneous uses of the same frequency band. Furthermore, in order to locate earth stations close to traffic sources, it may be advantageous to operate in one of the higher frequency bands, where interference is less of a problem. Fortunately, these two requirements go hand-in-hand, because frequency reuse is obtained by spatial separation of the satellite antenna beams, and beam isolation increases with frequency, for the same size antenna.

The use of higher frequencies will make beams more directional and should permit closer user spacing. Development of antenna sidelobe-suppression techniques will also help. The number of spacecraft in orbit could be reduced if varied services were combined on multipurpose space platforms. Aside from the serious technical problems that this last solution presents and the ensuing unavoidable reduction of orbit-spectrum capacity, it will require agreement among diverse institutions, with possibly opposing interests.

4.10.1 TECHNIQUES FOR FORMING RAPIDLY SCANNED BEAMS

A number of techniques exist for forming rapidly scanned beams. The simplest approach is to use a parabolic reflector having multiple feed horns in an array configuration. Each feed horn, when singly excited, produces a main-lobe radiation pattern that coincides with the intended coverage area on the ground. Because all the reflector's power is fed into a single horn, switching (which must be performed at high power levels) becomes lossy and slow. In addition, adjacent beams must overlap at their -3 db points for full-area coverage, necessitating an undersized feed horn that reduces antenna gain because of spillover losses. Significant cross-coupling loss into the adjacent feed horns further reduces reflector antenna gain. An alternative method is to form a beam by simultaneously feeding the center and adjoining horns at reduced power levels. This reduces spillover and cross-coupling losses, but complicates the feed structure and does not alter the fact that the center horn must still handle most of the antenna's power.

Another technique is to use a phased-element array, where a digital phase shifter is employed in each element. The phase shift is controlled by high-speed logic, and losses are overcome by low-power transmitters at each element. To make the array's gain large, either the number of elements or the gain of each element can be increased. As the number of elements increases over 100, the additional number of elements required to gain more decibels becomes worrisome. For example, adding 90 elements to a ten-element array will increase the gain from 10 to 20 db, but 900 additional elements are needed to raise the gain from 20 to 30 db.

There are imaging techniques, similar to classical optics, that allow the physical size of the elements to be greatly reduced. The patterns produced by the elements are magnified through a system of lenses and projected onto a single large aperture.

A newly devised satellite antenna, described later, would allow a scanning beam and several fixed spot beams to operate simultaneously. Thus we envision that a high-capacity station could be constructed by employing several fixed spot beams centered on the major users, and a scanning beam that operates on the orthogonal-polarization principle, to provide service to the remainder of the country through TDM. The fixed spot beams would operate in a satellite switched time-division multiple access (SS/TDMA) format. The scanning beam is also connected to the satellite switch so that all possible interconnections among the spot beams and the scanning beam are available.

This hybrid satellite of fixed and scanning beams is used as a model for the example system that is described here. Phase shifters, following the preamplifiers, point the antenna beam toward the earth station that is transmitting at any given moment. They change state very rapidly, consume very little power, and have relatively low insertion loss. Once the signals are phase shifted to produce a coherent signal, that signal is no different than any other spot beam as far as the satellite is concerned. It can be down-converted, passed through the satellite switch, and directed into any spot-beam down link.

4.10.2 SCANNING SPOT BEAM

A scanning spot beam requires many low-noise amplifiers, digital phase shifters, and power amplifiers. Considerable effort is being devoted to the 14 GHz preamplifiers and to 12 GHz power amplifiers for other applications, and we will not discuss these in any great detail here. The system requirements for the phase shifter make it different from anything that is commercially available.

An experimental digital 4-bit phase shifter that operates at 12 GHz was constructed recently by Bernard Glance of Bell Laboratories. It might satisfy the system requirements for a scanning spot beam--compactness and low transmission loss. The circuit was fabricated in a microstrip line using copper evaporated on a silica substrate. The RF and driver circuits are enclosed in a single package to minimize switching time.

The entire phase-shifter circuit consists of four cascaded microstrip cells providing phase shifts of 90, 180, 45, and 22.5 degrees. Each cell is made of a 3 db branch-line coupler whose coupling arms are connected to open sections of a transmission line, with a PIN diode in each line to change its electrical length. The cells are identical except for the position of the diodes, which are positioned to give the required phase shift.

It is especially important that the phase shifters be capable of changing state very rapidly, so that no large penalty is paid in overhead from the TDMA. It is also necessary that the phase shifter consume a very modest amount of dc power, since more than 200 of them would be needed for the two independent scanning beams.

The scanning spot beams must be controlled to move in a certain sequence. For the low earth orbiting Space Station, this must include the orbital dynamic timelines. The time spent at each location should be proportional to that area's traffic needs. Such beam times at a given location can be as little as 1 or 2 microseconds. To update 100 4-bit phase shifters in 1 microsecond requires a data rate of 400 Mb/s. Clearly, to attempt such updating from the ground would be foolish. Furthermore, once the scanning sequence started it would repeat many times before changing. Changing the sequence is only required as individual earth station's capacity requirements change. Thus, it appears best that the controller be on-board the Station.

Thanks to today's semiconductor technology, one can readily construct a sequencer that can cyclically perform the simple task of determining where the beam should point next and for how long. One way is by a table look-up that contains the beam's location-to-phase-shifter settings along with a simple counter that is set each time a new beam is formed. The counter merely counts clock pulses down to zero, which starts the process to move the beam to the new location. The clock is reset to the new count for that location and the process continues.

If a data channel to a master control station is provided, then all requests for changes in service could be monitored. The master controller could honor requests for changes in service by updating the sequencer for the scanning beam, and in a separate channel, let it be known to all earth stations that the sequence has changed.

If an earth station were to misinterpret the information from the master station and transmit out of turn, a small disaster might occur. Therefore, it would be wise in granting new requests to allow changes in the sequence as seldom as possible, perhaps by having a number of preassigned slots for each earth station. Such slots change very rarely, but additional service requests could be handled by having a pool of circuits (near the end of the sequence, for example) available strictly on demand.

It has been shown that a scanning spot-beam satellite is a blending together of two technologies: TDMA and spot-antenna beams. Both will appear in various forms in the next generation of commercial satellites. However, there are no commercial systems now underway that would utilize rapidly movable spot-antenna beams as discussed in this report, and their eventual use in a satellite is very difficult to predict.

Several advantages of a scanning spot-beam satellite have been pointed out, including high effective isotropic radiated power, high capacity, high trunking efficiency, and good utilization of the orbital arc.

The disadvantages could include high-speed channel operation (600 Mb/s); commercially available TDMA modems operate at only one tenth this rate today. Thus, it will be necessary to develop high-speed and relatively low-cost modems before systems of this nature become viable. There appear to be no fundamental reasons to prevent high-data-rate TDMA operations.

Another problem is the development of a scanning spot-beam transponder for the satellite. It has been shown that all of the necessary components exist to assemble such a transponder, but satellite vendors proceed cautiously --for obvious reasons. Before building such a satellite, a great deal of developmental effort would be required in space qualifying and life testing.

For example, PIN diodes suitable for a switch that could be used to reroute traffic among beams in a multi-beam satellite have been available since SS/TDMA was first discussed. Another example of conservatism comes from the very slow rate at which TWTs are being replaced by solid-state amplifiers. Implementation of scanning spot-beam systems reasonably can be estimated as several years away.

For very large trunks, one would probably choose to employ individual fixed spot-antenna beams. Also, a scanning spot beam would only be of limited use for broadcasting where the same message usually goes to a large number of users. The scanning beam would thus have to keep repeating a single message to different geographical areas. It is equivalent and undoubtedly simpler to transmit the message only once to a larger area.

However, for cases where several different messages are broadcast simultaneously to dispersed geographical areas, scanning spot beams could be employed, and it appears that their most useful application will be to provide communications among many small, geographically dispersed terminals. Examples include mobile communications, and the private networks, used by large businesses, where several networks share the same satellite. A scanning spot-beam could also be useful for trunking moderately large bundles of traffic, say about 1000 equivalent voice circuits.

SECTION 5
RECOMMENDATIONS

A major objective of phase one of this study was to identify data system technology elements that have a high potential for reducing life cycle cost of the Space Station. A wide range of factors in the total Space Station system implementation, operations, applications, and data systems techniques was touched upon during this study. There was a concentration on different approaches that might require long lead time development for fruition. Generally, concepts were considered because of a recognized potential system problem or because a concept offered an intuitive high payoff. It must be emphasized that this study is indicative of only the opening moves in what will unfold as an interactive epic spanning generations. Only the very best of the concepts should be the subject of extensive research and development. However, there is usually no finite line of demarcation between what is and is not likely to be fruitful. Rather a continuing process of further investigation and decisions on a case-by-case basis will be required. Some suggestions to an approach for selecting additional investigation as a function of available resources will be included in this section.

5.1 TECHNOLOGY INFLUENCE

The underlying idea that investment in technology will improve the implementation cost ratio is sound. In practice, the strategies are more complex. The model of the technology relationship to the Space Station system and the global environment is only vaguely defined. It is implicit in the decision making process but has not been committed to any formalism. Perhaps the first recommendation should be to formalize those relationships.

5.1.1 TECHNOLOGY MODEL

This era of rapid technological advances is primarily a result of economic pressures and an awareness by the world's population that technology offers a large return on investment. This environment adds a new dimension to the systems engineering of large complex systems with a long elapsed time from concept to operational deployment. As a system is refined from general requirements to specific designs, external environmental changes can invalidate earlier optimization decisions. The trick for success is to either work with sufficient abstractions at each stage in the development process so that environmental variance will remain within the boundaries of the abstraction, or to be skillful at predicting the environmental state for the time frame of interest. A generic model of the relationship of technology on the environment is presented in Figure 5-1.

This model is presented as a rudimentary concept. No claim of its validity is advanced and no supporting evidence is offered. The logical relationship will be briefly stated. The referenced numbers correspond to the numbers on the board activity that take place in the environment.

5.1.1.1 Planned Technology Programs

The degree of emphasis and funding of technology programs (1) will increase as technology advances. There exists some coupling of success and economics to (1) but it is not explored at the first level.

5.1.1.2 Technology Advances

This is the unknown of interest in this model.

5.1.1.3 Cost Effective Technology

This is a goal of a program such as this. As technology in general advances, there will be a larger pool of cost effective technology upon which to draw for system implementation. Of course, the next links are dependent upon the technology being applied or permitted by the specification to the system.

5.1.1.4 Features of System

Technology advance will also enable enhancement of the system capability. It can do more things for more applications, or do them better.

5.1.1.5 Component Performance

The performance of individual components will improve as technology advances. These performance improvements may be manifested in faster operation, lighter weight, less power consumption, or a variety of other parameters. Generally, this coupling has some natural value that is not strongly influenced by other factors in the model.

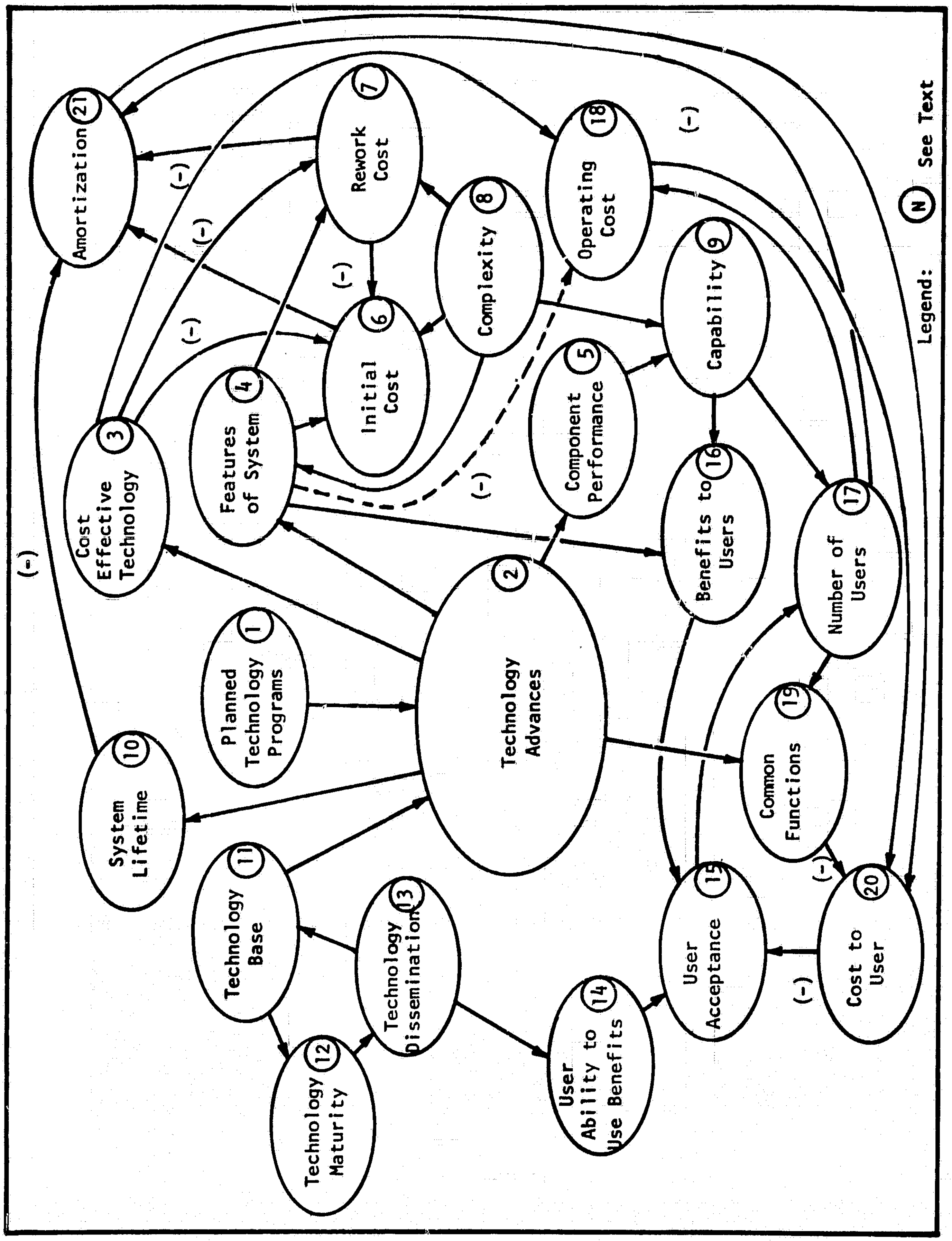

Figure 5-1. Impact of Technology on Users and Cost

5.1.1.6 Initial Cost

The initial cost of a system will be positively coupled to the features of the system and will be reduced by the influence of cost effective technology. The complexity (8) of the system will also increase initial cost. Generally, the initial system design optimization involves a trade-off between initial and rework costs. Savings in initial cost will incur greater rework cost.

5.1.1.7 Rework Cost

This is a necessary activity for long life systems. Changes in requirements, technology, and the environment become too drastic before the planned useful life of a system runs out. Rework can be a cost effective method of stretching useful life. This concept is now well recognized with catch phrases like PPPI, Pre Planned Product Improvement.

5.1.1.8 Complexity

Complexity is often the price paid for additional system features (4) and capability (9). It increases both initial and rework costs.

5.1.1.9 Capability

Capability is distinct from features. Capability is the measure of the amount of the functions the system is able to perform for a data system. Parameters such as throughput, millions of instructions per second, or storage capacity are representative. Capability will be positively increased as component performance (5) increases. It also is positively correlated with complexity (8).

5.1.1.10 System Lifetime

System lifetime is influenced by technology advances. This is the time a system will function without wearout. Obsolescence is not considered in (10).

5.1.1.11 Technology Base

The technology base is the industrial, economic environment. It accounts for more than know how of technology advances (2). This component (11) accounts for the breadth and depth of the means of production.

5.1.1.12 Technology Maturity

The rate of technology maturity increases as the technology base expands. There are more users of technology to discover needed improvements and whether they are economically worth pursuing.

5.1.1.13 Technology Dissemination

As technology matures more people are aware of it. This in turn increases the technology base.

5.1.1.14 User Ability to Use Benefits

The ability of a user to utilize benefits is dependent upon technology dissemination. An example of this correlation is image data and microprocessors. A few years ago, widespread availability of digital images would not be valuable to many users because they would not have the systems in place to accept digital formats. With the widespread dissemination of microprocessors and their cost reduction, virtually any user with a need for image data could accommodate the digital format.

5.1.1.15 User Acceptance

Another important factor in a successful system is user acceptance. This will be strongly influenced by his ability to use the benefits (14). Acceptance will also be negatively coupled with cost to the user (20) and the benefits (16) he receives.

5.1.1.16 Benefits to User

These are the end results of features (4) and capability (9) of a system. Only those that benefit the user will positively influence his acceptance.

5.1.1.17 Number of Users

The number of users will increase as system capability (9) and user acceptance (15) increases. As the number of users increase, there will be more common functions (19). Operating costs (18) will increase as the number of users increases, but amortization (21) will be spread over a greater number.

5.1.1.18 Operating Costs

Operating cost will be increased by the number of users. The availability of cost effective technology (3) will reduce operating cost. Operating cost will be positively coupled with the cost to the user. A more tenuous relationship exists between features (4) and operating costs. Features (4) should diminish operating cost, but could increase it.

5.1.1.19 Common Functions

Common functions are things that many users need. Technology advances permit greater utility of devices (flexibility). As the number of users increases, there will be increased intersection of the things needed to be accomplished. The result is a decreased cost to the user.

5.1.1.20 Cost to User

This is the actual cost to a user. Artificial influence such as through surcharge or subsidy is not considered. It is based upon operating cost (18) and amortization (21). As cost to user diminishes, user acceptance will increase.

5.1.1.21 Amortization

This is the accounting distribution of the capital costs, initial (6) and rework (7) over the lifetime of the system. As the system life (10) increases, per unit amortization, as would be passed on to the user, diminishes.

5.1.2 SELECTION CRITERIA

The selection criteria for a particular technology development project accounts for the following factors:

- Worth of project
- Time criticality of project
- Cost of performing project
- Environmental influence on technology
- Impact of lack of technology
- Risk

5.1.2.1 Worth of Project

The worth of a technology is an assessment of the potential benefits of having it. This has to be a discounted assessment because in some situations the worth is dependent upon the ultimate deployment mode or application of the system. In other cases, the worth is influenced by the availability or lack of alternatives.

5.1.2.2 Time Criticality of Project

In a budgeting process involving valuable resources, which may be dollars, personnel, or facilities, emphasis must be placed on those things that are needed first. Some very high potential projects may be excellent candidates for deferral if their utility will not diminish significantly by delay.

5.1.2.3 Cost of Performing Project

This is a necessary factor. Absolute cost is not a driver in prioritizing projects, but may be a real life constraint. The measure of significance for selection is the cost benefit ratio where the benefit is either the worth of the project or some weighted combination with the other factors.

5.1.2.4 Environmental Influences on Technology

This is a factor for evaluating the necessity of investment in a long term technology. For some needed technologies, the natural forces of the market place may bring them along without specific impetus for a program like Space Station.

5.1.2.5 Impact of Lack of Technology

Some technology projects have considerable worth in terms of enhancements possible when the technology becomes available. Equally critical and possibly more so are those technologies that will have disastrous repercussions if they are not available. These often are the ones that are almost available and become integrally associated with the overall system design. Then when problems are encountered, the total system development is impacted.

5.1.2.6 Risk

Some technologies may be pivotal in terms of major design decisions. There may be competing approaches or there may be a heavy reliance on a technology that is almost here. Additional development may be justified to obtain greater certainty of availability or to provide an alternative. Sometimes just being able to prove the principle will save considerable system design cost by removing the need to continue alternate concepts.

5.2 TECHNOLOGY CONCEPT SUMMARY

Many concepts involving different applications of existing technology of unproven techniques have been identified during this study. Some of these are identified in Table 5-1 with a cross reference to the paragraphs of discussion.

5.3 ASSESSMENT OF TECHNOLOGY CONCEPTS

All the technology concepts identified require additional investigation to fully assess this priority for development. The criteria can be applied analytically. However, a large number of the concept evaluations will be greatly influenced by the emerging configuration of the Space Station as a result of other studies. Applying the time criticality criterion, the judicious approach at this time is to defer temporarily further assessment on all but the following:

- Total life cycle ground support
- Architectural design
- Automated command management
- Self-organizing data bases
- Human gateway
- Technology model

Table 5-1. Technology Concepts

CONCEPTS	PARAGRAPH REFERENCES
Hierarchical Control	2.2.1
Virtual Architecture	2.2.2
Standard Interface	2.2.3
Overall Architecture	2.3
Separation of Operations and Mission	2.3
Asynchronous Architecture	2.3.1
Centralized Orchestration Architecture	2.3.2
Independent Kernal and Monitor	3.2
On-Board Logistic Management	3.5
Collision Avoidance	3.6
Direct Broadcast	3.8 4.10
Asynchronous Session Access Protocol	3.8.3
On-Board Data Analysis	3.9
Quick Look System	3.9.1
Ground Requirement Management	3.10.3 4.2
Total Life Cycle Ground Support	3.10.1
Ground Engineering Aids	3.10.2 4.3
Ground Software Management	3.10.5 4.4
Automated Work Planning & Scheduling	4.1
Automated Command Management	4.1
Self-Organizing Data Base System	4.5
Human Gateway	4.6
Electronic Mimic Board	4.6.11
Large Screen Display	4.6.1.2 4.8
Automatic Configuring Computer Architecture	4.7
Qualification System for Data System Components	4.9
Technology Model	5.1.1

APPENDIX A

SPACE STATION DATA SYSTEM FUNCTIONS

APPENDIX A
SPACE STATION DATA SYSTEM FUNCTIONS

1. OPERATIONS

These functions of the Space Station data system are required to provide a permanent inhabited Space Station independent of its mission requirements. These functions are operations control, communications, and data management.

1.1 OPERATIONS CONTROL

This function encompasses all those data system functions necessary to maintain the Space Station in a survivable state. It includes the necessary redundancy management and either fail operational or fail safe modes to permit the long term survivability of the system. The major functions are: subsystem control, subsystem performance analysis, command management, attitude operations, orbital operations, and docking maneuver.

1.1.1 Subsystem Control

This function encompasses the control and monitoring of each of the subsystems comprising the Space Station. The associated data systems with each of the Space Station subsystems are assumed to be a part of the specific subsystem and will generally be excluded from the functional requirements of the Space Station data system. There will be interfaces to each of these subsystems, which are included for reference.

1.1.1.1 Life Support

This subsystem provides for the special integration and redundancies required of the environment control, medical, and interlocks to support human life.

1.1.1.2 Power

This subsystem provides all the necessary power for the Space Station to survive and function. It may be subdivided into solar, nuclear, battery, backup, et cetera.

1.1.1.3 Attitude

This subsystem will control the attitude and pointing of the Space Station. It includes determining pointing error and drift, the automatic maintenance of the designated attitude, and the determination of and execution of the necessary commands to alter attitude when such commands are received.

1.1.1.4 Collision Avoidance

This function provides for collision avoidance by all methods practical including the tracking of known debris in the orbits of the Space Station system components and monitoring via both active and passive sensors for unexpected debris. These functions include the maintenance of required debris data bases, interfaces to ephemerides data for the spacecraft and other platforms such as OTV, real time signal processing and signature analysis of observed signals, annunciation, and display of resulting debris tracks and corrective action assistance information.

1.1.1.5 Environment Control

This subsystem acquires the necessary environmental data and generates the necessary stimuli to maintain the Space Station artificial environments within the prescribed limits. These environments include those suitable for human occupancy and those required for experiment and application subsystems within the environment control subsystem, including temperature, heating and cooling supplement, atmospheric conditioning, light, and elements required to accomplish these functions such as cryogenic pumps, radiators, piping, and ducting.

1.1.2 Subsystem Performance Analysis

This function ensures that the subsystems meet their operational and performance requirements. This function includes the evaluation and maintenance of the subsystem performance and monitoring and controlling operations. This function generally will include the execution of models of each subsystem to determine expected performance; accesses to data bases, analysis routines, and fault identification aids; and interfaces to human operators for interactive query and diagnostic action.

1.1.2.1 Life Support

This function provides on-line evaluation and current status of all life support components including active elements, consumables, anomalies, and parametric excursions from expected values.

1.1.2.2 Power

This function provides on-line evaluation and current status of each power subsystem. It includes interfaces with built-in test functions, the application of test stimuli according to acceptable protocol, models suitable for accelerated performance and life predictions, performance prediction under induced environment, consumable accounting, anomaly detection and annunciation, and identification of parametric excursions from expected values.

1.1.2.3 Attitude

This function provides on-line evaluation and current status of each attitude component and functional performance. It includes interfaces with the built-in test functions. It also includes the monitoring of drift, other signatures such as power consumption, and individual attitude subsystem performance trends such as momentum build up, wobble, and structural flexure.

1.1.2.4 Medical

This function provides on-line evaluation and current status of the crew. It includes the direct acquisition of physiological data from sensors attached to crew members and indirectly acquired data such as from atmospheric exchanges. The function also includes medical assistance and models for monitoring and detecting performance deterioration or abnormal stress conditions. It could include individual crew member physiological models, diagnostic aids and access to pharmacological data.

1.1.2.5 Environment Control

This function provides on-line evaluation and current status of the environment control subsystem. It includes interfaces with the built-in test functions. It also includes the maintenance of parametric history and the analysis of trends, deviations, and consumable status. It may include models for control optimization under stressed environmental conditions such as long duration radiation exposure at fixed attitudes, abnormal sunspot activity, abnormal heating from equipment usage, contingency operations, loss of components, and consumable shortages.

1.1.2.6 Environment Monitor

This function provides continuous monitoring and data acquisition on the Space Station environment both internal and near external. It includes the monitoring of electromagnetic, particulate, acceleration, and any other environmental factor that would impact experiment and application subsystems.

1.1.2.7 Mechanical Strain

This function provides continuous monitoring and data acquisition on the Space Station structural strain and alignment. It includes the maintenance of a current state model of the relative locations of key components. It will be used by attitude, docking, and sensor processing subsystems, as well as for control of thermal stress induced structural damage.

1.1.3 Command Management

This function manages the operational commands between the ground control, the Space Station, the subsystems, OTVS, and the outlying platforms.

1.1.3.1 Establish Validity

This function establishes the validity of the command. It checks the user's authority to issue the command, determines the feasibility of the command and the availability of the system to perform the command.

1.1.3.2 Scheduling

This work planning function schedules the timeline for delivery and the planned execution of the commands.

1.1.3.3 Transfer Command

This function includes the transferral of commands between the ground, the Space Station, and other off-station locations.

1.1.3.4 Execute Command

This function executes commands.

1.1.3.5 Maintain Accountability

This function provides a timeline history of the commands, their receipt by the appropriate systems and subsequent action.

1.1.4 Attitude Operations

This function includes relating to predetermined orientations, holding the required orientation for as long as necessary, and providing precise pointing for the applications.

1.1.4.1 Determine Definitive Attitude

This function determines the definitive attitude of the Space Station and the outlying platforms for use by information extraction and performance monitoring subsystems. It may incorporate techniques such as the use of image control points.

1.1.4.2 Execute Changes

This function determines the desired attitude and compares it to the existing attitude. The function then determines and initiates a change maneuver which will be terminated once the desired attitude is reached. The selected maneuver may be dependent upon optimization strategies based upon the attitude change required, time, and consumable expenditure.

1.1.4.3 Space Station Model

This function provides for a current moment model of the Space Station. It allows for extended structures and docked vehicles that will influence the response to attitude change commands.

1.1.5 Orbital Operations

This function predicts the orbit ephemerides, the orbital maintenance requirement and determines the definitive orbits for the Space Station, the OTV, and outlying platforms. The data products of this function are used by the communication, rendezvous, information extraction, operational scheduling, performance monitoring, and other subsystems.

1.1.5.1 Ephemerides Prediction and Validation

This function produces a prediction of the Space Station's orbit by calculating the Space Station's position as a function of time based on a model of the current and anticipated drag coefficients, orbital parameters, and energy changes.

1.1.5.2 Orbital Maintenance

This function determines the deviations of the predicted orbit from the observed orbit and initiates necessary commands to achieve the desired orbit.

1.1.5.3 Definitive Determination

This function determines the definitive orbit of the Space Station. It includes the acquisition of the required measurement data whether it be from GPS, TDRSS, ground stations, laser trackers, star trackers, ground control points or combinations of sources.

1.1.6 Docking Maneuver

This function provides for docking of shuttles and the OTV with the Space Station and outlying platforms that comprise the Space Stations system.

1.1.6.1 Location

This function provides for the acquisition of position location data on docking vehicles. This data may be acquired using active transponders, radar, lasers, optical trackers, proximity sensors, tactile sensors, and combinations of techniques. It also includes the maintenance of a model of the docking components for determining predictive closures, et cetera.

1.1.6.2 Assistance

This function provides for active assistance in executing docking manuevers. It includes the interface to models, the display and interaction with human operators for closure, the automatic generation of commands and signals, and overrides for certain attitude and experiment functions.

1.2 COMMUNICATIONS

The communications function is provided for both the operational and application needs and includes all external communications between the space station and other off-station location, ground, OTV's, TDRSS, and other satellites or platforms as well as the non-data bus internal communications, primarily voice and video.

1.2.1 <u>Channel Management</u>

This function includes the selection, scheduling, monitoring, and interface control of every electromagnetic communication channel irrespective of transmission media, frequency, modulation, or encoding.

1.2.1.1 Selection

This function includes the selection of the communication channel path, e.g., TDRSS, direct to ground, frequencies, etc., according to available option, priority, and optimizing strategies. Frequency selection can include such considerations as atmosphere attenuation and background noise. This function presumably would have access to error data and other environmental condition data as required.

1.2.1.2 Scheduling

This function includes the planning of communication channel requirements time lines, the coordination of internal and external network management functions, and optimization based on parameters of applications priority, available access time, external conflicts such as blocks of reserved communication time on TDRSS by the military, signal acquisition and loss times, and other constraints. This function encompasses internal access schedules, error requirements, TDRSS, and other channel usage.

1.2.1.3 Monitoring

This function has as its objective an optimized channel performance. Channels are to be monitored for both error degradation and subsystem failure. The function may include the generation of test messages. Other functions such as channel selection, the selection of channel coding options, overall system status monitoring, reporting, maintenance functions, and operational mode changes will use information from this function.

1.2.1.4 Interface Control

This function provides access for each Space Station subsystem and application system to the communication subsystem. It includes the validation of access rights, format conversion, and protocol.

1.2.2 Channel Support

This function includes the necessary antenna pointing, formatting and buffering required for each communication channel or subsystem.

1.2.2.1 Antenna Pointing

For each directional free space communication channel, the necessary antenna pointing must be determined prior to signal acquisition. A timeline of the pointing vector must be provided for gross tracking and a closed loop tracking maintenance function must be provided for each steerable antenna. This function requires ground station coordinates and information from the ephemerides data base for the Space Station and each satellite with which communication is required.

1.2.2.2 Formatting

This function provides the necessary format translations, protocol handling, and channel coding for each selected channel. Some agility of channel coding may be required with selection to be as indicated by the channel management function. Channel coding includes both companding and error detection and correction.

1.2.2.3 Buffering

This function provides for the necessary buffering to implement the various protocols and to provide access functions between channels and various subsystems.

1.2.3 Transmission and Receipt

This is the actual carrier and modulation function according to the particular communication channels involved. These channels include Space Station (SS) to ground, SS to TDRSS, SS to OTV, SS to other platforms, and SS to shuttle. SS to EVA could also be included. Internal, nondigital data bus communication, such as voice and video is included in other functions.

1.3 DATA MANAGEMENT

This function maintains the sets of permanent and semi-permanent data for both operations and applications.

1.3.1 Generics

This function provides the generic activities of data management.

1.3.1.1 Acquisition

This function interfaces both the subsystems and applications to acquire data.

1.3.1.2 Capture

This function demodulates data, ensures that all data has been received and corrects the biases caused by refraction, antenna offsets, transponder delays, et cetera.

1.3.1.3 Processing

This function includes the processing performed on the data including enhancements, filtering and corrections. It also includes editing the data for gross anomalies and storing the anomalous data for failure cause identification analysis. Also included is cataloging the data for permanent storage and creating the necessary directories to allow automated data access by authorized users.

1.3.1.4 Archiving

This function includes the long term storing of data and the necessary editing and preparation for long term storage.

1.3.1.5 Data Delivery

This function handles the data requests. It determines the user's access authority and the availability of requested data culminating in the transmission of and transmits the data. It also generates notification of data unavailability and accepts notifications of data delivery and nondelivery.

1.3.2 Operations

This function involves managing the operational data to ensure equipment and subsystem performance.

1.3.2.1 Subsystem Status

This function monitors the performance of the subsystems as reported by the performance analysis functions and annunciates or otherwise provides information required for operations.

1.3.2.2 Equipment Configuration Monitor and Control

This function ensures the correct operation of the equipment. It assigns roles in the event of a failure or as needed to adjust the workload, and notifies system operator of the failure.

1.3.2.3 Command Execution and Verification

This function executes commands received from operations control and verifies that the commands have been performed.

1.3.2.4 Computer Operations Support of all Subsystems

This function provides support of all the subsystems by way of computer resources, both computational and storage.

1.3.3 Crew

This function provides data relative to the crew members to ensure health, operations, recreation and training.

1.3.3.1 Health

This function monitors and records data concerning the health of the crew. This data may include such things as radiation, contamination, and zero-gravity effects on the crew members.

1.3.3.2 Duty Schedules

This function provides task scheduling for the crew members to assure specific duties are carried out.

1.3.3.3 Skills

This function provides skill requirements to perform certain operations to the crew members.

1.3.3.4 Entertainment

This function provides forms of entertainment for the crew.

1.3.3.5 Personal Recreation

This function provides personal recreation activities for the individual crew members.

1.3.3.6 Library Storage, Cataloging

This function stores and catalogs data.

1.3.3.7 Training

This function provides on-board training in the operation of equipment and subsystems.

1.3.4 <u>Logistics</u>

This function provides data on the logistics of consumables, supplies, spares, resupplies, and crew skills.

1.3.4.1 Consumables

This function provides logistic data on the consumables such as fuel, oxidizers, gases, and other resources that are automatically consumed during the normal function of the subsystems.

1.3.4.2 Supplies

This function provides logistic data on supplies such as food and experiment expendable items that have a scheduled consumption and replacement cycle.

1.3.4.3 Spare Parts

This function provides data on the nature and quantity of the spare parts. It includes those on-board the Space Station, in ready supply locations, on other vehicles such as shuttles, and available for cannibalization from other subsystems.

1.3.4.4 Resupply Scheduling

This function monitors the supply levels and schedules the resupply of the necessary resources when they reach a minimum level.

1.3.4.5 Entertainment and Recreation Supplies

This function provides entertainment and recreational supplies for the crew members.

1.3.4.6 Crew Skills

This function maintains a log of the skills possessed by each individual crew member.

1.4 CONFIGURATION MANAGEMENT

This function is a discipline applying technical and administrative direction and surveillance to: (1) identification and documentation of functional and physical characteristics of a configuration item; (2) control changes to those characteristics; and (3) record and report change processing and implementation status.

1.4.1 Configuration Identification

This function identifies and document the functional and physical characteristics of a configuration item as set forth in the current approved or conditionally approved technical documentation (specifications, drawings and associated lists, et cetera).

1.4.2 Configuration Control

This function is the systematic evaluation, coordination, approval or disapproval, and implementation of all approved changes in the configuration of a configuration item after formal establishment of its configuration identification.

1.4.3 Configuration Status Accounting

This function performs the recording and reporting of the information that is needed to manage configuration effectively, including a listing of the approved configuration identification, the status of proposed changes to configuration, and the implementation status of approved changes.

2. MISSION AND APPLICATIONS

These functions of the Space Station data system are required to support the missions with applications of the Space Station. Some of them also serve to support operational functions, although their primary role is mission related and would otherwise have been included as a minor role for strictly operational consideration. These functions include mission planning and support, user assistance, and mission specific functions.

2.1 MISSION PLANNING AND SUPPORT

This includes all functions that are performed prior to launch or shuttle release of a mission, or prior to the execution of an on-orbit Space Station maneuver. It also includes mission activity scheduling, resource allocation, conflict identification and resolution, and the identification of needed resources prior to actual need.

2.1.1 Scheduling

This function dictates the order in which tasks will be initiated. It sequences the tasks and assigns the resources to the tasks.

2.1.2 Support

This function supports the operations and applications of the Space Station and the outlying platforms.

2.1.2.1 Maintain Data Bases

This function maintains data bases of operational and mission specific data.

2.1.2.1.1 Maintain Data Base of Network Data. This function manages a data base of information about the tracking, and communications network, including station characteristics and geodetics.

2.1.2.1.2 Maintain Data Base of Ephemeris Data. This function maintains a data base of definitive and predictive ephemeris for each spacecraft involved with the missions.

2.1.2.1.3 Maintain Data Base of Physical and Environmental Constants. This function maintains a collection of constants such as atmospheric constants, gravitational constants, magnetic field constants, et cetera, for use by the operational and mission specific subsystems.

2.1.2.1.4 Maintain Data Base of Mission Specific Data. This function maintains a set of data that is unique to each mission.

2.1.2.2 Simulation

This function performs simulations to determine the system's ability to support specific activities such as launch, maneuvers, operations, and repairs.

2.1.3 Command Management

This function manages the mission and application commands between the user and the experiment.

2.1.3.1 Establish Validity and Constraint Check

This function establishes the validity of the command. It checks the user's authority to issue the command and checks constraints to ensure there are no conflicts with other experiments.

2.1.3.2 Scheduling

This work planning function schedules the timeline for delivery and the planned execution of the commands.

2.1.3.3 Transfer Command

This function includes command transfer between the user and the experiment.

2.1.3.4 Execute Command

This function executes commands.

2.1.3.5 Maintain Accountability

This function provides a timeline history of the commands, their receipt by the appropriate experiment, and subsequent action.

2.1.4 Instrument Operations Control

This function controls the operation of the various instruments required to accomplish specific missions. The instruments and the degree of data system integration in accomplishing this function falls into two categories. The first includes those instruments and their control that serve multiple mission requirements. While these instruments are mission dependent, they are expected to be a part of the Space Station facility and their data system requirements will be provided by the Space Station data system. The other category of instruments serves only a limited mission role. Their data system functions will be assumed to be provided as part of the mission experiment package. The impact of such functions on the data system is limited to interfaces, storage, communications, and environment maintenance.

2.1.5 Centralized Library Management

This function provides accesses, cataloging and reformatting of the support libraries.

2.2 USER ASSISTANCE

This function provides a friendly man-to-machine interface and guidance in interactive operations and procedures.

2.2.1 Library of Functions

This function provides the users with sets of data that support the processing of applications. This function also provides access to these support libraries.

2.2.1.1 Maintain Library of Statistical Routines

This library provides a collection of support routines that is used to generate statistics on the operation and performance of the system.

2.2.1.2 Maintain Library of Mathematical Routines

This library contains a collection of support routines that perform standard mathematical functions.

2.2.1.3 Maintain Libraries of Physical Models

This library contains a collection of physical models pertaining to applications and experiments on the Space Station. It will be available to support the principal investigators in their information analysis activities.

2.2.1.4 Maintain Libraries of Parameters

This function manages sets of parameters that control and sequence processing tasks.

2.2.1.5 Maintain Libraries of Display Formats

This function maintains formats of the various pre-defined system displays.

2.2.1.6 Maintain Libraries of Data Filtering Criteria.

This function maintains data sets that establish criteria for filtering data for specific information.

2.2.1.7 Maintain Library of Catalogs Describing On-Line Products, Services and Data Bases

This function maintains catalogs describing the products, and data bases as well as procedures for acquiring the described information resulting from Space Station mission acquired data.

2.2.1.8 Maintain a Library of On-Line Documentation

This function provides a library of on-line reference material, guidelines, procedures, reports in preparation, et cetera, pertaining to the Space Station systems and mission subsystems.

2.2.2 Computational Resources

This function provides the capability of processing and storing application specific data for the user. It also provides access to several utilities and data bases the user may require.

2.2.2.1 Processing

This function provides for the processing performed on the application specific data. It includes general purpose computers but may also include signal processors or other high performance devices that have multiple mission utility.

2.2.2.2 Storing

This function provides the capability of storing the application data.

2.2.2.3 Utilities

This function provides several utilities for the user such as data retrieval, pattern matching, search, translation, mathematical reductions, image processing, and any algorithmic process that has multiple mission utility.

2.2.2.4 Data Buses

This function provides data buses to transfer information as users require.

2.2.3 Interactive Analysis

This function provides a more friendly user interface. It controls the users' interfaces by means of menus, displays, graphics, heuristic feedback, expert system assistance, et cetera.

2.2.4 User Aids

This function provides a ready interface between the humans and the data system. It includes the necessary functions for natural language processing, voice recognition, voice synthesis, vision, video digitizing, and programmable function key displays. It also includes the maintenance of the required training sets or personality data bases to adapt the data system to the individual human users.

2.2.5 Communications Network

This function provides user access to the support libraries and data bases by means of gateways to external systems. These external data bases are assumed to be geographically distributed. This function includes the maintenance of the necessary identification, indices, and protocols to provide the access.

2.3 MISSION SPECIFIC FUNCTIONS

These functions impact the data system differently than the previously discussed functions. Generally, the specific data processing will be the responsibility of the mission data system. Some applications will require large data bases which may use common storage components. The following taxonomy of missions is cursory and hypothetical. For each, the significant data system impacts are identified.

The mission specific functions are divided into science and applications. Science is further categorized as Astronomy, High Energy Physics, Near Environment Monitoring, and Exploration. Applications are categorized as Materials Processing, Earth Viewing, Communications and Navigation, Experimental, and Power. Each of these is further subdivided. The taxonomy is arbitrary and intended as a tool for defining data system conceptual alternatives. No claim is made for the validity or worth of the missions.

2.3.1 Science Missions

By the taxonomy applied, science does not include any earth viewing sensors except as some physical element of the earth might aid the non-earth object of the observation. For example, the earth limb may be used to investigate a stellar or solar phenomenon.

2.3.1.1 Astronomy

Astronomy is arbitrarily divided into solar, planetary, and stellar.

2.3.1.1.1 Solar Astronomy. Solar astronomy includes all investigation of the sun and its close environment. Imaging sensors are presumed, with sensitivity ranging from microwave radiometers, through infrared and visible to X-rays. Particle counters, and starlight detection behind the corona are also possibilities. Devices to monitor solar pressure are also included.

The data system considerations are:

- Constant pointing toward the sun. This would include a constraint on the Space Station attitude to avoid shading the instruments.
- Data acquisition of the particle counter and radiometer are expected to be moderate, but could be of a long duration.
- Data rates for visible band sensors could be substantial. Likewise for the higher frequency region such as X-ray.
- Sensors will be passive and will neither interfere with nor be disturbed by most other missions. Presence of man will not have adverse consequences.
- Temperature sensitive measurements will use cryogenic sensors. Heating is only likely perturbation.

2.3.1.1.2 Planetary Astronomy. This includes both observational and physical interactive investigation. Observational investigations will have similarities with solar observations, possibly excluding particle counters.

The data system considerations are similar to solar considerations except with fewer constraints. Pointing angles will be more varied according to mission scheduling. Constraint of position of Space Station relative to sun, earth, and targets is a consideration. Distances are sufficiently close that probes are feasible. Probes will include planetary orbiters which then imposes scheduling, communications relaying, and data processing associated with many of the earth applications. An additional input is the control of interactive probes, including teleoperator and robotic devices. Provisions for processing returned samples, remote telemetry acquistions, planetary models, and material handling all impact data system functions.

2.3.1.1.3 Stellar Astronomy. Stellar astronomy includes the mapping, change detection, and measurements of the stars. The sensors will be similar to the solar missions except the focusing devices, radio and optical, will have far field optimization. Very large baseline interferometry may be employed. Some large structures and remote, off-station devices are likely.

Data system considerations are similar to solar with additional precision locations for interferometry and the precision pointing requirements. Some long term stability impacts are also expected.

2.3.1.2 High Energy Physics

These science missions may involve both observation of natural phenomena and the generation of artificial particles. The vacuum and potential large distances with little field perturbations are advantageous for some investigations. Counters, particle sources, and accelerators may be involved.

Data system considerations include precise control of sources and accelerators. Good pointing accuracies are also expected. Some long duration experiments may require long term stability from the data system.

2.3.1.3 Near Environment Monitoring

This encompasses all close proximity monitoring, including remote probes. Magnetic, gravitational, particle and electromagnetic field mapping are the principal data sources.

The data system considerations are relatively modest data acquisition rates from any single source; however, there may be many simultaneous sources. Remote control functions and physical models with extensive computational requirements may also be needed.

2.3.1.4 Exploration

These missions include both manned and unmanned sorties. They could be to lunar and planetary surfaces. Since they are well into the future, no elaboration will be included in this list of mission specific functions.

The principal data system impacts will be on the specific operations, assembly, and checkout requirements as well as supporting operations for remotely placed experiments such as sensors placed on the moon.

2.3.2 Applications

These missions include all of the earth viewing and near earth experiments and operational missions.

2.3.2.1 Materials Processing

Materials processsing applications include research, experimentation, and production. The applications have been categorized into chemical and fluid; melting, solidification and vaporization; biological; and space mining. With a few exceptions, the early functions will involve only minor production activity. However, future growth may have implications on the data system requirements.

2.3.2.1.1 Chemical and Fluid Processing. These applications capitalize on the microgravity of space. In some applications, a controlled low acceleration environment may be induced. Manned presence may be detrimental and drive the implementation toward structures that are mechanically uncoupled from the habitation center. Applications will include chemical reactions and polymerization, fluid convection, phase transition, surface, and bubble phenomena. Initially, applications will be experimental with some potential pilot production processes expected. Commercialization will be some years into the future.

Data system considerations will involve controls, including closed loop servomechanisms, and possibly some fail operational functions to prevent the loss of considerable investment in long duration experiments through short duration interruptions. As pilot projects and later commercial projects evolve, the logistics management of raw materials and finished products must be accommodated. Data rates will be minimal except for isolated experiments involving imagery. Even they will be small compared with the earth viewing image sensors. Physical separation of facilities from the habitation center may require free space or other communication channels such as fiber optics.

2.3.2.1.2 Melting, Solidification, and Vaporization. These applications include crystal growth, ultra-purification, preparation of glasses and amorphous solids, vapor deposition, solidification, preparation of ceramic material processes, and the determination of chemical and physical material properties. The microgravity environment makes containerless processing and its accompanying lack of side wall contamination feasible. Not all these applications will be as susceptible to minor acceleration perturbations. Some may be suitable for accommodation on the habitation center. Pilot production systems are possible within the initial time frame of interest with potentially some commercial applications. Large commercial applications that would exceed the physical accommodations of the habitation module are not likely within the early time frame.

Data system considerations are expected to be minimal. They will be similar to other materials processing applications.

2.3.2.1.3 Biological Processing. These applications include both the preparation of biological materials and biological separations for scientific purposes. Most will involve the eventual removal of the resultant material. Pilot systems and possibly some commercial production systems will be operational during the early time phase. Small perturbations of the zero acceleration environment are not likely to be a problem.

Data system considerations are expected to be minimal. They will be similar to other materials processing applications.

2.3.2.1.4 Space Mining. Space mining may involve sorties to discrete objects such as the asteroids or sweeping operations. They will involve large scale operations that are not likely in the early time period. Early time period may involve some experimental missions.

Data system considerations will be for specific assembly and checkout systems to support the space operations. Initial processing of the gathered material will likely be incorporated into other materials processing applications.

2.3.2.2 Earth Viewing Applications

All earth viewing applications have the point in common that the resultant product is data. Consequently, they will be drivers for the majority of the data system considerations. They also are high potential candidates for inclusion of the function in subsystems of the Space Station system facilities. A distinction is made, somewhat arbitrary for this study, between operational earth viewing applications and experimental. All those applications in this paragraph are considered operational for data system considerations. The distinction for data system purposes is the operation applications are expected to have well-defined requirements in terms of data acquisition periodicity, targets, freshness criteria, and processing. Total data quantities are also likely to be greater than for experimental applications. They are categorized further as: Earth Resources Detection and Monitoring, Earth Dynamics Monitoring and Forecasting, Ocean Condition Monitoring and Forecasting, Environmental Quality Monitoring, Weather Observation and Forecasting, and Climate Research.

2.3.2.2.1 Earth Resources Detection and Monitoring. These applications include the detection and mensuration of non-reusable resources such as minerals and hydrocarbons and the monitoring of renewable resources such as water, flora, and in some instances fauna. There will be interaction with other applications data such as weather, climate, and environmental quality. These have been categorized as: agriculture; forestry; rangeland; hydrology and limnology; geology; geography, demography, and cartography; and coastal zone applications.

2.3.2.2.1.1 Agriculture Applications. These applications include the identification, mensuration, and assessment of agricultural products. Implicit in assessment is the detection of anomolous conditions such as insect, weather, or human-induced stress. Future operational systems will merge image and discrete data acquired with multiple sensors in multitemporal observations with collateral data bases. The information content of the remotely sensed data will be dependent upon the primary sensors used, the time of the observation, and the environmental conditions, particularly atmosphere and sun angle, when the data was acquired. Operational applications are presently accomplished with free flyers. In the time frame of interest, additional sophistication may be expected. The principal evolution may be expected to be toward a greater variety of spectral bands and increasing collateral data bases.

Data systems considerations include large bandwidth communications and data processing requirements as well as data base management impacts. Some near real time uplink control paths and associated command management will also be required.

2.3.2.2.1.2 Forestry Applications. These applications have similarities to the agriculture applications. The major difference is the longer cycle of variations which will generally require less frequent data updates. However, stress detection may be equally demanding. Additional applications are fire detection and fire fighting information.

Data system considerations are comparable to those of agriculture. The collateral data storage and manipulation requirements may be less. Some real time uplink control may be required.

2.3.2.2.1.3 Rangeland Applications. These applications have similarities to the agricultural applications. There may be some high resolution monitoring of selected regions for stock count and errosion.

Data system considerations are similar to forestry applications.

2.3.2.2.1.4 Hydrology and Limnology Applications. Hydrology applications include the monitoring of surface and subsurface water, either directly or indirectly, and the maintenance of models of water tables and flows. These applications require interfaces wtih geographic and topographic data, ice data, and weather data. Uses include drainage and water resource management, flood control environmental impact studies, percolation prediction, and so on. Direct measurements would involve the identification and mensuration of water bodies, subsurface water detection using microwave sensors, and telemetered in situ data. Indirect monitoring would measure other phenomena as surrogate indicators. An example might be vegetation stress.

Limnology is the study of rivers and their interface with the ocean bodies. Applications and data requirements are similar to hydrology. Some limitations may be expected to result from low inclination orbits since some necessary data must be acquired from the polar region for both hydrology and limnology.

Data system considerations are comparable to other earth resources monitoring applications.

2.3.2.2.1.5 Geology. Geology applications include the detection and mapping of earth crustal material. In addition to the sensor data needed for rangeland applications, other sensory data indicative of subsurface information is required. This includes microwave, thermal inertia, and magnetic maps. The spatial resolution for visible and near infrared images are likely to be greater than for renewable resource monitoring. The period between observations is longer. Overall data volumes are expected to be less.

Data system considerations are similar to other earth resources detection and monitoring applications. Unique data bases are required with the associated storage and management implications.

2.3.2.2.1.6 Geography, Demography, and Cartography. These applications can tolerate long periods between observations but require greater spatial resolution. Multiple observations to detect seasonal variations are potentially useful but updates on the order of years are reasonable. Low inclination orbits will restrict the application to less than full global coverage.

Data system considerations involve the need for precision spatial resolution and registration as well as storage and management of extensive collateral data sets.

2.3.2.2.1.7 Coastal Zone Monitoring. These applications combine elements of agriculture, limnology, and other earth resources applications with ocean monitoring in the limited region of coastal zones. The major difference is in the collateral data sets.

Data system considerations are similar to other earth resources applications.

2.3.2.2.2 Earth Dynamics Monitoring and Forecasting. These applications include tectonics, geodynamics, geology, and geomagnetics. They are characterized by needs for high spatial resolution and precision registration of images acquired over long periods of time, possibly measured in years. Sensors will generally be comparable to those used for other earth viewing applications with the addition of some of the field mapping sensors similar to those used for geology.

2.3.2.2.2.1 Tectonics Applications. This application involves the precise measurement of the location, extent, and movement of the plate structure in the earth shell. Precise simultaneous measurement from space is advantageous. Laser ranging and very long baseline interferometry are two techniques.

Data system considerations include the need for precision location of the Space Station. The data rate and volume impacts will be low.

2.3.2.2.2.2 Geodynamics Applications. These applications include detecting and monitoring changes in the earth's physical structure. It includes ephemeral phenomena such as vulcanism and earthquake detection. The sensors will be similar to those needed for geology and other earth dynamics applications.

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Data system considerations, in addition to those common to other earth dynamics applications, are driven by the need to detect and monitor ephemeral events. This may require real time uplink or onboard interactions and command management. Some real time scheduling and work planning functions are involved.

2.3.2.2.2.3 Geodesy. This application involves precision measurement of the earth. The basic sensor is a precise radar altimeter.

The major data system considerations are the need to know precisely the position of the sensor platform. This may require extensive orbital model processing. The major driver is the need to determine the average height of the ocean when the measured surface is fluctuating due to wave, surface irregularity, and tidal phenomena. The relative measurement is against a platform that has positional ambiguity. Data rates and quantities are low.

2.3.2.2.2.4 Geomagnetics. This application involves the measurement and mapping of the magnetic structure of the earth. The principal sensors are magnetometers. Application will be restricted by low inclination orbits.

Data system considerations are primarily to avoid contaminating the measurements by the structure supporting the sensors. A tethered probe is one way to minimize such effects.

2.3.2.2.3 Ocean Condition Monitoring and Forecasting. These applications involve the monitoring and interpretation of phenomena in the seas, at the air/sea boundary and in the low atmosphere near the sea surface. Currently, the microwave region is the most successful. Instruments include passive radiometers and active microwave sensors such as radars and scaterometers. Currently, the highest resolution is obtainable using synthetic aperture radar (SAR). Information is also obtained in the visible range, particularly as it applies to biological content such as plankton formation. Models and data bases are maintained and executed to forecast the various conditions.

2.3.2.2.3.1 Physical Oceanography Applications. These applications are concerned with such ocean parameters as temperature, wave height, sea state, currents, salinity, and plankton locations.

The major data system considerations involve the high data rates and volumes and the high bandwidth processing required for processing the SAR data. The active microwave sensors also consume large quantities of power. Other present problems include the difficulty of registering microwave images from different spectral bands when the targets are oceans with changing but not distinct surface features.

2.3.2.2.3.2 Sea Ice. These applications involve the monitoring of the location of sea ice and properties of the ice. These properties include thickness, salinity, temperature, and age. Age is often inferred from salinity at present. For navigational purposes, the maintenance of an iceberg map would be useful. Interrogation of the data base by remote user systems could be included in the scenario. In addition to tracking by remote sensing from space, in situ transponders seeded by aircraft could be employed.

Data system considerations are similar to physical oceanography with the addition of interrogation access functions.

2.3.2.2.3.3 Surface Atmosphere. The interface between the sea surface and the atmosphere is a complex physical relationship. Surface phenomena are indicators of wind speed and direction. Scaterometers, especially polarized signals, are also used. Atmospheric measurements at or near the sea surface provide indications of water vapor content.

Data system considerations are similar to physical oceanography. Powerful computational resources are required to ascertain the correct surface atmosphere models. The information must be extracted from a complex of multiband sensor information. Essentially, the surface data must be processed such that the noise from the near surface atmospheric distortion is backed out of the signal complex and the primary signal is discarded.

2.3.2.2.4 Environmental Quality Monitoring. These applications include air, water, and land pollution.

2.3.2.2.4.1 Air Quality Monitoring. This application concerns the monitoring of the air for constituents such as chemicals and dust particles. Data sources include the noise due to atmospheric scattering that can be determined from the various multispectral sensors, especially in the microwave regions, atmospheric sounders, laser instruments such as LIDAR, and limb sounders.

Data system considerations are similar to those for physical oceanography with additional instruments.

As models with greater resolution are constructed, the data storage and access impact will become significant. The vertical dimensions approach 100 miles. This has the potential to become very large for a global coverage model.

2.3.2.2.4.2 Water Quality Monitoring. This application concerns the detection of pollutants in water. Many of the data sources and sensors will be similar to the earth resources applications, particularly hydrology and limnology. Some LIDAR sensors are also being considered.

Data system considerations are similar to hydrology and limnology.

2.3.2.2.4.3 Land Quality Monitoring. This application is a special subset of some of the earth resources monitoring applications. Visible band sensors will be a primary information source. There will likely be some near real time human interaction involving pointing of high spatial resolution sensors.

Data system consideration will be comparable to rangeland and coastal zone monitoring applications with possible added functions of work planning, scheduling, and command management.

2.3.2.2.5 Weather Observation and Forecasting. These applications involve data acquisition on a global scale from high and low atmospheric and sea surface targets as well as some solar measurements. Generally, an integration with other satellite and ground based data acquisitions can be expected. The users may be both institutional (e.g., National Weather Service) and individual organizations. The sensors include particle counters, scanning radiometers, sounders, and associated ocean monitoring sensors. The applications have been classified into: Nowcasting, Short Range Forecasting, Long Range Forecasting, Mesoscale Meteorology, and Agriculture Meteorology.

2.3.2.2.5.1 Nowcasting Applications. Nowcasting involves the determination of present or within the last hour weather conditions. It includes the detection and tracking of severe storms, agricultural freeze conditions, and icing or road hazards such as fog. It is characterized by the need for current, detailed, but localized information. Pointable sensors may be expected.

Data system considerations include the need to manage, including all the included acquisition and processing steps, the various imaging and sounder sensor data. In addition, there are the needs to manage commands and to process data with a critical timeliness requirement. Maximum throughput delays on the order of fifteen minutes from command to delivery of information to the user may be expected.

2.3.2.2.5.2 Short Range Forecasting. This application involves world-wide models that are computationally intensive and require data from a multitude of sources. Currently, the models execute every four hours. In the time frame of interest, one or two hour updates may be expected. The forecast is for near time weather conditions of now to three days in the future. Inputs to the models include solar insolation, earth radiation, sea state, temperature, winds, and atmospheric temperatures and pressure at several layers. The current significant feature is the need to deliver answers from the models on an operational schedule with or without updated data input. An innovative system in the time frame of interest could be based on a more interactive process whereby input data is acquired as needed by the models rather than as a scheduled pipeline process.

Data system considerations are the need to manage the data from the various sensors and to deliver it operationally. Availability of the data management resources will be important. Some interaction and access to remote data bases are also considerations.

2.3.2.2.5.3 Long Range Forecasting. These applications are similar to those for short range forecasting except they involve more parameters, particularly the effects of solar and earth radiation and ocean/atmosphere interaction. The models are structured differently, but the data inputs are similar.

Data system considerations are similar to short range forecasting.

2.3.2.2.5.4 Mesoscale Meteorology. These applications are similar to short and long range forecasting except the geographic areas of interest are more restrictive, usually regions around population centers, and data is acquired on a higher spatial resolution but often smaller areal coverage. They may also exhibit closed loop user control. The models usually include more provisions for local effects.

Data system considerations are similar to the forecasting applications with the need for management of user commands.

2.3.2.2.5.5 Agriculture Meteorology. These applications are a combination of short range forecasting, mesoscale meteorology, nowcasting, hydrology, and earth resources monitoring. Temperature, solar insolation on the earth surface (not atmosphere), and ground moisture are determined. Sensors are similar to those used in the above named application. Coverage is targeted to areas of agricultural interest. This may vary with seasons and stress conditions. Some user initiated data acquisition may be expected.

Data system considerations are similar to sea ice monitoring.

2.3.2.2.6 Climate Research. These applications involve the acquisition and management of synoptic data on a global scale. The information sources are similar to other applications, particularly in the weather observation and the earth resources areas. Some of the downstream processes differ. Climate research applications are classified into: global biomass monitoring, ice and snow pack, atmospheric constituents, global surface water, and energy budget.

2.3.2.2.6.1 Global Biomass Monitoring. These applications have a great deal of commonality with agricultural, forestry and rangeland data acquisition needs. The timing of the observations are not as critical but the extent of targets must be throughout the global land mass.

Data system considerations are comparable to the indicated earth resources monitoring applications.

2.3.2.2.6.2 Ice and Snow Pack. These applications involve the mensuration both spatially and qualitatively of the ice and snow in the world. The extent, water content, and other properties are inventoried. Many functions common to sea ice monitoring are required. Similar sensors and processing is required. Timeliness and update periods are not stringent. Low inclination orbits will severely restrict the necessary data acquisition.

Data system considerations are comparable to that subset of the weather observation applications.

2.3.2.2.6.3 Atmospheric Constituents. These applications involve the detection, quantification, and cataloging of atmospheric constituents. There is commonality with air quality monitoring and some of the weather observation functions. Additional sensors and special processing will be involved. Timeliness and observation periodicity are not as stringent.

Data system implications are comparable to those similar applications identified above.

2.3.2.2.6.4 Global Surface Water. These applications involve the detection and mensuration of water on a global scale. The sensors, processing, and functions are similar to those required for hydrology, except on a global scale. Timeliness and observation periodicity are not stringent, although there are certain constraints to obtain synoptic data.

Data system considerations are comparable to those for hydrology. The total information handling requirement for any given synoptic coverage will be larger.

2.3.2.2.6.5 Energy Budget. These applications involve the monitoring and cataloging of the earth energy budget in all spectral regions. It is comparable to the similar subset of the weather observation application. Sensors are predominantly radiometers and solar particle counters. Some will be solar directed.

Data system considerations are comparable to mesoscale meteorology and nowcasting.

2.3.2.3. Communication and Navigation

These applications include: voice and data relay, in situ telemetry data acquisition, control, surface navigation, and surface and near earth tracking. Intentionally, land-based point-to-point communications as currently being performed with geosynchronous satellites are excluded from these potential mission specific functions of the Space Station.

2.3.2.3.1 Voice and Data Relay Applications. This application includes the communications required to support the other applications. Communications could include those with a remote logical connection. For instance, the experimental facility might have need for some data transfers or voice communications that might use other satellite links but because of the need to support specific experiments, the channels would be established anyway. Under those conditions, the facilities of the Space Station could provide the relaying applications. This is distinct from the communications functions identified in the list of operational functions.

Data system considerations are comparable to those for operational communications. The only impact would be an increase in the channel capacity requirements.

2.3.2.3.2 In Situ Telemetry Data Acquisition. These applications would involve the command and receipt of data acquisition from other space platforms and earth or sea-based platforms. Some logical association with other applications is assumed.

Data system considerations are generally the need for telemetry command and data acquisition from inexpensive communciation devices. Frequencies and bandwidth requirements will be low. The need to maintain a data base of transceivers, formats, locations, and access protocol must be considered.

2.3.2.3.3 Control Applications. Some applications in remote locations may require control from the Space Station. Discrete signals will not have much bandwidth requirements. Some applications, such as those involving teleoperator may require greater bandwidth. Some control applications may involve closed loop feedback such as video imagery.

Data system considerations are comparable with the operational communications requirements. These applications will increase the system sizing requirements.

2.3.2.3.4 Surface Navigation. These applications involve navigation aids to surface vehicles. Ranging devices and tracking models would be required.

Data system considerations are the need to provide for user interrogation, direct broadcast to users, and the need for precise Space Station location.

2.3.2.3.5 Surface and Near Earth Tracking. These applications will involve transponders and maintenance of location models. Active sensors such as radar and visible imagery may also be involved. Ship tracking and aircraft control are possibilities.

Data system considerations are a function of the extent of implementation. The need to passively detect and track ships and aircraft would have a major impact. An integration of Space Station capability with ground based systems is a possibility. Any implementation in the near term of interest will likely be on a pilot project basis. Antenna systems with broad coverage would be required.

2.3.2.4 Experimental Application

These applications will span the materials processing, earth viewing and communications and navigation applications. The distinction in their being experimental is there will be less stringent timeliness requirements, the extent of coverage and consequent data volumes will be restricted, and the processes will be less defined. These areas will also most likely be encountered in the near time period of interest. There will likely be a need for frequent changes in processing and direct human interaction.

Data system considerations include the need to provide for any or all of the functions previously described in the application areas. In addition, there will be the need for direct operator involvement and frequent change in processing. Flexible data system support including software development support will be required.

2.3.2.5 Power Applications

These applications include the acquisition of energy and the generation of power for use external to the Space Station. Any near term applications are expected to be in the nature of a pilot system. Eventually, separate structures and platforms may evolve. The type of the energy acquisition may be solar, space mining, or nuclear. Methods of packaging and transporting the energy must evolve. The nearest term considerations involve microwave transporting to earth's surface.

Data system considerations will involve complex pointing and control systems as well as the space operations associated with full scale commercial materials processing.

APPENDIX B

MINUTES OF SPACE STATION BLUE RIBBON PANEL MEETING
JUNE 30, 1982

MINUTES OF SPACE STATION BLUE RIBBON PANEL MEETING
JUNE 30, 1982

1. INTRODUCTION

A Blue Ribbon Panel comprising both NASA and General Electric personnel with background and experience applicable to the Space Station Data System met June 30, 1982. This meeting was convened under contract to NASA Goddard Space Flight Center NAS5-27194. The express purpose was:

> **"To focus the study on key issues of Space Station Data Systems with an emphasis on technology that has a high potential for reducing life cycle cost."**

The meeting was held at the General Electric AFO Conference Room, Room 727, 777 14th Street, Washington, D.C.

1.1 ATTENDEES

A list of the participants of the meeting is provided in Table 1.

1.2 AGENDA

Bruce Lees, Manager Communication and Space Systems Programs, Aerospace Field Operations, hosted the meeting. The meeting, under the moderation of Tom Thompson, adhered to the agenda of Table 2. The meeting was structured to identify significant data system issues by approaching them first in a straightforward manner, then via potential applications, and finally from a technology viewpoint.

Some specific goals for the meeting are listed in Table 3.

1.3 BACKGROUND

Jim Neiers presented a background on the study along with the initial guidelines and assumptions. Copies of those charts identifying the project, study guidelines, some strawman objectives for the Space Station and some additional assumptions are included as Figures 1 through 4, respectively.

Table 1. Attendees

Name	Organization/Location	Phone
Tom Thompson	GE/Huntsville	205-837-7701 (Ex. 30)
Carl Mosley	GE/VF	215-962-4094
Frank Lynch	GE/CR&D	518-385-4171
Linwood Jones	GE/VF	215-962-3008
Lee Holcomb	NASA/HQ	202-755-2364
Jim Neiers	GE/Huntsville	205-837-7701 (Ex. 33)
John Anderson	NASA/HQ	202-755-2413
Ed Chevers	NASA/JSC	713-483-2851
Harry Benz	NASA/HQ	202-755-3273
Howard Kraiman	GE/VF	215-962-4674
Arch Park	GE/Lanham	201-459-2900 (Ex. 456)
Robert C. Axtell	GE/Sunnyvale, CA	408-734-4980 (Ex. 429)
John C. Conrad	GE/VF	215-962-4967
Richard W. Heckelman	GE/IC Sys. Lab, Syracuse	315-456-3067
Hank Graf	GE/Huntsville	205-837-7701 (Ex. 32)
Sheryl Golden	GE/Huntsville	205-837-7701 (Ex. 50)
Ted Connell	NASA/GSFC	301-344-7992

Table 2. Agenda

8:00	Assemble
8:30	Introduction - Agenda
8:40	Overview of Program - Purpose - Ground Rules of Study - Strawman Definition
9:00	Issues - Identification - Discussion
10:15	Break
10:30	Applications Influencing Data System Requirements - Uses - Data System Requirement - More Issues
12:00	Break
12:45	Technology - Data System Impact - More Issues
2:00	Technology Needs
3:00	Break
3:15	Review - Summary - Study Direction
4:00	Adjourn

Table 3. Specific Goals of Meeting

1.	IDENTIFY DATA SYSTEM ISSUES FOR FURTHER STUDY - PRIORITIZE BY POTENTIAL PAYOFF
2.	PROVIDE GUIDANCE FOR STUDY - IDENTIFY INFORMATION SOURCES - IDENTIFY APPROACHES - ACQUAINT STUDY TEAM WITH OVERVIEW OF ISSUES - REDUCE PRECONCEIVED BIASES ON ISSUES

EIGHT MONTH STUDY THAT WILL PRODUCE REPORTS RECOMMENDING IMPLEMENTATION ALTERNATIVES AND DATA SYSTEM TECHNOLOGY DEVELOPMENT PROJECTS BASED ON TECHNICAL ANALYSES OF SPACE STATION OBJECTIVES, "NEEDS" CONCEPTS, USER REQUIREMENTS, OPERATIONAL ENVIRONMENT AND EMERGING TECHNOLOGY.

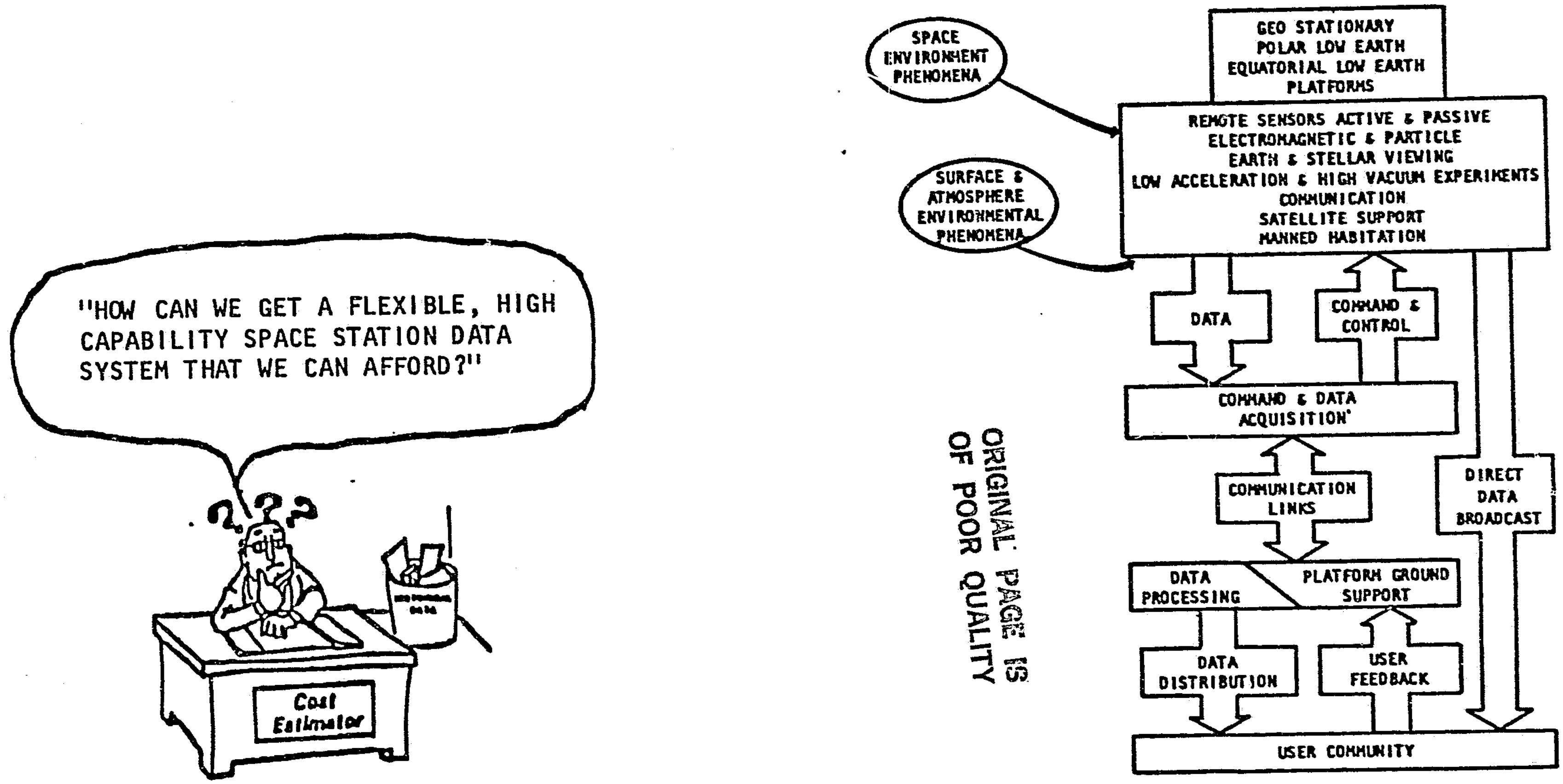

Figure 1. Project Identification

1. STUDY WILL BE RESTRICTED TO THE DATA SYSTEM COMPONENT OF THE SPACE STATION.
2. STUDY WILL FOCUS ON MEETING EXPECTED DATA SYSTEM REQUIREMENTS FOR GENERAL FUNCTIONS OF THE SPACE STATION AS OPPOSED TO MISSION SPECIFIC DATA SYSTEM REQUIREMENTS.
3. STUDY WILL EMPHASIZE EARLY PHASE OF SPACE STATION, WHICH WILL INCLUDE PERMANENT OCCUPANCY.
4. SPACE STATION WILL BE IN LOW EARTH ORBIT (LEO).
5. SPACE STATION WILL BE SUPPORTED BY THE SHUTTLE ON 90-DAY CYCLE.
6. SPACE STATION DESIGNED FOR INDEFINITE LIFE THROUGH ON-ORBIT MAINTENANCE.
7. MODULAR-EVOLUTIONARY DESIGN THAT PERMITS GROWTH AND ACCEPTS NEW TECHNOLOGY.
8. LIFE CYCLE COST (DEVELOPMENT, OPERATIONS, MAINTENANCE, UTILIZATION) IS A TECHNOLOGY DRIVER.
9. ASSUME A PHASE C/D START BY OR BEFORE FY 1986 TO SUPPORT A FLIGHT AS EARLY AS 1990.
10. COMMUNICATIONS TO BE COMPATIBLE WITH TDRSS/TDAS, FREE FLYERS UP TO GEOSYNCHRONOUS ORBITS, OTVS UP TO GEOSYNCHRONOUS ORBITS, AND SHUTTLE.

Figure 2. Study Guidelines

OBJECTIVE / SUBOBJECTIVE
PROVIDE FOR MANNED PRESENCE
o MAINTAIN HABITABLE ENVIRONMENT o ACHIEVE ULTRA RELIABILITY FOR LIFE DEPENDENT FUNCTIONS
ACHIEVE ECONOMICS OF MULTIMISSIONS
o SUPPORT MULTIPLE CONCURRENT EXPERIMENTS AND APPLICATIONS o PROVIDE FOR COMMON FUNCTIONS o EXPERIENCE USER ACCEPTANCE
SUSTAIN AN INDEFINITE LIFETIME
o BE EXPANDABLE TO SUPPORT MULTIPLE STATIONS IN BOTH GEOSYNCHRONOUS AND LOW EARTH ORBITS o BE FLEXIBLE TO SUPPORT CONFIGURATIONS WITH CHANGING SENSOR MIXES o EXHIBIT TECHNOLOGICAL TRANSPARENCY TO SUPPORT FUTURE EXPERIMENTS
BE ECONOMICALLY JUSTIFIABLE
o BE IMPLEMENTABLE IN A PHASED SEQUENCE TO MINIMIZE UNPRODUCTIVE INVESTMENT o REDUCE MANPOWER LEVEL REQUIRED FOR SUSTAINED OPERATIONS

SUPPORTING SUBOBJECTIVES	
o PROVIDE EXPERIMENT ENVIRONMENT	o PROVIDE SENSOR DATA PROCESSING
o PROVIDE STATION OPERATIONS	o PROVIDE DATA MANAGEMENT
o SUPPORT USER/EXPERIMENT INTERACTIONS	o PROVIDE FOR MULTIPLE MODES OF DATA DISTRIBUTION
o SUPPORT DATA ACQUISITION	o PROVIDE FOR USER DATA REQUESTS
o PROVIDE AUTOMATIC COMMAND GENERATION	o BE COMPATIBLE WITH NEEDS DATA ARCHIVE CONCEPTS
o MEET NEEDS TIMELINESS CRITERIA FOR DELIVERY OF PROCESSED DATA TO USER	o APPROACH OPERATIONAL AVAILABILITY OF 0.99
	o ACHIEVE 0.9999 AVAILABILITY FOR CRITICAL FUNCTIONS

Figure 3. Strawman Station Objectives for Purpose of Study

1. A SINGLE SPACE STATION SYSTEM IN 28.5 DEGREE INCLINATION ORBIT OF APPROXIMATELY 400KM ALTITUDE.

2. SYSTEM WILL COMPRISE A MANNED BASE STATION PLUS A COLONY OF UNMANNED STATIONS WITHIN "ENERGY PROXIMITY".

3. BASE STATION WILL BE A "PERMANENTLY" MANNED HABITAT, WITH CAPABILITIES FOR DOCKING SHUTTLE AND STATIONS, SERVICING PAYLOADS, INTEGRATING UPPER STAGE, CONSTRUCTION, AND ASSEMBLY FUNCTIONS.

4. BASE STATION WILL HAVE SOME INITIAL TIME WHEN THERE IS NO MANNED PRESENCE.

Figure 4. Assumptions for Purpose of Study

2. OVERVIEW

During the course of the meeting, three charts were developed.

a. Data system issues.

b. Applications with expected data system impact.

c. Technologies with data system impact.

Each item on the chart was then reviewed and assessed as to the relative importance or emphasis that should be given to that topic during the remainder of the study. Each item on the technology chart was ranked high (h), medium (m), or low (l) as to need for emphasis for the Space Station. The assumption was that the item was on the list because it was going to impact the Space Station data system. Therefore, it was a question of progress without specific additional involvement. If other agencies or commercial needs were driving the development, that item received a low ranking. Those needing specific attention were rated high.

It was recognized that this was a "quick and dirty" and premature attempt since the data system requirements had to be developed first. This list will serve as a check list later in the study.

Next, the data system issues were rated high, medium, and low as to a weighted judgment of impact and importance. This was the major output of the meeting. The resultant list will serve as guidance as to where our attention will be focused during the remainder of the study. These lists of issues, applications, and technologies with potential impact on the Space Station system are included as Tables 4 through 6, respectively.

3. DETAILED NOTES

The following notes apply to the detail discussions that transpired during the meeting. They are generally chronological except when it was obvious that some rearranging would benefit understanding.

3.1 SCENARIO TO BOUND EXPERIMENTS

An upper limit on the number of experiments that can be handled in parallel on a Space Station is a desirable constraint when considering data system

Table 4. Issues

H	PARTITION OPERATIONS (HOUSEKEEPING) VS. MISSION (APPLICATIONS)
H	AUTONOMY - CONTROL/MISSION/OPERATIONS - LIFE CYCLE COST - NATIONAL RESOURCE - TIME PERIOD - ON-BOARD SCHEDULING
M	SURVIVABILITY
H	ARCHITECTURE - STANDARDIZATION - AVAILABILITY - DATA SYSTEM END-TO-END COMPATIBILITY
H.	AUTOMATIC FAULT DETECTION/ISOLATION/RECONFIGURATION
H	ACCELERATE AVAILABILITY OF SPACE QUALIFIED HIGH TECHNOLOGY HARDWARE - COMMERCIAL HARDWARE
H	LOGISTICS
H	DATA BASES - LOCATION/SIZE
H	CREW MAKEUP/REQUIREMENTS - MAN/MACHINE INTERFACE - ROLE OF MAN - EXPERT SYSTEMS
H	ROLE OF GROUND DATA SEGMENT
L	ROBOTICS
M	SECURITY
H	AUTOMATION OF SUBSYSTEM
H	FLEXIBILITY/GROWTH
M	COMMUNICATIONS
H	POSITION AND ATTITUDE

H - High impact or importance to the data system
M - Medium impact or importance to the data system
L - Low impact or importance to the data system

Table 5. Applications

FEATURES LONG DURATION CAPABILITY
LARGE STRUCTURE
ON STATION REPAIR/REFURBISH/RECONFIGURE
MANNED PRESENCE

L	LIFE SCIENCES
L	MATERIALS PROCESSING - ROBOTICS
H	ASTRONOMY
H	SATELLITE REFURBISH/REPAIR/SERVICE/CALIBRATE
L	SPACE CONSTRUCTION
H	SATELLITE COMMAND & CONTROL & DATA MONITORING
H	COMMUNICATION RELAY
H	EARTH OBSERVATION - EQUATORIAL/POLAR
H	MANEUVERABILITY - COLLISION AVOIDANCE
H	MANNED ORBITAL TRANSFER
M	DEBRIS TRACKING
M	CLOSE ENVIRONMENT MONITOR (INTERNAL & EXTERNAL)
H	OPERATIONS PROCESSING (INFORMATION EXTRACTION)
?	WEAPONS SYSTEM RESEARCH
L	VLBI
H	HIGH RESOLUTION RADAR
H	VIRTUAL SENSORS
L	MANUFACTURING
L	ZERO-GRAVITY RESEARCH
M	PROPULSION RESEARCH

H - High impact or importance to the data system
M - Medium impact or importance to the data system
L - Low impact or importance to the data system

Table 6. Technologies

	COMMUNICATIONS
L	LASER LINKS
L	FIBER OPTICS (COUPLERS)
M	COMPRESSION
M	CODES - REDUNDANCY
H	STEERABLE ANTENNAS/ELECTRONIC
H	MULTIPLEX
H	TRANSMITTERS
	DATA STORAGE
M	DATA BASE ARCHITECTURE/SYSTEMS
M	NON VOLATILE MEMORY
H	RADIATION HARDNESS
L	VIDEO DISC/BUBBLE
H	UPLINK DB UPDATE/QUERY
H	ARCHIVING (MORE DENSE)
	PROCESSING
L	DISTRIBUTED & PARALLEL
L	HARDWARE
L	MICRO
H	CONTROL CENTRALIZED OR DISTRIBUTED
H	**MAN/MACHINE INTERFACE**
	AUDIBLE
	DAMAGE ASSESSMENT
	DISPLAYS - VISUAL INPUT/OUTPUT
L	**ARTIFICIAL INTELLIGENCE**
	NATURAL LANGUAGE PROCESSING
	INDUCTIVE REASONING
	INFERENTIAL REASONING
	HEURISTIC ANALYSIS
	SOFTWARE
H	STATION OPERATING SYSTEM
H	DEVELOPMENT METHODOLOGY
L	METRICS
H	**ARCHITECTURE**
L	**ROBOTICS**
H	**SPACES STATION SUBSYSTEM AUTOMATION**
H	**FAULT TOLERANCE**
H	**SUBSYSTEM & EXPERIENCE INTERFACE STANDARDIZATION**

H - High impact or importance to the data system
M - Medium impact or importance to the data system
L - Low impact or importance to the data system

alternatives. The discussion to establish this limit was postponed and not resumed later as planned.

3.2 ACCOMMODATION OF MILITARY MISSIONS

There was considerable discussion throughout the meeting as to factors and subissues involving military missions. There should be some allowances for inclusion of military missions, even in the low inclination orbit. We cannot ignore the military applications, but there is a question as to the degree we should complicate the data system requirements. Subsequent discussions provided some guidelines as to reasonable boundaries. For instance, defense from overt attacks will not be considered as a legitimate data system function. Special security and encryption will be provided by the user and only bandwidth implications would be considered. However, the summary statement is "As long as the Space Station is a national resource, it is safe to say that military applications will exist."

3.3 FUNCTIONS OF EARLIER CONCEPTS

Howard Kraiman presented some material from a study performed for a Space Station concept, subcontracted to Rockwell 12 years ago. While the technology has changed, many of the functions are still valid. In this study, functions were split into those in support of the applications and those of a housekeeping nature. An interesting concept included station controllers' consoles and a captain's station. This is probably still valid.

In this study, Information Management System (IMS) was analogous to the data system in the current study. Two charts from Howard's presentation are included as Figures 5 and 6. These charts list on-board functions and ground functions.

3.4 SECURITY

Some security needs were discussed. How do we handle the problem of keeping data separate for joint military and commercial missions, or even between commercial users? Also, the problem of keeping data away from outside intruders exists. Each group will want to protect its own data.

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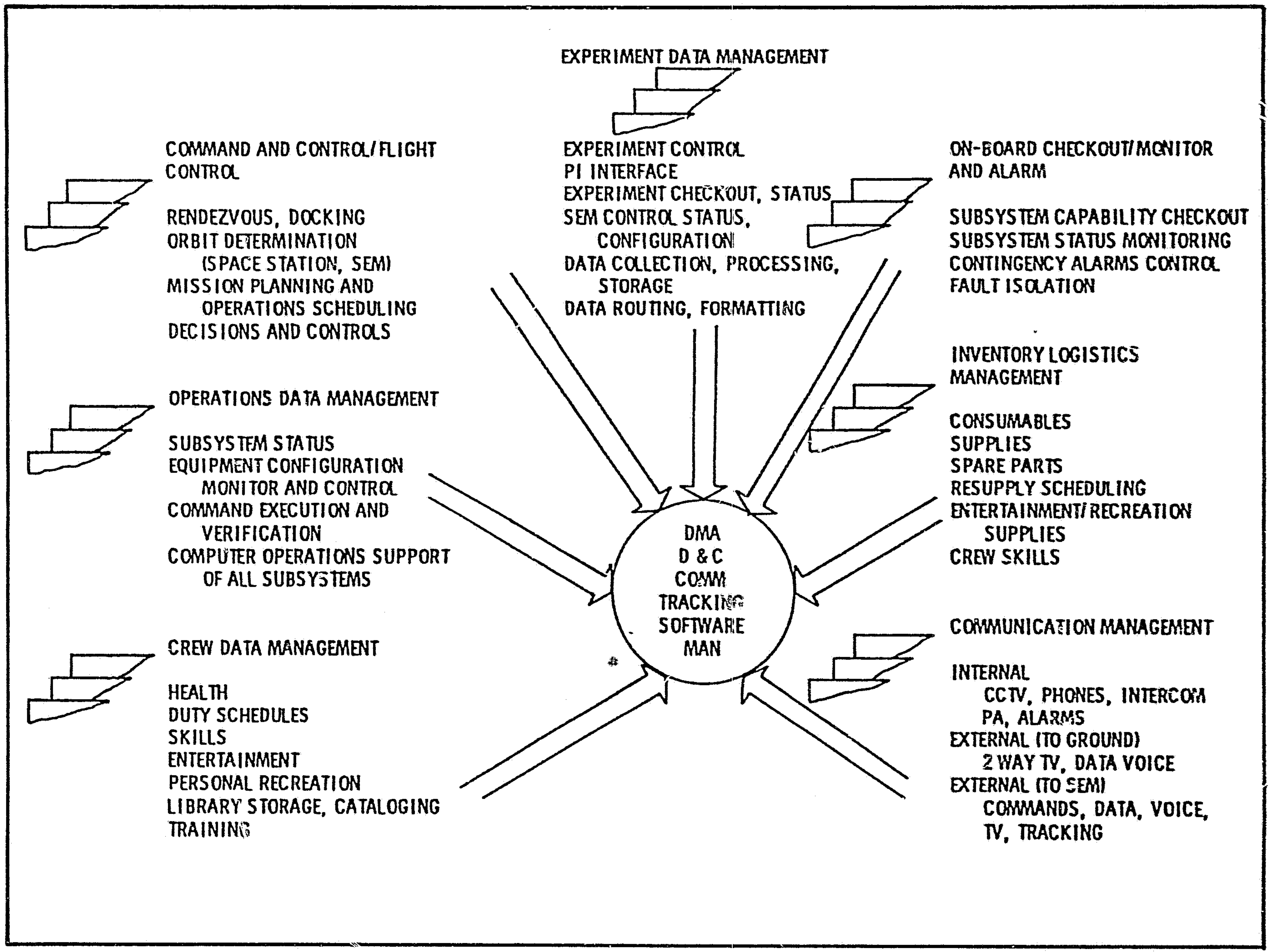

Figure 5. On-board IMS Functions

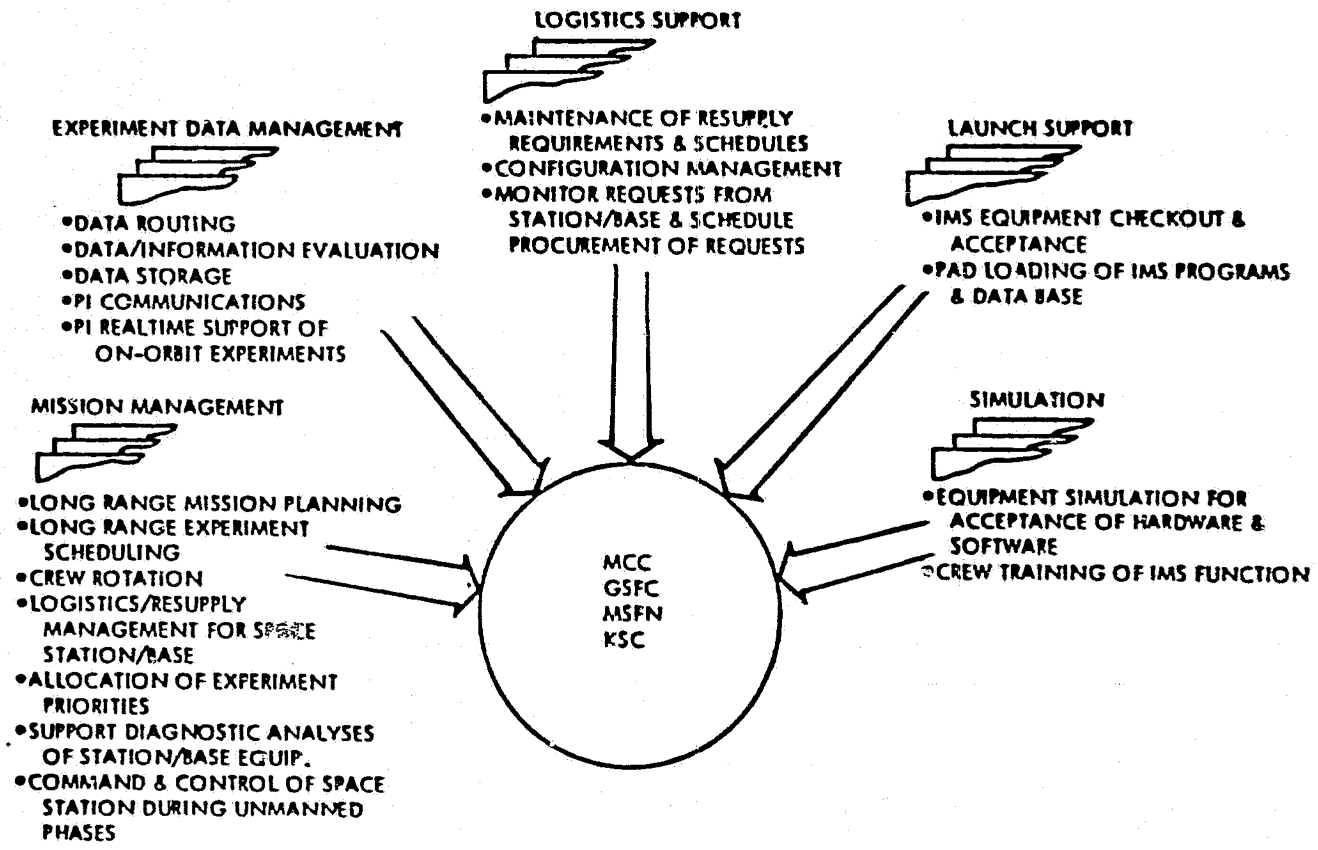

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Figure 6. Ground IMS Functions

Proprietary rights can probably be adequately safeguarded through non-disclosure agreements and policy regulations. Military security will probably be effected by separation of subsystem components and black boxes.

3.5 CONTROL, OPERATIONAL OR MISSION

There is an issue in the concept of operational vs. mission control. The resulting data system requirements may be different. Operational control would be similar for all missions. It may constrain the mission or it may result in a more complex data system to accommodate all missions; but it may be easier to train operators and to interface other systems. Mission control might differ significantly for each mission. An in-depth understanding of both operations and mission applications is necessary for a balanced implementation. Some partitioning of the data system may be the best approach.

3.6 AUTONOMY

This is a very big issue and raised several questions. Additional issues also surfaced during this discussion. The first was the question of how long the Space Station would remain autonomous (several days, one month, between shuttle flights, etc.)? Autonomous period in study ground rules is 90 days. It was felt that this is too long. With five shuttles, it may only need to be autonomous for several days. The minimum period was not defined by panel.

Another question was, "do both manned and unmanned conditions need to be considered?"

There was a lengthy discussion on "autonomy." It was unanimous that the Space Station be capable of autonomous operations. That meant different things to different people.

- that the Space Station and personnel could operate for extended periods without benefit of ground support or other systems.
- that the Space Station system, including the ground segment, could operate for extended time without support from other non Space Station systems.
- that the Space Station in orbit could operate without human intervention, continuing automatically to acquire data and perform its function.

- that the Space Station system, including both the in orbit and ground segments, could operate automatically without human intervention.

There are two reasons the Space Station needs to be autonomous:

- reduce the number of operators - NASA wants less than 100 people in the control centers because they cannot afford them and they don't really need them unless there's an emergency. Apollo had 900 people and Shuttle has 600.

- DoD wants the Space Station to be autonomous in case the ground station is lost, to increase chance of surviving on the Space Station.

Three areas for autonomy were defined as:

- Health and Maintenance
- Routine (those normally performed by the ground station)
- Navigation

A recent NASA study identified seven levels of autonomy culminating with an intelligent robot.

3.7 GROUND INVOLVEMENT

Two basic concepts to be developed during the study should have different degrees of autonomy.

- Approach maximum on-board autonomy.
- Fair degree of ground support.

3.8 ROLE OF SPACE STATION IN EMERGENCY

The role of the Space Station as a national resource during an emergency was raised. If a national asset, it may have to survive an attack. If mission were military, it would need a lot more security because of chance of attack from hostile nations. It was decided that extreme military applications were out of scope of our study. We should assume it is not necessary to plan for any specific data system impact.

3.9 SURVIVABILITY

The issue of survivability was raised. A lot of redundancy is required to ensure survivability. The question was raised as to whether military applications should be considered here because military men are hired to "put their life on the line" in case of emergencies. It is a real factor, but only in the sense of natural or accidental threats. We may allow some temporing with regard to loss of life. However, some radiation hardening, etc., is worth considering. It is probably prudent to expand the system from an initial system with relatively few survivability features.

3.10 COLLISION AVOIDANCE

The role of the Space Station as a national resource probably drives the need for some degree of collision avoidance as a data system function. The ground rule is to detect only accidental objects and not to consider overt intentional aggression. Threats such as space debris must be avoided.

3.11 MANEUVERABILITY

The function of protection and safety, particularly collision avoidance, was discussed. There is a legitimate need for debris detection and assessment, modeling, tracking, and so on. The resulting action is not a consideration for this study. If orbital maneuvering, debris sweeping via a teleoperator type device, directed energy destruction, or other schemes are employed, they will be devised by others.

There was some discussion on station keeping and orbital plane changes. The general concensus was that we should assume the propulsion system would be for drag make-up only. Orbital plane changes would be ruled out.

3.12 DEBRIS TRACKING

Detection of debris, especially crosstrack items of small cross section measuring just a few centimeters, is a vital concern because of the size of the Space Station and the length of time in orbit. There are four sizeable objects in Space Station's intended path. Possibly, defense against debris should be provided. Question was raised, "do we need a data base of space debris on-board?" Other items are also of such a small size that they may not be in the data base of tracked items. These are the real concern and may require an active detection subsystem.

3.13 FAULT TOLERANCE

There were additional topics related to autonomy and survivability including health, maintenance, and navigation. Automatic fault detection, isolation, and reconfiguration was discussed. Some replacement and repair would be performed by human intervention. Fault tolerance design and techniques for automatic fault detection and isolation are reasonably well in hand for digital systems. That is not true for analog and hybrid systems.

3.14 SURVIVABILITY THROUGH DISTRIBUTION

The concern for survivability in a collision situation may lead to other data system considerations. For instance, the distribution of functions with some redundant capabilities in case some circuitry is lost. Automatic damage control is probably one of those subsystems that will have an interface but will not be addressed in any detail. Damage control may include certain sensor processing to detect the problem, some decisions as to its severity, and then reactions such as power interruption, system segmentation, bulkhead closing, purging, and so on.

3.15 MAN'S ROLE IN APPLICATIONS

There was extensive discussion on the role of man in the system. There were two camps when it came to the applications data processing. In the information extraction activity, there are numerous cases of evidence that manned interaction is more cost effective than complete machine automation. For earth observation activities, man in the loop can pinpoint rare occurrences and zoom in on them to analyze their cause and effect.

3.16 MAN'S ROLE IN OPERATIONS

In pursuing the discussion of the role of man and the influence on data system functions, the need for man to effect repairs was emphasized. Built-in fault detection, etc., can direct man to the replacement items.

The shuttle provides a case history with regard to autonomy. When first conceived, the shuttle would fly automatically without pilot interaction. The astronauts did not like that and insisted on manual control. They then discovered it was too complex and needed help in the form of increased automation, which has now been effected.

3.17 AUTOMATION

Because of the differences in understanding of autonomy, we might want to make the distinction between automated and man interactive.

Automation can reduce operating costs. Apollo required about 900 people at consoles; Shuttle requires about 600. The goal for the Space Station is below 100.

It is hard to keep people at a console when nothing happens. There is a need to have a much more autonomous system. One approach is to design the system architecture such that as the system evolves, increased intelligence can be incorporated to perform more functions automatically and even adaptively.

3.18 CREW MAKEUP

A point was made of crew makeup having an impact on data system requirements. There is a difference in philosophy the approach NASA has used, which is to select "supermen" and then build the data system to support them. The military approach has been to establish requirements for the system, partition functions to the data system or the personnel, and then identify the necessary skill level required based on a task and skills analysis. We should assume man is not a superman; neither is he a drop-out.

A separate NASA group is working the human factors area for Space Station. We should probably not stress this area.

3.19 MAN-RATED DATA SYSTEM

The idea of "man-rated systems" may not be continually viable in the previous sense, although no pronouncement on that policy may be expected. A greater degree of risk may be acceptable and to some extent, the man-in-the-loop may be expendable. A few extra data channels may be required.

3.20 MAN SUPPORT

There was some discussion on the role of other subsystems such as medical systems. The data system must interface to them and in some cases provide data management functions.

With 6, 10, or 15 people on-board, the Space Station is a potential incubator. What are medical implications? In the past there have been no major problems. A thorough medical examination before missions has prevented serious difficulty.

3.21 MAN/MACHINE INTERFACE

Man/machine interface is clearly an issue for the data system study which we should address. The extensive involvement of graphics was discussed and indicated as an accepted part of the generally friendly man/machine interface requirements.

3.22 ACCIDENT CONTAINMENT

The idea of accidental problems was discussed. No nuclear power sources are being considered due to political considerations. A reactor can be launched cold and come back in safely. There was some disagreement if this is feasible from a safety standpoint. Damage detection, assessment, and containment functions in support of other subsystems are legitimate roles for the data system. Lithium batteries can provide backup power.

A high degree of automation of such subsystems as power and life support can be expected. The data system will perform some related functions. For this study, we should not dwell on them but merely recognize them. There are other working groups addressing other subsystems. We should look at the Skylab function list as a good starting point.

3.23 DATA BASE

The approach to providing the necessary data base was discussed. There is probably a need to provide multiple accesses to distributed, heterogeneous data bases. The Space Station could be a node in the applications data service (ADS).

There is an issue of accessing data bases on the ground as opposed to having all data bases on-board. The idea of staging, which has to do with loading necessary data bases into readily accessible memory prior to when it will be needed, was also discussed.

3.24 INTERNATIONAL INVOLVEMENT

The question of international involvement was raised. The answer was yes; current NASA plans point to involvement of other nations. A restrictive assumption as to the data base is it will be English and the numerals will be Arabic.

3.25 MISSION MIX

The need to accommodate a continuing change of mix of subsystems was recognized. The need to provide some degree of interface definition and standardization with a definite modularization of the data system is an important concept to maintain low life cycle cost and technological transparency.

3.26 SCHEDULING

Work planning and scheduling, including experiment and application activities is an important role for the data system. Ground network scheduling may prohibit the users from using the TDRSS because of high priority military mission. If scheduling is done on-board, this becomes a data system problem.

3.27 COMMUNICATIONS

The need for the Space Station data system to provide communication services was discussed. Some free flyers are expected to be required for special orbits or other reasons. The Space Station will not compete with TDAS or TDRSS but there will be a need to provide some communications relaying, up, down, and as a cross link with other satellites. There will be a need for data storage and ephemerides determination for antenna pointing, and data acquisition.

Communications need to include commercial (i.e., to a commercial communication satellite or direct to ground) channels.

3.28 VIRTUAL APERTURE SENSORS

The need to process data from virtual aperture sensors was discussed. This seems to be a definite need. While there may be some large pushbroom arrays constructed, the thermal stresses will prevent the construction of sufficiently large antennas to achieve the desired resolution. Both SAR and

LIDAR are viable sensor programs that we can expect to see deployed on the Space Station.

3.29 ATTITUDE AND POSITION DETERMINATION

The issue of attitude and position determination was raised but little discussion or exploration of ideas took place due to time constraints. Time annotation must be included. This should probably be a service provided for all applications, experiments, and subsystems. It needs some investigation.

3.30 TIME PHASING OF ISSUES

The need to identify a time phasing for the issues is important since they obviously will not all be implemented at the same time.

3.31 MISSION TYPES

An approach to driving out issues based on applications and uses of the Space Station was employed. A list of generic applications was developed with specific considerations of the impact on the data system as a result (see Table 5).

Different types of missions were discussed. The idea of robotics within the materials processing was considered as only incidental to the data system. Some interfaces may be required, but the robotics would not be included.

3.32 ORBIT IMPLICATIONS

In discussing missions, it was determined that earth observations might not be a big driver for the assumed 28.5° orbit. However, if this is a precursor to a near polar orbiter, then the impact should be considered.

We may want to relax or modify the assumption of 28.5° orbit for just such reasons. (We probably will, but without admitting the added loading of data system requirements caused by such phenomena as added radiation hazards to personnel and components.)

3.33 MICRO-GRAVITY APPLICATION

Zero gravity (micro-gravity) research represents applications in addition to those covered by materials processing and life sciences. The concept of artificial gravity has been abandoned, so far, as not necessary and causing undue additional problems.

3.34 SPECIAL SPACE PLATFORM CONSIDERATIONS

The question was raised here "If we can do it now on satellites, why do we want to duplicate it on the Space Station?" Answers were 1) we now do the minimum because of the cost requirements, and 2) sometimes a real time decision is needed which cannot be done without the man-in-the-loop. These implications are important when considering the Space Station Data System.

3.35 LIFE SCIENCES

Life sciences include medical and biological applications.

3.36 ENVIRONMENT MONITORING

There will be a need to monitor the close environment, both internal and external to the Space Station, to analyze effects of contamination on sensor characteristics. This will have some data system implications.

3.37 OTHER OPERATIONAL APPLICATIONS

Satellite repair/refurbish/service and space construction should be considered.

3.38 WEAPON SYSTEM RESEARCH

Weapon system research such as directed energy is more of a military application with which we can do little. We should define it out of study.

3.39 TECHNOLOGY

Additional issues were approached from a technology viewpoint. A list of technologies available now or in the near term was derived, along with any resulting data systems issues (see Table 6).

3.40 FIBER OPTIC COMPONENTS

Advances and expected advances in fiber optics components were discussed. Couplers are presently a problem but will probably be solved. The availability of fiber optic technology in the time frame of interest may be assumed.

There are plans for a Long Duration Exposure Facility (LDEF) to evaluate new components, such as fiber optic elements, in the space environment.

3.41 INTEGRATED LASER COMPONENTS

Bell Labs currently has a working device generated by molecular implantation (which literally means built molecule by molecule), which has several tiny lasers built around an IC chip.

3.42 COMMUNICATIONS FREQUENCIES

In the communications area, SHF and EHF can be expected with millimeter waves being used for crosslinks. There is no need for very low frequency applications on the Space Station. Laser links will provide links to ground and other free flyers. One study said one gigabit/second rate will be needed in the 1990s. 300 MB/S down link capability exists for TDRSS. 1 SAR + 1 Thematic Mapper would exceed 300 MB/S.

Work is progressing in the 20, 30, 40 GHz carrier region with Gallium Arsenide components.

Active aperture antennas in the 20/30 gigahertz range will have some impact on communications, fault tolerance, and software drivers. This is currently adequately funded and can be expected to be available. Gallium Arsenide components to replace short life-time traveling wave tubes will also be important.

3.43 DATA COMPRESSION

Data compression is a viable technology. Communication bandwidth requirements will be reduced both through on-board information extraction (automation and man-in-the-loop) and channel coding.

3.44 DATA SYSTEM ARCHITECTURE

Computer system architecture and access is an important technology with many issues. Modularity of the data system architecture and the software is a must. The interfaces must be well defined and standardized. "User education" will play a major role. The users must know what the interfaces are and must be made to understand that certain guidelines and standards must be imposed. Then the pieces can be "plugged in" with minimum impact on the rest of the system. There must be provisions for different modes of operation according to degree, with different change authorities required.

3.45 PROCESSING CONTROL

In the technology of computers and processing, the control of the processing is probably the most critical concern.

3.46 STANDARDIZED INTERFACES

The concept of standardized interfaces to station subsystems and experiments is important. The overall data system architecture must accommodate changing conditions of interfaced subsystems. (This has some important implications on software addressed in later notes.)

3.47 USE OF NEAR COMMERCIAL COMPONENTS

The use of near commercial components in space provided for considerable discussion. The biggest problem involves safety. Certain materials are prohibited in space. Often commercial vendors do not know if they are using them or not. The relaxation of performance and reliability requirements for space hardware may be the best way to achieve economy. Space qualification has the added disadvantage of introducing a two or three year delay in the availability of new technology. Adequate attention to logistics, on-board replacement of failed components, and redundancy may be a better approach. At the same time, better knowledge dissemination and standardization of space materials may be the optimum approach. The space qualification problems of ICs are slight. The problem is with the multilayer boards, soldering, insulations, etc., due to outgassing and safety hazards.

A more desirable approach is to achieve economy by providing spares and requiring lower availability; have man-in-the-loop to effect repair. This affects the whole position on architecture.

3.48 SPACE QUALIFICATION

The initiation of some degree of space qualification of emerging technologies appears desirable. NASA presently is doing just that for optical discs. Progress in data system technology and its subsequent applications in space is being addressed. For example, Storage Technology in Colorado has a 60 million dollar development program for a commercial laser optical disc system that is expected to be available in 1984/85. NASA has a correlary program to try to qualify this for space with a one year lag.

Carousels to increase on-line storage are also being developed for ground applications. This could be used for archive or permanent copy. Discs could be shipped to the ground on resupply visit.

3.49 ARTIFICIAL INTELLIGENCE

There was some discussion of algorithm development and alternatives such as artificial intelligence (AI). Can the data system develop some of the required algorithms in real time? There did not seem to be much support for the position that this is possible in early phases of the Space Station. NASA is interested in AI. They recently had William B. Gevarter of National Bureau of Standards perform a survey and prepare a report NBSIR-82-2505 "An Overview of Expert Systems" - May 1982 (J. Neiers has a copy).

Heuristic planning for mission scheduling is promising. NASA has a plausible inference system call "DEVISER" that performs automated intelligent scheduling. It was developed by JPL for planetary "flybys."

3.50 RADIATION HARDENING OF VHSIC

Space radiation hardening is a necessity. NASA and other agencies have programs addressing this need for VHSIC. There is an issue here as to whether VHSIC will be radiation hardened.

3.51 DATA BASE MANAGEMENT

The whole area of data base management is very important. Recently it has become easy to buy data base management systems. Relational systems are in vogue. The experience has been, "Everyone needs DBMS; they are easily purchased -- and they don't work very well." The problem should be addressed.

There will be a need for a large data base. It will also be distributed and heterogeneous. That should be recognized and addressed.

3.52 SOFTWARE

In related discussion, the cost of software development and verification must be reduced. Some ideas on natural language programming and machine-assisted code generation must be explored. There are two major areas of interest in NASA today:

- development of cost effective tools that will reduce the cost of software, and
- reliability and the development of tools to ascertain reliability.

3.53 SOFTWARE FAULT TOLERANCE

The impact of fault tolerance on the software is an issue to be addressed.

3.54 ON-BOARD SOFTWARE CHANGES

There was considerable discussion over the question "Will software changes be allowed on the station?" This was probably the most controversial issue addressed. The panel was divided and opinionated as to the correct answer. On the one hand, permanent and continuous operations while specific mission mixes change almost dictate some degree of on-board software changes. The role of the man interacting with the experiments and operational sensors for serendipitous observations also drives the need for semi-real time software changes. On the other hand, experience and related horror stories dictate definitely "NO."

4. SUMMARY

Those issues and technologies that were considered of high priority and deserving special attention were identified on the appropriate tables. A first attempt at identifying key areas is presented in Table 7. These are all high priority topics with no significance implied by their order.

Table 7. Key Areas

Architecture
Autonomy
Data Base
Functions
Logistics
Man's Role
Software
Space Qualified Components

4.1 ARCHITECTURE

The data system architecture should exhibit features of flexibility, technological transparency, and fault tolerance. Flexibility and technological transparency can be enhanced by defining standard interfaces. This concept of modularity and standardized interfaces should carry through to include software. Fault tolerance includes an attention to survivability through functional modularity, distribution, redundancy, and protective functions.

4.2 AUTONOMY

The data system should exhibit characteristics of autonomy as defined in various modes that include survival without external systems or ground support and automatic operation without human intervention. Autonomous operations is a driver for the architectural implementation.

4.3 DATA BASE

The data base, its architecture, contents, size, and location are important factors in the data system. A distributed data base, with a portion being ground resident should be at least one alternative. Technological advances in access methods, including user friendly natural language query systems should be considered.

4.4 FUNCTIONS

A dichotomy of functions of the data system should be identified. One partition should include housekeeping or operations type functions. The other partition should be application oriented. These two partitions may be thought of as operation oriented and mission oriented. Especially, the mission functions will be dependent upon a comprehensive consideration of potential applications.

4.5 LOGISTICS

The data system will play a major role in logistics and logistics management. Because of the indefinite lifetime and manned presence, the entire operational philosophy will be different from previous spacecraft. Fault detection, isolation, and manned repair will be normal. Spare parts management will be a significant role for the data system. The whole reliability requirement will also change with an emphasis on availability.

4.6 MAN'S ROLE

The role of man is yet to be decided, but he will definitely be an integral part of the overall data system. The interface must be friendly, with both visual and audible interfaces. Interactive analysis of extracted information may be assumed. The guided repair role will also fall to man. Routine operations will likely be automated.

4.7 SOFTWARE

Software will be a significant factor in the data system. An emphasis on tools for lower cost development and for improving software reliability is suggested. Natural language processing and heuristic implementation of some functions, particularly planning, is worth investigating.

4.8 SPACE QUALIFIED COMPONENTS

The correct consideration of space qualified components will have a major impact on life cycle cost. The changing role of manned presence and indefinite life calls for new considerations of reliability and maintainability. Technological advances of commercial components should not be forfeited because of excessive space qualification processes. Yet, because of safety concerns, especially outgassing of materials, commercial products cannot be used carte blanche. A relaxation of reliability requirements along with a materials certification and education program probably offers the best potential for reduced life cycle cost. Some consideration should be given to advancing this idea during this study.

Prepared by: J. W. Neiers
J.W. Neiers
Program Manager
Space Station Data System Study

APPENDIX C

DEFINITION AND DERIVATION OF EXPRESSIONS FOR RELIABILITY, COMPUTATIONAL CAPACITY, AND DEGRADATION

DEFINITION AND DERIVATION OF EXPRESSIONS FOR RELIABILITY, COMPUTATIONAL CAPACITY, AND DEGRADATION

The terms or parameters reliability, computational capability or capacity, and degradation are defined and mathematical expressions are derived relating these to the idealized model to be considered. Although an intuitive feeling of the meaning of these terms presently exists, a brief qualitative definition of each is in order to possibly avoid later confusion or misunderstanding. The standard definition of reliability will be used which is the probability of success of the particular item under consideration over some period of operation. It will be assumed that the sample space is dichotomous, i.e., an item either falls in a good or a bad category; thereby, a discussion of what constitutes a failed circuit, module, etc., is avoided. Degradation, as applied to parallel processing or multiprocessing elements and not to individual circuits, means the dropping off of parallel elements, or in some cases, a parallel processor, as failures occur. As used herein, it will apply only to multiprocessor operation; for the fault-tolerant mode of operation, reliability represents a form of degradation. If a multiprocessor initially starts with n processors, after some period of time, one fails leaving n-1 available processors, etc. Thus, the term "graceful degradation" is often applied to this type of application. It should be noted that this definition of degradation also yields instantaneous computation capacity; however, for the purposes herein, computaional capability or capacity will be derived from both the reliability and degradation parameters. It simply represents the area under the degradation - time curve and is defined as follows: In the case of n initial modular multiprocessors, after some period of time one module fails; thus, the number of computations performed up to that time is the product of n processors and the time increment from initiation up to when the first failure is expected to have occurred. Similarly, the mean time of the second processor failure is determined and the product of n-1 processors and the time difference between the expected values of the first and second failure yields the computing capability over this time frame. This quantity is then added to the previous value to obtain total computational capacity up to the second failure. Notice that a module failure does not necessarily result in a processor being removed from the system. This is only the case when the minimum number of modules available in any stage drops below that previously available in the system. If r represents the maximum number of processor failures allowed, then n-r is the minimum number of modules required in any stage in the system, and the summation must stop when the mean or expected number of functional processors has fallen below this number. Briefly then, computing capability represents the total number of operations performed by a multiprocessor system before the system becomes too minimal to handle the total application requirements. Computational capability will be normalized about a single processor; i.e., it is represented as the ratio of the computations expected from a multiprocessor system to those expected from a single processor before each system fails. Although, as far as is known, this definition of computational capacity is unique, it is by no means the only definition which can be applied. However, it serves the purposes of this paper and allows tradeoffs in the desired parameters.

With these brief preliminaries disposed, we turn our attention to the main problem at hand; i.e., in treating the effects of modularity upon reliability, computational capability, and degradation, and indicate how it can be advantageously employed in a single architectural design which is automatically reconfigurable to a wide range of applications. Consider the idealized modular system shown in Figure 1. A single processor system has been divided or segmented into m modules, denoted by M_{11}, M_{12}, ... M_{1m}, which will be assumed for simplicity

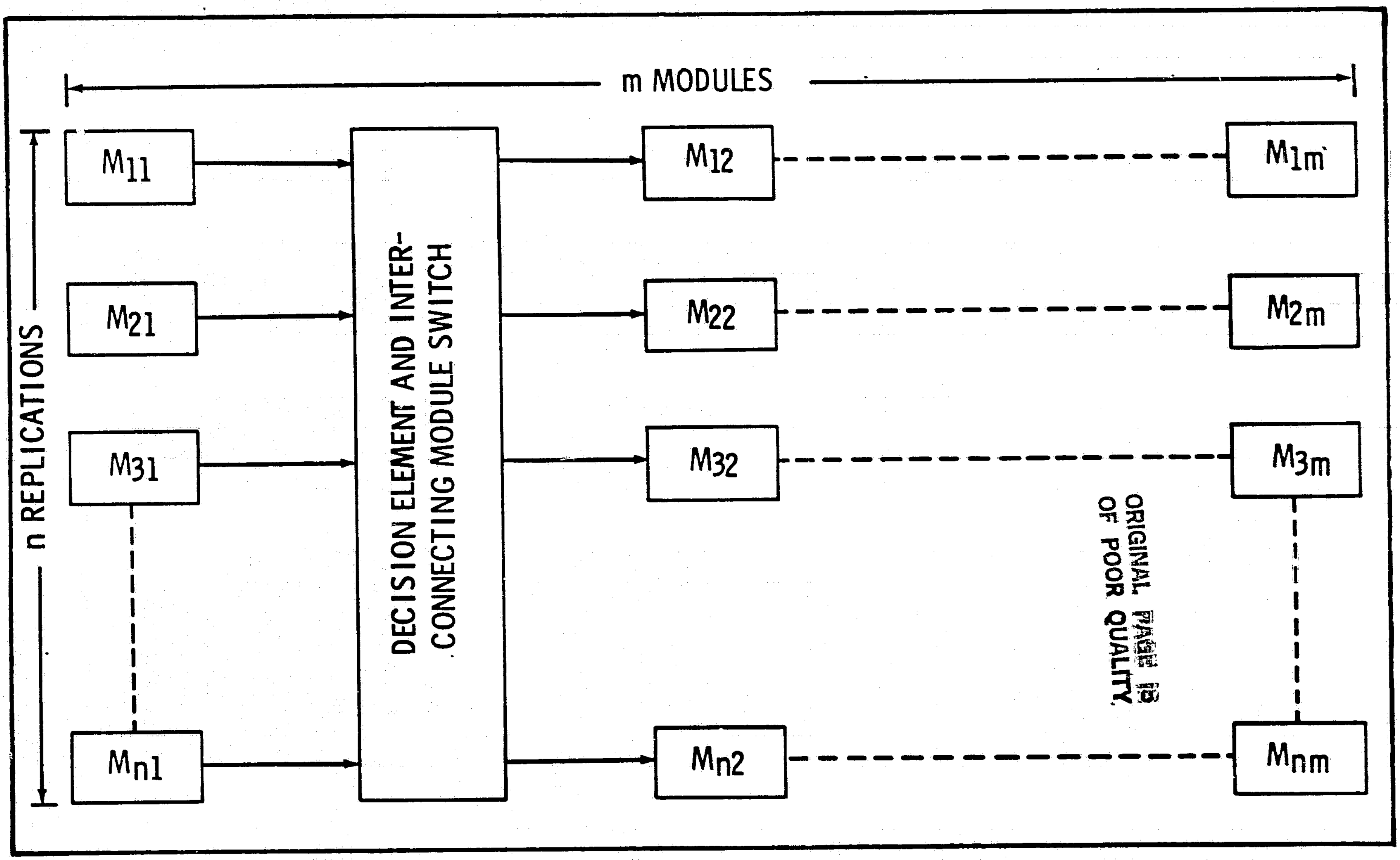

Figure 1. Idealized Modular System with N Replications and M Molules

to have equal reliabilities. Equal reliabilities imply that the system has been segmented into modules of equivalent complexities. Each of these modules is then replicated n times. A stage will be defined as n replications or a group of functionally identical modules; thus, modules M_{11}, M_{21}, ... M_{n1} shown in Figure 1 form a particular stage. It will be assumed that any module in one stage can be connected to and used with any module in the next stage. A switching element is used with each module and can mathematically be thought of as being functionally part of that module. The switching element is used either for error detection, isolation, and module switching when the system is operating in the high reliability mode or as an interconnection switch allowing any module of one stage to be connected to any other module of the next stage when the system is operating in the multiprocessing mode.

Let R represent the reliability of a simplex processor; e.g., the product of the reliabilities of modules M_{11}, M_{12}, ... M_{1n}. Since the m modules into which a processor has been segmented are assumed to have equivalent reliabilities, the reliability of a single module R_m, is given by the expression

$$R_m = R^{1/m} . \qquad [1]$$

Let R_e be the reliability of the decision and switching element and let α be the complexity of this element relative to that of the module; i.e.,

$\alpha = \frac{n_e}{n_m}$, where n_e and n_m are the number of equivalent component parts, gates, or chips. in the switching element and module respectively. The reliability of the switching element can now be expressed in terms of module reliability yielding

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$$R_e = R_m^{\alpha} , \qquad [2]$$

or, the reliability of the switching element expressed in terms of a simplex processor is given by

$$R_e = R^{\alpha/m} .$$

Because a switching element is assumed to be employed with each module, mathematically, these reliabilities can be lumped together and treated as a single identity, denoted by R_C and expressed by the relationship

$$R_c = R_m R_e = R^{1/m} R^{\alpha/m} = R^{\left(\frac{1+\alpha}{m}\right)} . \quad [3]$$

The reliability of a simplex processor is usually assumed to be given either by the binomial or Poisson distribution each of which leads to the expression

$$R = \epsilon^{-\lambda t} \quad [4]$$

where λ is a simplex processor failure rate, or $\frac{1}{\lambda}$ is the mean time between failures (mtbf) and t is the system operating time.

The probability that no failures have occurred in the total system consisting of nm modules is equivalent to the probability that all m stages contain n functional modules and is found from the binomial distribution. This probability is given by the expression

$$P_{x=0} = \left(R_c^n\right)^m . \quad [5]$$

The probabilities of one or less, two or less, and r or less failures in all m stages are given by the expressions

$$P_{x \le 1} = \left[R_c^n + nR_c^{n-1}(1-R_c)\right]^m \quad [6]$$

$$P_{x \le 2} = \left[R_c^n + nR_c^{n-1}(1-R_c) + \frac{(n)(n-1)}{2!} R_c^{n-2}(1-R_c)^2\right]^m \quad [7]$$

$$\vdots$$

$$P_{x \le r} = \left[R_c^n + nR_c^{n-1}(1-R_c) + \ldots\ldots + \frac{(n)(n-1)\ldots.(n-r+1)}{r!} R_c^{n-r}(1-R_c)^r\right]^m \quad [8]$$

respectively. Equation (8), therefore expresses the probability that there are at least n-r functional modules in each stage or, consequently, that the system contains at least n-r functional parallel processors. Thus, r represents the maximum number of failures allowed in any stage or the maximum number of failed processors permitted. This equation will be used to represent overall system reliability when operating in the high reliability mode.

An auxiliary equation may be developed which will be extremely useful in describing the mean number of processors expected to be functional at any instant in time. Notice the probability that there are exactly n-1 functional modules in each stage or that there are exactly n-1 functional parallel processors is

$$P_{x=1} = P_{x\leq 1} - P_{x=0}$$

$$P_{x=1} = \left[\sum_{i=0}^{x} \binom{n}{i} R_c^{n-i}(1-R_c)^i\right]^m - \left[\sum_{i=0}^{x-1} \binom{n}{i} R_c^{n-i}(1-R_c)\right]^m$$

$$P_{x=1} = \left[R_c^n + nR_c^{n-1}(1-R_c)\right]^m - \left[R_c^n\right]^m \qquad (9)$$

Therefore, the probability that there are exactly n-r operational processors in

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the system is given by the expression

$$P_{x=r} = P_{x\leq r} - P_{x=r-1} \quad . \tag{10}$$

Equation (10) which can be evaluated through recursive operations can also be expressed formally as

$$P_{x=r} = \left[\sum_{i=0}^{r} \binom{n}{i} R_c^{n-i}(1-R_c)^i\right]^m - \left[\sum_{i=0}^{r-1} \binom{n}{i} R_c^{n-i}(1-R_c)^i\right]^m$$

$$P_{x=r} = \left[R_c^n + nR_c^{n-1}(1-R_c) + \cdots\cdots + \frac{(n)(n-1)\ldots(n-r+1)}{r!} R_c^{n-r}(1-R_c)^r\right]^m$$

$$- \left[R_c^n + nR_c^{n-1}(1-R_c) + \cdots\cdots + \frac{(n)(n-1)\ldots(n-r+2)}{(r-1)!} R_c^{n-r+1}(1-R_c)^{r-1}\right]^m . \tag{11}$$

The mean number of parallel processors expected to be functional at any time is a measure of the degradation of the multiprocessing system and is found again by the binomial distribution and can be expressed in the form

$$\mu(t) = \sum_{i=0}^{r} (n-i)\, P_{x=i}(t) \quad . \tag{12}$$

Expansion of Equation (12) through substitution of the previously derived equation yields

$$\mu = n\left[R_c^n\right]^m + (n-1)\left\{\left[R_c^n + nR_c^{n-1}(1-R_c)\right]^m - \left[R_c^n\right]^m\right\} + \cdots\cdots$$

$$+ (n-r)\left\{\left[\frac{(n)(n-1)\ldots\ldots(n-r+1)}{r!} R_c^{n-r}(1-R_c)^r\right]^m\right.$$

$$- \left[R_c^n + nR_c^{n-1}(1-R_c) + \frac{(n)(n-1)}{2!} R_c^{n-2}(1-R_c)^2 + \cdots\cdots\right.$$

$$\left.\left. + \frac{(n)(n-1)\ldots(n-r)}{(r-1)!} R_c^{n-r+1}(1-R_c)^{r-1}\right]^m\right\} \tag{13}$$

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where μ and R_c are understood to be functions of time since R_c is found from Equations (3) and (4). Equation (13) expresses the mean number or the expected number of functional parallel processors after some specified operating time and is the analytical expression which will be used to represent system degradation.

A simple example may help clarify some of the mathematical symbology used in the above development. Suppose three fair coins are tossed simultaneously. What is the expected number of heads? By a "fair coin" is meant one where on any particular toss the probability of a head equals the probability of a tail; $P = 1/2$. The probability of exactly three heads, two heads, and one head is P^3, $3P^2(1-P)$, and $3P(1-P)$ respectively. Thus, the mean number of heads is found by applying Equation (12) which in expanded form yields

$$\mu = 3\left[P^3\right] + 2\left[3P^2(1-P)\right] + 1\left[3P(1-P)\right]$$
$$= 3P$$

Since $P=1/2$,

$\mu=3/2$.

In the work which follows, μ will be rounded to the nearest integer value.

We now have the tools to develop an analytical expression for computational capability. This term or parameter may be considered from several different aspects. Equation (13) yields the number of parallel processors expected to be operational at any instance in time; therefore, it represents instantaneous computing capability. Herein, computing capability will be defined as a relative quantity representing the ratio of the total number of operations performed by a modular multiprocessor system before it can be expected to have dropped below its minimal requirements to the number of total operations obtained from a single processing unit before it is expected to have failed. Thus, when Equation (13) is plotted as a function of time, the total computational capability is represented as the area under the curve between t=0 and the point in time where $\mu_{i(t)} \leq n-r$; i.e., the point in time where the integer value of the number of processors that are expected to be functional drop below the minimum specified number.

Mathematically, the computational capability of a system can be expressed as the product of the mean number of parallel processors expected to be operational over some incremental time frame and the value of that incremental time frame.

Thus,

$$
\begin{aligned}
C(\Delta t) &= \Delta t\, \mu_{i(\Delta t)} \\
C(2\Delta t) &= \Delta t\, \mu_{i(2\Delta t)} \\
&\vdots \\
C(j\Delta t) &= \Delta t\, \mu_{i(j\Delta t)} ,
\end{aligned}
\qquad [14]
$$

where Δt represents an increment of time and $\mu_{i(j\Delta t)}$ is found by determining integer values for Equation (13) at successive points in time; i.e., $t = j\Delta t$. Therefore, when Δt is taken as a constant time interval, the total computational capability is given by the expression

$$
C(t) = C(\Delta t) + C(2\Delta t) + \ldots\ldots + C(j\Delta t), \qquad [15]
$$

or from Equation (14) by the more compact expression

$$
C(t) = \Delta t \sum_{j=1}^{t/\Delta t} \mu_{i(j\Delta t)} . \qquad [16]
$$

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EVALUATION OF SYSTEM PARAMETERS FOR AN IDEALIZED COMPUTATIONAL SYSTEM

The parameters reliability, computational capability, and degradation which were analytically defined and derived will now be numerically evaluated for an idealized system. The term "idealized system" is used because of the following simplifications:

(a) A single or simplex system is assumed to be segmented into modules of equal reliabilities; i.e., equivalent complexities.

(b) For the high reliability mode of operation, the effects of the switching element have been neglected.

(c) For the high computational mode of operation, the efficiency of a multiprocessor has been neglected; i.e., assumed 100 percent.

In Figure 2, reliability, degradation, and computational capability, as determined from equations (8), (13), and (6) respectively with substitution of equation (4) have been plotted as a function of normalized time for a six-processor system. Time has been normalized about the mean time between failures (mtbf) of a simplex system. Thus, at K=1, a single processor would have a reliability of 0.368; it would have accomplished one machine's worth of computations, and it could be expected to have failed at this point in time. For each parameter, the number of modules into which a system is segmented varies between one and five. In this figure, it is assumed that only one module out of each stage or one computer system out of six is required to be functional.

The stairstep curves represent computer degradation. For example, it is expected that the system will undergo transactions from a two-processor to a one-processor system at K=1.375, 2.050, 2.625, 3.150, and 3.650 depending on

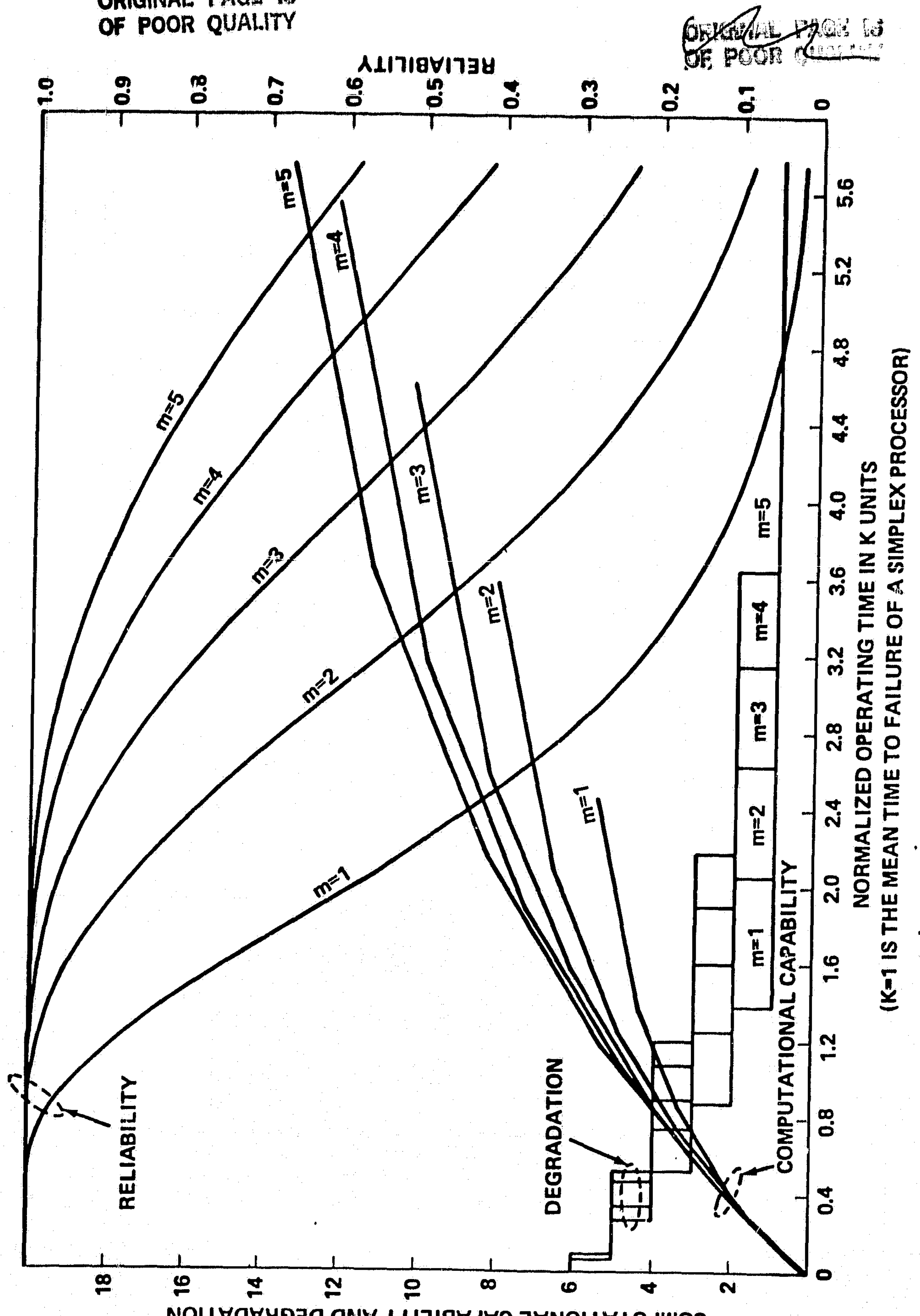

Figure 2. Plot of Six Processor System with r=5

whether m=1, 2, 3, 4, or 5 respectively. The points in time where the system can be expected to degrade, i.e., where each failure in the system is expected to occur, is clearly indicated as a function of m and the normalized operating time.

The area under the degradation curves has been integrated with respect to normalized operating time and represents computational capability. For example, with m=1, the system can be expected to yield approximately 5.5 times that of a single processor. This point corresponds to K=2.45, where the number of systems expected to be operational drop below 0.5 and thus, the curve is terminated. Without using integer values for the expected number of operational processors, when the area under the curve is integrated to $t = \infty$, a computational capability of six is obtained; i.e., with six parallel processors which are not modularized, one could expect six times the processing capability as with a single processor. Thus, the end point of the computational capability curves indicate two quantities.

(a) When read with respect to the ordinate, it represents total equivalent computational capability relative to a simplex system.

(b) When read with respect to the abscissa, it represents the point in time where the last computer system is expected to have failed (an exception is m=5 where operating time was limited because of scale).

Thus, for a modular six-processor system with m=1 through 4 respectively, the total computational capabilities are 5.5, 8.0, 10.25, and 12.25; the operating times where the last system can be expected to have failed are 2.45, 3.6, 4.6, and 5.5. The total computational capability of an idealized system is, therefore, directly proportional to the time the system is expected to be operational. This follows directly from definition and is clearly indicated by the figure. The effect of modularity on both degradation and computational capability is well demonstrated through these two sets of curves; a six-processor system with m=4 yields more than twice the computational capability obtained from six parallel processors with m=1 and can be expected to be functional more than twice as long.

The effects of modularity on reliability is demonstrated in the upper set of curves. For example, with K=3.6 reliabilities of 0.155, 0.440. 0.690, 0.840, and 0.915 can be expected for m=1, 2, 3, 4, and 5 respectively. It has been assumed that at least one module per stage must be functional for an operational system. Conversely, for a given reliability goal, it can be seen that modularity increases the operating time over which the system is expected to be operational. For instance, with a reliability goal of 0.9, values of K=1.15, 1.90, 2.55, 3.15, and 3.75 are found for m=1, 2, 3, 4, and 5 respectively. Thus, by increasing m from 1 to 5 the operating time frame to maintain a reliability of 0.9 has been extended by a factor of 3.3.

As an example, assume a hypothetical system consisting of six processors, each of which has been segmented into four modules. Assume that a redundancy technique is employed where only one of six modules is required in each stage; i.e., r=5. Further, assume that in the high computational mode a single processor can provide the minimum computational requirements. What can be said of the system's reliability, computational capability, and degradation? From Figure 2 for m=4, in the high computational mode, the system is expected to be functional for a period of K=5.55 times as long as a simplex processor. The first, second, third, fourth, and fifth failures can be expected to occur at K=0.100, 0.475, 1.075, 1.900, and 3.150 times the mtbf of a simplex system respectively. The total computational capability of the system is expected to be greater than twelve single non-modular processors operating in parallel. If used in the high reliability mode, a reliability in excess of 0.9 is obtained at

K=3.70. A system consisting of six parallel processors (m=1) would have a reliability less than 0.140 at this point in time.

The parameters of a six-processor system where at least two processors are required to be functional are shown in Figure 3. This figure is used similarly to the previous figure. Notice the decrease in the times at which failures are expected, the computational capabilities, and the reliabilities.

The results obtained herein have demonstrated that by modularizing a processor system, reliability, computational capability, and system operating time can be significantly enhanced.

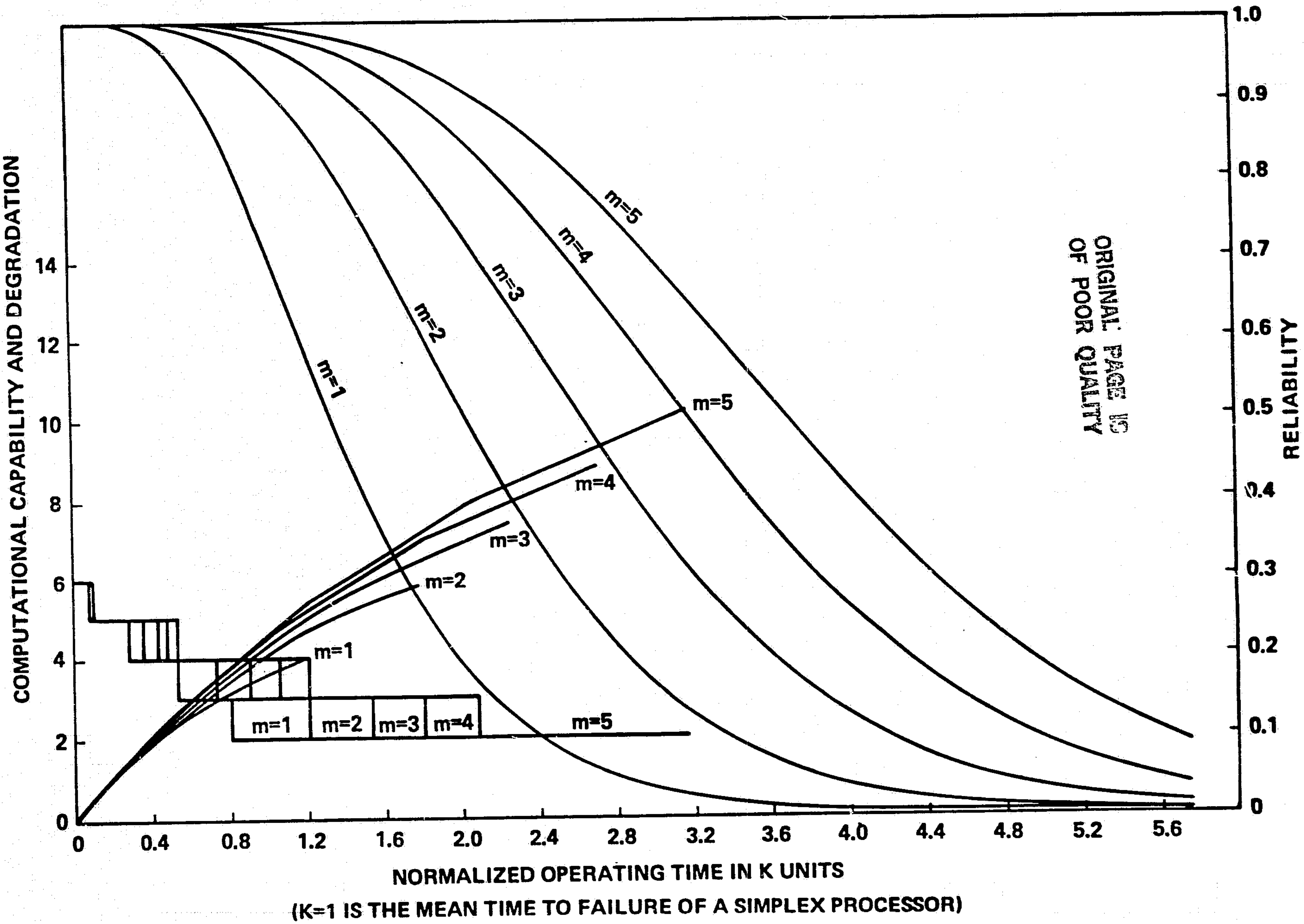

Figure 3. Plot of Six Processor System with r=4

LIST OF SYMBOLS

a — Shaping constant used in determining complexity of the switching element.

b — Shaping constant used in determining complexity of the switching element.

C — Computing capability normalized about the capability of a single processor.

i — Lower index of summation representing the least number of failures which can occur.

m — Number of modules into which a simplex system has been segmented.

K — Normalized system operating time factor.

k_1 — System operating constant used in determining multiprocessor efficiency.

k_2 — System operating constant used in determining multiprocessor efficiency.

N_T — Total number of equivalent components (discrete parts, gates, chips, etc.) in a simplex system.

n — Number of module replications in each stage, or the total number of parallel processors in the system.

n_e — Number of equivalent component parts or gates in the switching element.

$P_{x \leq r}$ — Probability of success of the total redundant system where x is the number of failures that are expected to have occurred in each stage and r the maximum number of module failures allowed in each stage.

R — Reliability of a simplex system.

R_c — Reliability of the combined module and switching element, $R_c = R_m R_e$

R_e — Reliability of a decision and switching element.

R_m — Reliability of a single module.

r — Maximum number of module failures allowed in any stage; n-r represents the minimum number of operational processors required.

t — System operating time.

Δt — Increment of system operating time.

Z — Throughput of the multiprocessing system.

α — Relative complexity of the decision element when compared to that of a module.

β Efficiency of the multiprocessing system.

λ Failure rate of a simplex system.

μ Mean number of processors expected to be operational at any instant in time.

μ_i Integer value of mean number of processors expected to be operational at any instant in time.

APPENDIX D

REFERENCES

APPENDIX D

REFERENCES

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