Solar Mesosphere Explorer Control Center
and
OASIS

Lessons Learned in Control Center Technologies and Non-Technologies

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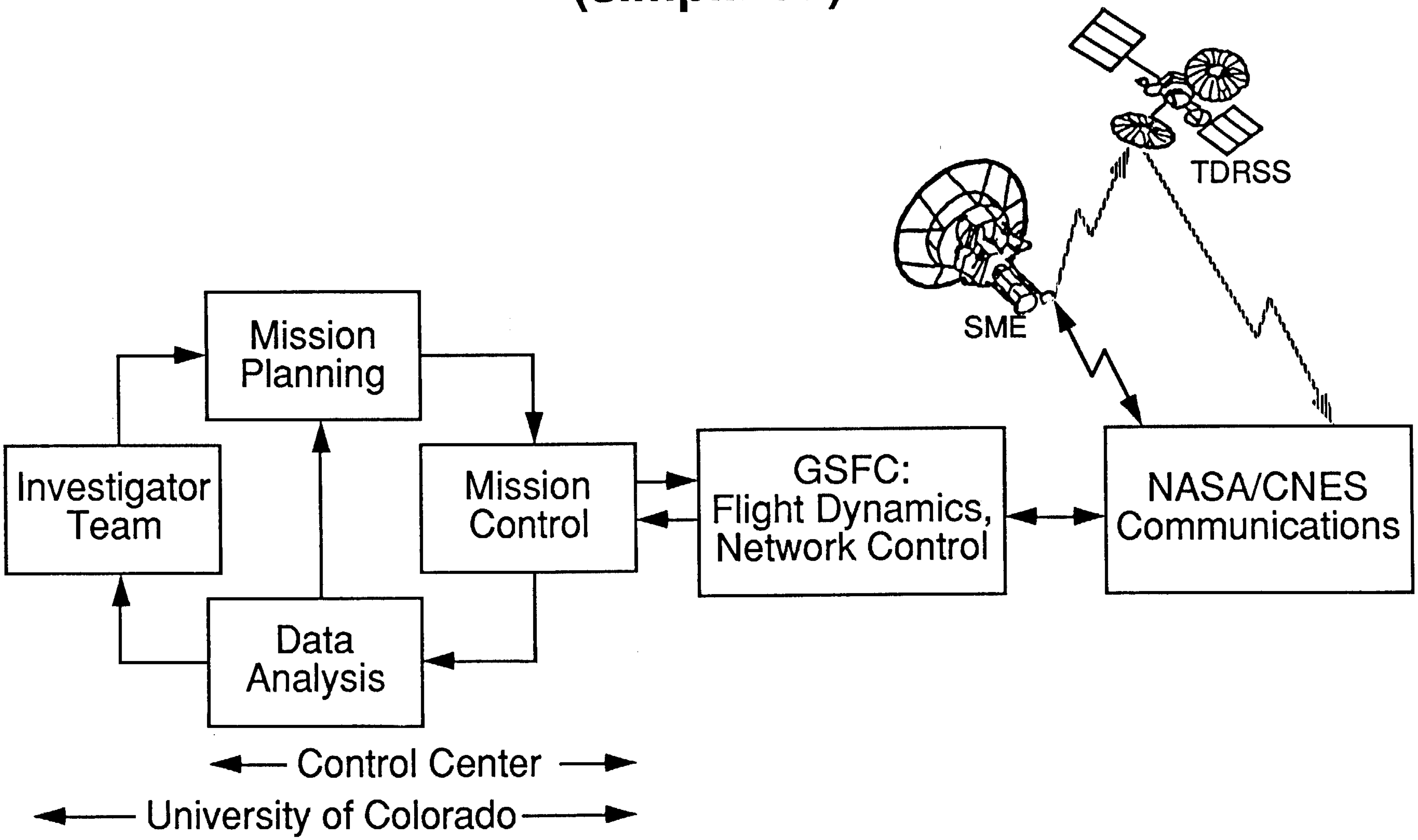
SME Control Center and OASIS: Lessons Learned in Control Center Technologies and Non-Technologies

— Outline —

- The Solar Mesosphere Explorer (SME) Mission
- Features of the SME Control Center: Technical and Non-Technical
- Can these features be applied to other missions?
- OASIS: Software tools to support some common Control Center functions

SME Mission Operations Functions (simplified)



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SME Control Center and OASIS: Lessons Learned in Control Center Technologies and Non-Technologies

— The Solar Mesosphere Explorer (SME) Mission —

Characteristics:

- To determine what causes ozone variations in our upper atmosphere
- A coordinated set of measurements
- Interactive science operations
- Realtime, quicklook, and in depth analysis
- Control Center located at University of Colorado - Boulder

SME Control Center and OASIS: Lessons Learned in Control Center Technologies and Non-Technologies

— The Solar Mesosphere Explorer (SME) Mission —

Results:

- Low cost: spacecraft, six science instruments, the entire ground data system, and one year of post launch operations for $17M
- Accomplished on schedule, within budget
- Strong personnel motivation
- All mission objectives met
- Control center performed well over the 7 1/2 year mission lifetime

SME Control Center and OASIS: Lessons Learned

— Features of the SME Control Center: Technical and Non-Technical —

1. University Based
2. Student Participation
3. Project Management
4. Integrated Design/Systems Design
5. Common Tools for Common Functions
6. Continuity over Project Lifecycle
7. Human Factors

— Technical and Non-Technical Features of SME Control Center —

1. University Based

   - Scientists and engineers able to work at their home institutions
   - Able to demonstrate advantages of "telescience" and "teleoperations"
   - Freedom to maintain and enhance system in response to changing mission, insights, and available technologies

— Technical and Non-Technical Features of SME Control Center —

2. Student Participation
   - Major contributors to control center
     - 10 - 25 Undergraduate students per term
     - 2 - 4 Graduate students per term
   - Variety of responsibilities
     - Controllers
     - Analysts — science and mission
     - Planners — science and mission
     - Teachers and tour guides
     - Programming assistants
     - Advanced development
   - Providing perpetual motivation and ideas for enhancement
   - Invaluable educational experience

— Technical and Non-Technical Features of SME Control Center —

3. Project Management — JPL

- Development teams motivated for on-orbit performance
  - — Award fee
  - — Science pay-off
  - — Continuing operations responsibility

- Therefore, it was beneficial to
  - — Help other teams
  - — Maintain full and open communications between teams
  - — Develop a reliable, usable, and maintainable operations system
  - — Reveal and correct problems early

- Early involvement by control center designers

- Encouraged system level trades
  - — Between science, instruments, spacecraft platform, control center, analysis system
  - — To increase efficiency, reliability, capability and eliminate frills - with no effect on science objectives

- Simple interfaces between elements

- Project Management supportive of new operations approaches

— Technical and Non-Technical Features of SME Control Center —

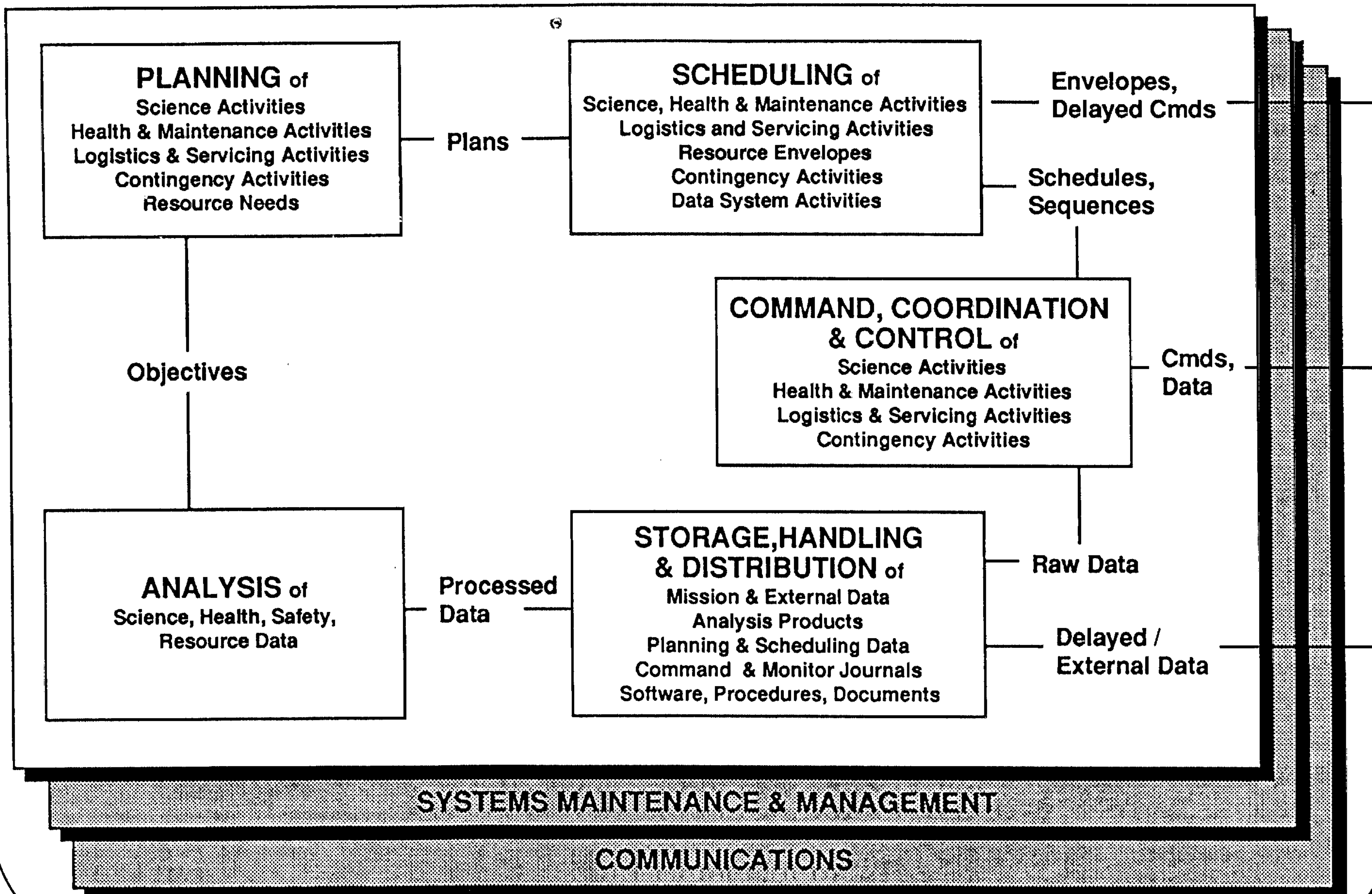
4. Integrated Control Center Design
   - OK to develop *new* control center designs and tools
   - Top-down design approach
     - — Based on science objectives and project requirements
     - — For end-to-end (user-to-instrument) operations
     - — For full lifecycle of operations support from early instrument tests through on-orbit operations
   - Functional elements defined from functional requirements
   - Functional interfaces to facilitate information exchange among elements
   - Functional elements arranged to minimize information interfaces
   - Processes and needs common to multiple elements identified
     - — Common tools implemented
     - — These tools duplicated for use in multiple elements

Technical and Non-Technical Features of SME Control Center

5. Common Tools for Common Functions
   - Evident in continuing mission that even more control center functions are actually common and could be accomplished by common tools
   - Evident that these common functions are not unique to SME Mission but are part of essentially all missions

University of Colorado at Boulder

General Tasks & Objects Within SSF Ground System Nodes



General Task Functions Within SSF Ground System Nodes

PLANNING of
Science Activities
Health & Maintenance Activities
Logistics & Servicing Activities
Contingency Activities
Resource Needs

- Accept External User Inputs
- Present Planning Information
- Integrate Requirements
- Modify Requirements
- (Re)Submit Plan Inputs
- Modify Plan Inputs
- Integrate Plan Inputs
- Translate Activities to Resource Needs
- Provide Data Security

STORAGE,HANDLING & DISTRIBUTION of
Mission & External Data
Analysis Products
Planning & Scheduling Data
Command & Monitor Journals
Software, Procedures, Documents

- Capture Data (raw and processed)
- Process Data to Level Zero
- Check Data Quality
- Route Data
- Produce Standard Data Products
- Store Data
- Archive Data
- Catalogue Data
- Provide Data Access
- Present Data Management and Distribution Processing Summary
- Provide Data Security

COMMAND, COORDINATION & CONTROL of
Science Activities
Health & Maintenance Activities
Logistics & Servicing Activities
Contingency Activities

- Accept Resource Envelope Information
- Receive Data
- Provide for Command Authorization
- Provide for Interlocks
- Accept Commands
- Check Commands
- Present Commands and Controls
- Initiate and Relay Commands
- Automatically Initiate and Relay Commands
- Verify Command Acceptance and Execution
- Relay G/A Voice, Video
- Check Science, Health, Ancillary and Resource Data
- Present Science, Health, Ancillary and Resource Data
- Monitor A/G Voice, Video
- Troubleshoot Anomalies
- Initiate and Relay (manually or automatically) Contingency Response Commands, Auto Sequences, Memory Loads, Rescheduling Requests
- Support Coordinated Campaign Operations
- Provide Data Security
- Provide Command and Monitor Journals
- Provide Planning Input

ANALYSIS of
Science, Health, Safety, Resource Data

- Access,Select Data
- Format, Manipulate Data
- Generate Data Products
- Present Analysis Information
- Store Processed Data
- Provide Data Security
- Provide Planning Input

SCHEDULING of
Science, Health & Maintenance Activities
Logistics and Servicing Activities
Resource Envelopes
Contingency Activities
Data System Activities

- Access Planning, Scheduling Data
- Present Activity Timeline Information
- Present Resource Timeline Information
- Determine Resultant Resource Needs
- Develop Timelines
- Integrate Timelines
- Iterate Timelines
- (Re)Submit Timelines
- Perform Conflict Resolution
- Develop Command Sequences
- Relay Resource Envelope Information
- Relay Timelines and Resource Information

SYSTEM MAINTENANCE & MANAGEMENT of
Hardware, Software, Databases, Procedures, Documents, Personnel (Ops, Crew and Science)

- Provide Development Services
- Provide Test, Training and Simulation Services
- Update and Enhance Systems
- Provide for Systems Test and Verification
- Provide Configuration Management
- Present Configuration Management Reports

Level of Commonality
(by a grass roots evaluation)

Task	Hardware	Software	Procedures	People	Average
Command, Control & Coordination	4	4	3	1	12
Storage, Handling & Distribution	4	3	3	1	11
Scheduling	4	3	2	1	10
Planning	4	3	2	1	10
Analysis	4	2	2	1	9
System Maintenance & Management	3	1	1	1	6

Commonality is defined as extent to which this task/function can be accomplished by a common set of hardware, software, or procedural tools or by people.

4 = Almost always

3 = Generally

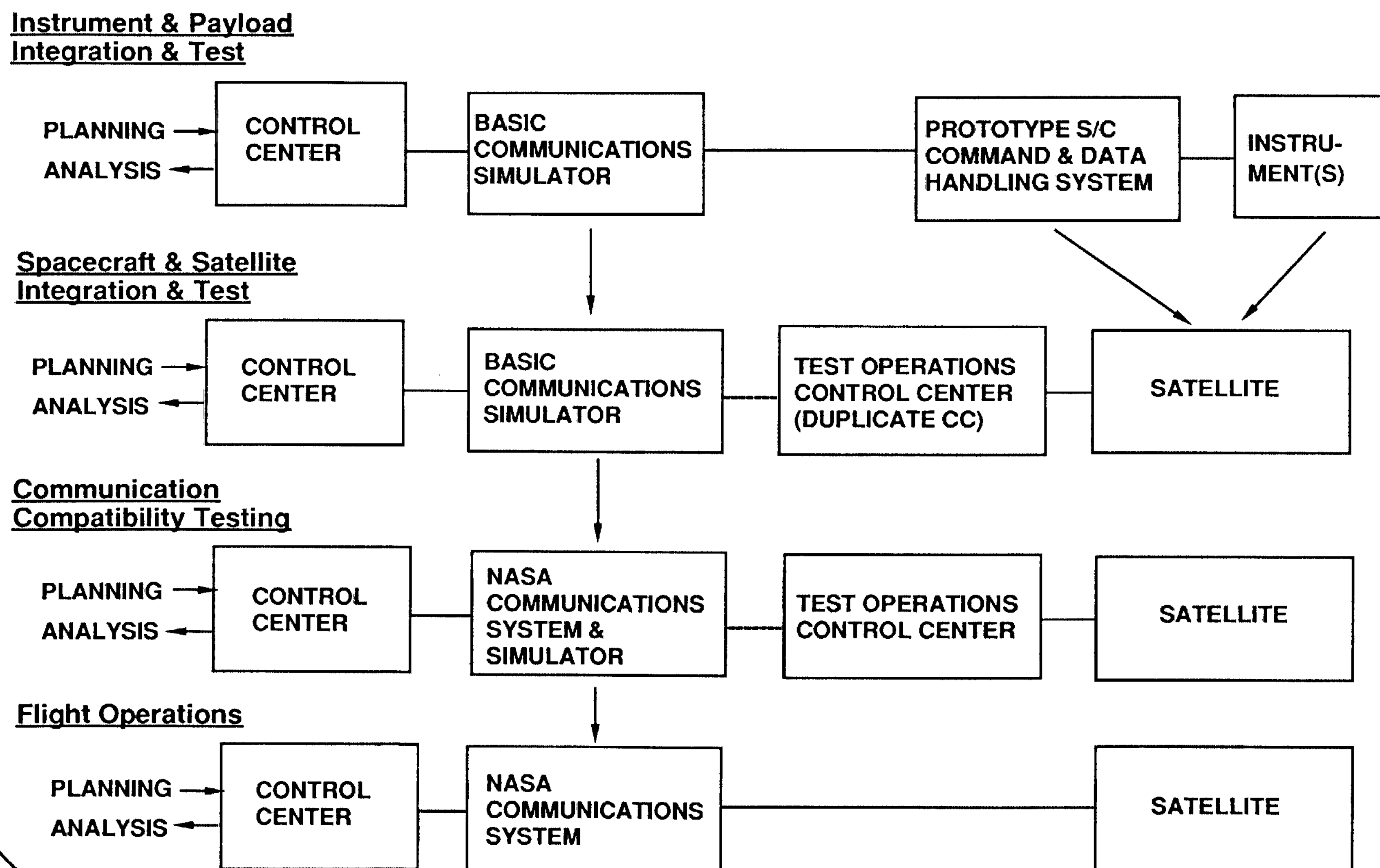
2 = Sometimes

1 = Hardly ever

— Technical and Non-Technical Features of SME Control Center —

6. Continuity over project lifecycle
   - Since common functions needed through lifecycle, a single operations system used throughout project lifecycle (prelaunch test, calibration, integration, and in-flight operations)
   - Benefits include:
     - Thorough and early system-level verification of the system hardware, software, procedures, facilities and personnel readiness
     - Early and continuing training
     - Control center bugs and enhancements determined and implemented early
     - Early test of the critical interfaces between major systems
     - Early and full access to capabilities of full operations system
     - Benefits in cost, schedule, reliability, and usability

Continuity Between Phases of SME Project Lifecycle is Maintained

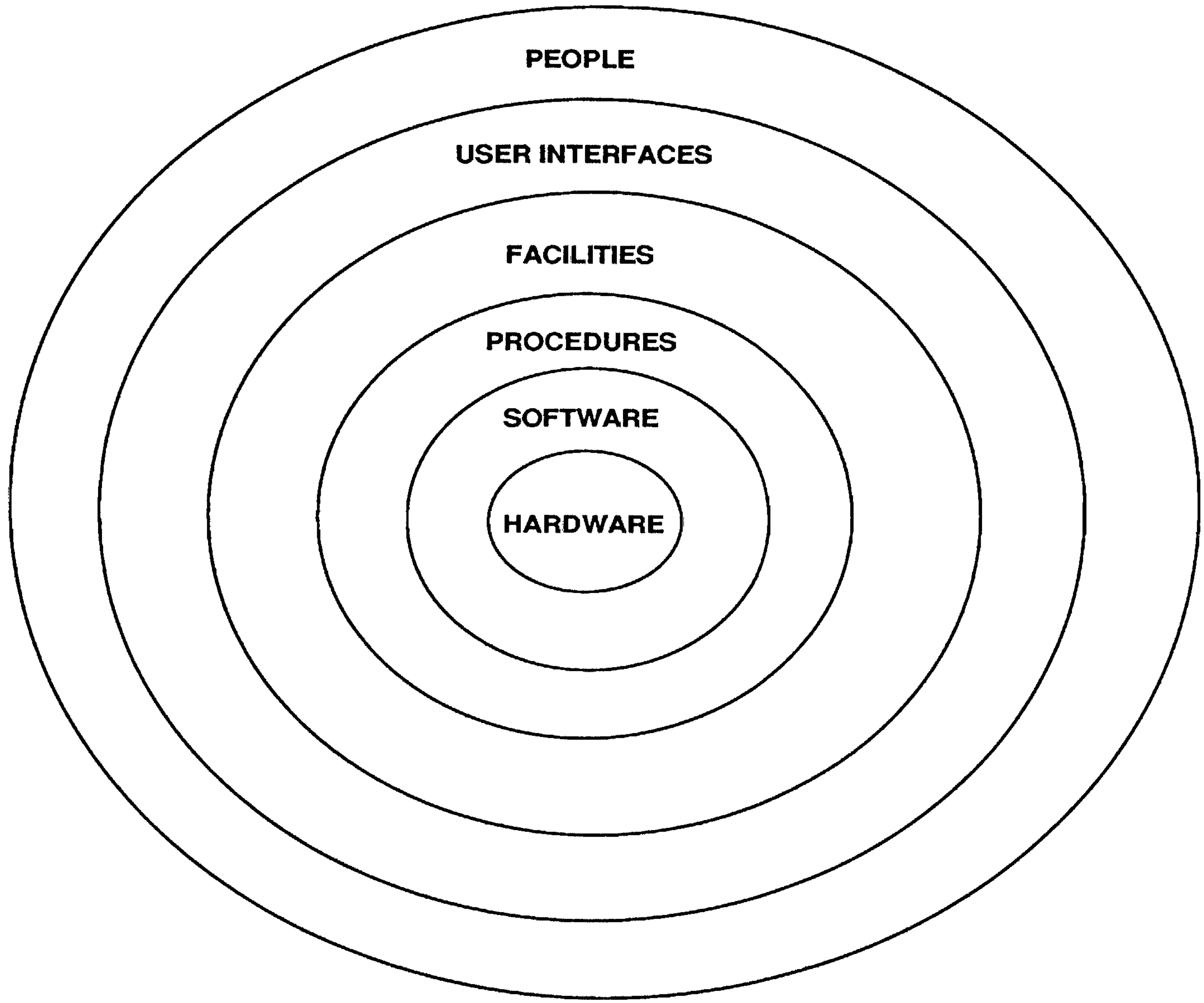


— Technical and Non-Technical Features of SME Control Center —

7. Human Factors

Control center elements composed of the following layers:

- People, user interfaces, facilities, procedures, software, and hardware
- People layer:
  - Defines people's roles and needs
  - Drives design of deeper layers
- SME users wanted to interact with the control center without going through intermediate programmers
  - Through interactive English-like languages and menus
  - Through user-specified, graphic displays
- Users preferred automation of tasks that are:
  - Predictable, routine, repeated, computational, critical, or potentially hazardous
  - But wanted ability to monitor most activities



The Control Center is designed in layers where the outer layers are used to drive the design of the deeper layers.

SME Control Center and OASIS: Lessons Learned — Can These Features be Applied to Other Missions? —

Feature	Applicability
1. University Based	• Yes, if appropriate • Telescience/teleoperations/ distributed operations approaches enable capabilities at user nodes
2. Student Participation	• Great if possible
3. Project Management • Motivation • Early involvement • Systems trades • Simplify interfaces • Supportive of change	• Yes!
4. Integrated Design/Systems Design	• Yes! Seen as a major deficiency in current missions

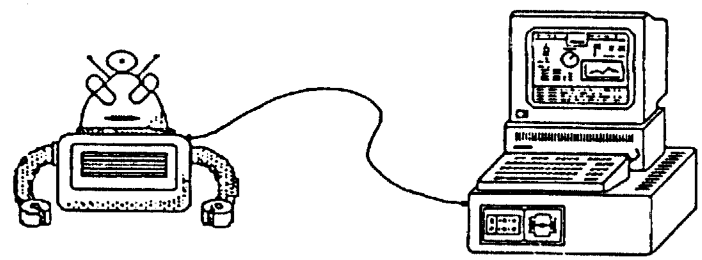
5. Common Tools for Common Functions	• Yes, a major opportunity for lowering costs and increasing reliability • Biggest payoff at hardware and software layers • Little payoff in personnel and procedural layers • Results in interoperability between missions, within a mission, and throughout a mission's lifecycle
6. Continuity over Project Lifecycle	• Yes, can see no technical or financial reason for not following
7. Human Factors • Layered design to optimize work environment	• Yes, should be standard design technique

OASIS Realtime Control and Monitoring Package "OASIS-RT"

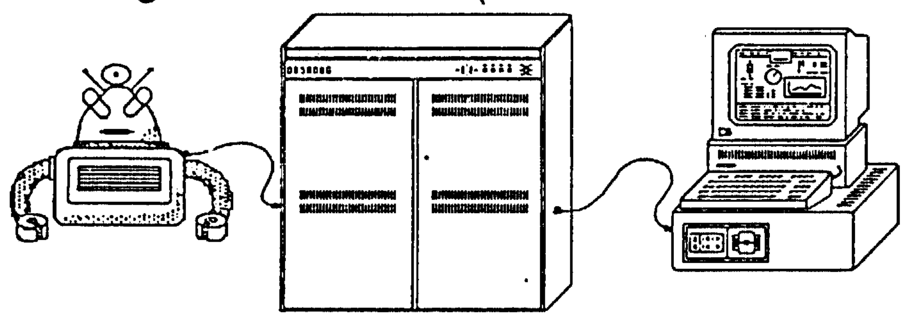
- OASIS-RT allows scientists and engineers to control and monitor space instruments and subsystems throughout the entire project lifecycle
- OASIS-RT provides capabilities similar to those found in large spacecraft operations systems
- OASIS-RT is flexible and can be tailored to a particular application with no software changes
  - Procedures written by users in high level language
  - Spacecraft capabilities defined by database tables
  - User interface specified by database tables
- Ties with external diagnostic packages, analysis packages, etc.
- Coded in Ada

OASIS is Useful Throughout the Project Lifecycle

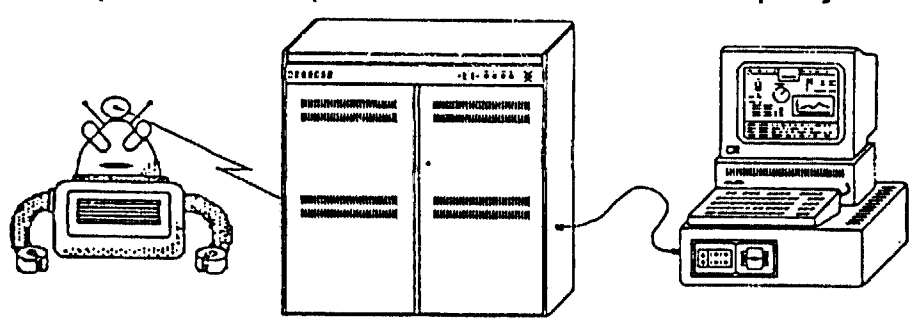
- During instrument test (connected directly to instrument)



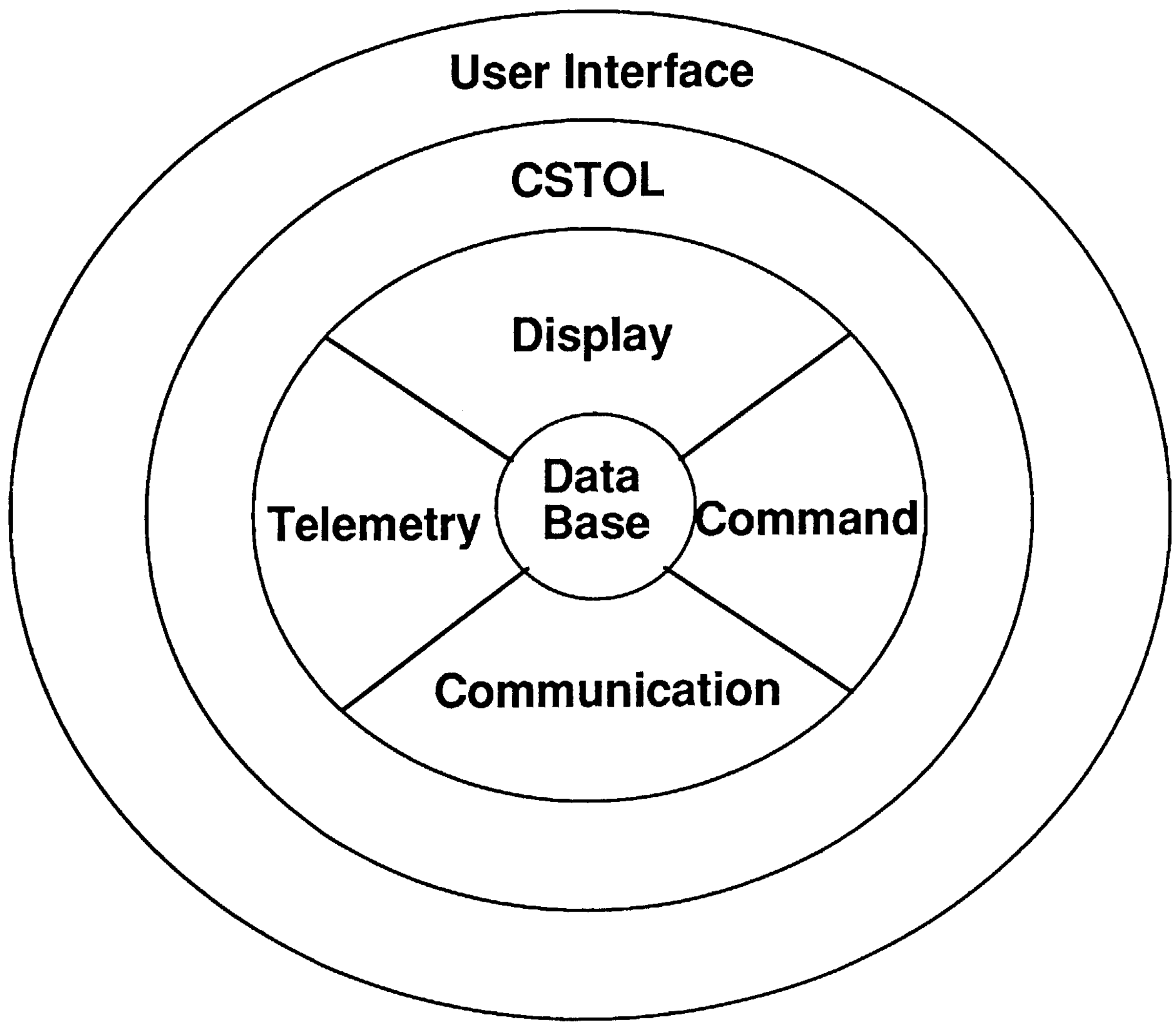
- During systems integration and test (connected to remote test systems)



- During on-orbit operations (connected to remote project data systems)



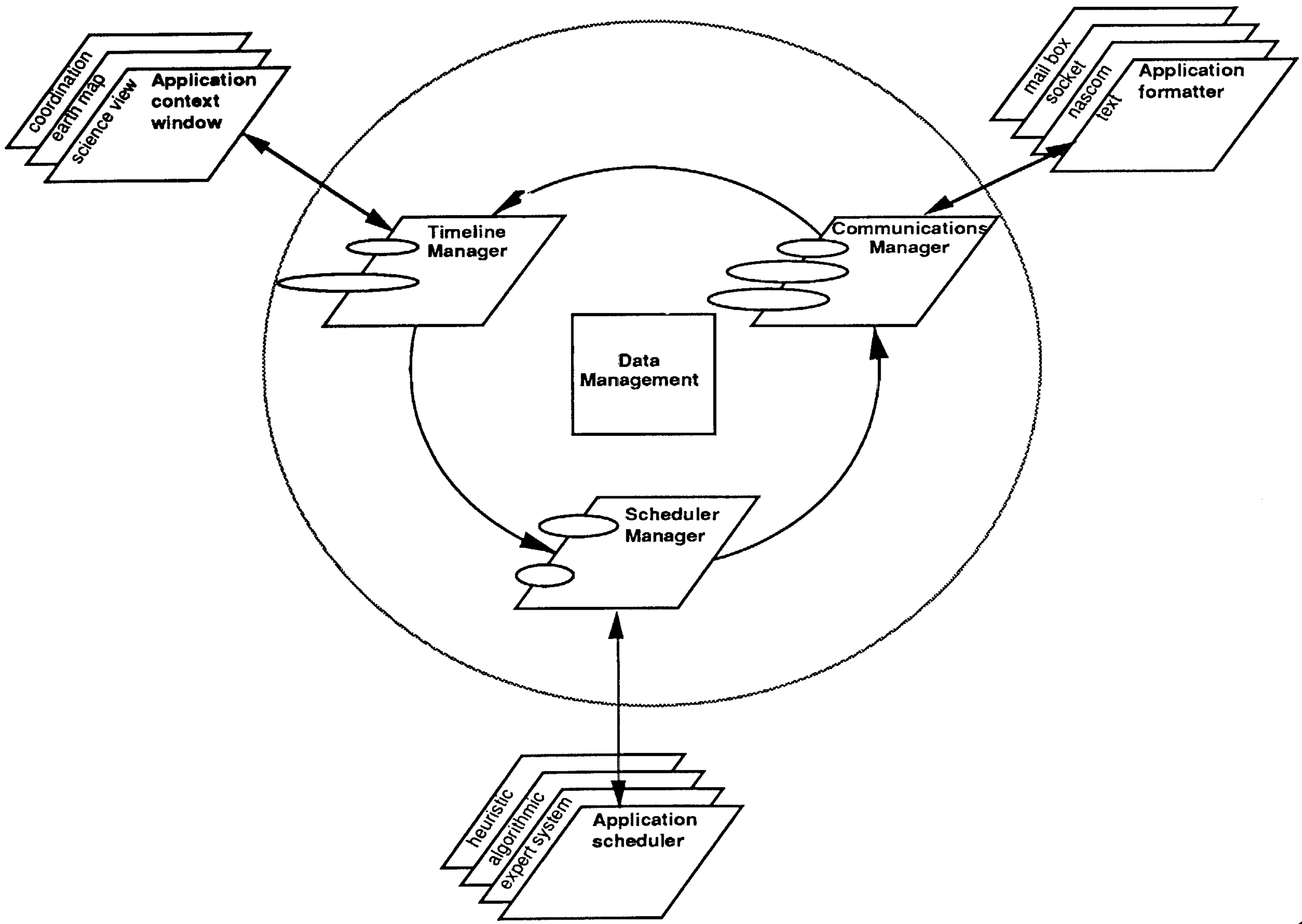
How OASIS is Organized



OASIS — Planning and Scheduling Package "OASIS-PS"

- OASIS-PS allows scientists and engineers to plan and schedule experiments and subsystem activities throughout a program
- Case-based planning and scheduling system
  - Core systems independent of application
  - Designed to accept application-specific code
- Provides planning and scheduling in appropriate context for user
  - Application specific windows interact with scheduling components
  - Application specific database tables accessible by all components
- User defined "schedulers" attached to any scheduling timeline
  - Can have any type of scheduler tool, ie., expert system, heuristic, algorithmic, etc., working on a specific timeline in concert
  - Can have many different schedulers working at once
- Application driven communications protocol
- Coded in Ada

OASIS-PS Architecture



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Summary

- Lessons learned from SME are indeed applicable to range of future missions
- Both technical and non-technical lessons are important
- Largest deficiency in today's systems seems to be a lack of an integrated systems perspective
- Software toolsets are available today to support some of these common control center functions