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)

- Investigator Team
- Mission Planning
- Mission Control
- Data Analysis

GSFC: Flight Dynamics, Network Control

NASA/CNES Communications

Control Center

University of Colorado

TDRSS

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

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

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

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

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

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

General Task Functions Within SSF Ground System Nodes
### Level of Commonality
(by a grass roots evaluation)

<table>
<thead>
<tr>
<th>Task</th>
<th>Hardware</th>
<th>Software</th>
<th>Procedures</th>
<th>People</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Command, Control &amp; Coordination</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>1</td>
<td>12</td>
</tr>
<tr>
<td>Storage, Handling &amp; Distribution</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>11</td>
</tr>
<tr>
<td>Scheduling</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>Planning</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>Analysis</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>System Maintenance &amp; Management</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>6</td>
</tr>
</tbody>
</table>

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
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

**Instrument & Payload Integration & Test**

- **PLANNING** → CONTROL CENTER
- **ANALYSIS** → BASIC COMMUNICATIONS SIMULATOR
- **PROTOTYPE S/C COMMAND & DATA HANDLING SYSTEM** → INSTRUMENT(S)

**Spacecraft & Satellite Integration & Test**

- **PLANNING** → CONTROL CENTER
- **ANALYSIS** → BASIC COMMUNICATIONS SIMULATOR
- **TEST OPERATIONS CONTROL CENTER (DUPLICATE CC)** → SATELLITE

**Communication Compatibility Testing**

- **PLANNING** → CONTROL CENTER
- **ANALYSIS** → NASA COMMUNICATIONS SYSTEM & SIMULATOR
- **TEST OPERATIONS CONTROL CENTER** → SATELLITE

**Flight Operations**

- **PLANNING** → CONTROL CENTER
- **ANALYSIS** → NASA COMMUNICATIONS SYSTEM
- **SATELLITE**
— 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?

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

User Interface

CSTOL

Display

Telemetry

Data Base

Command

Communication
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, i.e., 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

Application formatter

Communication Manager

Data Management

Scheduler Manager

Timeline Manager

Application context window

Application scheduler

Editor view

Connection
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