Human Factors and Systems Engineering Explorations of Spaceflight Operations

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*GMRSG, Minneapolis, Sept 2010*
Presentation Overview

- A Bit of Background
- Group Performance Environments Research (GROUPER) Lab Description
- Problems in Task Coordination and Information Flow
- Coordinating Expertise in Spaceflight Lifecycle Operations
- Ongoing Questions / Recent Projects
Where / When It Began

› Apollo 8 Mission, 1968: I want to be an astronaut!
The Group Performance Environments Research (GROUPER) Laboratory mission is to be a premier research and development team in the design, evaluation, analysis, and improvement of informed systems on Earth and in space.
Group Performance and Information Flow Factors

- Task needs
  - Type of information to share (e.g. system status)

- User characteristics
  - Expertise levels, level of interest, time willing / able to spend, system performance expectations

- Situational constraints
  - Information criticality, alternative sources, total time available to complete task
Systems Engineering Design Issues

› System Definition
  - What problems are you addressing?

› Components
  - What features are important to you?

› Flows and Interactions
  - How does stuff get from one “place” to another?

› Performance Criteria
  - How do you know when you’ve improved anything?
Tulga / Sheridan task paradigm
(from Sheridan, 1992, pg. 61)

Figure 1.32
Tulga multi-task selection paradigm. Displayed blocks are “tasks” to be done, which convey importance, duration required for completion, and time to deadline.
Multi-Tasking Issues and Problems

› What To Optimize?
  – People seem to optimize gain / cost, not absolute gain

› Performance Modeling
  – Multitasking vs Production processing

› Challenges Across Time Scales
  – “It took too long to write the to do list!”
  – Cognitive cues for lower-level tasks (indirect pointers)
The Challenge of Task Switching

› Effortful Cognitive “Executive” Function

› More Tasks = More Value of Expertise
  - Task evaluation
  - Task production speed
  - Task switching speed

› More Complex Rules = Less Performance!
  - Complexity of strategy: Tulga and Sheridan, Moray
  - Marginal gains from satisfactory to optimal
An “Information Clutch” for Task Coordination

INFORMATION SYSTEMS

PRODUCTION TASK OUTPUTS

TEAM & ORGANIZATIONAL INTERACTIONS

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Challenges to Support Clutch Coordination

› Experts Can Only Access Limited Domain Knowledge (Depth, Breadth)

› Mutual Awareness of Others’ Expertise and Activity

› Remote Systems Require Sensor and Communication Flows

› IT Not Self-Monitoring for Knowledge--Requires Human Support
Limiting Cases for Effective Task Load Management

› Time Available (Task Urgency)

› Time Available vs Time Required (Time Pressure)

› Overall Workload (Task Load)

› Success Criteria (Optimal vs Satisficing)

› Processing / Production Rules
Changing Roles for Human System Interfaces

- Person (operator, not always designer)
- Direct Observation
- Information and Communication Technology (ICT)
- Context Sharing
- Machine or Other Robotic Agent
  - IT usage
  - Context
  - ICT-2
  - Machine-2
  - ICT-3
  - Machine-3
Complex Expert Teams as Systems

› Components with Differing Functions

› Interactions of Information Technology, Human Expertise, and Task Context

› Linking Reference Information to Operational Experience via Context and Experience

› Problem Solving Approach to Improving Operational Performance
Time Scales in Research Fields

› Distinctions between individual and social processes

› Event dynamics ranging from attention to strategy

› Similar terms, but different tasks

Knowledge Development Research Emphases

- I/O Ψ & Management
- Grouper
- Social Psych
- Cog. Psych
- Indv
- Grp
- Org

10^{-1} \quad \text{time (sec)} \quad 10^7

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Complex Expert Team
Management Issues

› Managing Complex Engineering System Technical Components and Interactions

› Managing Distributed Expertise in Team Members with Domain Responsibilities for Engineering System

› Managing Human Performance Elements for Distributed Team Members
Dimensions of Expertise in Expert Communities

- Communication Effectiveness
- Process
- Subject Matter Domain
- Information Flow Paths
- Interface Tools
- Application Context
- Expertise Distribution Network
Expertise Dimensions Linked

› Subject Matter and Application Context
  - Discipline ("Traditional") expertise and Situation Awareness (SA) for current context

› Expertise Distribution and Communication Effectiveness
  - "Know Who" and how to share information / coordinate tasks with them

› Interface Tools and Information Flow Paths
  - Interactions with technologies and interfaces, getting data and information to right place

› Compare to Multiple Intelligences and Group Performance Paradigms
  - Mathematical, Physical, Interpersonal; Task, Social, Tools
History of GROUPER
“STINGRAY” Projects (1997-2006)

› Spaceport Technologies and Information for Near-Earth and Ground Resource Analysis

› Analysis of Mission Control Center (MCC) Voice Loop Utilization During STS and ISS Simulations (Research Grant)

› Analysis of Flight Rule Change Requests and “Operations to Reference” Cycles (Summer Faculty Fellowship)

› Analysis of MCC Voice Loop Utilization During Live ISS Missions (SG Project)
History, page 2 (2006-present)

› Ground Operations Concept of Operations (SG Internship)

› *Ground Operations Information Flow (SG ESMD Project)*

› *Electronic Procedures for Ground Operations Technicians (SG Internship)*

› *Lunar Information Flow Modeling (SG S/F, Research)*

› Crew Autonomy Modeling (SG Internship, SBIR)
NASA Mission Control IT

Local Displays for Individual Experts

Shared Displays for Coordinated Awareness

White Flight Control Room: Shuttle Operations

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Distributed Supervisory Coordination (DSC) Model

Supervisory Controller Systems

Human-Human Communication Interfaces

Human Supervisory Controller

Human System Interfaces

Engineering System Being Controlled ("The World")

Human-Human Communication Interfaces

Human Supervisory Coordinator

Human-Human Communication Interfaces

Human Supervisory Controller

Human System Interfaces

ICT Systems

Comm Processes

System Expertise

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Information Alignment as Coupling

› Effective Transfer from Entity to Entity
  - Flows without loss or entries of noise
  - Understanding of causes through effects

› Timing Coordination
  - Flow velocity compared to material velocity
  - Decision and task value depends on “right information in time”
Challenges to Mission Control

Alignment

› Multiple Sources of Delay
  - On-board processing and buffers
  - Satellite hops and transmission bandwidth
  - Knowledge processing among controllers

› Coordinating Team Understandings
  - Effective sharing between team members
  - Recognition of relevant expertise
Support for Hybrid Coordination

Engineer tagups

Asynchronous, task directed flows

New system capabilities

Synchronous flows (meetings)

Technician work orders

Hybrid flows during problem resolution

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Focus: Ground Operations

› Improving Information Clutch Capacity to Assembly Tasks
  - Less real-time knowledge sharing and alignment
  - Costs, delays, availability risks are greatest during least informed phase of system operations

› Assembly / Test / Integration Tasks as Events

› Documentation and Reporting as Command and Network Flows

› Collaborative Anomaly / Problem Resolution
Tools to Support NASA Hybrid Coordination

› Device and Infrastructure Designs and Architectures Required

› Support for Mobile Technicians

› Electronic Work Control Systems (EWCS)
  - Reduce amount of paper
  - Reduce time delay in knowledge flow
  - Improve updating and management of versions
ECWS and Threat-Error Management

› Procedure Correct / Flawed

› Technician Correct / Flawed Performance

› Catch of Prior Errors
  - Local catch of local error
  - Catch of prior operational error
  - Resolution of design flaw or unintended consequences

› “Appropriate Non-Compliance”?  
  - *Interesting challenge to HRA research paradigms*
Improving NASA Knowledge Sharing through Mobile Devices?

Cognitive Science and Systems Engineering Problems

- Gains of Smaller Screen Size Devices:
  - *Increased mobility*
  - *Decreased memory (delay) demands from display to task*

- Costs of Smaller Screen Size Devices:
  - *Decreased display access real estate*
  - *Increased memory (integration) demands of complex display*
ECWS Field Testing

› Thanks to Marshall Space Flight Center
  - Unexpected proof of concept / TRL - RRL jump

› Byrd Dissertation using Fujitsu Lifebook
  - Similar screen size, additional power and security

› Demonstration of Actual Device and Procedure
  - More interface and infrastructure testing needed
Elements of C3I Architecture Design

› Command & Control: decision-making and supervisory control networks as supported by an operational exchange of information via a comm relay network

› Communication: ground and space networks of multiple comm & data nodes for information production and relay

› Information: commands, telemetry, & data in varying formats
SoS refers to a class of design problems:
- that are comprised of an evolving collection of distributed and interoperating networks of heterogeneous systems,
- with multiple owners and operators,
- that require trans-domain solutions,
- which produce emergent behaviors not achievable by any one system in isolation, and
- satisfy a “global” need.
Analogues → C3I Architecture Trade Space

<table>
<thead>
<tr>
<th>C3I Design Trade Space Variables</th>
<th>Architectural Trade Space Options</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>COMMAND AND CONTROL</strong></td>
<td></td>
</tr>
<tr>
<td>allocation of decision-making rights</td>
<td>centralized (unitary)</td>
</tr>
<tr>
<td># of ground control room console operators</td>
<td>none</td>
</tr>
<tr>
<td>roles of in-situ operators</td>
<td>science: research</td>
</tr>
<tr>
<td>planning &amp; scheduling of mission objectives</td>
<td>in-situ</td>
</tr>
<tr>
<td>planning &amp; scheduling of daily ops</td>
<td>in-situ</td>
</tr>
<tr>
<td>anomaly &amp; fault detection, diagnosis, &amp; resolution</td>
<td>in-situ</td>
</tr>
<tr>
<td><strong>COMMUNICATION</strong></td>
<td></td>
</tr>
<tr>
<td>in-situ inter-element communications</td>
<td>RF: VHF and/or UHF</td>
</tr>
<tr>
<td>in-situ comm network design</td>
<td>habitat centralized and fixed</td>
</tr>
<tr>
<td>exploration assets can act as relays for other systems</td>
<td>no relay capability</td>
</tr>
<tr>
<td>in-situ base to external support relay modes</td>
<td>direct (outpost to ground)</td>
</tr>
<tr>
<td>in-situ base to external support relay visibility</td>
<td>sparse</td>
</tr>
<tr>
<td>multiple in-situ to external routes (includes backups)</td>
<td>none: just one route</td>
</tr>
<tr>
<td>external link protocols</td>
<td>point-to-point manually configured links</td>
</tr>
<tr>
<td>external link types (data distribution)</td>
<td>on-demand / shared</td>
</tr>
<tr>
<td><strong>INFORMATION</strong></td>
<td></td>
</tr>
<tr>
<td>type of data exchanged</td>
<td>engineering</td>
</tr>
<tr>
<td>form of information exchanged</td>
<td>data</td>
</tr>
<tr>
<td>format of data packaging</td>
<td>commercial (e.g., HAIPE)</td>
</tr>
<tr>
<td>storage and archival of project data</td>
<td>local</td>
</tr>
</tbody>
</table>
Tool and Graphical User Interface

Simulation Inputs
- Systems
  - Type
    - Manned vs. Unmanned
  - Location
    - Lunar, Space, and Terrestrial
- Links
  - Continuous and Dynamic
  - Connectivity from STK
- Activities
  - Functions
    - System assignment
    - Human vs. Machine Workload
Input Sensitivity Analysis for Model Verification

Verification within scenarios based on realistic SoS performance

Example input variable: human workload (vs. automation) assignment

As human workload ↑, we observe:
- affordability ↑
- safety is not affected
- human operability ↓ (amount that “machines” need crew or ground operators)

These behaviors match the equations for these FoMs.
Follow-up Projects

› Simulation Development with Java Tool for JPL

› NASA SBIR Project on Crew Autonomy Measures and Models for JSC
  - Phase 1 Completed July 2010
  - Phase 2 Proposal in Review

› Additional SBIR and Research Concept Development (Pending)
Questions?

› Ask Me Now

› Contact Me Later

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