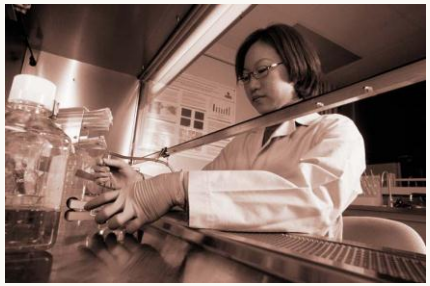
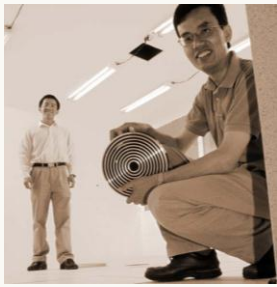



PURDUE UNIVERSITY

College of Engineering

Human Factors and Systems Engineering Explorations of Spaceflight Operations

Barrett S. Caldwell, PhD, CHFP

Schools of Industrial Engineering / Aeronautics & Astronautics

Purdue University

GMRSG, Minneapolis, Sept 2010

Presentation Overview

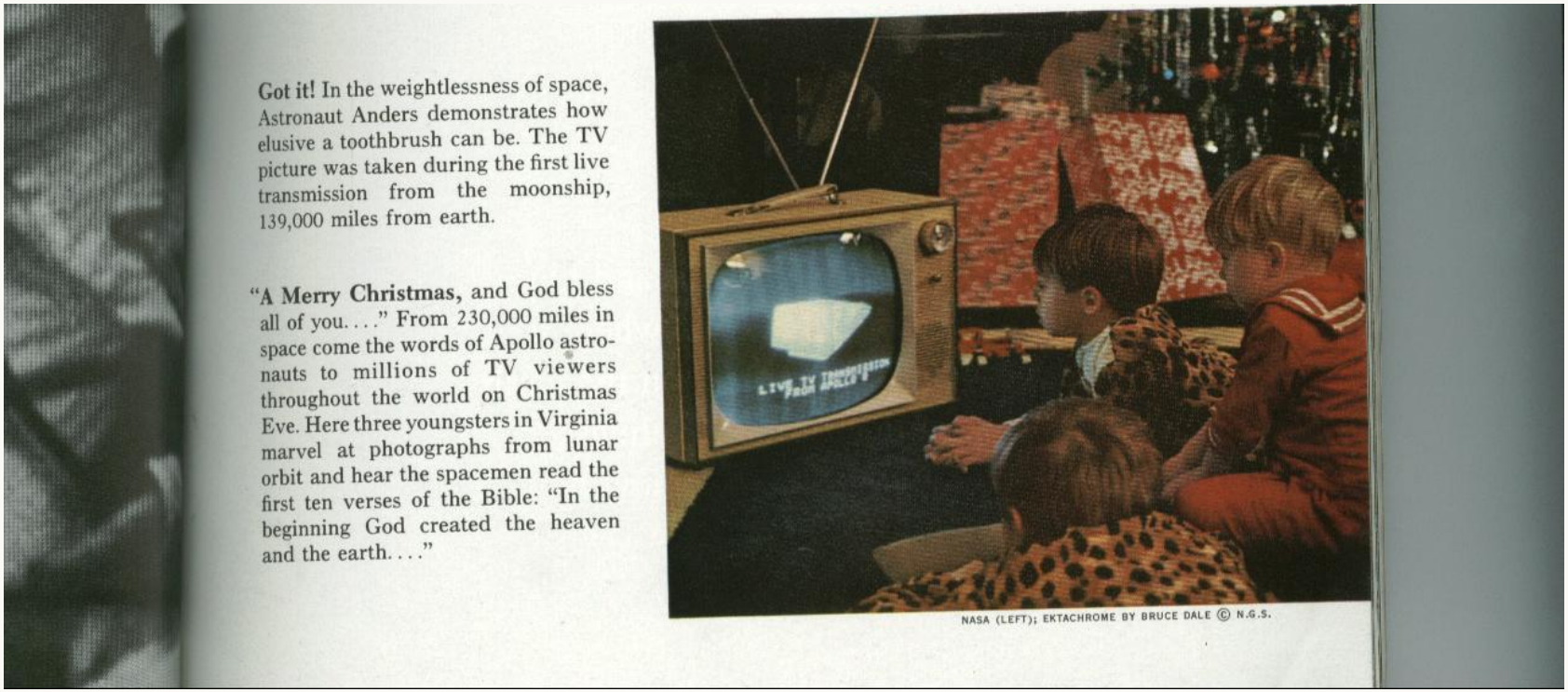
- A Bit of Background
- Group Performance Environments Research (GROUPER) Lab Description
- Problems in Task Coordination and Information Flow
- Coordinating Expertise in Spaceflight Lifecycle Operations
- Ongoing Questions / Recent Projecs





Where / When It Began

› Apollo 8 Mission, 1968: I want to be an astronaut!



Got it! In the weightlessness of space, Astronaut Anders demonstrates how elusive a toothbrush can be. The TV picture was taken during the first live transmission from the moonship, 139,000 miles from earth.

"**A Merry Christmas,** and God bless all of you. . . ." From 230,000 miles in space come the words of Apollo astronauts to millions of TV viewers throughout the world on Christmas Eve. Here three youngsters in Virginia marvel at photographs from lunar orbit and hear the spacemen read the first ten verses of the Bible: "In the beginning God created the heaven and the earth. . . ."

NASA (LEFT); EKTACHROME BY BRUCE DALE © N.G.S.





GROUPER Mission Statement

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 informated 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)

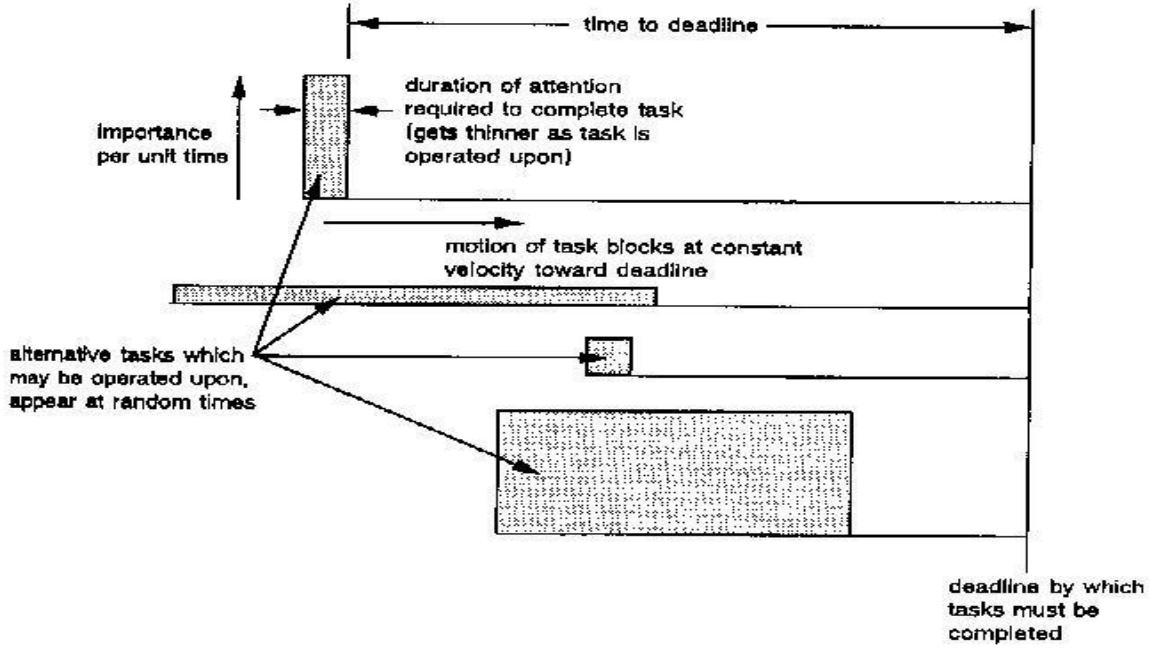


Figure 1.32
Tulga multi-task selection paradigm. Displayed blocks are "tasks" to be done, which convey importance, duration required for completion, and time to deadline.

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)





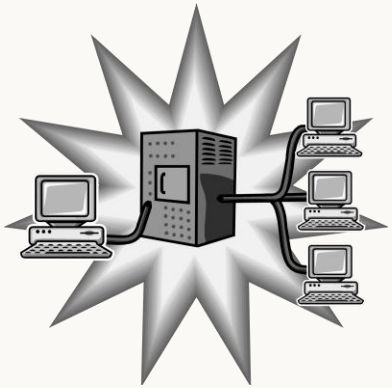
The Challenge of Task Switching

- 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

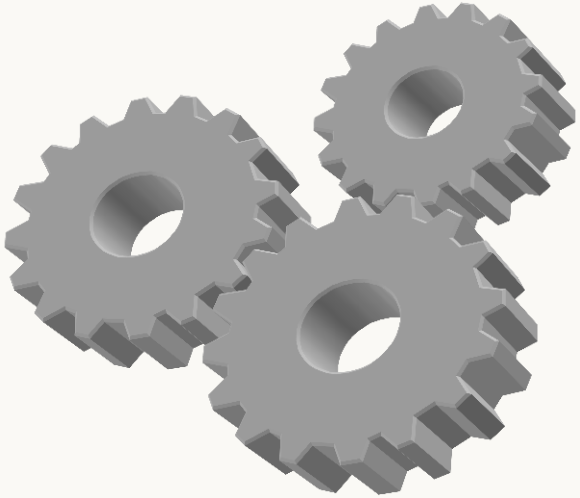




An “Information Clutch” for Task Coordination



INFORMATION SYSTEMS



PRODUCTION TASK OUTPUTS

TEAM & ORGANIZATIONAL INTERACTIONS

GMRSG, Minneapolis, Sept 2010

Purdue Engineering





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





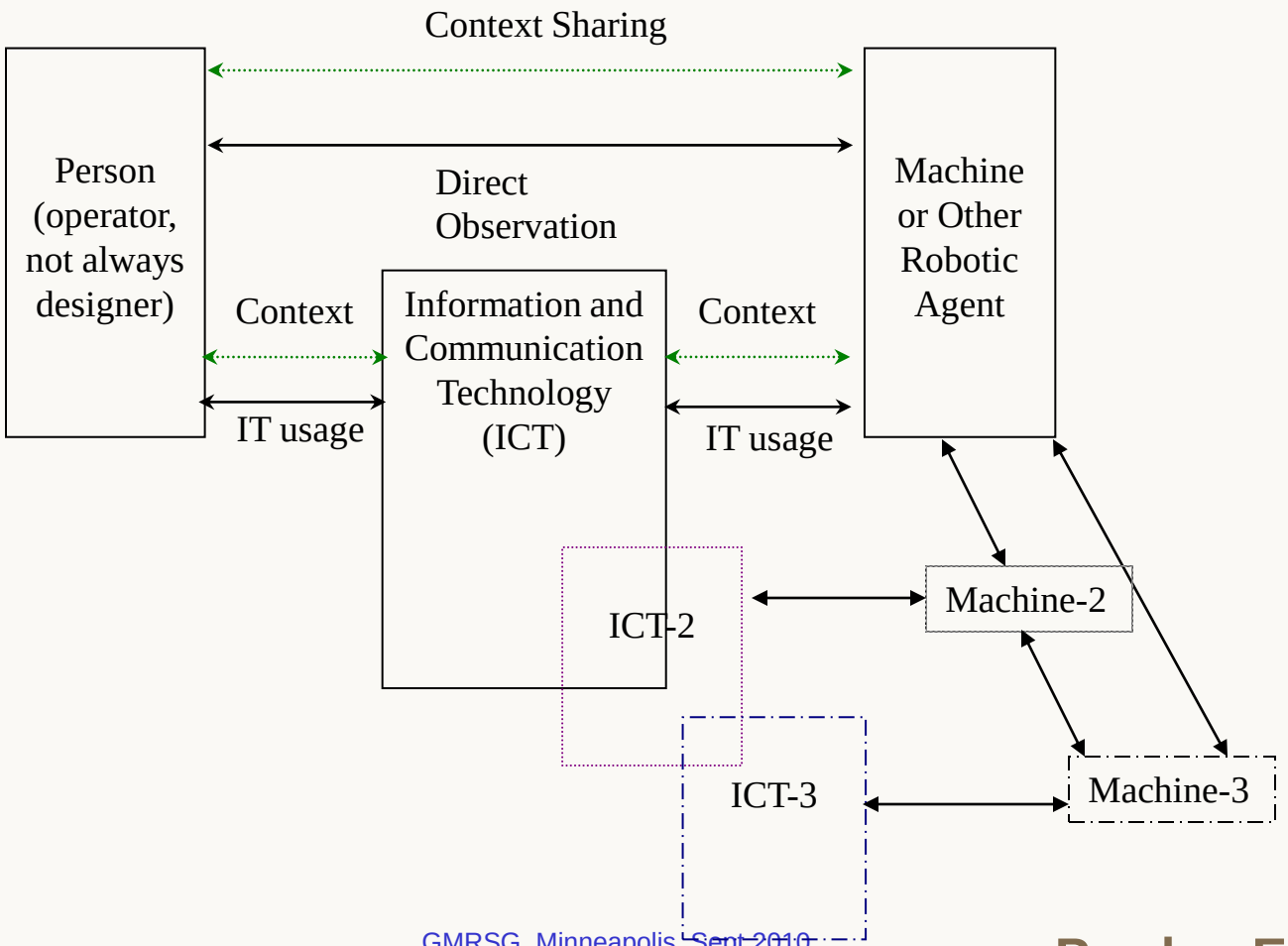
Limiting Cases for Effective Task Load Management

- 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



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

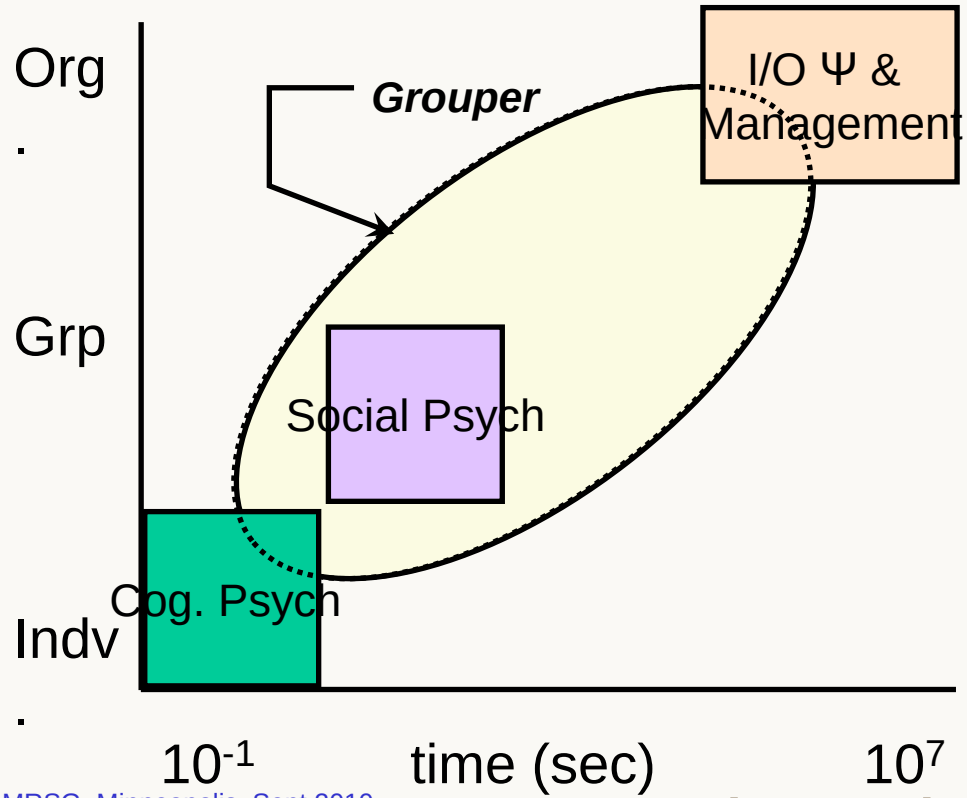




Time Scales in Research Fields

- Distinctions between individual and social processes
- Event dynamics ranging from attention to strategy
- Similar terms, but different tasks

Knowledge Development Research Emphases



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



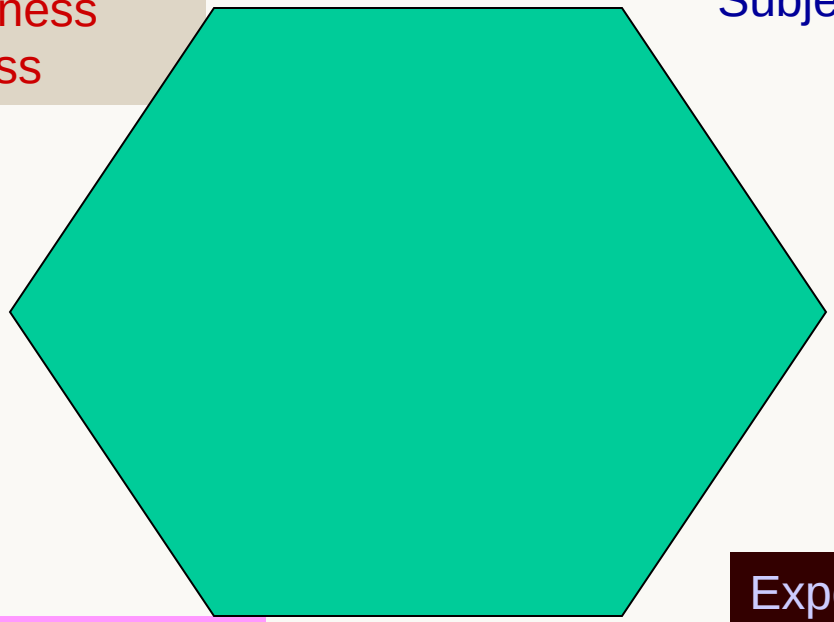


Dimensions of Expertise in Expert Communities

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

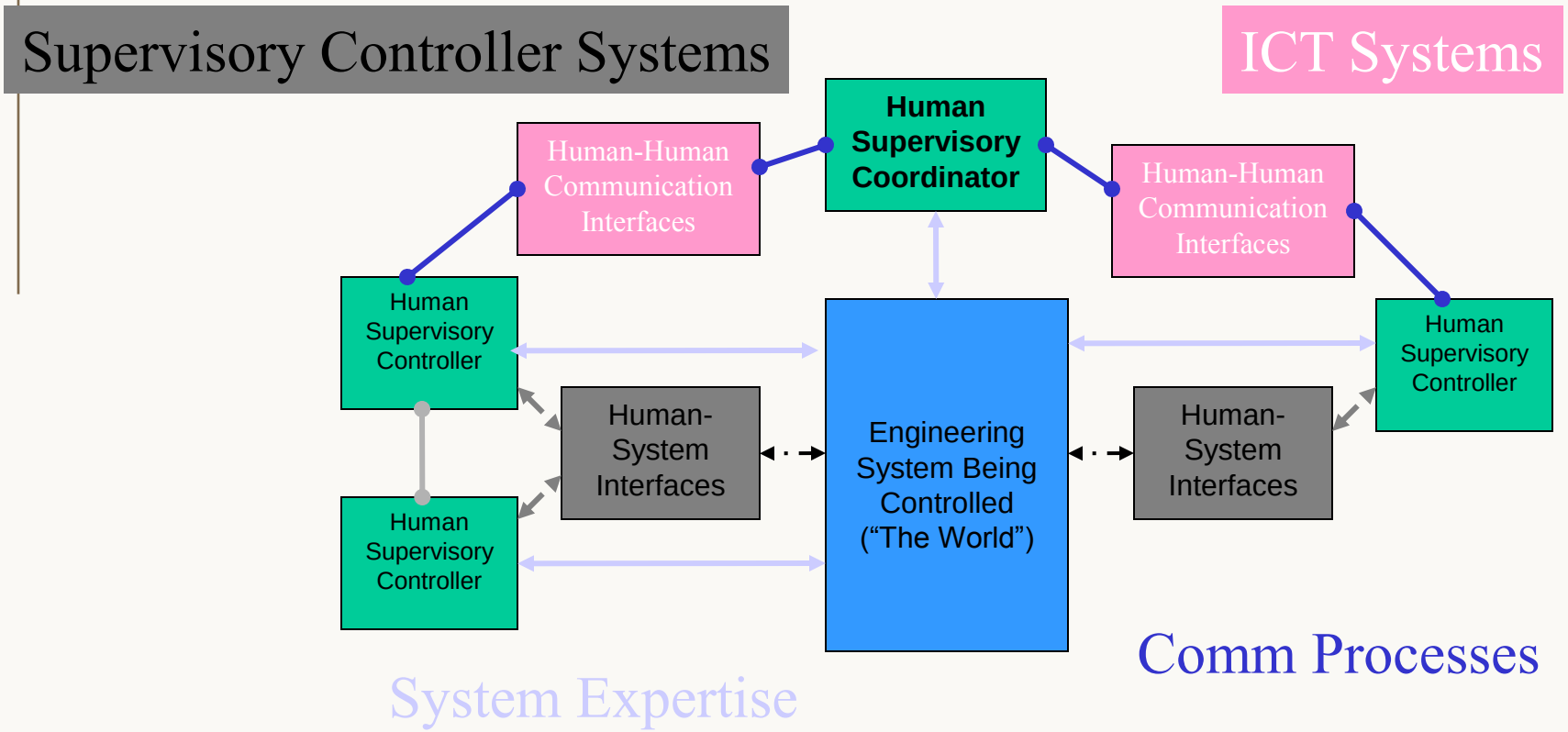
- Local Displays for Individual Experts
- Shared Displays for Coordinated Awareness

White Flight Control Room: Shuttle Operations



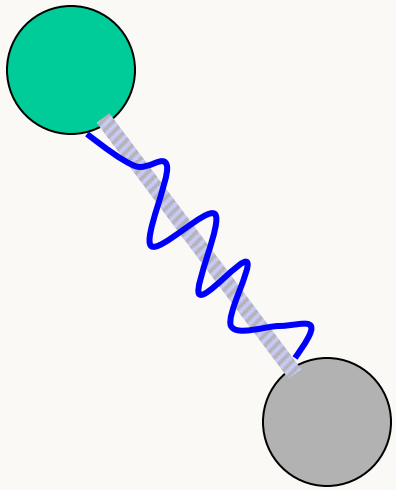


Distributed Supervisory Coordination (DSC) Model



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



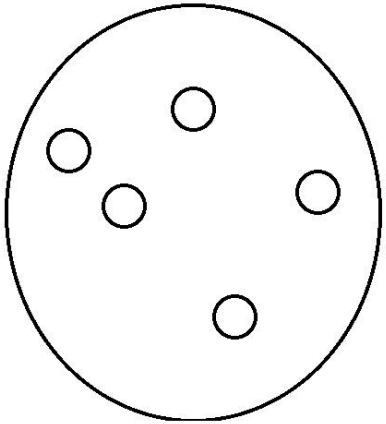


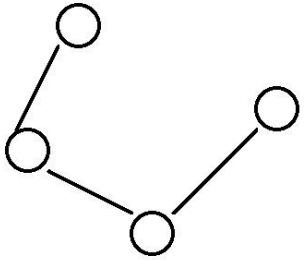
Support for Hybrid Coordination

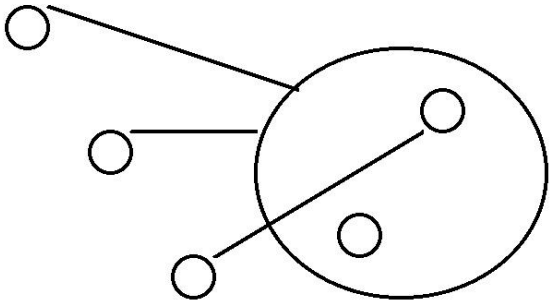
Asynchronous, task directed flows

Engineer tagups

New system capabilities







Synchronous flows (meetings)

Technician work orders

Hybrid flows during problem resolution





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 informated 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

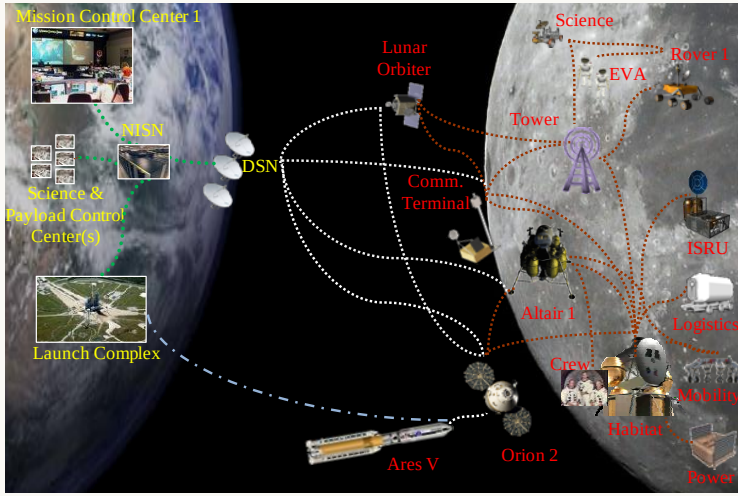
- Command & Control: decision-making and supervisory control networks as supported by an operational exchange of information via a comm relay network
- Communication: ground and space networks of multiple comm & data nodes for information production and relay
- Information: commands, telemetry, & data in varying formats





Lunar C3I Architecture as System-of-Systems

- 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.



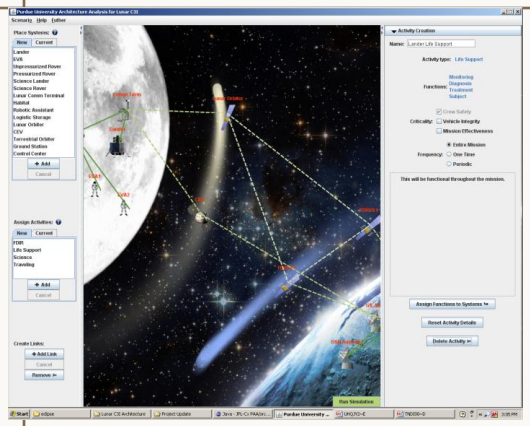
Analogues → C3I Architecture Trade Space

C3I Design Trade Space Variables	Architectural Trade Space Options			
COMMAND AND CONTROL				
allocation of decision-making rights	centralized (unitary)	distributed (ad-hoc)	shared (peer-to-peer)	
# of ground control room console operators	none	1-10	11-20	> 20
roles of in-situ operators	science: research	technical: support	observation: report	all
planning & scheduling of mission objectives	in-situ	mixed	external control center	
planning & scheduling of daily ops	in-situ	mixed	external control center	
anomaly & fault detection, diagnosis, & resolution	in-situ	mixed	external control center	
COMMUNICATION				
in-situ inter-element communications	RF: VHF and/or UHF	speaker (public address)	phone (sat or land lines)	internet applications
in-situ comm network design	habitat centralized and fixed		mesh and reconfigurable	
exploration assets can act as relays for other systems	no relay capability	some: treats data from other systems via private/unique interfaces (e.g., manual data exchange)		yes: can provide true general relay capability
in-situ base to external support relay modes	direct (outpost to ground)	satellite relay	point-to-point tower relays	
in-situ base to external support relay visibility	sparse	moderate	high	
multiple in-situ to external routes (includes backups)	none: just one route	varies: at least one	at least two routes at all times	
external link protocols	point-to-point manually configured links		reconfigurable links via routable network	
external link types (data distribution)	on-demand / shared	dedicated channels		
INFORMATION				
type of data exchanged	engineering	navigation/mobility	science	personal
form of information exchanged	data / text	voice	video	images
format of data packaging	commercial (e.g., IP)	military (e.g., HAIPE)	unique to program	CCSDS
storage and archival of project data	local	at control center	ground distributed	

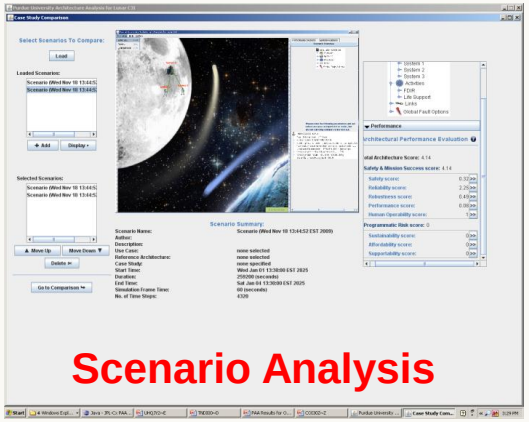




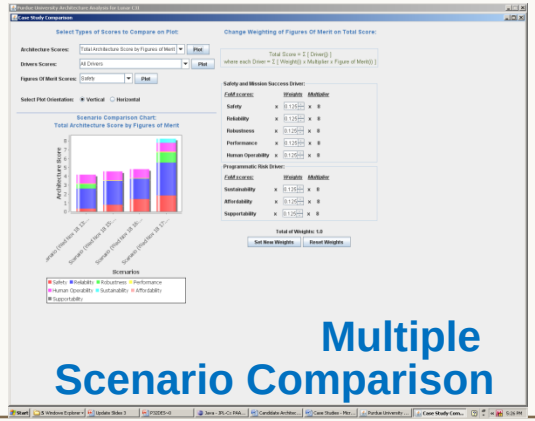
Tool and Graphical User Interface



Scenario Setup



Scenario Analysis



Multiple Scenario Comparison

- 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

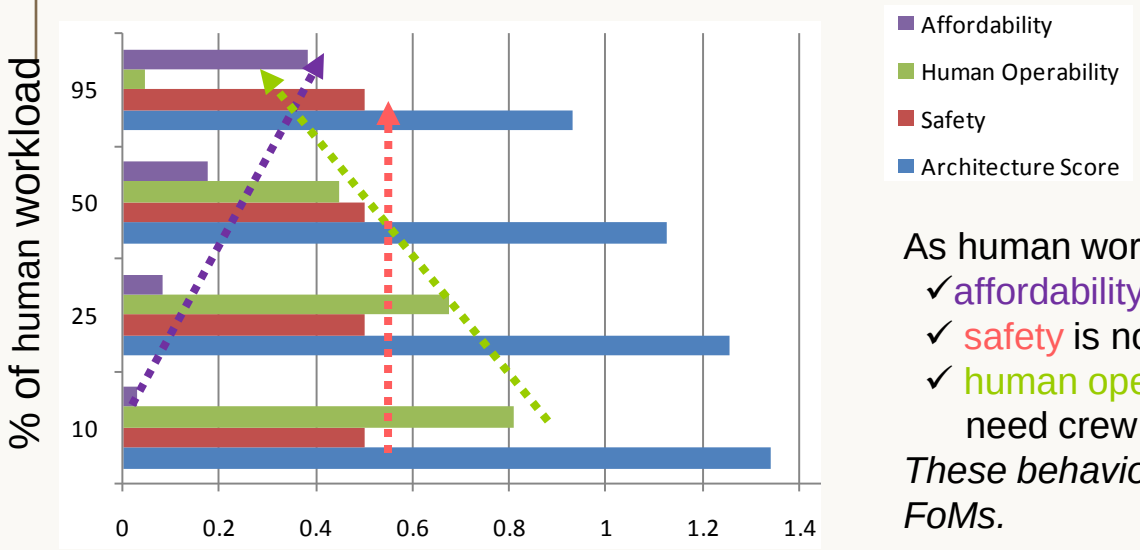




Input Sensitivity Analysis for Model Verification

- Verification within scenarios based on realistic SoS performance

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



Figures of Merit and Total Architecture Scores

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
  - bscaldwell@purdue.edu
  - http://web.ics.purdue.edu/~bcaldwel
  - http://www.grouperlab.org
  - http://www.insgc.org