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Examination of Communication Delays on Team Performance: *Utilizing the ISS as a Testbed for Analog Research*

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Outline

- Background – autonomous ops in the context of exploration Missions – what is autonomous ops,
- What we've accomplished, where we are
- Study Overview – method, data collection, current results – DRATS, NEEMO 15, Integrated Sims, ISS
- Lessons Learned

What is Autonomous Ops in Relation to Spaceflight?

- History of Autonomous Operations
  - As human spaceflight evolved over the past five decades, the control of space operations remains primarily dependent on the ground or 'mission control'
    - Ranges from setting flight rules, mission objectives, timeline/scheduling, problem-solving, decision-making
  - In spaceflight context, autonomy refers to the extent to which the crew acts independently from mission control to complete objectives and/or respond to complications or emergencies, as well as prioritize mission objectives (Reagan and Todd, 2007)
  - Bounded autonomy is a concept recently developed (Autonomy Workshop, 2009), to represent a continuum of autonomy from low to high
    - Defined as the various conditions, constraints, and limits that influence the degree of discretion by the astronaut or the crew over choices [decisions], actions, and support in accordance with standard operating procedures

What is Autonomous Ops in Relation to Spaceflight?

- Quality of Communication
  - Numerous ground based research demonstrates the impact on team performance, dynamics (e.g., cooperation, coordination, cohesion) and perceived stress from communication-related problems (e.g., quality of information, quality of the signal, duration, frequency, mode, style)
  - Communication quality is one aspect of the environment that would cause an increase in the autonomy of a team during an exploration mission
- Communication Delay
  - One component of communication quality is comm. delay
  - Comm. delays were a prevalent characteristic during early missions (e.g., anecdotally estimated between 78-82% during Skylab) they continue somewhat today during ISS operations (periodic of loss of comm)
  - NASA has implemented throughout the years effective means to improve the quality of the communication between the space crew and mission control (and families), and reduce the delays or lack of communication

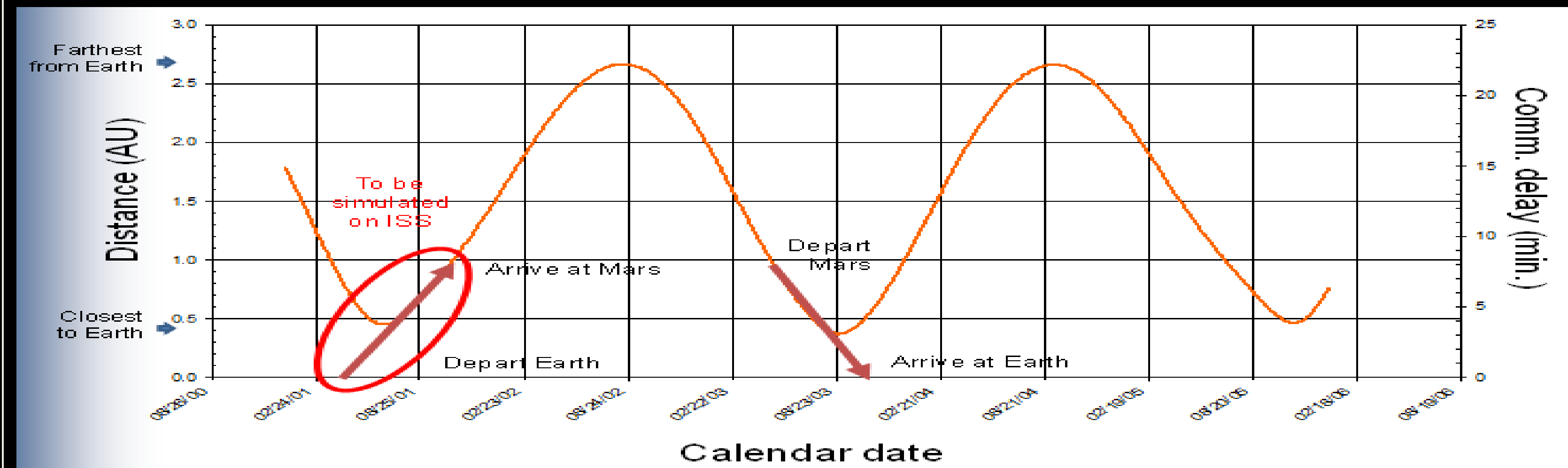
Counteracting Comm. Quality Problems

Table: History of ISS Communication: Ku videocon and IP Phone Milestones

Date	Expedition	CREW-EARTH COMM CAPABILITY	SPEED
Oct 2000-Jan 2001	1	Video conferencing w/ground required crew to manually flip a switch to enable high data transfer rate and resulted in ISS losing telemetry. Videoconferencing could only occur in Mission Control.	128 kbps
Feb 2001	1	Ku band came on-line with data rate ~ 50mbps	50 mbps
2001	4	**1 IP Phone activated. Calls averaged ~15-20 hrs/crewmember/month**	50 mbps
Nov 2002	5	2-way remote videoconferencing from crewmember's family home was possible via Polycom videoconf. systems	50 mbps
Feb 2003	6	After Columbia/STS-107 accident, a second IP Phone added when ISS crew was reduced to 2 person crew	50 mbps
July 2006	13	**Total IP Phone lines increased to 4**	50 mbps
Oct 23, 2007	16	Moving P6 solar array from Z1 truss increased acquisition signal (AOS) to about 25-30 minutes	50 mbps
2007	~16/17	ISS Downlink data feed increased, tripling the bandwidth so video could be routed w/o interrupting the bandwidth required for payloads and science	150 mbps
2007	17	**Total number of IP Phones increased to 8**	150 mbps
2011	27/28	Laptops issued to ISS crew families to conduct Private Home Family Conferences from locations other than Home	150 mbps
2012	~30	Potentially Ku updates will increase the downlink rate to 300 mbps	300 mbps

Honing in on the Problem

- Transits to/and from Mars, or a NEO, present new challenges regarding communications between space and ground crews
  - Logistics of a Mars mission are expected to result in comm. delays of up to 20 minutes each way
  - Team members will need to work semi-autonomously from ground control
  - Team interaction becomes increasingly more important as team members rely more on one another to accomplish work tasks, mitigate uncertainty, and address emergencies



- Knowledge Gap: We don’t know the nature of the relationship between comm. delay and performance, and how various psychosocial factors may support or impede team performance when technical means cannot support or better quality communications
- It’s possible that communication delays may change the very definition of teamwork needed for long duration exploration missions!

What We've Accomplished Regarding Autonomous Ops

Studies in Analog Environments (Kanas)
2008 - 10

- Positive effects of autonomy condition on participants- positive affect- mirrors previous plethora of research in organizations
- Possible negative affective outcomes for ground controllers; need additional research to more fully understand

Autonomy Workshop
2009

- Bounded Autonomy: involves the conditions, constraints, and limits that influence the degree of discretion by the individual and [crew/team] over their choices, actions and support in accord with standard operating procedures.
- Most important for training and selection implications: novel and time-critical tasks

M[illegible]ng Autonomy Technology Development (SBIR)
2010

- Development of a theoretical framework to operationalize autonomy
- Will lead to an optimal level of autonomy

NEEMO 14: Autonomy Study
2011

- Found positive impact on team cohesion, team performance, and team interactions in high autonomy condition
- Want to replicate findings with larger n to gain larger effect size

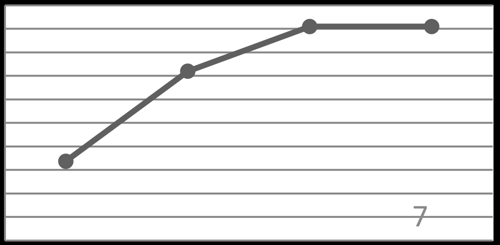
NRA
2011

- Seeking development of selection, composition, and training strategies to ensure optimal performance with autonomous crews
- Possibility to test in spaceflight

Five Dimensions (Flight Operations):
- Mission Objectives
- Flight Rules
- Plan
- Procedure
- Command

Example for Mission Objs:
Low = Ground Control defines objectives for the mission, Crew has no input.
High = Crew defines objectives for the mission, Ground Control has no input.

Mission Day 4	Mission Day 6	Mission Day 10	Mission Day 11
1. High Novelty Task	2. Low Novelty Task	3. Low Novelty Task	4. High Novelty Task
Low Autonomy Mission Phase		High Autonomy Mission Phase	



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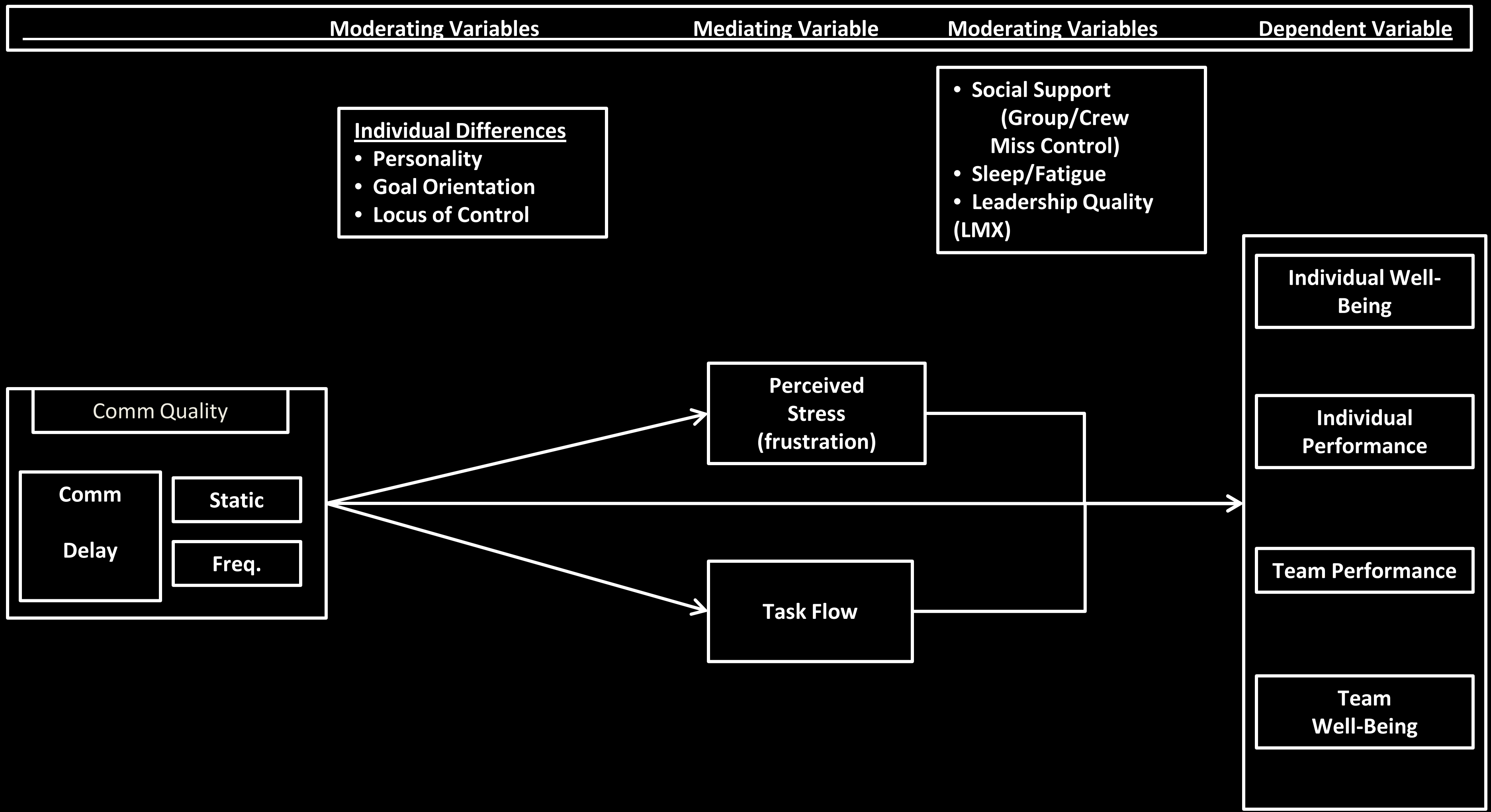
- **Study Objective: Determine if (and how and when) communications delays likely to be experienced on a mission to Mars or to a NEA will result in clinically and operationally significant decrements in crew behavior and performance.**

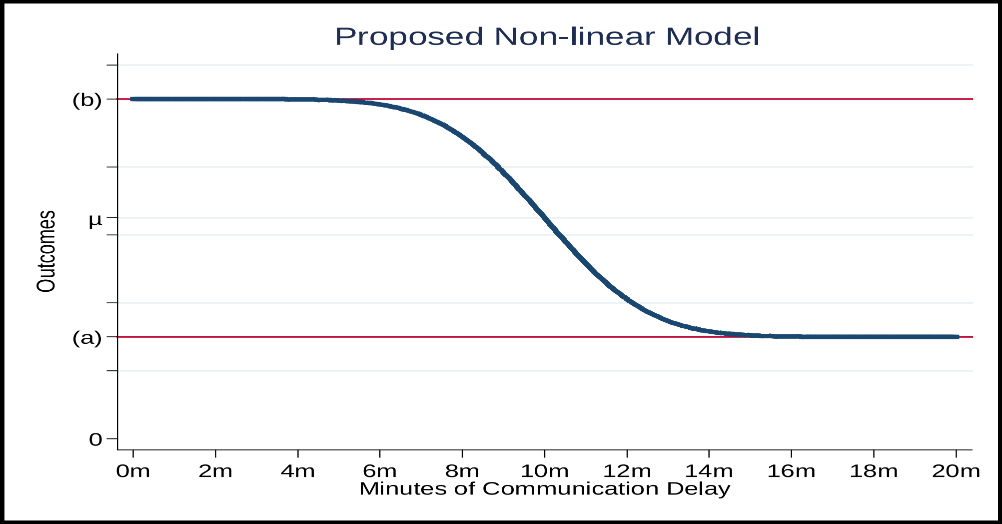
  Follow-up studies will then address how best to augment these quantified decrements through countermeasure development and testing.

Research Model



Comm Delay Proposal

- **NEEMO 15**
  - ***Risk Characterization*** **for trend between comm delay and performance**



- **Determine if there is there an association between comm. delay and individual and team performance and well-being**
- **Determine a rate (length) of comm. delay that is associated with the rate of behavior and performance and well-being decrements**

Comm Delay Proposal - ISS

- Preparatory work
  - Increment 31/32 (ISTAR IPT xDTO) will evaluate text messaging countermeasures
  - BHP will work with MOD to identify high/low novelty/criticality ISS tasks
- Integrated Simulations
  - Aims: evaluate feasibility of implementing comm delay
  - Hone in on specific time delay (from NEEMO experiments), vary tasks (introduce novelty x criticality matrix)
- ISS Study- Increment 35/36
  - Aims: validate relationship between comm. delay and performance and well-being in space
  - Validation of novelty x criticality of tasks
- Later Increments
  - Countermeasure testing

		Criticality	
		Low	High
Novelty	High	High N & Low C	High N & Hi C
	Low	Low N & Low C	Low N & Low C

Expected Outcomes

- Risk Characterization: will identify magnitude of effect comm delay has on identified outcomes of interest (e.g., well-being and performance)
  - Will identify the breakpoint for comm delay knowing where countermeasure development is needed and what the most critical issues will be that need to be addressed
- Provides a systematic assessment that identifies what types of tasks are affected, which are more critical, and what workarounds can be pursued, the role of various psychosocial factors
- Operations can use information to:
  - Identify which tasks are most vulnerable / disrupted by comm delay
  - Identify points in the increasing time delays where comm. become disrupted, and where in the mission profile this occurs
  - The relative criticality of those tasks and support measures
  - Workarounds and solutions generated by crew and mission control/ground support

Initial Results

- **DRATs**
  - Planned
    - 50 second comm. delay for entire mission
    - Data collection comm. quality measures before and pre-identified critical tasks during course of mission
  - Actual
    - Due to real-time operational changes, comm. delay was abandoned; guidance provided to crewmembers that all science-related research would only be collected one time from each crewmember
    - BHP data was a one-time completed comm quality measure by each crewmember at which time there was no comm delay in effect
    - There was no quantitative or qualitative insight into the effectiveness of the comm quality measure, which was the intent of this research

Initial Results – NEEMO 15

- Designed to provide support for proposed model, and insight into at what point team performance and behavioral health is highly affected by a comm. delay
  - NEEMO 15 was scheduled as a 13-day mission with tasks that followed an incremental increase in delay (30 sec., 1 min., 5 min., 7 min., 10 min., and 20 min.), also baseline data
  - Due to inclement weather, only 2 of the 12 tasks were implemented and data collected (a baseline with no delay; task with 30 second delay)
    - Data were collected from all crew and CAPCOM on console
    - Pre-assessment survey and interviews were conducted
    - Audio recordings and video footage were captured
  - Both tasks were high criticality, high novelty (an emergency medical and an emergency fire scenario) and lasted 60 minutes
- In general, data point to a difference between the two tasks, likely due to communication delay
- Slight differences in some important outcomes (teamwork behaviors and performance) and communication quality between the two tasks
- Further data collection, to support the proposed model, is warranted

Lessons Learned

- Successful data collection from high fidelity analogs requires:
  - Acceptance and compliance of study requirements by analog operators
- Implementing a different way of operations requires:
  - Frequent communication and coordination with multiple levels of operational experts
  - Respecting expectations
  - Stick-to-itiveness
  - Realizing acceptance of change is a slow process
  - Some compromises