Assessing the Impact of Communication Delay on Behavioral Health and Performance: An Examination of Autonomous Operations Using the International Space Station

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What is Autonomous Ops in Relation to Spaceflight?

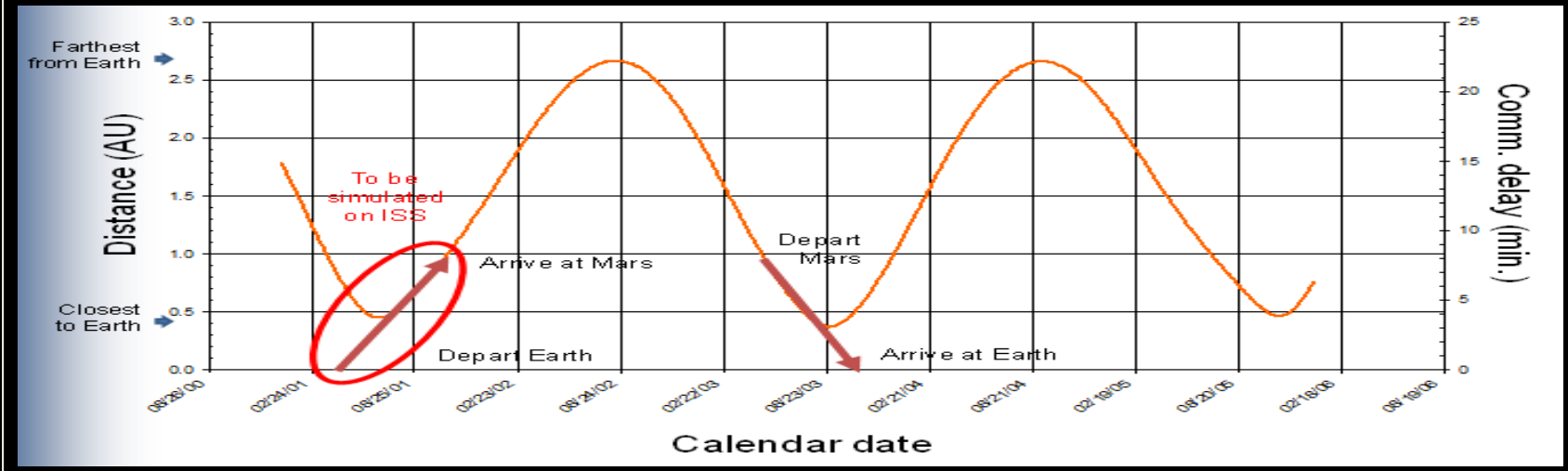
- History of Autonomous Operations
  - As human spaceflight evolved over the past five decades, the control of space operations remains primarily dependent on the ground or 'mission control'
    - Ranges from setting flight rules, mission objectives, timeline/scheduling, problem-solving, decision-making
  - 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

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

Modeling 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

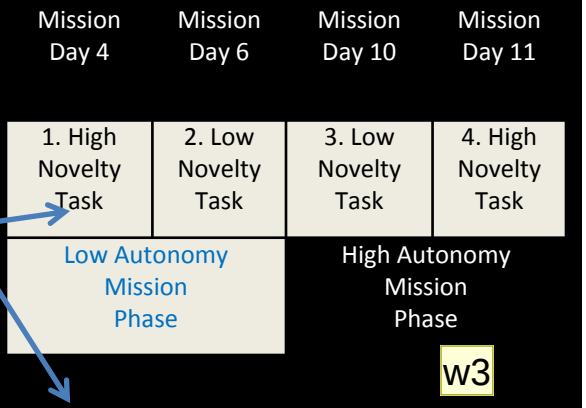
NRA
2011

- 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.



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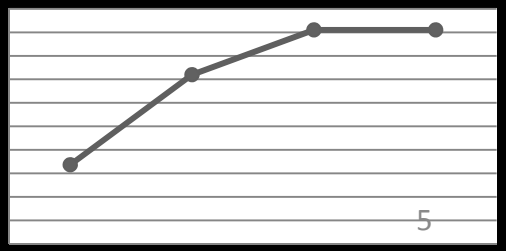


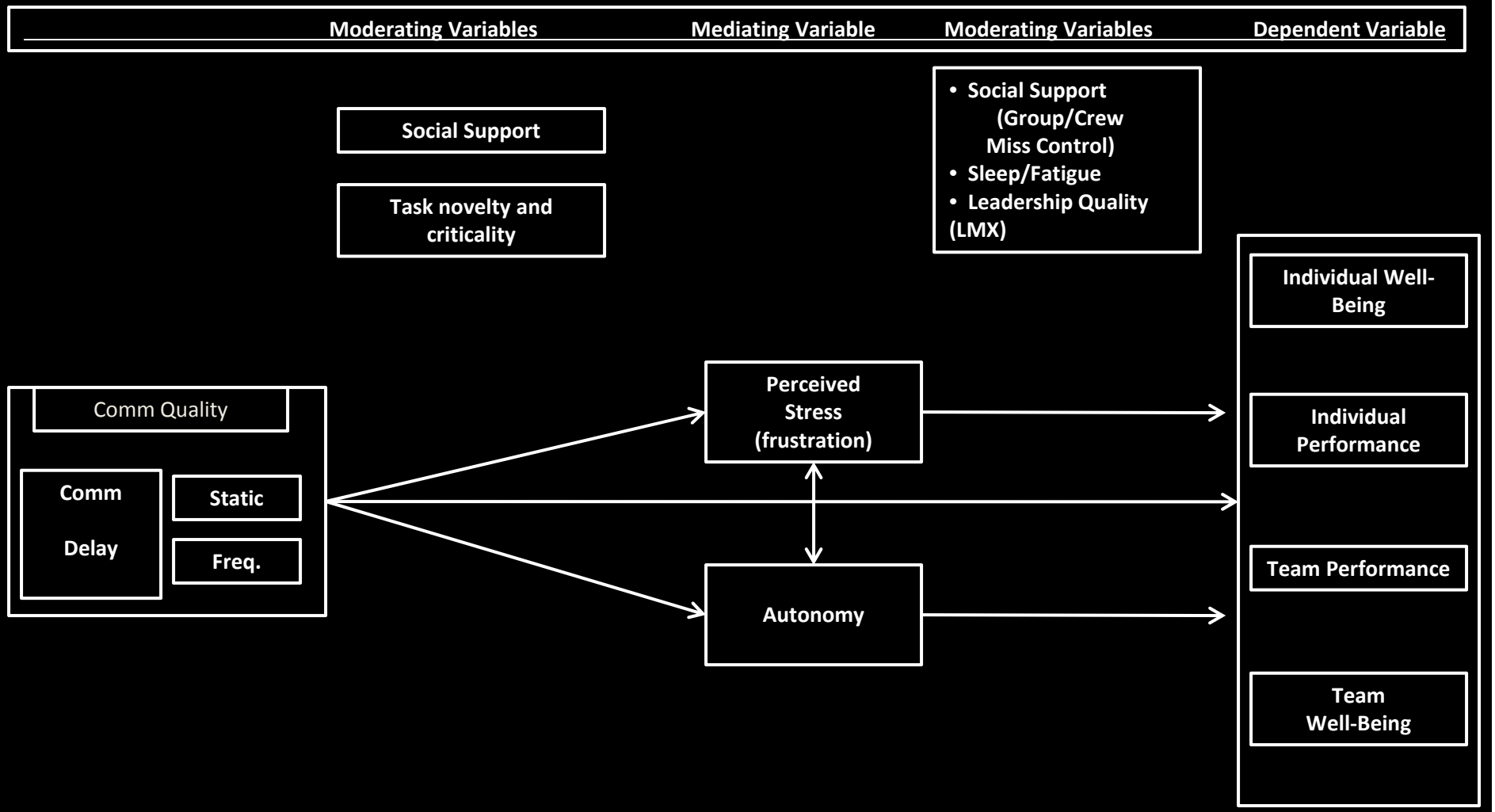
Slide 5

w3 I would delete this graph-- don't remember what it is supposed to be representing anyway
wyleuser, 2/1/2012

Assessing the Impact of Communication Delay on Behavioral Health and Performance: An Examination of Autonomous Operations Using the International Space Station

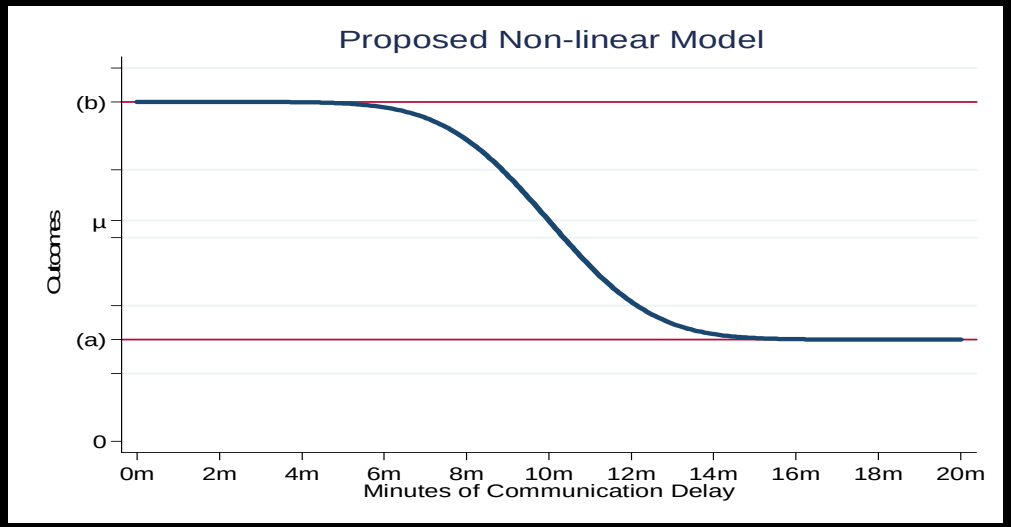
- **Study Objectives:**
  1. Determine the feasibility and acceptability of conducting a study of communication delays on the ISS.
  2. Determine if there is an association between delays in communication, individual and crew performance and well-being.
  3. Determine whether this association is affected by task complexity (criticality and novelty), social support, perceived stress, and task autonomy.

Research Model



Comm Delay

- **NEEMO 15 and 16**
  - ***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**

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

Initial Results – NEEMO 16

- Aquarius crew and ground control participated in performing 3 highly critical and novel tasks under conditions of no delay, a 5-minute one way delay and a 10-minute one-way delay.
- A 5 minute delay in communications was perceived as equivalent to no communications.
  - "Whether it was 5 minutes or 20 minutes, we were on our own"
  - Countermeasure development should take into consideration changes in behavior and performance likely to occur at shorter delays.
- Although not statistically significant, increase in comm delay duration was associated with an increase in autonomy.
- Participants understood the importance of developing countermeasures to address experienced decrements in performance
  - Safety of crewmember in 5 minute lionfish sting scenario was compromised by delay in communications between crew and flight surgeon.
  - Responses of MCC were based on old observations of crew behavior and did not take into account behavior that had occurred since last message or observation.

Comm Delay ISS

- **ISS Study- Increment 39/40**
  - **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

Study Hypotheses

- *Main Effect Hypotheses:*
  - **Hypothesis 1: There is an inverse relationship between communication delay and individual and team performance.**
  - **Hypothesis 2: There is an inverse relationship between communication delay and individual and team well-being.**

Study Hypotheses

- *Interaction Hypotheses:*
  - **Hypothesis 3: The relationships between communication delay and individual and team performance and well-being are moderated by level of crew perceptions of social support.**
  - **Hypothesis 4: The relationships between communication delay and individual and team performance and well-being are moderated by level of task novelty and criticality.**

Study Hypotheses

- *Mediation Hypotheses:*
  - **Hypothesis 5:** The experience of **perceived stress** mediates the relationships between **communication delay** and **individual and team performance and well-being.**
  - **Hypothesis 6: The level of task autonomy mediations the relationships between communication delay and individual and team performance and well-being.**

Experimental Design

Preflight	Inflight	Postflight
Participant Survey (L-60-90)	Perform selected tasks under nominal and “Comm Delay” scenarios	Participant Survey (R+14, +/-7)
Structured Interview (L-60-90)	Post-Task Questionnaire (“Control” and “Comm Delay” tasks)	Structured Interview (R+14, +/-7)

Test/Session Descriptions

- Inflight
  - Participants will complete 16 assigned study tasks during the increment
    - 1 task per day x 4 days x 4 weeks
  - Tasks will vary by novelty (hi/lo) and criticality (hi/lo)
    - A low critical/low novel task
    - A low critical/high novel task
    - A high critical/low novel task
    - A high critical/high novel task

Test/Session Descriptions

- Inflight
  - 8 of the 16 tasks will be completed under conditions of a 50-second one-way delay in communications with mission control and 8 of 16 tasks will be completed under conditions of no communications delay
    - A week will be devoted early and late in the mission to completing a task a day under nominal communication conditions

EH1

Tasks to be Targeted for Increment 35/36																	
		Early								Late							
		Week 1				Week 2				Week 1				Week 2			
Task	**Vary by Novelty and Criticality**																Total Tasks
Delay	**No Delay**	X	X	X	X					X	X	X	X				8
	50-min one way delay					X	X	X	X					X	X	X	X	8

Slide 17

EH1 Will it be a requirement for the 4 tasks to take place on back-to-back days or will there be a tolerance. If there will be a tolerance, it may be easier to just state "A week will be devoted..."

ERIK HOUGLAND, 7/17/2012

Test/Session Descriptions

- Inflight
  - At the end of each task, participants will complete a brief questionnaire assessing communication quality, autonomy, performance, support from mission control, affect, and crew

Expected Outcomes

- Risk Characterization: will identify magnitude of effect comm delay has on identified outcomes of interest (e.g., well-being and performance)
- 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