Assessment of the State of Communication Delay Research in Preparation for Missions Beyond Low Earth Orbit

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2025 Human Research Program
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Background

- NASA's current mission operation paradigm is based on a **near-complete real-time dependence on a ground team** to manage combined state of the mission, vehicle, and crew.
- This operation paradigm will be significantly challenged by the communication latencies arising in long-duration exploration missions to the Lunar surface and Mars.
- Certain roles and responsibilities will need to shift from the ground team to the onboard crew, depending on latency duration.

Type (All through DSN)	Nominal (seconds, one-way)	Worst Case (seconds, one-way)	Basis
Command	2.7	3.9	Estimates, informal tests, calcs, reqts
Telemetry	5.9	8.65	Estimates, informal tests, calcs, reqts
Voice and video	5.65	6.5	Estimates, informal tests, calcs, reqts

Path begins with Crew in Orion and ends at FCs in MCC-H (or vice versa) via DSN
Major unknowns: optical comm, HLS paths

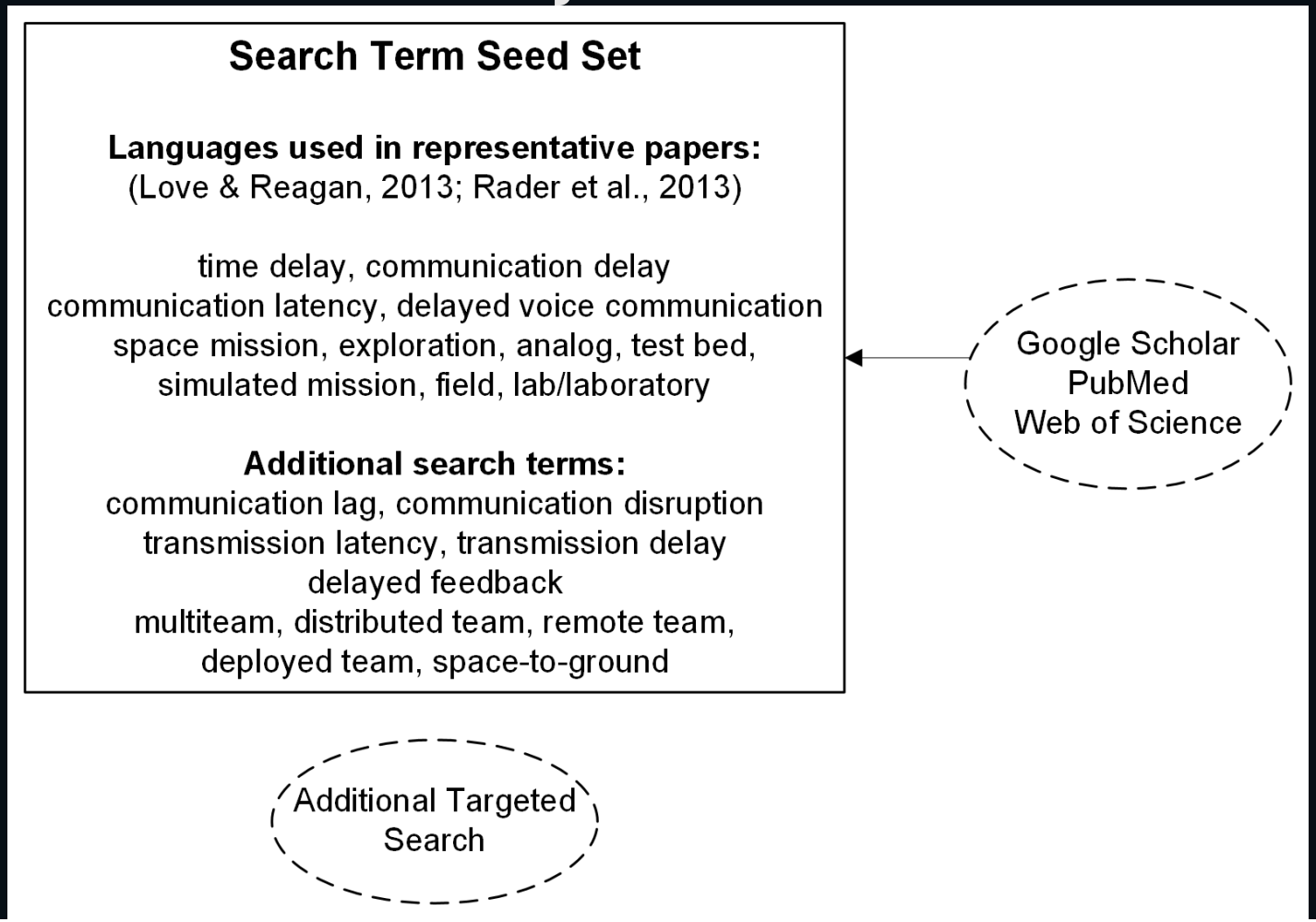
Time (days)	Distance (AU)	Communication Latency (min, one-way)
90	0.4	4
180	1.0	8
240	1.4	11
300	1.8	15
360	2.3	19
480	2.7	22

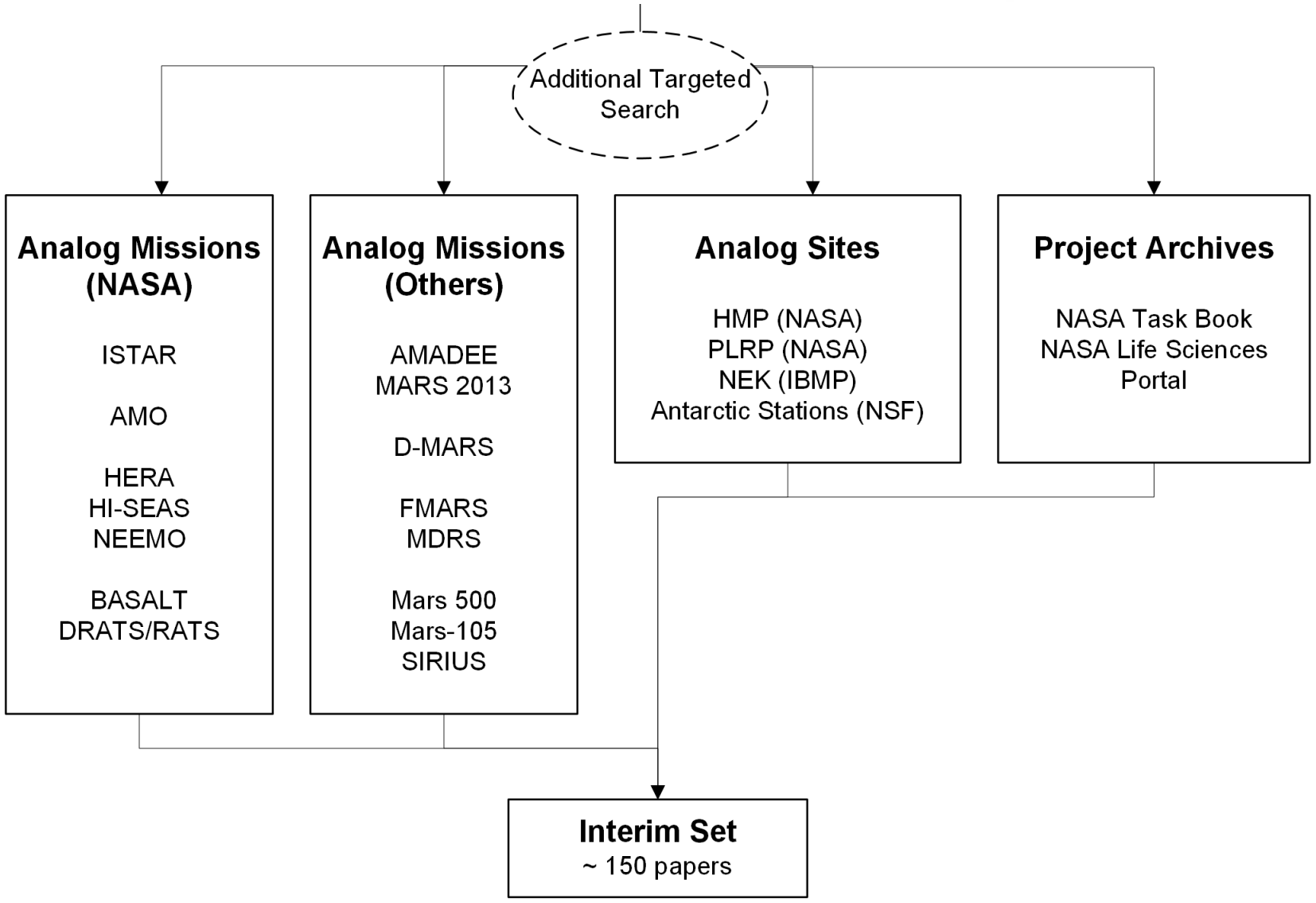
Example 2001-2005

Purpose

- **Examine the evidence generated through 20 years of communication delay research as an integrated set across BMed, Team, and HSIA Risks**
  - Develop a coherent picture of what has been studied and how, as well as the resulting measured outcomes, using published research
  - Gain additional perspectives from the research participants themselves
  - Seek program (e.g., Orion) perspectives on communication latencies and what is being worked to mitigate those issues
- Specific aims:
  - Examine and compare study parameters, including operational regimens and measures of simulation fidelity, outcomes (e.g., "degraded capabilities"), and situational or task complexity
  - Review results and implications for mission plans
  - Assess limitations, including small sample sizes, lack of repeatability, and controls

Communication Delay Literature Search Flow




Additional Targeted Search
Analog Missions (NASA)
ISTAR
AMO
HERA
HI-SEAS
NEEMO
BASALT
DRATS/RATS
Analog Missions (Others)
AMADEE
MARS 2013
D-MARS
FMARS
MDRS
Mars 500
Mars-105
SIRIUS
Analog Sites
HMP (NASA)
PLRP (NASA)
NEK (IBMP)
Antarctic Stations (NSF)
Project Archives
NASA Task Book
NASA Life Sciences Portal
Interim Set
~ 150 papers

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~ 150 papers

Inclusion Criteria

✅ Research papers from journals and conference proceedings with descriptions of method and results

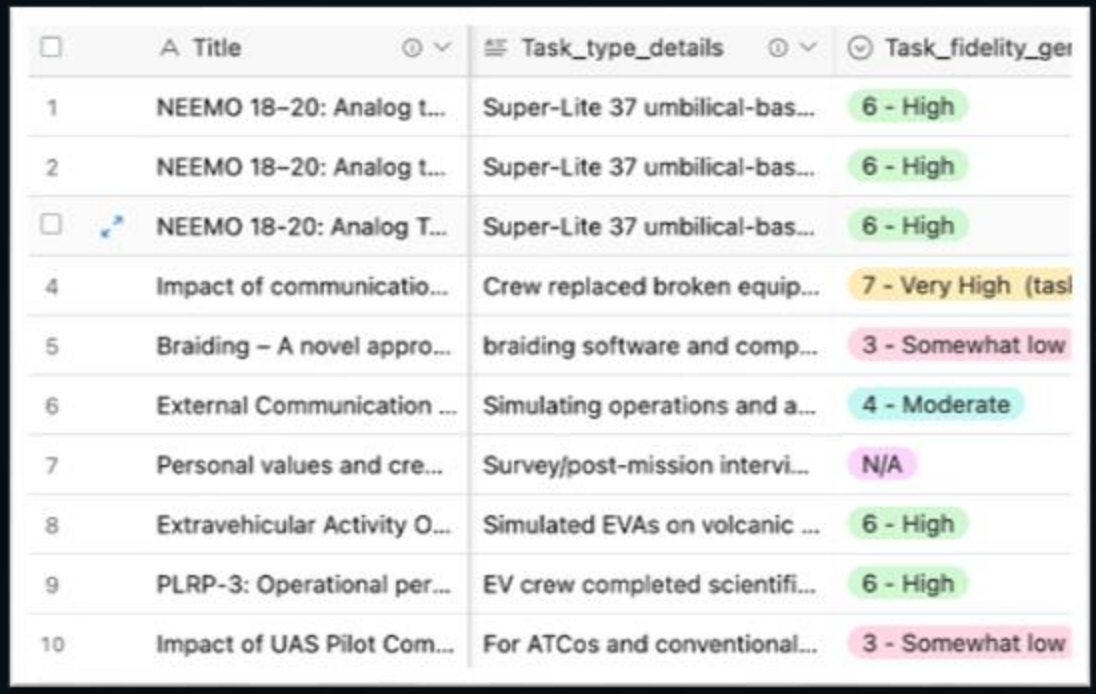
Excluded:

❌ theses/dissertations, unpublished work (reports, posters, abstracts),
❌ reviews, summaries, thought/concept papers,
❌ papers without spaceflight relevant tasks, papers on telerobotics/telesurgery, and
❌ papers with no communication delays

Resulting Set
48 papers (52 studies)

Taxonomy Development & Coding

- **Developed taxonomy and codebook with key constructs of interest for EIHSO, Team, and Behavioral Health Risks.**
- High-level categories include:
  - Setting/Analog Meta-data
  - Work/Task Activities
  - Recreation Activities
  - Individual Outcomes & Predictors
  - Team Outcomes & Predictors
  - Multi-Level Support Team Outcomes & Predictors
  - Measures



	Title	Task_type_details	Task_fidelity_ge
1	NEEMO 18–20: Analog t...	Super-Lite 37 umbilical-bas...	6 - High
2	NEEMO 18–20: Analog t...	Super-Lite 37 umbilical-bas...	6 - High
	NEEMO 18-20: Analog T...	Super-Lite 37 umbilical-bas...	6 - High
4	Impact of communicatio...	Crew replaced broken equip...	7 - Very High (tasl
5	Braiding – A novel appro...	braiding software and comp...	3 - Somewhat low
6	External Communication ...	Simulating operations and a...	4 - Moderate
7	Personal values and cre...	Survey/post-mission intervi...	N/A
8	Extravehicular Activity O...	Simulated EVAs on volcanic ...	6 - High
9	PLRP-3: Operational per...	EV crew completed scientifi...	6 - High
10	Impact of UAS Pilot Com...	For ATCos and conventional...	3 - Somewhat low

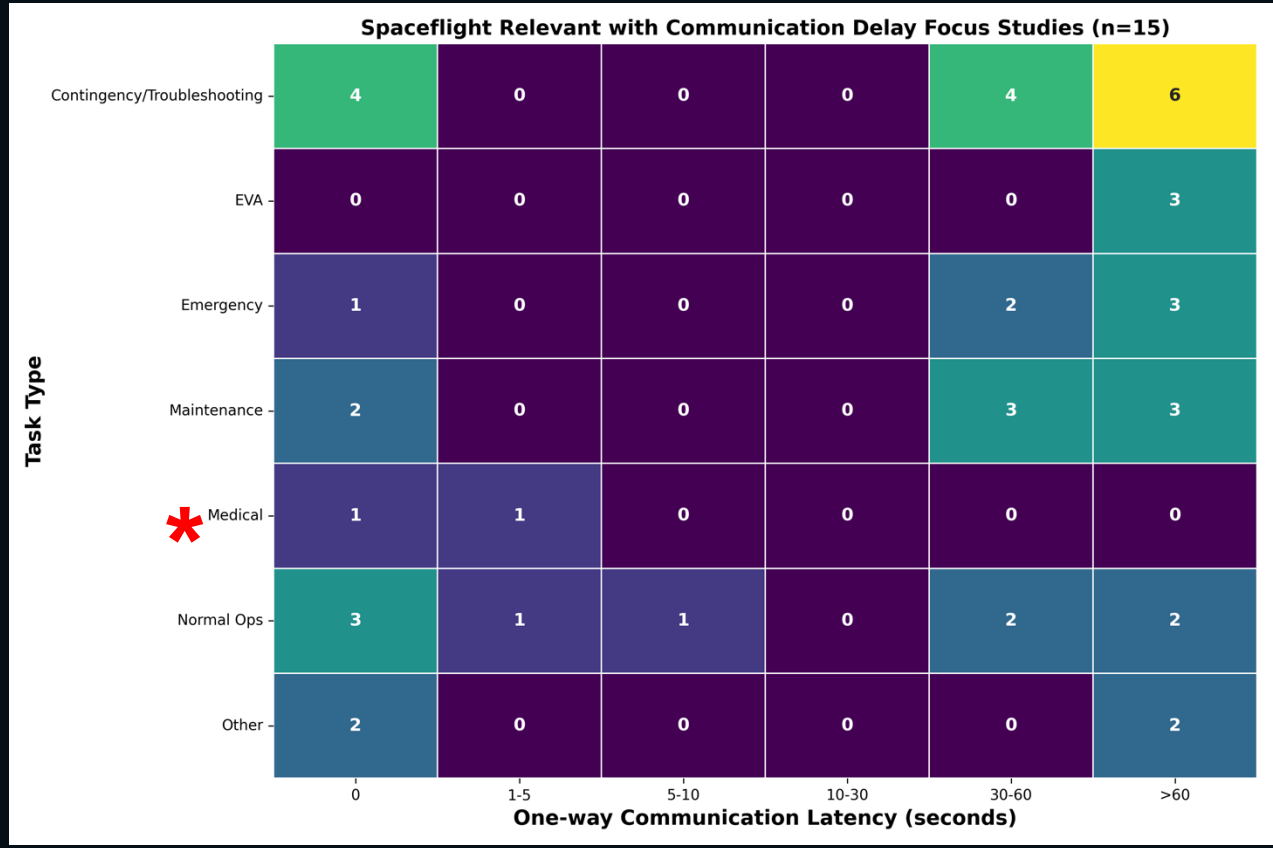
Results of Coding

- We coded **52 studies** (research experiments) from **48 papers**.
- To determine if a study was focused on the effects of communication latency, we asked:
  - Does (1) this study vary communication delay/latency as an independent variable in their experiment and (2) report/discuss the effects of the delay?
- **15 studies were both spaceflight relevant and focused on the effects of communication latency.**
  - 11 of these were focused on risk characterization, while 4 investigated the effects of countermeasures to mitigate the risk.
  - The one-way study latencies were primarily appropriate for Near-Earth Objects (50s) or Mars (>60s), with 2 papers investigating lunar delays (<15s).

Task Type

- Contingency/Troubleshooting tasks are the most common types of tasks we found.
- * We excluded telemedicine/ telerobotics from our literature review, which likely caused us to undercount Medical tasks.

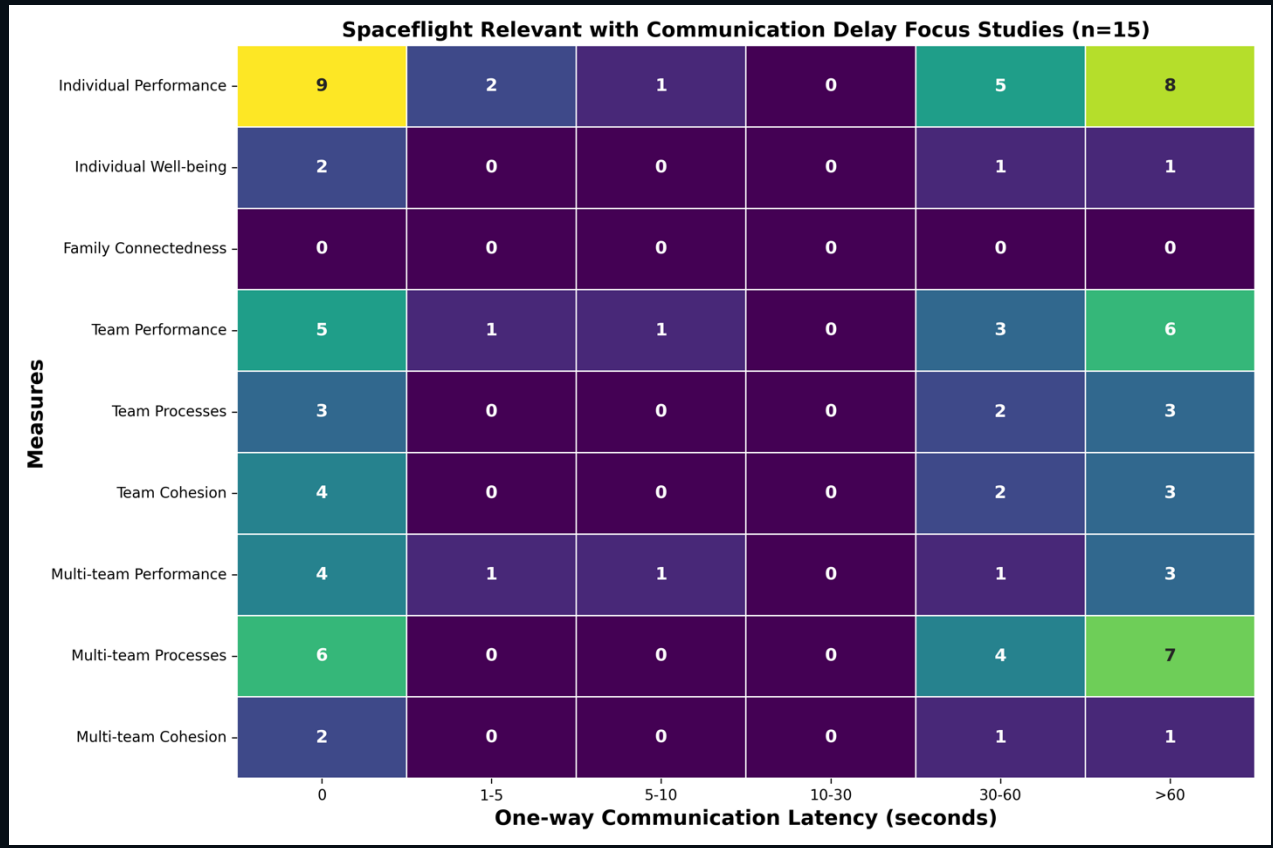
(Note that many studies included multiple task types and appear multiple times here.)



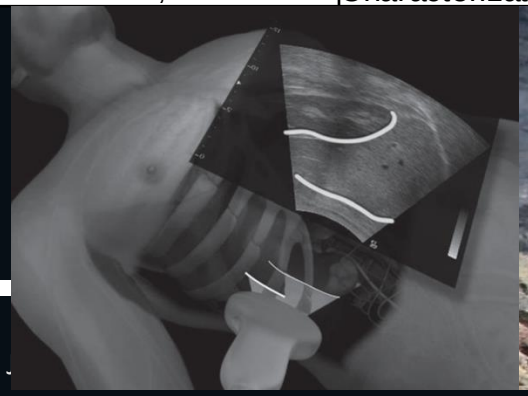
Measures

- Individual/Team Performance and Multi-team Processes are among the most studied.
- Family Connectedness did not appear in this set of literature.

(Note that many studies included multiple task types and appear multiple times here.)



Title	Study Aim	Study Type	Outcomes
Armstead & Henning, 2007	Risk Characterization	Lab Study	Longer **communication delays were predictive of progressively poorer performance** on the resource management task.
Fischer & Mosier, 2014	Risk Characterization	Lab Study	Teams took significantly longer to repair system failures under time delay than when they had no time delay. The difference was concentrated in the voice medium. The data suggest that **the no time delay condition may have been more conducive to incorrect repairs than the time delay condition.**
Hurst et al., 2015	Countermeasure Development	Lab Study	The study demonstrates that a **one-way communication delay of 2.5s did not affect an expert's ability to guide non-US experts to collect diagnostic-quality US images.** However, further **increases in communication delay could impair the effectiveness of RG, especially in complex procedures requiring more than mere identification** of standard and easy-to-recognize target images.
Beaton et al., 2017	Risk Characterization	Field Analog (BASALT)	There were **little to no reported differences** between the 5 minute one-way latency and 10 minute one-way latency.
Stevens et al., 2019	Risk Characterization	Field Analog (BASALT)	There was an interesting juxtaposition of the perception of how much the MSC could influence the EVA activities and the time pressures introduced by the communication latency. **In the 5 min OWLT low latency case the decisions in MSC were generally more "frantic" and pressured in an attempt to influence the EVA more directly.** This is counterintuitive but seemed related to the fact that the MSC felt better connected to the EV crew under low latency, whereas under high latency there was less opportunity to directly influence the EV crew. **In the high latency case there seemed to be a more "measured" approach as the MSC knew that it was more limited in how much it could influence the EVA.**



Title	Study Aim	Study Type	Outcomes
Kanas et al., 2011	Risk Characterization	Mission Simulation (Mars 500)	The results suggest that high crew autonomy is well received by crewmembers working in isolated space analog settings, and crewmember mood, self-direction, and freedom to plan work were rated as being higher. However, **the effects of high autonomy were confounded with the communication time delay, and it is difficult to partial out the relative influence of these two factors.**
Fischer & Mosier, 2020	Risk Characterization	Mission Simulation (NEK)	Crewmembers' **perception of MTS social and task cohesion was not highly impacted by communication delay**; but instead may have declined as the mission progressed, especially after the midpoint of the mission.
Fischer et al., 2013	Risk Characterization	Mission Simulation (AMO/DSH)	Transmission **delays disrupted the timing and structure of turns as communications by different speakers cooccurred or were out of sequence.**
Frank et al., 2013	Countermeasure Development	Mission Simulation (AMO/DSH)	Workload ratings and coordination difficulty between the flight control team and the crew increased with time delay. Workload and coordination difficulty decreased as a result of the mitigation configuration. **Flight controller workload ratings responded differently to configuration and time delay than the crew workload**; specifically, crew workload was reduced by time delay in the Mitigation configuration, while flight controller workload increased with time delay regardless of configuration.

Title	Study Aim	Study Type	Outcomes
Chappell et al., 2016	Risk Characterization	Mission Simulation (NEEMO)	The science team reported that **better tools are necessary to provide input within a 5 minute window compared to a 10 minute window**.
Fischer & Mosier, 2015	Countermeasure Development	Mission Simulation (NEEMO & HERA)	The present research suggests that **asynchronous communication may be facilitated by protocols that aid conversational partners in keeping track of conversational threads and the temporal sequence of messages.**
Mosier & Fischer, 2023	Countermeasure Development	Mission Simulation (NEEMO & HERA)	Trained crewmembers rated the effectiveness of their interactions with MC during time delay on a par with those on non-delay days, suggesting that the protocols did facilitate crewmembers' communications with mission control on days with communication delay. In contrast, untrained crewmembers gave considerably lower effectiveness ratings on time-delayed days compared to days with synchronous communication. **MC noted they performed tasks improperly with poor compliance with procedure and required time-consuming additional assistance from ground**. Control over task performance was another issue apparent in MC comments; for instance, **MC stated that communication delay impacted their ability to assert themselves on the crew.**
Tanaka et al., 2020	Risk Characterization	Mission Simulation (HERA)	At the team level, communication **delays negatively impact the message routing** completion rate. In the 180-second communication delay condition, only one out of five reached the destination, compared to four out of five in the no communication delay condition.
Lungeanu et al., 2023	Risk Characterization	Mission Simulation (HERA)	Our findings suggest **aspects of social isolation and communication delay affect task duration, information network development, and MTS performance.**

Title	Study Aim	Study Type	Outcomes
Kintz et al., 2016	Risk Characterization	Spaceflight (ISS)	The **quantitative results suggest self-reports of crew well-being and the quality of communications were significantly reduced in communication delay tasks compared to control.** In addition, both **quantitative and qualitative data suggest communication delays were associated with stress and frustration.**

Interviewees & Method

Sources

- **Conducted formal interviews about research on, support for, and living under communication delay**
  - 13 interviewees: 5 HERA crewmembers, 2 analog scientists and mission support, 1 analog support psychologist, 5 communication delay researchers
- **Leveraged comments from Team Risk Custodians' risk status update discussions with operations personnel on lunar delays**
  - 13 SMEs: NASA program officers, chief training officers, flight controllers, and other FOD personnel developing ops products and conducting sims with lunar delays

Method

- 2 coders tagged topic areas and identified themes within topics

Themes

- Problems/ frustrations
  - More difficult to coordinate
  - MCC has to play “catch up” with the crew
  - Cumulative impact
  - People overestimate their ability to handle communication delays

- Cohesion
  - Reduces space-to-ground cohesion
  - Interviewees speculated it would not be as bad for lunar delays
  - Pre-mission relationships mitigate issues throughout

Themes

- Communication delay increases isolation but increases autonomy.
  - Reduced distractions and micromanagement
  - Crew relied more on each other, less on MCC during communication delay
  - Led to crew bonding
  - Some severe loneliness; impacted by team dynamics
- Family connectedness
  - Very important for well-being - researchers and analog interviewees
  - Crew families need training and practice on communication delay
  - Mars-like delays = emails, but crew missed hearing voices
  - Recordings were treasured

Themes – Managing communication delay

- Comm methods shift from voice and video to text as delay increases
  - Future reference
  - Careful wording
  - Longer messages
  - Reduced messages over time
- Impact on tasks
  - Greatest impact on back-and-forth collaboration, time pressure tasks
  - HERA crew ignored MCC messages if they were irrelevant to current task or outdated
  - Design or adapt tasks “on the fly”

Themes – Countermeasures

- Training
  - Set expectations for ALL
  - Pre-mission practice is necessary for skills, cohesion
  - High-performing crews less affected by communication delay if they are well-prepared
- System design/tools
  - Built-in oversight and guidance
  - New tools and protocols are needed

Overall Findings

- Communication delay increases risk (mostly)
  - Threat to well-being, (multi)team cohesion, and performance
  - Biggest effect measured so far is increased time pressure (especially for highly coordinated tasks, Mars latency, long duration missions)
  - FOD deemed it lower-priority concern for lunar operations
- Even if the effect seems small, worsening dose effect over time
- But, if leveraged or managed carefully, some negatives can be neutralized and/or positives emerge
  - E.g., lunar EVA tests allow science teams to evaluate sampling locations to direct final sampling during the EVA
  - E.g., tools maintain a sense of connection during a few minutes delay

Key Research Gaps

- Lunar communication delay (4-12 seconds one-way) – only 2 studies!
- Direct comparison of different delays (including no delay)
  - Identify specific needs by task type, interaction type, etc.
  - Isolate effect of delay vs other factors
- True multiteam system, beyond just space-to-ground, and other team structures
- Family connectedness (military literature offers some insights)

- …more studies!
  - Only a handful of studies for each task type – no “one size fits all”
  - Smaller studies before large-scale countermeasure tests
  - Higher fidelity simulations
  - FOD and military partnerships

References (15 spaceflight/comm focus papers)

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Thank you!