Issues of Grounding and Team Coordination in Asynchronous Mission Control-Space Crew Interactions

Ute FISCHER[a], Kathleen MOSIER[b], and Judith ORASANU[c]
[a]*Georgia Institute of Technology*
[b]*San Francisco State University*
[c]*NASA Ames Research Center*

ABSTRACT

Introduction: During long duration missions space-ground communications will involve delays up to 20 minutes one way, a reality that poses a formidable challenge to team communication and task performance. In the present paper we examined how transmission delays impacted the interactions between mission controllers and space crews and their joint performance during routine and off-nominal tasks. **Method**: Four teams of NASA mission controllers and astronauts participated in a space simulation study involving two 1.5-hour scenarios with transmission delays of 50 sec and 300 sec. Team communications were transcribed and coded. Analyses focused on communication problems as well as identified communication strategies that may have helped the mission controllers and space crews establish and maintain common ground. **Results and discussion:** Inefficiencies in team communication pertained to structural aspects (turn taking) and the content of communications (missing identifications by speakers and ambiguous listener feedback). Strategies supportive of grounding processes were also identified.

KEYWORDS

Common ground; coordination; manned space operations.

INTRODUCTION

Effective and efficient communication between Mission Control and space crews is essential for successful task performance and mission safety. The importance of team communication is heightened when unforeseen problems arise, such as system failures that are time-critical and require extensive coordination and collaboration between space and ground crews. However, fractious interactions between space crews and mission control personnel have been observed during past missions and space simulation studies and posed a risk to mission success (Kanas & Manzey, 2008). These problems are likely to be exacerbated as missions travel further from the Earth. During long duration missions and missions beyond Low Earth Orbit, space-ground communications will involve delays up to 20 minutes one way, a reality that poses a formidable challenge to team communication and task performance.

Team communication requires the collaboration between speakers and addressees. Conversational partners need to coordinate the communication process (e.g., when to speak) as well as its content (e.g., speakers present information and addressees have to confirm their understanding or request clarification) to ensure that the information becomes part of their common ground—that is, is accepted as mutually understood, accurate and relevant to shared goals (Clark 1996). To do so effectively, partners need to adapt their behavior to the opportunities and constraints associated with different communication situations and media (Brennan & Lockridge, 2006). During face-to-face interactions conversational partners are co-located and thus may presume as mutually known information that is in their shared visual field. Turn-taking between partners is rapid and in sequence, and partners may rely on gestures and facial expressions to direct the other's attention and provide feedback on their understanding. Remote partners that communicate synchronously—e.g., air traffic controllers and pilots—lack a shared visual flied and visibility; however, turn-taking can be rapid, with messages received almost instantaneously, and their order easily determined. Co-present partners are also able to indicate understanding and agreement as messages are produced. In contrast, remote collaborations that involve time delays in team members' communications come with a considerable "cognitive overhead" (Olson, G. & Olson, J., 2003). The timing of turns is challenging, and individual contributions may be out of sequence, making it difficult for team members to follow the thread of a conversation and thus to develop shared situation models (Olson, G., & Olson, J., 2003). Grounding is more effortful and misunderstandings more likely in asynchronous communication due to a lack of immediate feedback.

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Investigations of asynchronous communication in domains such as telemedicine have identified communication delays as a primary impediment to effective telesurgery, and have prescribed faster transmission technology (e.g., asynchronous transfer mode) as the solution (e.g., Eadie, Seifalian, & Davidson, 2003). However, given the current limitations of earth-space transmission technology, it is essential to explore solutions that focus on communication processes per se, rather than on transmission speed.

Our project involves several studies with the overall goal to develop and validate protocols supporting mission control–space crew communication and collaboration under time-delayed conditions. In the present paper we report initial findings from a space mission simulation study. Analyses examined how transmission delays impacted the interactions between mission controllers and space crews and their joint performance during routine and off-nominal tasks. Specifically, analyses focused on communication problems as well as identified communication strategies that may have helped the mission controllers and space crews establish and maintain common ground (i.e., mutual task and situation awareness).

METHOD

The present study analyzed communications between mission controllers and space crews that were collected as part of the Autonomous Mission Operation (AMO) study conducted by Frank et al. (2012). The AMO project addressed the allocation of responsibility among flight crew, ground crew and automation given time delay between the space vehicle and earth. These issues were examined during simulated anticipated off-nominal (procedural), and unanticipated off-nominal (ill-defined) situations involving four space crew and mission control teams.

Participants

Four teams of NASA mission controllers and astronauts were recruited for the study. Each team consisted of eight mission controllers and four space crew members.

Procedure

The teams participated in six simulated space missions over two days. Simulations took place in NASA's Deep Space Habitat. Each day consisted of one training session and two experimental sessions. The first day of the experiment, the Baseline condition, involved present day equipment and space crew and mission control (MC) communicated via voice-loop. The second day, the Mitigation condition, introduced new automation and communication equipment (texting) to support space crew – mission control collaboration. Both experimental days included one scenario in which space-ground communications were delayed by 50 sec (representing missions to Near Earth Objects, NEO) and one in which the dealy was 300 sec (representing missions to Mars). Each experimental scenario lasted for 1.5 hours and required teams to complete 12 activities. One of these was either a medical emergency or a system failure (= ill-defined task); the remaining 11 activities were routine maintenance (= procedural) tasks. The present analysis considers only the team communications that occurred during the two experimental sessions on day 1 (i.e., when team members communicated by voice loop).

Communication Coding

Communications between mission controllers and space crews were transcribed and subsequently coded. Our analysis of team members' communications addessed both structural and content variables. Coding categories were adopted from past research on team communication, in particular from studies of distributed but co-present teams, such as air traffic controllers and pilots (Fischer, McDonnell, & Orasanu, 2007; Morrow & Fischer, 2013). The analysis of structural aspects concerned the timing and sequence of turns. In particular we examined whether there were turns that were out of sequence (i.e., related turns by partners did not follow each other as one partner inserted a turn before addressee could respond to the initial contribution), and we looked for instances in which mission controllers and space crew members talked over each other (i.e, step-ons). We also noted the presence (and absence) of strategies that facilitate turn taking, such as the use of specific phrases (i.e., *over*) to mark the end of one's turn. The analysis of communication content focused on participant identification, the presentation of information and on addressee feedback. As communications between mission controllers and space crew members had one designated channel, the identity of a speaker and his or her intended addressee could be ambiguous. Conventions, such as call signs that are used in Air Traffic Control (ATC) – pilot communications could mitigate against potential confusions. We also examined whether speakers and addressees employed strategies supportive of mutual understanding. In particular we looked for instances in which speakers structured complex information into concise units, or repeated critical pieces of information ; and we classified how addressees provided feedback on their understanding—that is, whether they simply acknowledged receipt, or gave more specific indications of what they understood. Instances of misunderstandings were noted, as well as the presence or absence of repair attempts.

RESULTS AND DISCUSSION

Presently the communications of three (of the four) mission control – astronaut teams have been transcribed and analysed. Accordingly, we will present here only a descriptive analysis of instances of communication problems and of strategies that likely facilitated common ground and team coordination as illustrations of our analytic approach.

Structural issues in asynchronous communication

Inefficiencies in turn taking

Disruptions in the turn sequence were observed under both time delay conditions, and involved contributions that were out of sequence or occurred simultaneously. Figure 1 depicts an exchange between Mission Control (MC) and a flight engineer (FE-2) and illustrates how a delay of 50 sec can disrupt the orderly progression of individual contributions. In the example FE-2 requested input from MC concerning step 4 in a procedure. As he did not hear back from MC in time, he proceeded with the procedure just to encounter a new ambiguity in the next step, and thus turned to MC for help. However, MC answered his initial request before they received his second request, and, apparently because they did not hear any acknowledgment from FE-2, they repeated their by now superfluous answer instead of responding to FE-2's second request. Meanwhile FE-2 repeated his second request, which ultimately got answered 4 minutes after it was posed.

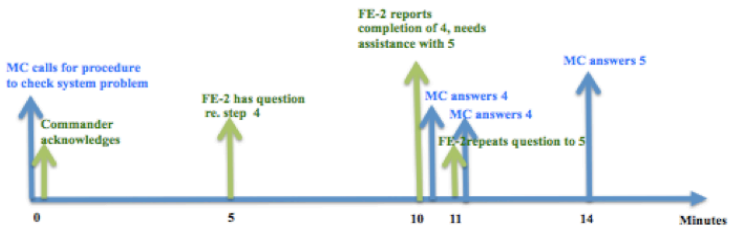

Figure 1. Depiction of an exchange in which turns are out of sequence

The turn sequence could also be disrupted by simultaneous transmissions from MC and the space crew. Step-ons occurred when a team member—for instance a space crew member—was speaking as a communication from MC came in that they had transmitted 50 sec or 300s before. Step-ons may not be easily resolved as partners could concurrently request a repeat from one another resulting in a second step-on.

Strategies to facilitate turn taking

In one of the teams we analysed, MC and space crewmembers announced a specific time (e.g., *we will have step 3 to copy in five seconds*) at which their partner could expect further communication from them. This strategy has not been observed in past research on synchronous team interactions, presumably because co-present partners can immediately respond to one another and thus an orderly progression of turns is rather effortless. On the other hand, when team members communicate asynchronously, they do not know when their partner will talk to them. Setting a time for one's communication eliminates this uncertainty at least during routine and procedural tasks and my thus mitigate both out of sequence communications and step-ons.

Mission controllers, in particular, as well as some space crewmembers tended to mark the end of their turns with phrases such as *over*; *that's all*; or *Thank you*. In so doing they explicitly handed the floor to their partner, a strategy that may support the sequencing of turns, even in non-routine situations.

Issues concerning the content of communication

Inefficient collaborations on content

Space crew members occassionally did not identify themselves when they called MC. This omission required MC to infer the identity of the caller from the content of the message. While dropped identifiers apparently did not hamper MC-space crew communications in our sample, this behavior could potentially impair mutual understanding as it creates ambiguity concerning the identity of the speaker. In time-critical or high workload situations, addressees may fail to make the correct inferences and thus may mistake the identity of the speaker and ultimately may misunderstand the intended meaning.

Listener feedback was at times not optimal as space crews and mission controllers provided minimal or ambiguous evidence of their understanding, or failed to respond altogether to a partner's communication. Minimal and ambiguous responses, such as *we copy all*, or *we copy your last* (after several transmissions by the same speaker), are short acknowledments with which addressees indicate receipt of a message and their belief that they correctly understood. However, these responses do not convey what addressees understood and thus deprive speakers of the opportunity to verify that their message was understood as intended. Read-backs are standard operational procedure in space operations and are intended to catch misunderstandings before they lead to incorrect actions. Missing responses by addressees also introduce ambiguity as they could indicate that addressees did not hear, are too busy to respond, or disagree. They likely increase speakers' workload and could result in frustration and miscommunication. For example, in one situation the flight surgeon had to instruct a space crew member (FE-3) on how to conduct an ultra sound for a bladder scan. As FE-3 did not respond to the surgeon's communications, she apparently got concerned that there was a transmission problem and finally requested: *Make sure that you copy after you received this message, please. I would like to have an understanding that you are hearing me correctly*.

Strategies to support mutual understanding

Addressees can facilitate mutual understanding by repeating what they heard and understood. In so doing, speakers can verify that their message was understood as intended and if necessary, can correct any problems. Mission controllers and space crew members predominantly followed standard operational procedures and provided proper read-backs. The value of read-backs was apparent in an instance in which a flight engineer (FE-3) misunderstood one value to be used in configuring a robotic camera. Fortunately, MC caught the error and corrected it right away. Even though there was a transmission delay of 50 sec, MC's correction reached FE-3 just after 2 min and thus in time before he could start the survey with an incorrect configuration.

Mutual understanding was likely aided by team members presenting information in a well-structured manner. Mission controllers and space crew members frequently prefixed complex messages with a summary, akin to a subject header in emails, such as *Houston FE-3 with a status on procedure 8 decimal 1*. In so doing, team members grounded their contribution in their ongoing discourse and thus likely facilitated comprehension. This strategy seems particularly helpful when communication is asynchronous and team members need to keep track of individual contributions and their relationship over an extended period of time. Likewise, mission controllers supported grounding by packaging complex instructions into meaningful chunks. A typical example of this behavior is the follwing communication by MC: *We have DPC comments for you today. First off with respect to the fluid transfer we have a supply tank level of 81% and atrium trank level of 19 % and a desired tank level of 90%. The comma value that we will use in step 2 is 39 minutes. That takes care of it for the fluid transfer. With respect to the vehicle survey in procedure 8 decimal 1 we like you to give us a heads up after you completed step 1 decimal 4. ... And that's all we have from Houston.*

CONCLUSIONS

Team communication requires the collaboration of conversational partners to ensure common ground. Our analysis of mission control – space crew interactions identified some problems that distributed teams may encounter when their communications are asynchronous. We also characterized strategies that these professionals employed, apparently in an effort to overcome some of the challenges associated with remote collaborations. However, the present study is limited by its small sample and the fact that there was no synchronous condition included in the experimental design. To determine the impact of time delay on team communication we are currrently conducting a lab experiment that involves a large sample and examines team communication under synchronous and asynchronous conditions.

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