Soft Skills for Hard Missions: Ethnographic Insights of Mars 2020 Space Operation Team Dynamics

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Abstract. The Mars 2020 mission, characterized by its complex science and technological objectives and rapid decision-making requirements – presents a unique context for examining effective team collaboration across multiple disciplines. Conducted at the NASA Jet Propulsion Laboratory, the current ethnographic study spanned five Martian days (SOLs), focusing on the team decision-making processes among science, engineering, and space operation teams. Building on previous findings from the Mars Science Laboratory study, we delve deeper into the soft skills that facilitate deliberation among teams with varying technical expertise and agendas. Through systematic observation and coding of verbal exchanges, we identify key soft skills that enhance team efficiency and decision-making. Our findings reveal four overarching soft skill functions: Corporate Knowledge Gluers, Bridge Builders, Efficiency Optimizers, and Vibe Dispatchers. Together, these skills filled in knowledge gaps, fostered shared understanding, streamlined processes, and built trust and empathy in multidisciplinary teams. The study proposes a refined soft skills framework, applicable not only to space missions but also to other technically demanding and collaborative work environments. This framework serves as a guide for team design, emphasizing the integration of soft skills alongside technical

competencies. Our results underscore the Gestalt of technical and interpersonal skills in achieving successful outcomes in complex science and engineering projects.

INTRODUCTION

Cross-disciplinary teamwork makes the dreamwork. In a rapidly evolving landscape of sociotechnical work environments, organizations are increasingly seeking multidisciplinary collaboration to harness diverse perspectives and drive innovation[1]. As teams draw upon a multitude of expertise from heterogeneous disciplines, questions arise concerning effective communication, shared context, common language and coordinated decision making[2]. Conversely, a contrasting approach involving more centralized decision-making and compartmentalized execution offers potential advantages in terms of time efficiency and reduced coordination complexities, albeit potentially leading to less optimal outcomes[3].This study explores the interplay between organizational challenges and team design within cross-disciplinary contexts, focusing on space mission operations teams at the NASA Jet Propulsion Laboratory. Our findings provide insights on how cross-disciplinary teams can surmount inherent inefficiencies by studying communication dynamics, collaboration strategies, and demonstration of essential soft skills.

The current study. We conducted an ethnographic investigation of the Mars 2020 mission operations, where robotics engineers, instrument camera engineers, spacecraft system engineers, to name a few, are collaborating with various science teams (geology, astrobiology, atmospheric). Mars 2020, like many mission operations teams, are highly cross-disciplinary, and deep technical expertise is required from all of these diverse disciplines to make optimal decisions in a timely manner. Each science and engineering team has different, sometimes contradicting, objectives which may require commanding the rover to different directions[4][5]. Together they have to decide on what data to collect, how to maximize science return, and how to do it safely in an almost daily cadence [4][5].

Building upon previous findings. The current study expands upon previous interview results with Mars Science Laboratory team members[6] that explored how the spacecraft activity planning intent is communicated between team members. The goal of that study was studying the formulation of activity planning intent as an input to autonomous activity planning agents. That study revealed a large array of soft skills and core competencies that is required to enhance communication and coordination among the science and engineering teams during plan formulation. The richness of our findings in human-to-human collaboration shifted our focus from implications for autonomy to team design in cross disciplinary contexts.

Specific aims. This study validates and refines the soft skills model in space operations that emerged from the previous interview findings through a more in depth ethnographic approach[6]. Our team has observed the Mars 2020 mission operations team over the course of five Martian days (i.e., SOLs), documenting and coding the verbal exchange between key roles. The rigorous scientific method that we applied to data collection and analysis is described in the methodology section. The resulting framework informs team design in cross disciplinary contexts, and opens up venues to incorporate soft skill requirements in role definitions besides the required technical skills[7]. The discussion and conclusions provide valuable insights to the ongoing discourse surrounding the optimization of team structures and organizational frameworks in the face of cross-disciplinary complexities.

METHODOLOGY

Background & Context. The study involved observing Mars 2020 mission operations team over a period of 5 days. At a high level, Mars 2020 mission objectives are searching for past microbial life on Mars, collecting samples that potentially include evidence of past life, while testing technologies that will enable future exploration[8]. Given such complex scientific and engineering objectives, the operations room is a unique place that brings very many diverse disciplines in one room, to make high stake decisions at a fast pace[9]. In several adjacent rooms, the operators interpret data received from the rover, make decisions for the next planning cycle, translate them into instructions for the Perseverance rover and uplink them. There are key coordination meetings where all teams participate, and there are time slots in between, where they break into smaller groups and work on implementation details of specific areas. In one of the adjacent rooms, long-term planning takes place, with the objective of ensuring that the tactical plan for the day does not deviate significantly from long-term plan which focuses on the next five planning cycles. Long-term plan objectives feed into formulating the tactical plan, while emerging tactical plan decisions have to be evaluated for long-term impacts.

During this highly intricate, multi-step process, some of the operators played particularly crucial roles including facilitation of discussions and resolving conflicts between sub-system engineers and science teams during the coordination meetings. For example, these operators mediated negotiations between geological science teams and robotic engineers responsible for driving the rover, balancing scientific exploration objectives with the rover safety concerns in the hostile Martian environment. Based on the previous interview study, we have identified key role titles, and on the day of observations we have identified the personnel acting in these particular roles.

Participants. While researchers on our team have been present in multiple rooms where all operators came together, our objective was to capture verbal exchanges between identified key roles and their counterparts. Overall we have followed several key roles, and captured their interactions with others. In each day, certain verbal exchanges of about 15 operators have been captured. While some operational roles were represented by the same people across different days, some roles were filled by different people across the days. We have recorded observations from approximately 45 different individuals.

Procedures. Researchers have followed grounded theory methodology to collect and analyze the data. In the grounded theory approach, data is collected prior to hypothesis, and afterwards at the data analysis stage, hypotheses are formed through consistent coding and classification of the data[10]. Hence emergent concepts and theories are grounded in empirical evidence.

Data collection. Five researchers conducted systematic live stream observations of planning and decision-making behaviors. During each observation session, researchers, working in pairs, meticulously documented all verbal exchanges related to planning decisions, their contexts (such as timing, involved parties, and outcomes), at both Tactical and Long-term Planning levels. 2 researchers in each room documented the noteworthy verbal exchanges. The researchers recorded both formal and informal, as well as in-person and remote interactions, to contextualize these planning decisions. Often, researchers have clarified the context or missing fragments with the participants when a quiet opportunity has risen. A total of 527 specific behaviors were logged in Tactical planning, and 558 in Long-Term planning sessions (total of 1085 data points). Certain data points were discarded as irrelevant, such as instances when one operator repeated a sentence that another one could not hear. Overall about 500 data points were discarded, and remaining 585 data points were coded with a single category.

Open Coding. After collecting the data, the researchers collectively coded approximately 10% of the corpus, which equated to around 100 data points. They initially employed the behavioral attributes from the previous interview study as their starting codes. However, to conform to the data, the researchers held discussions to address conflicting codes, redefine them, and make necessary revisions.

The remaining corpus was independently coded by three researchers, with regular checkpoints to compare results and resolve conflicts, often with senior researchers' input. This conflict resolution process included axial coding, where both individual codes and their groupings were revisited to improve data characterization. Codes and their groupings were rigorously operationalized and cross-validated, occasionally leading to refinement or consolidation. The resulting framework is discussed in the next section.

RESULTS

Through a rigorous process involving four iterations of coding and analysis, the study identified a total of 19 distinct 'soft skills' observed during 5 SOLs of the M2020 mission operation. This identification was informed by the research team's previous studies in space mission operation processes, which aided in refining these behaviors into coherent categories of latent functions [3 Chan].

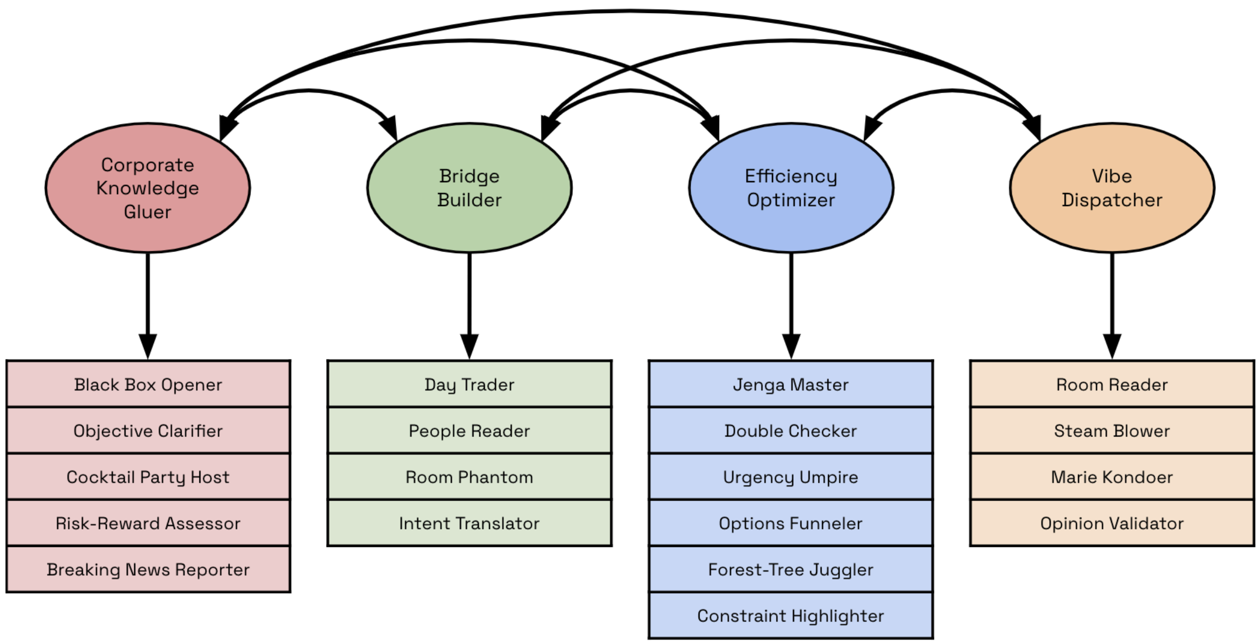

Figure A: Soft skills framework for consensus-based, highly diverse and technical teams

The 19 behaviors were categorized into four primary latent functions, each representing a cluster of behaviors with shared characteristics. These classifications aimed to elucidate the role of soft skills in enhancing team decision-making efficiency. The breakdown of the latent functions, as illustrated in Figure A, showed that 'Efficiency Optimizer Functions' were predominant, accounting for 38.68% of all coded behaviors. This was followed by 'Bridge Builders' (22.64%), 'Vibe Dispatchers' (19.79%), and 'Corporate Knowledge Gluers' (18.89%). Detailed descriptions of each behavior within these latent functions are presented in Table A below.

Corporate Knowledge Gluers conduct overarching soft skill behaviors that "**get everyone on the same page**." They recognize where everyone is on their knowledge and either catch them up or clarify plans by filling in any mission-relevant knowledge gaps to update rotating or missing personnel. The kinds of knowledge span from specific engineering capabilities and algorithms, decisions and rationales of the day before, and updates from operations such as newsworthy results from the activities executed by the spacecraft. This function ensures that the current mission operations team can build and maintain the collective situation awareness as accurately as possible.

Bridge Builders conduct overarching soft skill behaviors that "**get everyone speaking the same language**." They are conduits that foster this collective communication among different disciplines and personalities, but in particular, between science and engineering teams. This function tends to require a good understanding of multiple disciplines to be able to bridge the gap between different teams, and plays a critical role in negotiation between scientists and engineers, in particular.

Efficiency Optimizers conduct overarching soft skill behaviors that "**get everyone working towards the same purpose in the here and now**." They streamline the tasks and attention of teams to meet mission deadlines. This function enables the convergence of decisions during the operations process. This function is observed repeatedly in various steps in the decision making process, locally and globally - the smaller teams (e.g., geologists, astrobiologists, rover planners, thermal, power, etc.) are constantly fed up to the larger teams to ultimately reach the final decision step in which the set of activities for the spacecraft to perform in the next cycle.

Vibe Dispatchers conduct overarching soft skill behaviors that "**get everyone towards building group harmony."** They assess and perform specific actions based on emotional responses of the whole team, subteams, or individual. This function addresses the most "softy" part of a team decision make process: emotions whether that to be a collective morale or to be a specific individual's feeling.

Table A: Detailed function descriptions of behaviors that are grouped under primary behaviors.

Corporate Knowledge Gluer Fills in any mission-relevant knowledge gaps to update rotating or missing personnel	
Function	**Operationalization**
Objective Clarifier	Strengthens understanding of mission objectives and clears up any misunderstandings
Cocktail Party Host	Acts as the day to day point of contact to maintain mission structure
Breaking News Reporter	Broadcasts updates when plans go off-nominal and nominal updates
Risk-Reward Assessor	Explains the costs associated with a given option
Black Box Opener	Explains how specifics machines and algorithms work (e.g., ground tools, spacecraft, data modeling, instruments)

Team Bridge Builder Conduit to foster collective understanding between science and engineering teams	
Function	**Operationalization**
Intent Translator	Inform others and oneself about the motivation behind the decision being made
People Reader	Gauges specific personalities and working styles of individuals
Room Phantom	Toggles between rooms of different teams and listens for important updates
Day Trader	Facilitates compromises from the negotiations to achieve consensus

Efficiency Optimizer Streamlines the tasks and attention of teams to meet mission deadlines	
Function	**Operationalization**
Constraint Highlighter	Emphasizes the constraints of a given planning activity
Forest-Tree Juggler	Zooms in and out between long-term blueprints and current situations
Urgency Umpire	Facilitates teams to focus on immediate mission needs due to time constraint
Jenga Master	Takes current input into consideration and appropriately incorporates it into the plan
Double Checker	Asks for confirmation that the change modifications have been done correctly
Options Funneler	Narrows down decisions for science and engineering teams to pick from

Vibe Dispatcher Assesses and conduct actions based on emotional responses	
Function	**Operationalization**
Room Reader	Senses the overall tone of the team as situations unfold (they can also do this explicitly by asking for consensus)
Opinion	Acknowledges individuals' viewpoints and voices to increase their acceptability

Validator	with consensus decisions
Marie Kondoer	Promoting an idea that sparks joy for them or discarding ideas that do not spark joy
Steam Blower	Openly shares opinions with teammates, especially dissenting opinions

DISCUSSION

While conventional wisdom acknowledges the intangible yet vital nature of soft skills, these skills often receive inadequate attention in domains heavily focused on technical skills[11].

Our ethnographic study of the Mars 2020 operations team at the NASA Jet Propulsion Laboratory, reveals how significant and how diverse the necessary soft skills are for efficient decision making in large teams. Below we summarize three high level learnings derived from the empirical data we collected. We reflect upon each point briefly, as we believe they can help guide future research on team design principles and collaboration dynamics.

This study can support the design of roles of an operations team. Typically, to staff an operations team, the roles and responsibilities descriptions for required roles tend to be on technical expertise and tasks. Soft skills are described at a high level with limited discernibility as to exactly what types of soft skills are required for the particular role[7]. This study revealed and defined the specific types of soft skills presented in the context of the Mars 2020 mission operations, and henceforth needed in other contexts that require technical collaboration across disciplines. When designing a new team, these soft skills can be distributed to the roles as desired attributes. Or when filling a role within an existing team, a set of missing soft skills can be added to the role description. This was validated when the study was presented to an Mars Science Laboratory mission manager as she was in the search of candidates for a vacant role.

This study also can support the design of the overall decision making process of consensus-based, highly-constrained, multidisciplinary teams. Once the initial process is designed, using a method such as design simulations[1], the overall process can be tested and empirical data can be collected similar to this ethnographic study. The data can be analyzed to reveal what types of soft skills are pervasive or absent. Processes that demonstrate intense soft skills may be ripe for improvement. For example, if the Objective Clarifier and Efficiency Optimizer functions equally dominate an activity, that activity may be better split into two activities that start with ensuring all members of the team are fully briefed on the current status and key objectives of the operation for that day, and later followed by an activity that evaluates efficacy of the options.

Lastly, the study also reveals that while all functions can appear in any steps in the process, however, anomaly or diagnostic scenarios bring forth emphasis on certain functions. For instance, Objective Clarifier function shows up predominately when there are uncertainties in the mission objectives, current status, or specific constraints. On the other hand, the Efficiency Optimizer functions are pervasive when the deadline to make the decision is imminent. The details of these observed patterns are not in the scope of this paper, and will be published in the near future.

Future Directions. Our observation of the M2020 mission operations have been conducted about two years after the operations began. In that time frame, the operators have refined the process and the roles based on experienced impediments. Contrasting the predominance or lack of certain functions in different maturity levels of operations can inform a correlation between frequency of functions and efficacy of the operations.

In the future we are interested in evaluating how our framework applies at early stages of team formation and process design, ideally in different contexts other than space mission operations. We expect such an effort will help to turn our framework to be a pragmatic tool that can be used to assist role definitions and process design in early stages.

Finally, we aim to expand these findings to human and intelligent systems collaboration, and derive design guidelines for intelligent systems design that allows for more back and forth interaction, iterative decision making and improved shared contexts.

CONCLUSION

Our results underscore the necessity of both technical expertise and interpersonal competencies in achieving exceptional outcomes in cross-disciplinary teamwork, particularly in space exploration missions. This study, while centered on the operations room of Mars 2020, suggests that the soft skills framework we developed is likely applicable to other complex and high-stakes technical environments. In contemporary organizations, teams comprising diverse disciplines are increasingly common[2][3]. Yet, the efficiency of these teams in collaborative decision-making hinges on soft skills. These skills are crucial for communicating across disciplinary divides, envisioning and conveying overarching goals, and translating these into actionable steps[1][11]. The framework we propose offers valuable guidance for team formation in the initial stages and for evaluating team efficiency during later operational phases. Effectively harnessing soft skills can elevate the collective performance of a team, turning ambitious dream projects into reality. This concept aligns with the insights of British-American organizational author Simon Sinek, who aptly noted, “It’s better to have a great team than a team of greats.”

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