



TEAMNASA

Masters of Human Computer Interaction
Final Capstone Project
Spring 2009 Research Report

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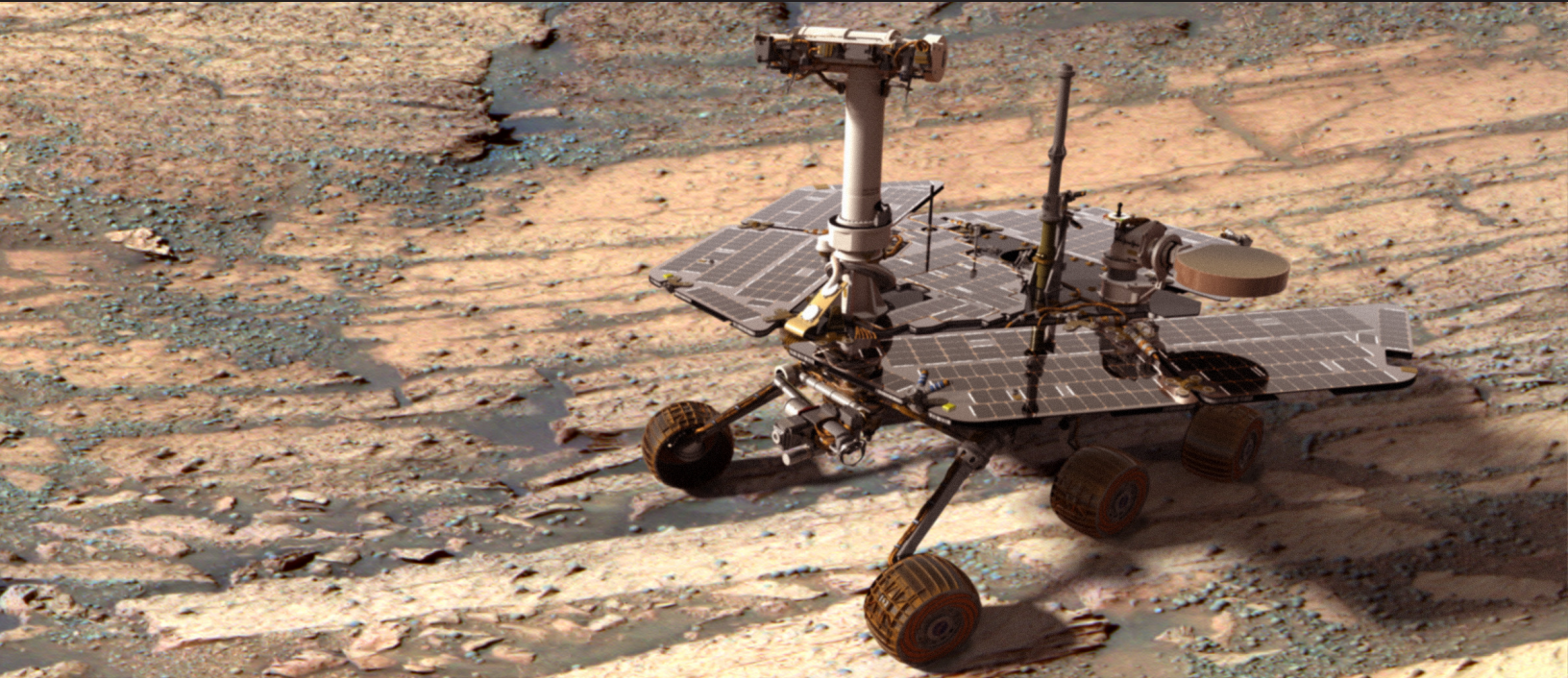
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PROJECT INTRODUCTION

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Executive Summary

With the International Space Station nearing completion, and the space shuttle soon to retire, NASA is setting its sights at returning to the moon. The moon, due to its proximity to Earth, is an ideal location for a permanent outpost to test new exploration technologies and act as a gateway to the human exploration of Mars and beyond. When lunar campaigns begin in 2020, astronauts will be on the surface only 10% of the time. Lunar rovers will support the rest of the mission. Robots will support crewed missions by mapping the landscape on the moon, and gathering surface data to optimize crew productivity and reduce the risk of human exploration. Managing these rover operations calls for a great deal of research in rover controls, and efficient planning for rover utilization.

Such massive undertakings require the cooperation and planning efforts of hundreds of people, including engineers, scientists, and operations specialists, who are often distributed across the country and the globe. To achieve success, everyone must work together to communicate their ideas in order to reach consensus in a timely manner. We studied the collaborative planning process through a set of interviews, contextual inquiries, a review of related literature, and a competitive analysis of existing collaboration software.

Based on our research, we have three recommendations for improving collaboration in mission planning. First, we found that scientists and engineers often had difficulties communicating their ideas to one another, making it difficult for the scientists to provide input for the plan. For example, engineers did not always understand the scientists' activity requests, and scientists did not always understand the spacecraft's constraints. Improving the visibility of constraint information and allowing scientists to comment on plans will improve the quality of scientists' planning input. Second, we found that planners had to switch between many different tools to create the plan. In addition, many of these tools were "homemade" which suggests that the tools provided by NASA were insufficient. Providing tools that are easily integrated and have a standardized format will reduce the need to switch between many different formats, saving time and minimizing errors. Third, during the planning process, people often have questions they need others to answer before they can proceed. We found a need for immediate communication across groups as well as within local teams. This was particularly difficult for distributed teams when questions needed to be answered right

Managing rover operations calls for a great deal of research in rover controls, and efficient planning for rover utilization.

To achieve success, everyone must work together to communicate their ideas in order to reach consensus in a timely manner.

away. Team members juggled many different communication tools that led to interrupted work and lost questions. Streamlining communication tools and allowing communications to link directly to the planning tool will reduce the time required to troubleshoot planning problems. We will design a collaborative planning tool that will address these issues in order to help science team members more efficiently analyze data while simultaneously planning robotic reconnaissance activities.

Using the data we collected during the Spring semester, we will design a planning tool to help the science team more efficiently analyze data while simultaneously planning robotic reconnaissance activities.

Robotic Reconnaissance Field Test

This summer, we will apply our research findings to design a planning tool for a robotic reconnaissance field test. Robotic reconnaissance is the act of operating a planetary rover via ground control, to scout planned traverse paths prior to astronaut activity. Scouting is an essential phase of field work, particularly for geology, and can be traverse-based (observations along a route); site-based (observations within an area); survey-based (systematically collecting data on transects); or pure reconnaissance. Robot instruments provide measurements, resolutions and viewpoints not achievable from orbit. Understanding how robotic systems can best address surface science needs will be a central issue.

Robotic reconnaissance has the potential to improve scientific and technical returns from lunar surface exploration. In particular, it may increase crew productivity and reduce exploration's operational risks. Additional research, development and field-testing is needed to improve robot and ground control systems, refine operational protocols, and specify detailed requirements.

The iterative traverse planning and execution process includes: initial planning using orbital data to create a baseline traverse plan, robotic reconnaissance to collect surface data and to update the traverse plan, and crew traverse supported by a ground-based science team and data systems.

Previous NASA studies on robotic reconnaissance have shown that simultaneously creating a plan and analyzing data is difficult for science team members. Currently, there are five tools being used by the operations team to create a plan, monitor robot status, analyze and store the data, and make fine-tuned adjustments to robot control.

Problem Space

The task of driving a rover requires the collaboration of experts in many different fields. Scientists propose activities for the rover to perform, engineers make sure the rover functions properly, operations specialists program commands for the rover, and mission management makes sure the rover's activities contribute to the mission's goals.

Each of the missions in the Mars Exploration Program, including the most recent Phoenix and the Mars Explorer Rovers (MER) missions, have relied on different planning tools and different methods of collaboration. Although planning tools have grown more sophisticated and continue to advance, there are many opportunities to refine collaboration among such diverse and distributed groups. Current collaboration methods range from passing around an Excel spreadsheet for comments and revision, to an open teleconference line that allows anyone to get their questions answered at any time.

We focused our research efforts on studying the collaboration between scientists, engineers and operations specialists during the planning process. Scientists request activities for the rover to perform in order to gain science data, but are often not aware of the rovers' engineering constraints. Scientists work with mission planners to sequence science initiatives, but often do not know whether the activity was performed as requested, or if an activity was bumped from the plan. On the other hand, mission planners must sequence science plans, but are not aware of all constraints and must work with engineers. We hope that improving the interactions between scientists, engineers and mission planners will increase the efficiency of planning and produce more valuable science from the rover's limited resources.



RESEARCH PROCESS

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We began our research with related literature and a competitive analysis to expand our understanding of the planning process and the collaboration that is involved in this domain. The literature review gave us insights into both the human and technological aspects that affect collaboration, as well as the analogous domain of operation room planning. The competitive analysis of commercial collaboration tools gave us an overview of what collaboration issues are currently being addressed and how the tools are addressing them.

The bulk of our research employed contextual design methodologies, which involve detailed observation of current user practices to understand the workflow and influences surrounding each user. The primary method used was contextual inquiry (CI), which is a special type of interview where we observe users in their workplace and ask questions in order to get an in-depth understanding of their work practices. We also conducted interviews to flesh out and refine our understanding, as well as interviews in the form of retrospective contextual inquiries, in which the interviewee walks us through their daily activities, to get an understanding of domains that were otherwise inaccessible.

Related Literature

A broad survey into collaboration literature helped provide several insights into areas that affect collaborative work, including cultural differences, establishing trust given distributed collaboration, and collaborating through digital medium. An in-depth look into planning for surgical suites provided an analogous planning domain with similar resource constraints. Operating rooms must coordinate hospital resources, patient health, and surgeon availability in order to reduce downtime.

The research revealed both problems with collaboration, and potential solutions for those problems. The research made explicit possible communication breakdowns. This was helpful in completing interviews and contextual inquiries because the research prepared us for noting sources of communication breakdowns, exploring plans in alternative domains, and in comparing the process of maximizing scarce resources to processes observed in the Mars mission-planning environment.

Detailed findings from our sampling of the literature can be found in Appendix A.



Competitive Analysis

We compared twenty popular commercial collaboration tools to see what features were commonly available and to provide us with an overview of what collaboration issues currently exist and how they are addressed. In order to understand the purpose of each piece of software, we answered four questions about each: Who is using this tool? What are they using it for? What are the main features of this tool? What collaboration issues does this tool address?

Viewing the tools' functionalities revealed design opportunities, because many important aspects of collaboration identified in our research are under-employed in popular business software.

Detailed results from our competitive analysis can be found in Appendix C.

Interviews

We performed eleven interviews over the course of this semester. Finding appropriate CIs proved difficult, because our focus dealt with planning in a very specific environment: people from different backgrounds working to create a plan based on constantly changing information. Furthermore, missions such as Phoenix are no longer running so it was not possible to conduct a CI in this environment. For this reason, interviews proved to be extremely valuable in accessing the information we needed. By

speaking with people from many different roles on a mission, we were able to gather different perspectives and form a detailed understanding of the organization and the interactions between mission planners, engineers, and scientists. The majority of our interviews investigated the Phoenix and Mars Exploration Rover missions. We also conducted a number of interviews in similar areas, both inside and outside of NASA, in order to understand how planning is done in other domains.

Mars Exploration Rover (MER)

We conducted interviews with three scientists on the MER mission, one of whom also acted as a chief payload uplink lead (PUL). The scientists offered a different perspective of the various interactions that occur on a daily basis, and solidified our understanding of MER's organizational structure. By interviewing the scientists we hoped to learn more specifically about the process they follow for creating a plan, as well as the collaboration between scientists and engineers from the scientists' perspective. We sought to explore differences between the scientists and engineers in terms of their culture and understanding of mission operations.

Phoenix

We conducted interviews with two strategic science plan integrators (SPIs), two tactical SPIs, and one instrument sequence engineer on the Phoenix mission. We carried out the interviews in the manner of a retrospective contextual inquiry, and asked each participant to walk us through a typical day during the mission. The purpose of the interviews was to gain a detailed understanding of the roles and responsibilities, the flow of information between roles, and the timeline of daily events during planning on Phoenix. We also hoped to learn about the different tools that planners and sequencers used during the mission, who used the tools, and how they were used.

Analogous Domains

We interviewed an ethnographer who studied collaboration during the planning process for the International Space Station (ISS). The ISS is a massive multinational effort, and we hoped that learning about the challenges involved in multicultural collaboration and planning.



In addition to researching NASA projects, we conducted interviews with two people in analogous areas in order to find the parallels between collaborative planning in the workplace, and collaboration between scientists and engineers during mission planning. We interviewed an IBM researcher in Boston, and a machine shop foreman in Pittsburgh, to learn about the artifacts they share, the language they employ, and the channels by which they communicate in the workplace.

Detailed summaries of all our interviews can be found in Appendix B.

Contextual Inquiries

Mars Desert Research Station

We conducted four contextual inquiries at the Mars Desert Research Station to learn more about how a group of diverse specialized experts, who have not previously worked together, behave and operate on a simulated mission. In this simulation they lived together and could not interact with the outside environment except under special circumstances. The team members came from different academic disciplines, and had different science goals on the simulation. We sought to witness how a diverse group of scientists worked together to execute plans, as a valuable analog to interdisciplinary group collaboration on NASA missions.

Roles

Each individual on this station had a designated role as well as their own experiments. However, almost all experts on the station needed some other involvement by members in order to accomplish tasks. Although participants had specific roles, the roles were not adhered to.

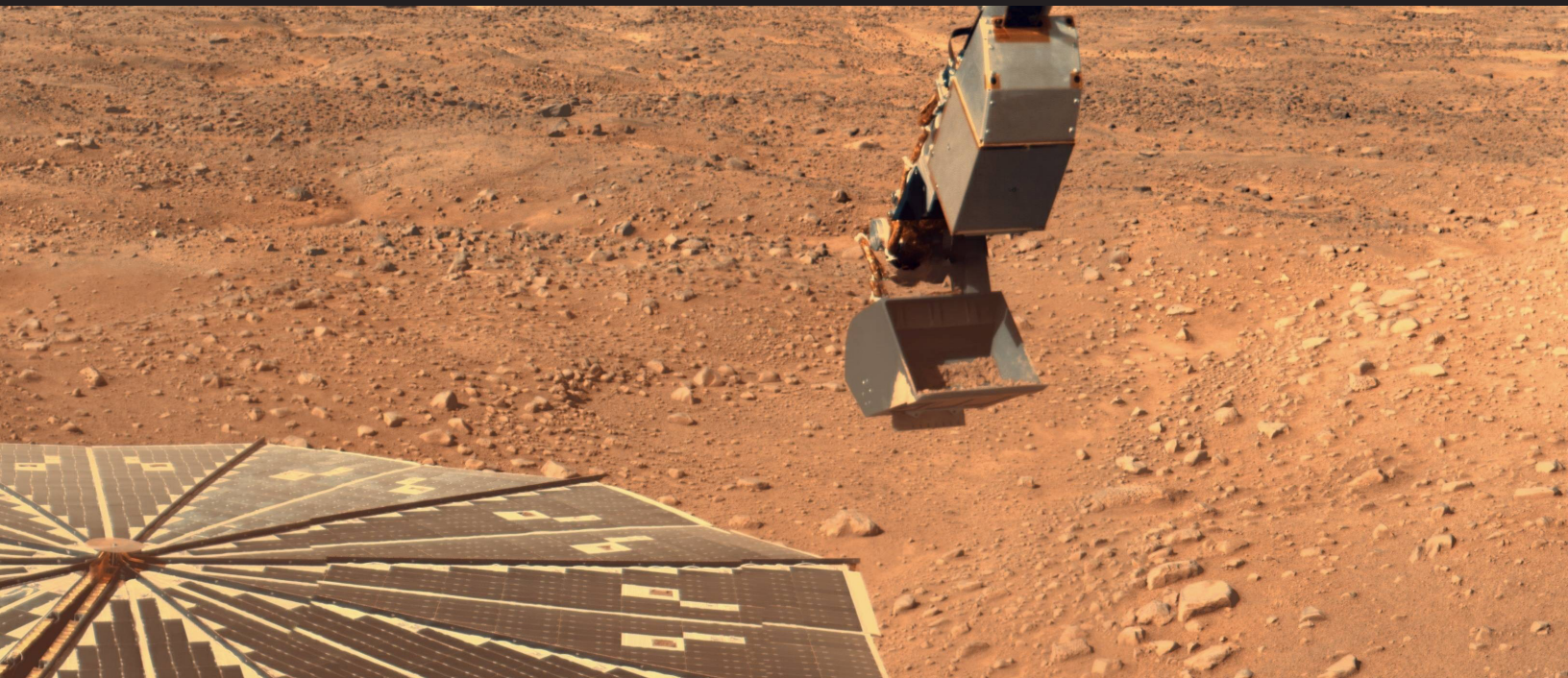
Mars Exploration Rover (MER)

We conducted two contextual inquiries with personnel on the Mars Exploration Rover mission. We sought to learn how a real life distributed Mars rover mission operates on a daily basis. This was done by observing panoramic camera (pan-cam) payload uplink leads (PULs) on the MER mission. We contrasted this information with that received while interviewing MER mission planners. Also, we were interested in seeing how a mature mission operates compared to other shorter duration missions.

Roles

The pan-cam PUL's role is to create rover sequences for the pan-cam that get uploaded to the daily rover from high level plans. In order to accomplish this, instrument sequencers have to start with a high level plan established that morning given to them by the Keeper of the Plan (KOP) for the day, refine it, discuss the plan with other sequencers, and create the sequences. This is done throughout the day with constant open teleconferences to keep in touch with all the individuals involved in the mission. We observed the instrument sequencer for the whole process, except for some meetings that we were unable to attend due to security reasons.

Detailed models from all contextual inquiries can be found in Appendix D.



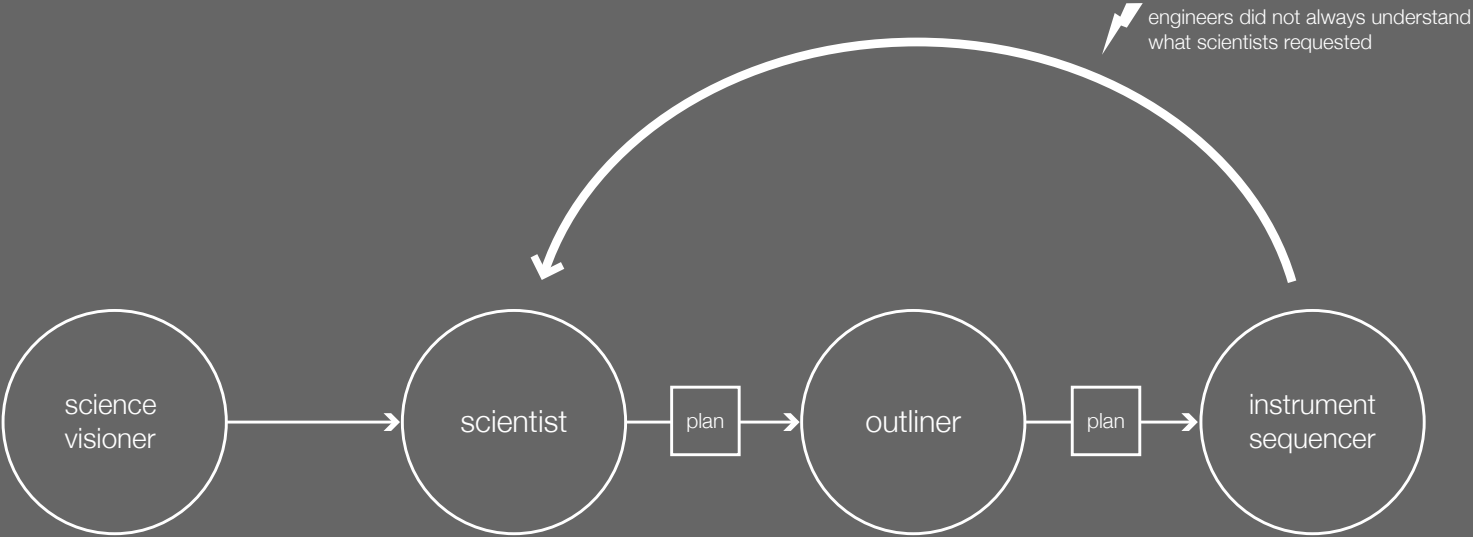
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Introduction

Through our interviews and CIs of the MER and Phoenix missions, we found three opportunities to improve the design of future planning tools. First, there is an opportunity to improve scientists' ability to provide quality planning input. Engineers often did not understand the reason behind science initiatives and many scientists were hesitant to interact with planning software and were often unaware of engineering constraints. Second, we observed an opportunity to improve tool centralization. We found that the Phoenix and MER missions employ many different tools, create homemade tools, and use unstandardized formatting in shift reports. Third, there is the opportunity to better support engineers' and scientists' ability to ask questions and get quick feedback. The missions we observed did not have standard methods and tools to help support quick communication troubleshooting. In the following section, we will present our major findings from from the research and provide suggestions for improvement, inspired by analogous domains.

Finding I:
Scientists were not able to communicate plans in a language engineers could use



“Scientists think that everything is possible all the time”

-Lead Tactical SPI

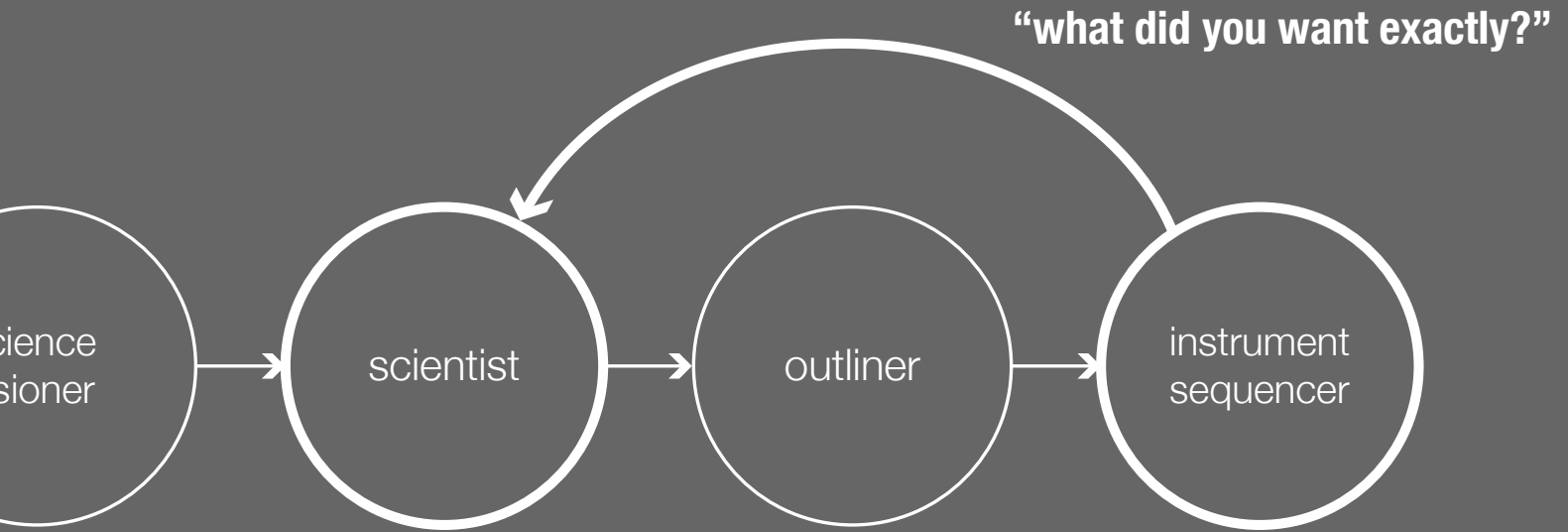
From our interviews with MER sequence engineers and Phoenix science plan integrators (SPIs) we observed considerable tension between science and engineering planning groups. This tension occurred when science intents were not communicated using vocabulary that sequence engineers and plan outliners could translate into concrete plans.

Scientists have goals that include collecting consistent, repeatable measurements and identifying similarities across measurements to test hypotheses. Engineers and SPIs have goals that focus primarily on spacecraft readiness and constructing science activity plans to send to the spacecraft. Each group works together during the planning process, however engineers expressed frustration that many scientists were not aware of the spacecraft’s capabilities and did not thoroughly explain the reasons for their science initiatives. Phoenix sequence engineers described instances when the intent of a science request was unclear or implausible given available resources saying, “Scientists think everything is possible all the time.”

The main tool scientists could use to communicate their science initiatives with sequence engineers was mission planning software, but many scientists on Phoenix found the software difficult to use. Phoenix and MER scientists received training on using PSI and Maestro, sequencing and planning software, however few were capable of creating a plan. On Phoenix, a tactical SPI reported that only “8 out of 60” scientists were capable of making a plan using the software. One strategic SPI on the Phoenix mission stated, “[the scientists] knew that they [were

Engineers expressed frustration that many scientists were not aware of the spacecraft’s capabilities

FINDINGS AND CONCLUSIONS



“How long it takes to turn an instrument on would constantly change and that information didn’t get out to all forty people that could be building a plan.”

-Tactical SPI

not good with] PSI, and they would tell us that.” Scientists had a difficult time using the planning software because it required them to account for many different constraints and engineers did not communicate constraint information to all of the members of the science team. For instance, a tactical SPI told us, “How long it takes to turn an instrument on would constantly change and that information didn’t get out to all forty people that could be building a plan.” However, the biggest hurdle to scientists’ adoption of mission planning software was scientists’ lack of interest in robotic operations. “Many scientists were just there to do science”, a tactical SPI described, “and they do not want to learn about constraint information.” A strategic SPI expressed frustration at scientists’ disinterest saying, “I don’t understand why more scientists aren’t involved in operations.”

Miscommunication about science intentions between scientists and plan outliners created tension during the mission planning process. Sequence engineers preferred that science requests be made using domain specific vocabulary when sequencing, such as “half-frame for half of a 1024x768 pixel image.” However, sometimes scientists did not provide appropriate information, as one sequence engineer described, “[only] two or three [scientists] knew what they wanted and knew what they were doing.” Plan outliners and sequence engineers often had to “stay behind and ask the scientist [to clarify] if there were questions.” Several sequencers told us that it was useful to understand why

scientists wanted to perform a certain activity because it helped them determine the appropriate parameters to set. Though the planning software provided a “note and intents” field to describe the reason for science initiatives, there were several challenges that people faced with this system. First, a technical SPI on Phoenix complained that there was no visual indication when a scientist had included a note in the plan. A SPI or sequence engineer would need to click on a part of the plan to see if a scientist had left a note. In addition, another tactical SPI told us that it was hard to know which notes were new. When someone copied a plan sequence in PSI to run again on another day, PSI would automatically copy the notes as well, and some notes were no longer relevant.

Unlike our observations from the Phoenix mission, during our MER CIs we observed that scientists had a good appreciation for the technical constraints involved in collecting science initiatives. For instance, we observed an atmospheric scientist on MER explain the reason why his science proposal was challenging to implement from an engineering perspective. We believe that the principal investigator on the MER mission improved scientists’ ability to understand engineering constraints by encouraging cross training between the engineers and scientists. For instance, during pre-operations, he asked scientists to give presentations about their science research and engineers to give presentations about the rover and its constraints. This gave the scientists and engineers a mutual understanding for each other’s work, helping to create unity and a common vision among the team.

Education also assisted the planning process at Carnegie Mellon’s rapid prototyping lab, where a machinist took orders from students who did not understand the operational constraints of his machines. The plans that students gave him were at various stages of fidelity and students often asked him to build things that were impossible. This machinist held one-on-one consultations with each of the students in order to understand what they wanted and explain what was possible. By patiently explaining the constraints, and working with the students to develop a high fidelity plan, the students learned about the engineering constraints. When we asked the machinist “do the students’ requests get better over time?” he quickly replied, “Absolutely.”

“One of us would usually stay behind and ask the scientist if there were questions.”

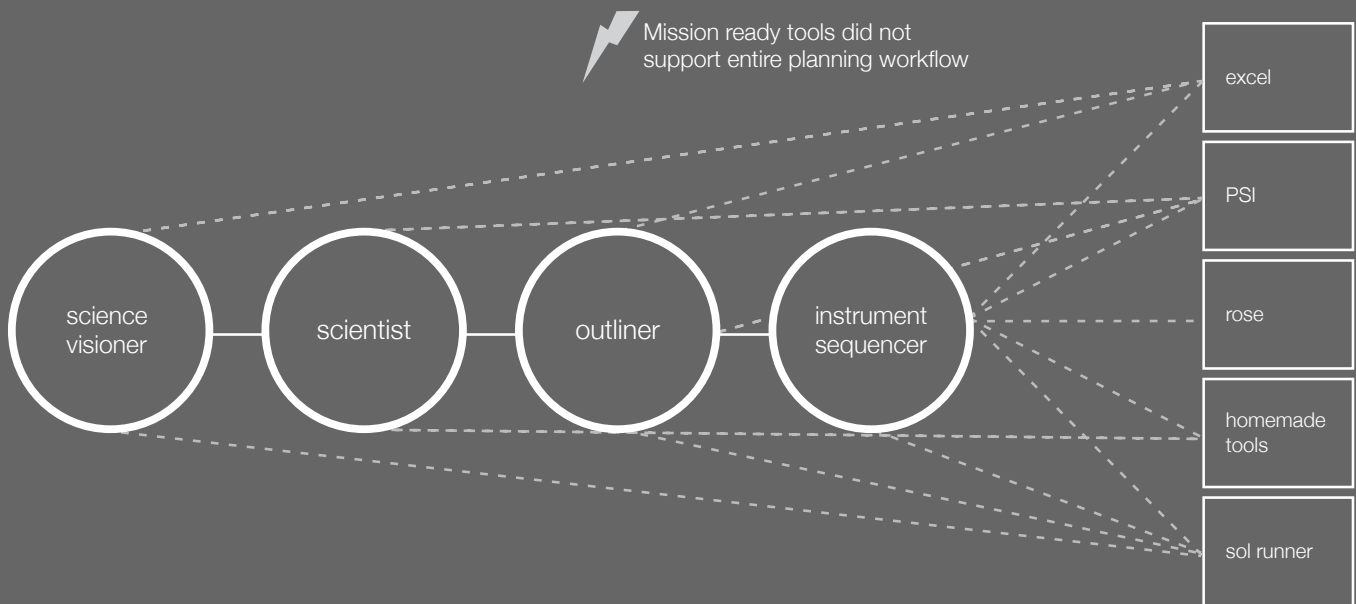
-Instrument Sequence Engineer

When we asked the machinist “do the students’ requests get better over time?” he quickly replied, “Absolutely.”

-Machine Shop Foreman

Finding II:

Specialized tools created fragmented planning workflow

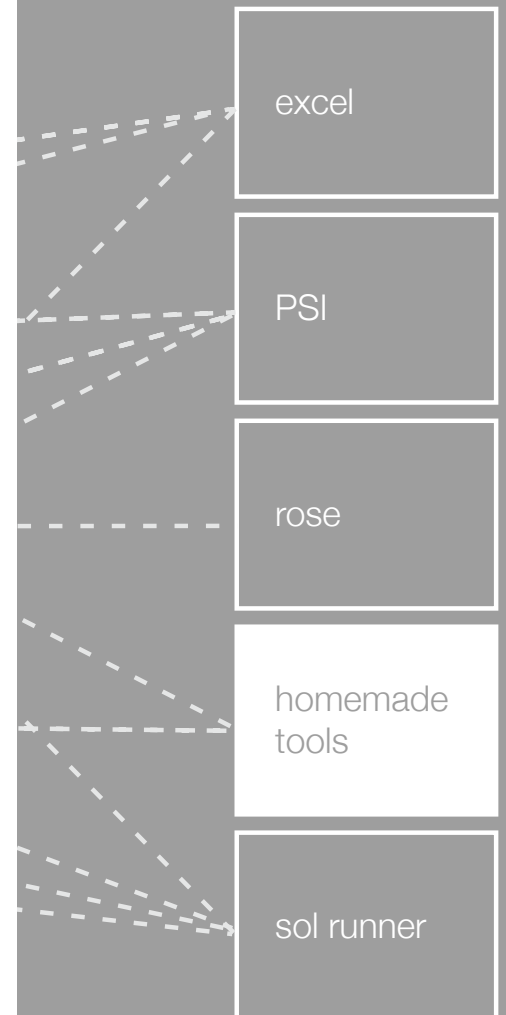



Across many of the missions, we observed that several domain-specific tools were used throughout the planning process. These specific tools only addressed one part of the mission planning process. For instance, RSVP was used on the MER mission for writing rover sequences but the issues such as resource modeling of the rover were addressed by another tool called Maestro. An individual would first resource model a template sequence in Maestro and then write the actual sequence in RSVP. Although these tools were designed to be used one after another, they were so domain specific that there was a workflow gap between these programs in the planning process. The direct result was that homemade tools were used to bridge this gap and generic tools were used to address cross-domain issues in the planning process.

This gap between domain-specific tools was prevalent in both the Phoenix and MER missions. On Phoenix, an engineering group created a homemade tool to predict where shadows may occur in images to aid in the rover sequences they wrote. In a similar vein, a MER engineer created a tool named Panseq to aid in creating sequences for the rover's panoramic camera. In addition to creating tools that bridged the gap between high level planning and sequencing, MER scientists also created their own tools for data analysis because the specific functions they needed were not available in the tools provided. For instance, a scientist in the group on the MER mission mentioned that "even simple functionality like contrast bounding was not present" in the tool they were provided and they needed, so they made their own tool to do their analysis. While the creation of these homemade tools brought the overall set of tools in line with the mission planning workflow, it created three problems.

First, the homemade tools increased the set of tools needed to accomplish a daily task. For example, we observed an instrument sequencer on MER go through eight different programs during daily operations. We infer that switching between these tools wastes time. In addition, some of these tools were computer architecture specific, requiring the instrument engineer to work through a remote desktop connection. This added a delay to the tool's interface, making it more tedious to use.

Tools are so domain specific that there exists a workflow gap between the tools in the planning process.



 homemade tools bridge gaps in mission planning workflow

FINDINGS AND CONCLUSIONS

RA IDE [[Edit](#)]

Summary. - - 2008-06-26 01:32:59 GMT
Last Updated: - 2008-06-26 04:34:58 GMT

General overview

Tosols RA activities consisted of delivering a sample to WCL0, a first time activity. Post delivery then moved to the acquire sample site and a RAC image taken. The scoop was then moved to the T ws followed by RA actuator characterization at an azimuth pose p from the sol 4 run of the same b

RA State

OK Channelized telemetry AVAILABLE
OK Channelized telemetry NOMINAL
OK Non-channelized telemetry AVAILABLE

Sol Runner shift report entry for Phoenix

In order to use homemade tools, engineers on the MER mission classified them as “Class C” software, which falls under more lenient testing and not meant to be mission critical.

Second, these homemade tools were distributed across each mission. For example, in both MER and Phoenix, either individual scientists or sequencers only used the homemade tools, and they did not share the tools across groups. In ISS, each nation had its own planning tool, which made negotiations more complex because nations did not share a common vision of the plan.

Finally, some tools created security issues. In order to use homemade tools, engineers on the MER mission classified them as “Class C” software, which falls under more lenient testing and not meant to be mission critical. But a sequence engineer on MER told us that these tools were in fact mission critical and technically should be subject to “Class A” testing. This more rigorous testing requires tools to not change during the mission, which defeats the purpose of using homemade tools, as they evolved as the mission progressed.

When members of the ISS, MER and Phoenix missions needed to communicate with individuals across disciplines they often used generic tools. We observed that many of the tools that were not domain specific used inconsistent formatting. For instance, we analyzed the content of shift report entries in a software called Sol Runner, and found that formatting was different between roles, individuals with a particular role, and within an individual across multiple entries. For example, the heading names in the “MECA IDE” entries changed slightly between individuals with that role, and changed within a single author’s entries over time.

FINDINGS AND CONCLUSIONS

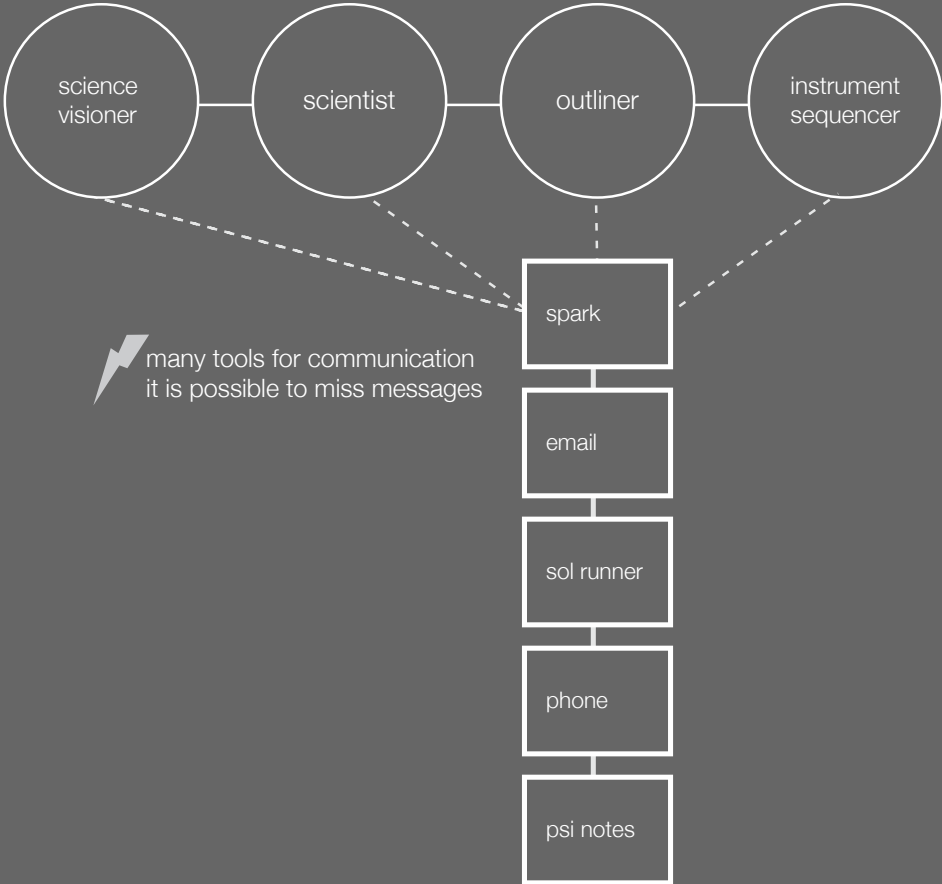
Planning day		PRIMARY MISSION						
Planning day of the week	Sol 57	Sol 58	Sol 59	Sol 60	Sol 61	Sol 62	Sol 63	Sol 64
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RA Interaction Limit (ISEs)								
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Surface Imaging		Photometry	Change Monitoring DodoGoldi, photom, Happy pan	Coordinated HiRISE		Change monitoring (DodoGoldi)	ATM and Remote Sensing focus	Pre-Trench in Cupboard Neverla
RAC	Doc clean scoop and divot		Image scoop				Dust Devil Movie	

Long-term planning excel spreadsheet for Phoenix

The slight changes in formatting suggest that individuals typed in new headers everyday, and were not typing information into a template. The most noticeable difference in shift report entries, however, was the length. Some authors consistently wrote entries that were nearly three times the length of other authors, suggesting that there were no standards about the amount of detail that instrument engineers were required to include in their shift reports.

We saw similar issues in long-term planning for the Phoenix mission, and on ISS, where members of the missions used generic excel spreadsheets to communicate the long-term planning goals. An ethnographer researching the ISS mission informed us that the excel spreadsheet was first created by a sequence engineers boyfriend, and changed in form over time. A strategic SPI on the Phoenix mission also informed us that the structure of their long-term planning excel document changed over time. While generic tools are great at being flexible, they do not provide a standardized structure for information. We infer that unstandardized formats make it difficult for mission members to compare entries over time. The use of homemade and generic tools reveals that missions need both domain specific and cross-domain tools.

Finding III: Ongoing local problem solving required immediate communication



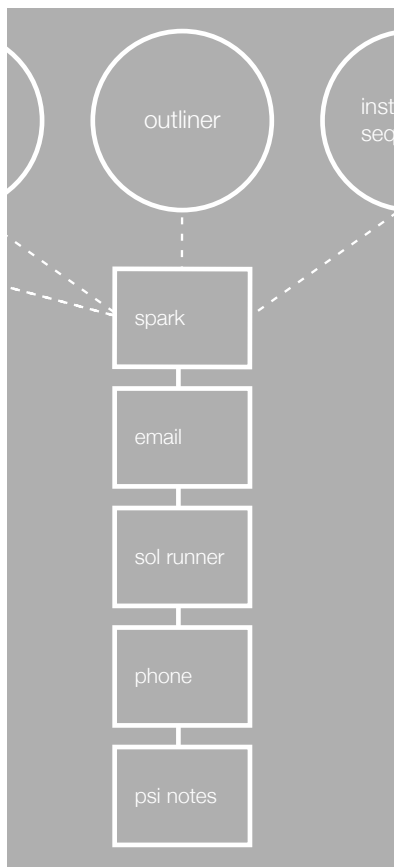
“It was frustrating because you knew there was someone who could answer your question right away, but they weren’t available.”

-Sequence Engineer

Members of the engineering team on Phoenix often had to ask urgent questions to science team members. Engineers had difficulty understanding scientists’ requests and tracked down scientists to ask questions. A Phoenix instrument sequence engineer told us she often needed to quietly interrupt group meetings to ask, “Excuse me, could you clarify this please?” When missions went distributed however, it was much more difficult to ask questions and get immediate answers. Scientists were not always at their computers or telephones, and they would often not respond to emails for many hours. “It was frustrating”, the engineer said, “because you knew there was someone who could answer your question right away, but they weren’t available.” If the question could not be answered in a timely manner, sequence engineers would be forced to drop part of the plan because it could not be completed in time to uplink to the spacecraft.

The MER planning team addressed the need for immediate communication in remote planning by implementing an all-day teleconference loop. We observed that sequence engineers listened to an on-going teleconference throughout the day, in case someone had an immediate question for them. However, there were a few problems with this system. First, most of the conversations on the teleconference were often not relevant to the sequencers. At any given time, the teleconference could include 20-30 people who were discussing a wide range of issues. As a result, the majority of the time an individual would not be listening, and

“You don’t have time to look in twenty different places to find out if you’ve been communicated with.” -Lead Tactical SPI



instead be working on something else. One sequence engineer commented, “Usually, I don’t have to pay much attention to this so I do my note taking at this point.” However, we observed that the sequencers occasionally did not hear questions directed at them, and those asking the question would need to repeat themselves before getting a response.

The Phoenix mission addressed the need for immediate communication by adding additional communication tools such as Spark, a secure instant messaging system. However, mission members also occasionally missed questions because there was no standard method for communicating information. The lead tactical SPI on Phoenix told us there were “so many different forms of communication. There was Spark, email, and so on and things could fall into holes.” Frustrated, she exclaimed, “You don’t have time to look in twenty different places to find out if you’ve been communicated with.”

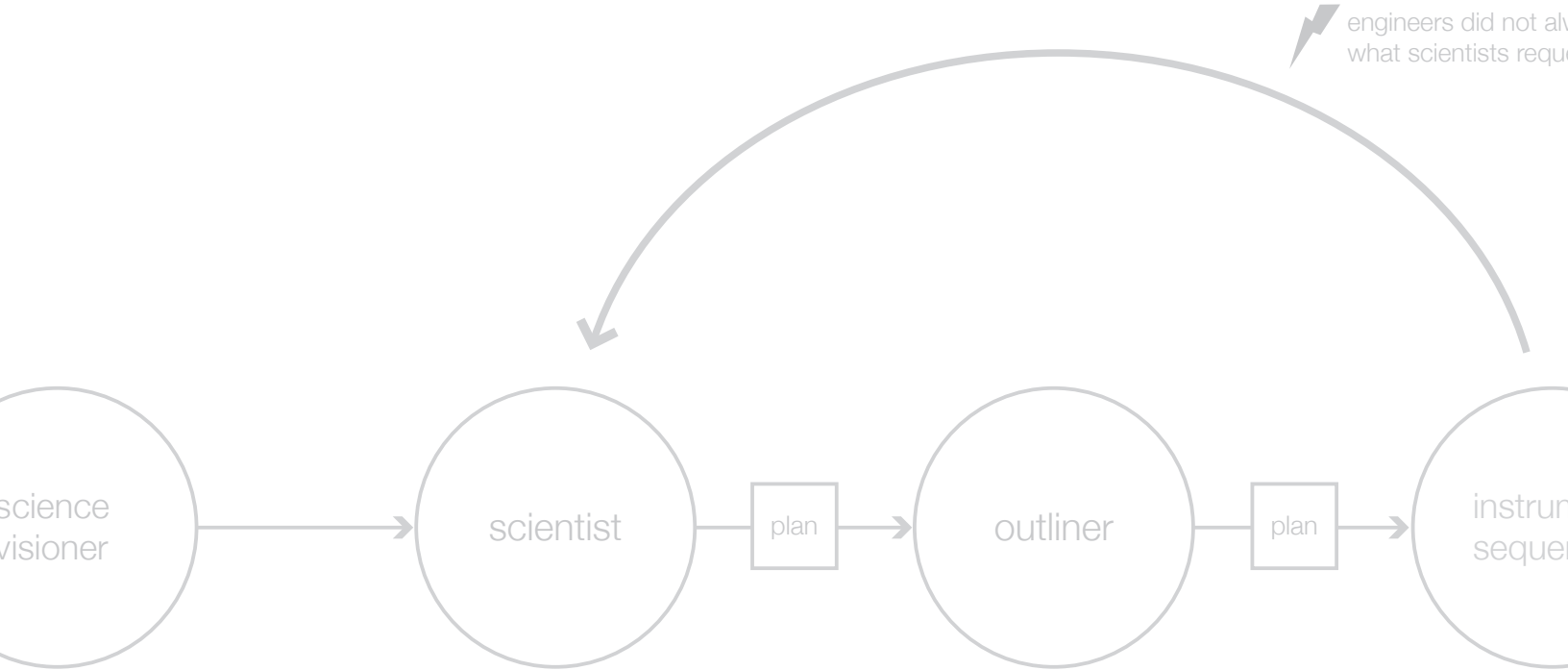
Design recommendations

1. Improve visibility of constraint information
2. Support common formats to enable planning software to evolve with the mission
3. Incorporate communication tools within planning

Improve visibility of constraint information

Current tools are too complex for many scientists to use well. We observed planning tools requiring detailed input and understanding of the spacecraft’s constraints, which only a few people were able to fully learn. Scientists will sequence their own plans during the robotic reconnaissance field test, and we need to provide tools that are easy for scientists to use, regardless of their familiarity with rover constraints. We propose to create tools that adjust the plans’ level of fidelity according to the experience of the user. For instance, an experienced user could view all the plan details in a high fidelity view, and an inexperienced user could view a simplified lower fidelity view.

Our interview with the foreman of a rapid prototyping lab suggests that education could help improve the quality of planning input. This is further supported by the cross-training the MER teams received, which we infer helped the scientists better understand the rovers’ constraints. Inspired by the homemade simulation tools that engineers created on Phoenix, future mission tools could better illustrate constraint information and violations in a visual manner in order to educate scientists about constraints. For instance, tools could simulate a proposed plan, and demonstrate a violation by illustrating a negative outcome for the rover.

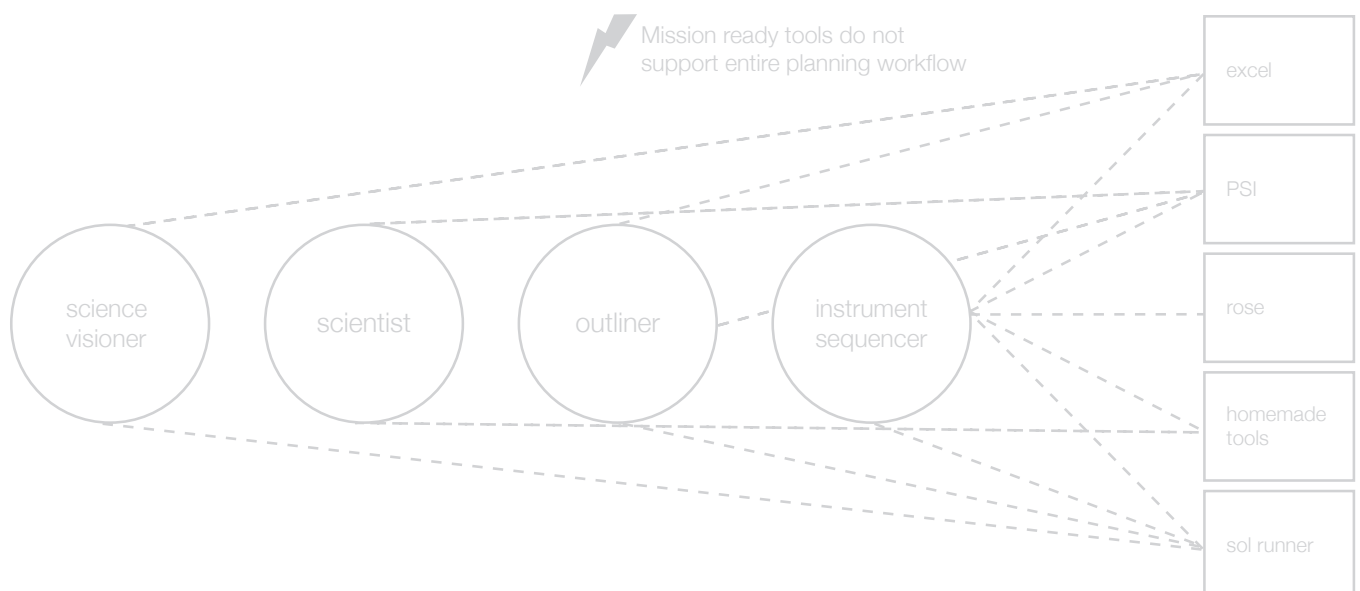


Support common formats to enable planning software to evolve with the mission

We found that planning teams had to use a multitude of different tools during the creation of a plan, including a high level outlining tool and a lower level sequencing tool. Switching between many tools can cause delays in planning, and errors when manually transferring data from one tool to another. We propose integrating tools in order to minimize risks and provide a shared visual workspace.

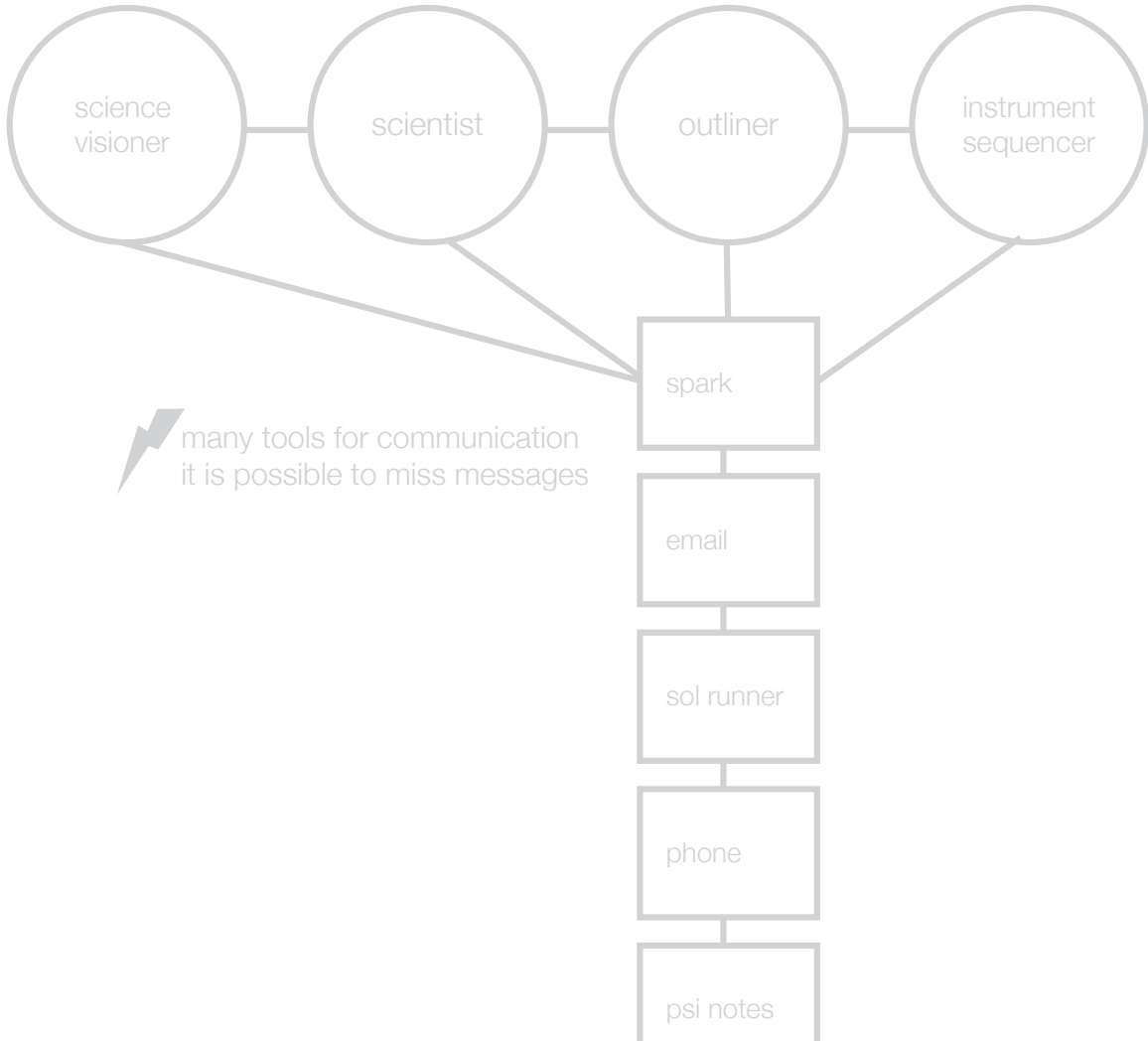
We found that both planners and scientists had created homemade tools to bridge the gap between specialized tools, as well as tools that filled specific needs. One scientist on MER revealed his concern about “one-size-fits-all” planning tools. He urged: “Don’t make generic science tools!” We propose creating a structured web-based planning system that allows users to add new functionality as needed.

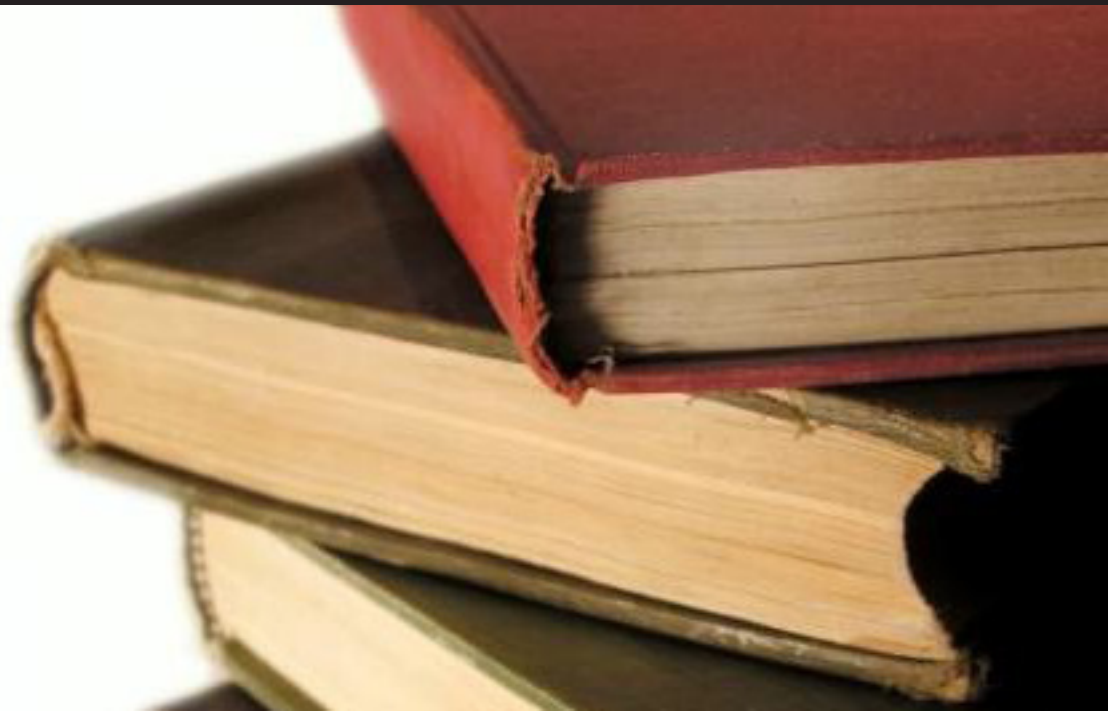
We observed the use of several ad hoc tools, such as Sol Runner and the Phoenix long term plan. Their flexibility was necessary so they could evolve with the mission, however they lacked a standardized structure for information. We propose a tool that could evolve with the mission in a more structured way. For instance, at the beginning of the mission it may not be well understood what information is most useful to include in shift reports, but standards emerge as the mission evolves. Shift report tools could incorporate formatting standards that each instrument team decides on over time.



Incorporate communication tools within planning

It was sometimes difficult to get answers on missions because people were unavailable or would miss the questions. Operations personnel on MER and Phoenix complained that it took a great deal of time to sift through so many tools, which disrupted work and could result in missed communication. We propose creating a unified communication platform to make it easier to get in touch with someone and reduce the number of questions that are missed. Scientists and engineers could tag their questions with images or parts of the plan that were questionable, which would provide context that could make it easier to provide answers. The unified communication platform would also allow us to create an archive of all questions and answers. Planners could refer to previous questions and answers as a reference when particular group members were unavailable.





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Collaboration

Cultural Influences

Cultural differences can have a large effect on group collaboration. Some cultures are more individualistic, encouraging autonomy and personal identity, while others are more collectivistic, prioritizing harmony and conformity to group norms. This difference can lead to difficulty in group activities, such as brainstorming. Hao-Chuan et al (2009) found that collectivistic participants were more talkative in a brainstorming task when communicating through a text-only chat room than with a video chat room. The lack of video allows these participants to feel less influenced by their collectivistic background.

When working in cross-cultural groups, collectivistic participants adapt their responsiveness, and tend to conform to the thinking of the group. This group's holistic thinking may make them more sensitive to cultural cues, increasing their likelihood to conform to the cultures of others on the team. Hao-Chuan et al suggest a need to provide dynamic feedback to increase participants' awareness of cultural differences in communication styles and thus to distribute the responsibility of cultural accommodation to all members of mixed-culture teams.

Conformity to group norms cannot be completely accounted for by either informational or normative influence. When interacting with other individuals, people tend to conform and behave as an individual themselves. However, when interacting with an anonymous source, individuals tend to conform to the group behavior and rely on this to make decisions. Regardless of the quality of the argument, deindividuation, or anonymity, leads to group conformity rather than individual thought (Lee, 2008).

Establishing Trust

Close physical proximity affects the development of social ties and work collaboration, which increase when coworkers are within 30 meters. Bradner and Mark (2002), showed that perceived physical distance impacts collaboration in a digital setting as well. Participants worked with a confederate on three tasks and were told their partner was either in the next room, or on the other side of the country. Participants who were told that their partner was physically distant to them were more likely to deceive their partners, less likely to consider their opinions, and less likely to cooperate with them.

Establishing trust in digitally mediated communications, rather than face-to-face communication, is however difficult. Bos et al (2002) showed that the richness of the digital communication tool impacts the level of trust that individuals establish. They assessed four different media channels: face-to-face meetings, high-quality videoconference, three-way telephone conference, and text. The trust that individuals demonstrated with text-based collaboration was significantly lower, but there was no significant difference in trust with the other three media channels. However, establishing trust in the digital communication channels took longer, and that trust was more easily broken. While face-to-face communication is still the best method for establishing trust, remote collaboration tools can increase trust between individuals by incorporating rich media types such as voice and video.

A great deal of group success is due to information exchange. Shared databases are one way to share information among a group, but there are problems with these systems because individuals are reluctant to contribute to the database, constricting the information exchange. The main reason for this is the belief that withholding information makes one more powerful within an organization. By using a “use-bonus” system where individuals received an economic incentive every time one contributed to the database, Cress et al (2006) were able to counteract this withholding effect. This increased information exchange in the group and therefore should increase potential success.

Distributed Collaboration

Previous research has shown that there are many intricacies of face-to-face communication that are lost in distributed work, and the frequency of face-to-face communication drops off sharply with the separation of coworkers offices even in the same building. There are also difficulties knowing whom to contact about what, how to initiate contact, and communicating efficiently across sites. The difficulties lead to a number of serious coordination problems.

Herbsleb et al (2000) showed a significant relationship between delay in cross-site work and the degree to which remote colleagues are perceived to help out when workloads are heavy. In particular, participants generally interacted more with local coworkers and had a difficult time getting in contact with distributed coworkers. Additionally, while participants indicated they try to assist both local and distributed coworkers equally with heavy workloads, they receive more help from local coworkers. This illustrates a breakdown in distributed communication, that either

APPENDIX A: RELATED LITERATURE

the coworkers' attempt to help cross-site is for some reason ineffective, or that it is difficult to convey a sense of urgency.

Herbsleb et al suggest instant messaging as a way to be aware of a coworker's availability and a continuous chat loop to avoid the intrusiveness of instant messaging, which demands an immediate response from a single respondent. They also cite the need for richer interaction in order to convey the more subtle nuances of face-to-face communication, suggesting the use of high quality audio or video.

One hypothesis given for superiority of face-to-face communication over videoconferencing is that many of the current videoconferencing systems are literally framed around the face. Although nonverbal cues are communicated, there is evidence showing that these cues are typically redundant to cues in speech. Nguyen and Canny (2009) showed that individuals are more empathetic when using upper-body framed videoconferencing rather than head-only framed videoconferencing. However, there is no significant difference between upper-body framed videoconferencing and face-to-face communication empathy.

The problems with text-only collaboration are already known, including the lack of nonverbal and paraverbal cues, turn taking, and giving of feedback about reciprocal understanding. Even videoconferencing systems continue to be less than ideal. Delays in the transmission of sound and picture over the audio/video connection may cause breaks or overlaps in the structure of the communication. Furthermore, the exchange of nonverbal and paraverbal cues remains impeded. Hermann et al (2001) argue it is crucial to coordinate collaboration, particularly with interdisciplinary partners, in order to ensure efficient work. This is done by specifying the objectives of the work, arranging the division of tasks between partners, and managing interdependencies of activities as well as their chronological order and temporal synchronization. They hypothesize the efficiency of collaboration would be increased by using a shared application and a videoconferencing system, because these tools support joint activities like discussion and joint writing. On the other hand, the facilitation of collaborative work could also affect the coordination negatively because less task division and individual work could result.

Hermann et al found that individuals using a telephone and email to work collaboratively significantly outperformed groups using a videoconferencing system. The coordination of collaboration was central for the quality of the problem-solving task measured, as well as its outcome. Participants in the condition with the telephone and email system managed to coordinate their

collaboration very well, combining individual, discipline-based working phases with phases of interdisciplinary collaborative work. On the other hand, the videoconferencing system provided a better environment for collaborative activities, and caused the participants to work jointly all the time.

Planning

Operating rooms (OR) use a “block planning approach” where departments are given a certain amount of time blocks and a certain amount of “planned slack” so that if there is an emergency there is room in the schedule. In order to plan for this, each surgical group needs to provide an OR with preliminary schedules two weeks in advance. These schedules must include three elements: maximum use of OR time, within block time allocations; planned elective cases using historical mean case durations; and planned slack to deal with emergency cases and variability of case durations. From these constraints, a series of algorithms are applied to maximize the use of the OR. One noteworthy step is the “portfolio effect,” which is an attempt to reduce slack time by grouping like operations together. This results in lower overall standard deviation and thus less planned slack than if operations were randomly assigned together (van Houdenhoven et al, 2007).

Cardoen et al (2009) suggest six approaches to operating room (OR) planning and scheduling: patient characteristics, performance measures, decision delineation, research methodology, uncertainty, deterministic planning, and applicability of research.

Patient characteristics include the elective (pre-planned) or non-elective (emergency) status of the patient. Non-electives divide into emergency (need room now), and urgent (can postpone if stabilized). Room utilization improves when some space is reserved for emergencies. Best sequencing rules smooth the flow of patients into space, rather than the “longest case first” rule which generates more over-utilized OR time. These sequencing rules focus on elective operations, since they involve more certainty and are easier to relate with expected financial gains.

Performance measures are a discussion of the performance criteria such as waiting time, patient deferral, utilization, financial value, preferences or throughput. Throughput is related to waiting time by Little’s law, and waiting time decreases as throughput increases. Regarding utilization, underutilized rooms represent unnecessary costs, but fully reserving rooms creates instabil-

ity. Room utilization can affect the whole system. Resources are balanced to minimize the risk of capacity problems caused by unexpected events like longer procedure times. Including quotas in the scheduling process, in order to streamline admittance without increasing waiting time, minimizes patient deferrals.

Decision delineation asks what type of decision has to be made and whether this decision applies to a medical discipline or a patient. Decision delineation can be considered together as a mix planning problem, with a number of weekly sessions for each discipline distributed over a set of operating room times.

Research methodology includes the type of analysis that is performed and the applied solution or evaluation techniques. Most problems are analyzed as combinatorial optimizations, while some are scenario analyses. When the problem exhibits a lot of randomness or is relatively complex, simulation is useful as it features extensive modeling flexibility and allows for a sufficient degree of detail.

Uncertainty involves the extent to which researchers incorporate arrival or duration uncertainty. Deterministic planning and scheduling approaches ignore such uncertainty or variability, whereas stochastic approaches explicitly try to incorporate it. Operations management techniques are able to deal with randomness, especially simulation techniques and analytical procedures, and an adequate planning and scheduling approach may lower the negative impact of uncertainty. However, one should first start to reduce uncertainty in the individual processes instead of immediately focusing on a reduction of the variability of the system that specifies the relation between the individual processes.

Applicability of research involves information on the testing of research and its implementation in practice. Most research is based on real data, but data about implementation “in practice” is limited.

Pham (2006) presents a surgical case-scheduling model for integrated hospital environments. Integrated hospitals serve both inpatients, as well as outpatients arriving from ambulatory surgical centers. These units must coordinate scheduling between hospital units to ensure that expensive resources are well utilized, and patients receive quality, timely service.

Elective cases require patients to wait three or more days for a surgery opening. Add-on cases, including emergency cases, require treatment in less than two hours. Urgent cases require attention within 24 hours with add-on elective filling available OR time.

Mapping hospital resources, patient health and surgeon availability is addressed as a multi-mode blocking job shop approach. Each surgical case job consists of a sequence of operations, containing a set of resources. Each case has a different priority and predictability. Block scheduling is often a preferred method of OR scheduling, reducing periods of downtime.

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Phoenix Lander

Interview 1

We interviewed a human-computer interaction (HCI) research scientist at the NASA Ames Research Center (ARC) HCI Group to get an overview of the planning process for the Phoenix mission. The interviewee worked as a strategic Science Plan Integrator (SPI) for Phoenix. Because of his work as an HCI researcher, he was able to reflect on mission planning and multidisciplinary collaboration between scientists and engineers working under a strict timeline.

As a mission planner on the Phoenix Mars Lander Mission, the interviewee assisted with development and day-to-day operations. He sequenced plans using the Phoenix Science Interface (PSI), a decision support software tool for coordinating a shared timeline of science activities and instrument commands.

There were some tensions that existed between groups on the mission. The interviewee described that “tensions occur at team boundaries or places where you have people from varying backgrounds come together to communicate”, usually because of cultural and technical issues. For instance, JPL provided personnel tools and management for Phoenix, but the mission was physically located at University of Arizona. There might have been tension that the mission was located in Arizona, while JPL had the operations expertise. In addition, there was a difference between the risk postures at different institutions. Universities tend to be less rigorous about testing, peer review and documentation, but work quickly and cheaply. JPL has more conservative risk posture and works more slowly. During Phoenix, JPL was concerned that the workings of one instrument could have an adverse effect on the other instruments and the spacecraft itself. To insure the safety of the mission, JPL needed to validate all science sequences and instrument sequences. Unfortunately, this caused an “operational bottleneck” because they did not have adequate resources to validate everything.

The planning tool Phoenix Science Integrator (PSI) was where the scientists express their plan, and the engineers use to implement scientists’ requests. In this way PSI acted as bridge between scientists and engineers. Led by Principle Investigator, Peter Smith, two groups of SPI planners coordinated two respective plans, a tactical plan that would be transmitted to the rover the next morning and a strategic plan that would provide the groundwork for the plan in two days.

“Tensions occur at team boundaries or places where you have people from varying backgrounds come together to communicate.”

-Sequence Engineer

The interviewee described the life of a scientist on a mission. Before the mission, scientists held science weekly working group meetings over the phone to discuss high-level aspects of the mission. For instance, the science operations working group would discuss: “How are we going to drive this spacecraft. How are the instruments working for us? How are we going to make sure we can get the data that we need?” The meetings would increase in their specificity as the mission approached, becoming more intense and more focused.

He also described the daily activity on a Mars planning day. Each day began with a time to read reports from the previous shift, followed by a kick-off meeting to discuss tactical operations for the next Mars day, which was set by the strategic team the night before. This meeting was followed by a period of downlink assessment as scientists and instrument engineers monitored images, sensor readings and spacecraft telemetry data sent from the rover back to earth as the sun set on Mars. This assessment was then factored into planning and discussion of how the current data affected the long-term plan. A midpoint meeting occurred and a final tactical plan agreed upon by a science lead and science team representatives. At that time scientists began work on a strategic plan and engineers worked on a tactical plan. A mixed team of collocated scientists and engineers were responsible for translating a long-term schedule of activities into a series of more specific steps using PSI before transmitting these sequences to the Lander via a Mars Reconnaissance Orbiter.

There were tensions between multiple organizations involved with the mission because of cultural difference regarding operational expectations and requirements.

Relevant Findings

Planning for the Phoenix mission required a great deal of coordination between two different planning groups, including both engineers and scientists, in order to simultaneously plan for the next day and the day after. In addition, there were tensions between multiple organizations involved with the mission because of cultural difference regarding operational expectations and requirements.

Interview 2

We interviewed an instrument sequence engineer for the camera team on Phoenix, who worked on the mission for three and half years. We hoped to learn more about how engineers account for constraints, and how they communicate with scientists and SPIs.

APPENDIX B: INTERVIEW SUMMARIES

Blame fell on the sequence engineer, but she told us, “I defended it until the end, saying ‘I talked to the instrument team, and there was either it was a miscommunication or we both missed something.’”

-Strategic SPI

The instrument sequence engineer took scientists recommendations and used those as a launching point for sequencing the rover, taking into account many constraints of which scientists were not aware. For example, she had to make sure the robotic arm was not in view of the camera when scientist requested images at the same time that the robotic arm was in use.

Communication was often key in getting the plans done. Many scientists, however, did not know how to communicate what they wanted to the engineers effectively, and some did not know exactly what they wanted in the first place. In addition, many scientists did not fill in the comments section on PSI, and some made slight mistakes when requesting activities, giving the engineers “something that...wouldn’t make sense.” Often, this meant a sequence engineer would have to stay behind to clarify any questions with the scientists, usually by having the scientists point to exactly what they wanted in an image. The engineer shared with us that it was very helpful when scientists “knew how to communicate to us and get across their main goal of that activity. It was refreshing that they understood what we had to do” to create the activity. The science leads were very helpful at communicating with the engineers because they could describe exactly what they wanted in their request, since they participated in planning the activities the day before.

In addition, the instrument sequence engineer talked to the instrument leads to get figures and constraint information. However, miscommunications sometimes occurred. In one example, the team was working on a sequence for drilling two holes. The sequence engineer needed coordinates for the instrument, however the instrument lead gave her coordinates for the wrong point on the instrument, and the image the next day revealed the drill had missed its target. Blame fell on the sequence engineer, but she told us, “I defended it until the end, saying ‘I talked to the instrument team, and there was either it was a miscommunication or we both missed something.’”

The transition from being collocated to working remotely was both difficult and frustrating at times. The biggest problem was not being able to get instant feedback from questions asked to scientists and instrument teams. As the interviewee described, “Some people were teaching classes and you couldn’t always get a hold of people. You knew there was someone who could answer your question right away, but they weren’t available.”

The second challenge to working remotely was loss of shared visualizations. Looking at images with scientists and talking with them about what they wanted was easier when everyone on the

mission was collocated. Working remotely, however, the scientists were not able to show engineers exactly what they wanted visually. Similarly, instrument teams could not point to an image when they needed the engineers to move something. This led to management putting in a big push to attach PDF files to reports online, because sequencing engineers needed images. This was helpful, but not everyone had the time or know-how to attach files. The interviewee said that the “visuals helped a lot when they were there.”

“visuals helped a lot when they were there.”

-Strategic SPI

Relevant Findings

This interview revealed the frustration that engineers experienced when they are not adequately informed about the reasons for science initiatives. During Phoenix, engineers often spent time tracking down scientists to ask them questions about their plan. When the mission went remote, engineers had a much harder time getting clarification about the plan because scientists were slow to get back to them. Supplementing PSI files with text descriptions and annotated image files helped the situation the most, but these methods were not regularly used.

Interview 3

We interviewed the lead tactical SPI for the Phoenix mission to learn more about the mission’s inner workings, the different perspectives on the organization, and people interactions with each other. The tactical SPI is responsible for putting together the rover’s plan for the next day, so this provided a unique look into process of rover planning.

The most difficult part of the lead tactical SPIs job was coordinating with many different people from varied backgrounds. She described that “scientists think everything is possible all of the time,” and did not understand how to account for constraints when creating PSI plans. Many scientists had difficulty using the tool, and did not understand the constraints. This required the SPI to take on extra work in cleaning up plans and oversights.

Scientists did not always know what went into a good plan, often forgetting details as important as turning on an instrument before having it perform some activity.

The SPIs worked on a very detailed level of planning, managing the big picture, something which not everyone was very good at. Scientists did not always know what went into a good plan, often forgetting details as important as turning on an instrument before having it perform some activity. The strategic SPIs were responsible for scrubbing the plans to catch errors such as

these before handing it off to the tactical SPIs, but the strategic SPIs skill levels varied quite a bit. In some cases the interviewee would come in two to three hours early to clean up a plan that she knew had been scrubbed by someone less skilled.

Deciding what activities to pull from the plan also came down to the tactical SPI knowing the personalities and skill levels of who was responsible for each sequence. If items need to be pulled from the plan, pulling something that was not ready to run was most efficient. Since there was no physical indicator in the tool to mark a ready sequence, tactical SPIs made this decision based on who was responsible for each sequence and whether the SPI knew that the person who made the sequence was skilled and reliable or not. Early in the mission, activities were pulled based on discussion, negotiation, and a vote by the scientists. However, plans could fail because ready activities might be pulled in favor of unready activities because voters were not aware of which plans were ready. Since there were certain “points of no return” where sequences can neither be readded or pulled, determining what to pull was critical.

The position of SPI was being developed from the very beginning. Early on, everything used to fall on the SPI, but many tasks and responsibilities were eventually delegated. However, “... some people never really got their position and responsibilities, and the SPI would have to run and find them.” This was in part because of insufficient training due to the budget, and sometimes because training sessions would just get missed due to lax rules. Also the mission was short staffed, so a lot of people had to perform more “nitty gritty” jobs that they resented. As the interviewee commented, “some people didn’t get [low level planning] and just didn’t want to.”

As the mission moved from being collocated to distributed, a group of the more skilled SPIs stayed on for the transition. Also, some of the instrument teams stayed on to disperse slowly. The distribution also changed communication greatly. With so many different forms of communication--including Spark, email, chat, etc--important information would fall through the holes. The interviewee commented, “You don’t have time to look in twenty different places to see if you’ve been communicated with.” She would compensate by forcing all information to be in one place, giving teams one way to reach her so she wouldn’t have to keep track of so many different communication venues.

**“some people didn’t get
[low level planning] and
just didn’t want to.”**

-Lead Tactical SPI

Relevant Findings

Tactical SPIs work on a very tight schedule and rely heavily on receiving quality work from others. As a result, many problems occur when people cannot be found right away, or do not produce the quality work expected. Often, the tactical SPI must make executive decisions about the plan based solely on their knowledge of reliability of those responsible for the components in question.

Interview 4

To learn more about the details of tactical planning versus strategic planning, we interviewed a PhD student working on analyzing data from the Phoenix mission. Involved with Phoenix before the spacecraft landed, he served as both a strategic and tactical SPI during the mission, responsible for scheduling activities for the Lander two days in advance and later finalizing plans to be uplinked the next day on Mars. He spoke a great deal about the daily tasks of the planning team, as well as elaborated on the role of the strategic science lead.

As a strategic SPI, the interviewee was in charge of taking top-level mission requirements and guidelines from scientists to build a mission plan in PSI. He would then modify the plan based on incoming downlink data from the rover because “ten times out of ten something changed” from the previous day’s plan. Multiple options of how to proceed were generated to present to the science teams. Based on the downlink, the strategic SPI would work with the science lead to narrow down the number of possible options.

The lead strategic science lead would discuss the options for the revised plan with the science theme groups. The SPI would then incorporate high-level requests from the science teams into a plan for a single day on Mars, often oversubscribing to prevent any downtime. Activities that did not fit or were affected by instrument dependencies were incorporated into a long-term plan, which outlined the next 7-10 days. Because predictions are not perfect for the next day little changes had long term ripple effects.

Building a strategic plan required independently tracking priorities and constraints from multiple stakeholders. These constraints came from the instrument teams, science lead and science theme groups. Instrument teams would provide parameters for when and in what sequence instruments needed to be used

“ten times out of ten something changed” from the previous day’s plan.

-Strategic SPI

and their requests would appear on the long-term plan spreadsheet. This Excel spreadsheet also contained science activities, maintained by the science lead, however the spreadsheet did not prioritize instrument requests or science activities.

The strategic science lead had the final say on what was left in the plan during the midpoint meeting. This role rotated between four people, usually respected senior scientists. In particular they needed to be good at running meetings, because the job often ran overtime. While the science lead would maintain the long term plan spreadsheet, they rarely touched the actual PSI plan. They would rarely even touch Excel, instead instructing someone else how the long-term plan should be edited. Science teams, engineers and the strategic SPI were present as a strategic plan for a Sol was constructed. The science lead was also a bridge to tactical planning, getting input from scientists and discussing priorities with the tactical SPI.

As the mission progressed, colocated teams of scientists and engineers transitioned into remote groups that collaborated over teleconference, screen sharing and a chat program. Doug assumed the role of both strategic and tactical SPI, strategically planning two days in advance and tactically executing that plan the next.

“because some people can take over the phone lines and it’s really hard to break in and get them to stop.”

-Tactical SPI

The transition between colocated to distributed changed how people interacted. The SPI would share his screen via VNC to discuss the plan with the rest of the team. However, discussions and arguments now occurred over the phone instead of face to face. It became harder to control suggestions “because some people can take over the phone lines and it’s really hard to break in and get them to stop.” The science lead would have difficulty moving on to a new topic, so they often used the chat system to help cut off the speaker and move the discussion forward.

Relevant Findings

The interview revealed a great deal about how strategic SPI would build a plan, juggling constraints from both scientists and engineers. In addition, the interview shed some light into the role of strategic science lead, and revealed difficulties in holding discussions via teleconference.

Interview 5

We interviewed a graduate student who worked as a science plan integrator (SPI) during the Phoenix Lander mission. The in-

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interviewee worked first as a strategic SPI and later as a tactical SPI. We used this interview to understand the difference between the two roles, and how the roles changed over the course of the mission.

Workdays for the SPIs were not very consistent. At the beginning of the mission, the entire crew worked on Mars time and switched to Earth time toward the end of the mission. Very rarely would the planning teams work on the exact same things from week to week.

Science planners were in charge of keeping the plan for each sol. The tactical team worked shift one, and would be planning for the next day's sol ($n+1$). They would start their day with the strategic team's plan from the previous day. The strategic planning team worked shift two, which started four to five hours after shift one, and plans sol $n+2$. The SPIs worked with the science teams, engineers, and various instrument teams to put together a plan for the day.

At the beginning of the mission, strategic SPIs were responsible for building the plan from the ground up. They essentially did everything, building the entire foundation for the plan, before passing it to the tactical team who would make changes based on the downlink data. The tactical team would finalize the plan before it was sent to uplink engineers who would translate the plan into code that was readable by the robot. Science and engineering teams would determine what changes needed to be made based on the downlink, and would instruct the tactical SPIs on what to do.

Strategic SPIs would receive an excel file from the spacecraft team, located in Denver, which included overflight information and the wake/sleep cycle for the robot. They would then upload these constraints into PSI, and would work on contingency passes that may be useful to add to the schedule. In addition to core science for each sol, they needed to consider drop-in science that could be added based on information from the science teams. Daily science was coordinated with the overflight information.

The strategic SPIs needed to come in early in order to complete their work. Sometimes during shift two, the strategic SPIs did not have all the information they needed from shift one. While the tactical team was making changes to the $n+1$ plan, the strategic lead was looking at how this would affect the $n+2$ plan and decide what observations needed to be built. The strategic team needed to plan ahead, and start building these observations early because the tactical and science teams would leave

at the end of their shift and were not available for clarification questions.

The long-term science plan was kept in an excel file. This sheet was confusing because multiple groups were constantly editing the file. The document was constantly evolving and specifically, the data needed by the strategic SPIs was constantly evolving. Observations for the day would be added to this document, along with hypothetical observations to compare with other plans, as well as instrument constraints. It was not always clear which version what the most up-to-date or correct version. In addition, each science lead had their own formatting leading to a lack of standardization within the document.

Relevant Findings

The strategic SPIs needed to come in early in order to start creating observations while the tactical team and science teams were still around. This caused shift two to be extremely long. Also, the long-term plan spreadsheet was inconsistent and edited by multiple individuals. It was not always clear which version of the file was most accurate.

Mars Exploration Rover (MER)

Interview 2

We conducted an interview with a scientist currently involved with MER in order to learn more about how scientists participate in mission planning and contribute to daily replanning. This scientist discussed pre-mission operations, current mission operations, and the differences between MER and earlier missions.

The scientist revealed a lot of issues during early and current MER operations in this interview. Scientists were involved with the mission early on, even before the rover was built. They were polled in an attempt to quantify specification for the rover design based on the science data they would like to receive, however there was difficulty in trying to place hard numbers on science objectives given the large amount of unknowns of Mars. This difficulty was mitigated by close negotiations with engineers to create specifications of both reasonable cost and good utility in collecting science data. Although scientists' feedback was also polled for development of some NASA software tools for the mission, much of their feedback was not utilized.

Scientists in general have a different mindset than engineers during the mission's actual operating phase. Engineers want to keep moving and exploring, while scientists are content to stay in one place and analyze the area. Upper management, such as the Principle Investigator (PI), usually resolves such mismatch in goals of the mission. The PI instilled a need for collecting good science as well as exploration in both groups. The PI's interest in instilling the values of both groups into the MER mission was credited for the excellent collaboration between groups. Pre-mission cross training between scientists and engineers was invaluable when the actual mission commenced. This and the 90 day collocated period created cross-disciplinary ties between groups integral to the mission, especially after the team became distributed.

Finally, the scientist we interviewed discouraged the creation of a generic science tool for mission use. Each scientist and science group has specific needs that do not overlap, so creating a generic science tool is not thought feasible or useful. Some scientists have the programming expertise to make their own analysis tools for use on the MER mission, whether for quick analysis of data or to advise day-to-day mission operations.

Relevant Findings

This interview provided valuable information on the benefits of cross-training diverse groups, the PI's abilities to unify the goals of these groups, distinctions between scientists and engineers, and the unique needs of scientists in data analysis tools.

Interview 2

We interviewed an atmosphere scientist, who has been part of the MER missions since the mission's beginning, to learn more about how scientists and engineers interact from the scientists' perspective. He discussed the need to work with engineers to get a science activity into the plan, and the importance of social skills and understanding personalities in effectively communicating ideas and values.

Early in the mission, meetings were a clash between scientists and engineers. The Skeleton document, which outlines how much power and time is available for engineering activities versus science activities, did not exist until much later. The Skeleton became something of a "sandbox" for scientists, clearly defining the limits they had to work with. During the pre-mission ORTs,

The Skeleton became something of a "sandbox" for scientists, clearly defining the limits they had to work with.

If proposed in the right way with the right motivations and reasoning, there can be a very quick turn-around time for having goals approved and in the plan, as short as a day.

atmospheric scientists pushed to operate rovers at night in order to get a temperature profile of atmosphere during shifts from night to day. However, many engineering hurdles need to be overcome for this, such as power and heat. The profile ended up being performed only about ten times, and required much give and take with the engineers to learn the restrictions, and communicate the importance of activity to the engineers.

The first 90 days of the mission were collocated, which made discussing things with engineers in person easier. Engineers seemed enthusiastic and wanted to help make the science initiatives work, but were very busy. This made talking to engineers to get them behind certain science ideas important to getting those ideas implemented. This is one example of how social skills really matter, because being able to interact with and persuade people is important. Scientists needed to sell their science and learn from the crowd, to be able to read to whom they are selling. Bashing against the crowd, by asking continually or whining, usually ended up backfiring. Subtly waiting for the right time to show people why the science is valuable worked better.

These skills get honed in daily meetings, but even after five years some people still do not know how to interact in a smooth way. For example, one scientist had a great idea for measuring the levels of argon in the atmosphere as a way of measuring the ice caps, but he had a hard time getting his idea in the program due to his approach. He came off headstrong, and did not have the credibility to back up his idea. Speaking to other atmosphere scientists to bring them on-board and back him up first would have worked better. Knowing the right channel, and providing motivations and rational arguments to show others why the science is valuable is very important. Making a formal proposal, much like a proposal for getting funding, was a better approach. If proposed in the right way with the right motivations and reasoning, there can be a very quick turn-around time for having goals approved and in the plan, as short as a day.

Surprisingly, learning people's personalities from distributed locations is not much harder for some, as some scientists can read personalities pretty well given their many years on the teleconference.

Relevant Findings

The importance of social skills in a collaborative environment was emphasized in this interview. Knowing how to propose ideas, learn from others, and persuade people that ideas are valuable is important. The pre-mission cross training encour-

aged by the PI also helped engineers and scientists to understand each others backgrounds

Interview 3

We interviewed a geologist who has been on the MER mission since the mission's beginning, and who also is a lead PUL, to learn more about how scientists work with engineers. The differences between the early mission, where everyone was collocated, and the current mission, where everyone is distributed, were discussed, as well as the importance to mission success of understanding others' roles.

The MER mission was originally only planned to last for 90 days. For these first 90 days, everyone was collocated in Pasadena. More resources were available at the mission's beginning, but competition over what science to perform was greater. This meant tagup meetings took a long time because of negotiations between science groups. Today, a 30 minute tagup covers most of the downlink portion of the day.

People who select the science teams, like the PI, work hard to pick people who like the operational side of things. The geologist shared with us that "It doesn't work well when people just say 'give me my images, I want to write my paper.'" Knowing what having a certain role means is also important. For example, although the geologist believed that Rover Programmers (RPs) were the most important link to getting science initiatives, he felt that "the science teams do not always know this." RPs have power; they have final say before the code goes up to the spacecraft, but they rarely abuse that power.

Working over teleconferences is harder now that the team is distributed. Knowing what is going on is easier for people who were there from the beginning. There is something "hanging in the air" when people collaborate with others who they have never met; knowing who they are and what they are looking at is difficult. Often people talk about other things in their lives on the open mic, but who they are, their personalities, and how hard their jobs are takes a long time to learn, yet helps people feel connected. Also, keeping track of people's role each day is difficult over the teleconference, since an individual's role is always rotating. Speaking face to face, people call each other by their name, but addressing them by their role over the teleconference is easier.

In remote collaboration there is little face-to-face communication, so telling how someone feels about what was just said is

"It doesn't work well when people just say 'give me my images, I want to write my paper.'"

-MER geologist

“I think it’s a generational thing, partly. I am twice as old as you are. I don’t text message.”

-MER geologist

difficult. In particular, telling when someone is able to be interrupted is impossible. The RPs, for example, are very busy people and have to deal with a lot of interruptions because others do not know when they are in the middle of something. For this reason, communication needs to be carefully managed to avoid making others angry. Moral is very important. In particular, the RPs need to feel encouraged by the science teams to be as creative and challenged as possible, to have their job be as complicated as possible. When RPs are not happy, the mission get less science done and moral goes down, but the science teams do not always knows that.

While text or instant messaging might seem like a good solution for communicating without interrupting people as often, the geologist believed that it brought up different issues. The culture on MER was supposed to be “wide-open”, meaning that if someone has a question or information about a certain instrument, the information may very well affect other instruments in unexpected ways. He also beleives that many people are hesitant to use instant messaging for generational reasons. “I am twice as old as you are. I don’t text message,” he said. In addition, text messages would be one more distraction, since text messaging creates another place needed to check for messages. He believed that it would be “better if people just use all the mediums that are currently available to them.”

Relevant Findings

There are a great deal of challenges working with a distributed team. In addition to the lace of visual cues indicating someone’s reaction or availability, connecting with people is difficult without meeting them face to face. This makes understanding and appreciating others roles hard, which is important for morale and helping the team work together to complete a successful mission.

International Space Station (ISS)

We interviewed an ethnographer, who researched issues with planning on the International Space Station (ISS), at NASA Ames to learn more about how different groups plan and collaborate. She discussed a number of issues involved with planning both unique to ISS as well as global planning issues that apply to many NASA missions.

The interviewee worked as an ethnographer in investigating collaboration tools for the ISS planning mission. The ISS is an international effort, a major distinction from other NASA missions. As such, decision-making is distributed across different organizations. With distributed decision-making comes a number of different challenges in the planning process for ISS. Primarily, cultural differences between the different agencies complicate issues, and tools used are not standardized across these groups.

The issue of different decision makers has two components that make planning difficult. The primary component is the lack of centralized control and the decision-making groups' distribution. These decision-making groups typically only saw each other once a year, and even then the whole team did not meet each other because ISS operations occur 24/7. In day-to-day operations, these groups conversed over a teleconference like system to discuss planning. Translators are physically present, although the primary language used to communicate with one another is English. Other than the language barrier, the manner in which decisions and consensus occurs is different for each agency because of the inherent cultural differences. Some groups are very polite, silently pushing off arguments, whereas others are blunt and quick to disagree with anything new. This dynamic requires careful understanding when plans are negotiated because agreement from one agency may not actually mean true agreement.

In addition to these cultural differences, the tools used for planning are also different across each agency. Within an agency, some individuals have access to a planning tool that helps define constraints, but changes are always exported out into an excel spreadsheet format because everyone does not have the more specific planning tools. Within NASA this is the plan's primary form and is the format people refer to during planning meetings. This excel spreadsheet is then made accessible to all other agencies and used as reference during global planning meetings.

One important distinction is that while these tools are different across agencies, communication is standardized. All ISS agencies utilize a LOOPS system, which is similar to several teleconferences running simultaneously, with each LOOP having a specific function or group assigned to it. These LOOPS are completely public to every ISS agency and is the main tool for communication.

Some groups are very polite, silently pushing off arguments, whereas others are blunt and quick to disagree with anything new.

Relevant Findings

The interview gave background on how non-robotic missions are planned and operated. Many of the issues of working with distributed decision makers will have a great deal of relevance to future rover missions, such as MSL where a major portion of the mission will be distributed.

IBM Research

We interviewed Michael Muller at the CHI conference in order to learn more about IBM's social networking site "Beehive", and his efforts to development metrics that measure the success of social software applications in the workplace. The possibility of incorporating aspects of social networking in a planning tool design in order to improve collaboration between scientists and engineers made this interview interesting.

Michael Muller is a Research Scientist with the Collaborative User Experience group at IBM researching social collaboration, and is a co-developer of many participatory design practices. Muller strongly believes that social software benefits the workplace by increasing empathy and collaboration among group members. However, corporate supporters are not interested in hypothetical benefits, and want to know exactly how social software will help them make money. Muller has attempted to develop quantifiable methods to measure social software's success. He created an algorithm that counts the number of people who produced content and divides this number by the number of people who view content. This algorithm attempts to determine the effectiveness of these services. Muller is still working to try to measure the cost savings to a company by using social networking, and determine whether the benefits of workplace social networking out-way the time spend using these services.

Relevant Findings

Muller provided insights into the benefits of social networking in the workplace and advice utilizing such benefits. Empathy and collaboration are important among group members for increasing efficiency and productivity in the workplace, however quantifying these benefits remains a challenge.

Machine Shop

We interviewed a machine shop foreman to get an understanding of the planning process that goes into creating a machine part. He works with customers who may or may not know the capabilities of the equipment in the shop, and may not be aware of the constraints they work with. The dialog between the foreman and his customers is similar to that between the scientists and engineers during the mission planning process.

The shop foreman has expertise in design for manufacture. His customers often have an idea of what they want, but they do not have a drafting background so they cannot communicate through a drawing. Also, they may not know how to design or fabricate a device to fit their need.

The foreman will interpret drawings that his customers bring in, or help them to create a drawing for their part. He then creates a mental sequence of operations that are needed in order to create the part. This sequence may be passed to the other crew members in the shop, depending on who is completing the work. However, the other crew members in the shop do not have the same expertise as the foreman. Sometimes, they will ask the foreman questions regarding design specifics, and he will suggest more efficient ways of machining the part.

The process is very iterative, and the foreman stays in constant communication with the customer. He will call if problems arise, and to discuss new options. He also helps the customer work through their design and come up with a concrete part to be machined. Some customers rely on his design expertise in order to manufacture the part to fit their needs.

Relevant Findings

The customers do not always know exactly what they want. Often, they know the end goal, but are not aware of the part that may be needed to achieve that goal, or the process involved to make the part. The foreman must interact with a range of customers, from those with no machining, drafting, or design knowledge, to experienced faculty with a clear vision.

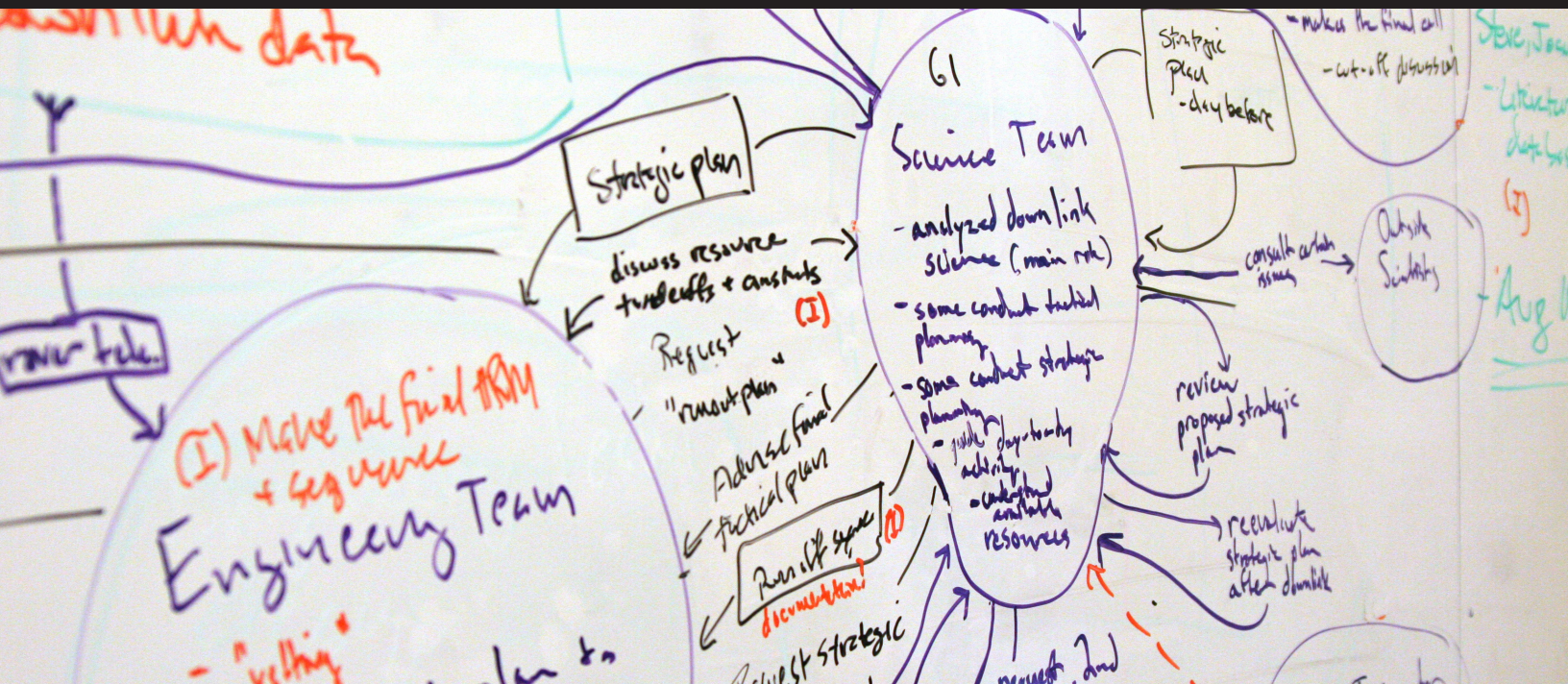
The process is very iterative, and the foreman stays in constant communication with the customer. He will call if problems arise, and to discuss new options.

APPENDIX C: COMPETITIVE ANALYSIS

	Chat	Video Conferencing	Screen Sharing	Real-Time Document Editing	File Sharing	Teleconferencing	User-Generated Polls	Blogging	Social Networks
Microsoft Sharepoint			✓		✓			✓	
Alfresco	✓	✓		✓	✓		✓	✓	✓
Cicso WebEx Connect	✓	✓			✓	✓			
grapeVINE	✓	✓		✓		✓		✓	✓
Oracle AutoVue Enterprise Visualization		✓	✓		✓				
Collaber	✓		✓	✓	✓				✓
Cisco TelePresence	✓	✓		✓	✓	✓			✓
IBM Lotus Notes & Domino	✓			✓	✓			✓	✓
LiveMeeting	✓	✓		✓	✓	✓			
Qnext	✓	✓			✓	✓			
Vignette Collab	✓	✓	✓		✓	✓			✓
Cisco Unified MeetingPlace		✓	✓		✓	✓			

APPENDIX C: COMPETITIVE ANALYSIS

	Chat	Video Conferencing	Screen Sharing	Real-Time Document Editing	File Sharing	Teleconferencing	User-Generated Polls	Blogging	Social Networks
IBM Lotus Sametime	✓	✓	✓		✓	✓	✓		✓
GoToMeeting	✓	✓	✓	✓	✓	✓			
Ramius Sixent Enterprise	✓		✓		✓			✓	✓
Documentum					✓			✓	
ooVoo	✓	✓			✓	✓			
IBM Cognos Business Intelligence					✓		✓		
TeamViewer			✓	✓					
Ramiu CommunityZero	✓							✓	✓
Aardvark	✓								✓
Google Voice		✓				✓			
BackType								✓	✓
Skype	✓	✓				✓			



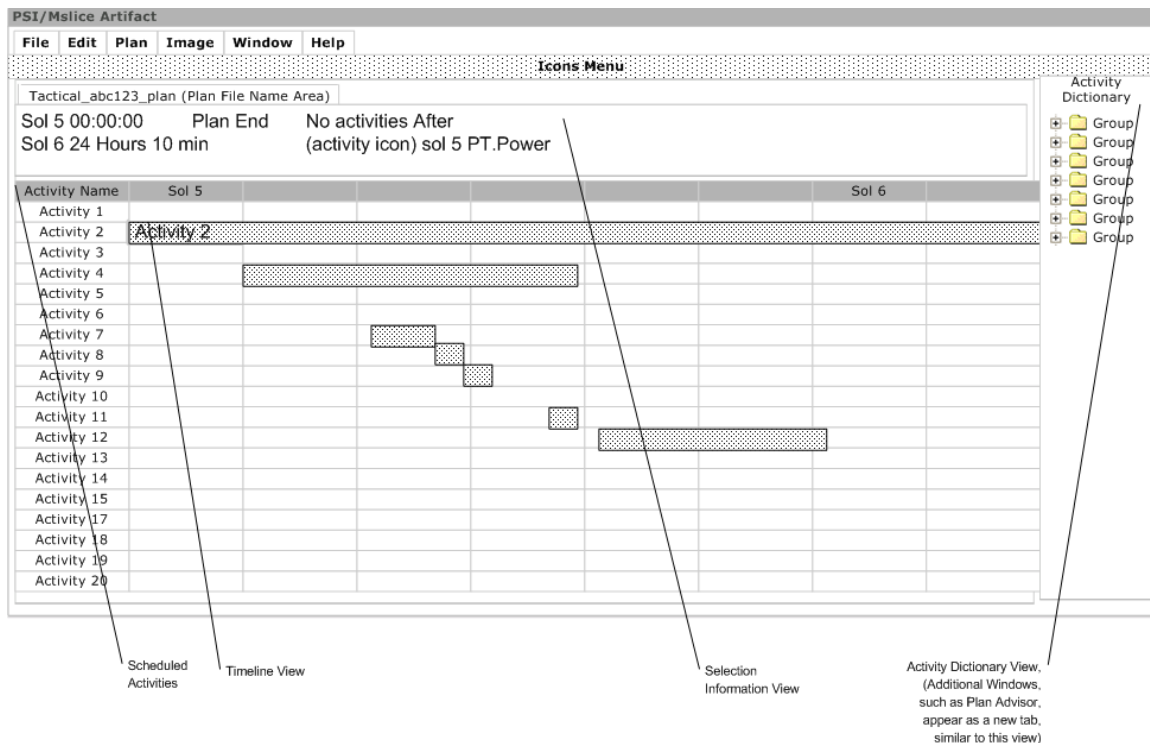
APPENDIX D: CONSOLIDATED MODELS

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MER Cultural	74
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MDRS Cultural	78
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PSI and MSlice

PSI, or Phoenix Science Interface, was the mission planning software used on the Phoenix Mars mission. As access to software was not possible, we analyzed hundreds of screenshots to determine functionality. Our focus was on the planning functionality as that most directly corresponds with our research focus. The software planning functionality is extremely timeline centric, with current scheduled activities shown on the left, and possible activities typically shown on the right. As the interface is based off of Eclipse, user interface elements can easily be moved around. The most notable features were the plan advisor and the selection tool. The plan advisor analyzes the current plan, checking for basic plan conditions letting the user know if it has any major holes or gaps. The selection tool, used to interact with the timeline indicates absolute time range selected, time duration, and closest scheduled activities to this range. Each activity is grouped by instrument on the rover and graphical resource visualizations of these instruments can be seen alongside scheduled activities.

MSlice, slated for use on the Mars Science Lab mission, is based off PSI and hence has very similar functionality. The interface layout is similar to PSI, using the same Eclipse software as a base. For planning we were interested with the different activity placement/constraint tools. Activities can be loosely bounded in either one or both directions (earliest, latest, or both), chained together in sequence (preserves order but allows individual movement), grouped (preserves order and inter-sequence position but allows group movement), pinned (absolutely locked at a point in time), as well as more complicated constraints. All noted functionality in PSI appeared to be present in MSlice.



APPENDIX D: CONSOLIDATED MODELS

LTP Spreadsheet

The Phoenix long term planning spreadsheet was meant to facilitate the strategic planning process, and to become a historical record of the activities that were carried out for each sol. This spreadsheet by its nature is very ad hoc, and evolved a great deal as the mission progressed. In addition to changing formats, the spreadsheet was also used to create multiple hypothetical plans, so keeping track of the final long term plan was a challenge.

Other challenges from this ad hoc nature include inconsistent activity listings. Individual listings of the same type of activity would vary slightly in the way they are listed and described. In addition, there is a great deal of variability in what actually appears in the long term plan. In comparisons with Sol Runner entries, often some activities occur that are never listed in the long term plan, and some activities in the long term plan are never listed out in Sol Runner. This problem is again highlighted with activities in the long term plan that reference past activities that are not actually listed in the spreadsheet.

Using Excel itself presented its own challenges, including the need to scroll through a long document in order to compare sols, as well as prevalent copy/paste errors.

The image shows a screenshot of a spreadsheet titled 'LTP Spreadsheet' with various annotations. The spreadsheet has columns for 'Planning day', 'PHASE NAME', and 'date'. Annotations include:

- 'due dates for plans (extended mission), about 2 days in advance' pointing to the 'Planning day' column.
- 'multi-instrument activities' pointing to a row with 'Restricted Power' and 'RA Interaction Limit (ISEs)'.
- 'camera sequences' pointing to rows for 'Sampling Interop' and 'Surface Imaging'.
- 'individual instruments' pointing to rows for 'instruments' and 'Coordinated Science'.
- 'activities coordinated with overhead satellites' pointing to the 'Coordinated Science' row.
- 'software updates, clean up, etc' pointing to the 'Engineering' row.
- 'downlink first pass' pointing to the 'D/L 1st PM Pass' row.
- 'dates listed for extended mission' pointing to the 'date' column.
- 'Inconsistent activity listings' with a red lightning bolt icon, pointing to a note: '-multiple activities can be listed under one instrument', '-short description, with note to clarify', '-very high level'.
- 'Excel not ideal tool' with a red lightning bolt icon, pointing to a note: '-comparing sols requires a great deal of horizontal scrolling', '-copy/paste errors easy to occur'.

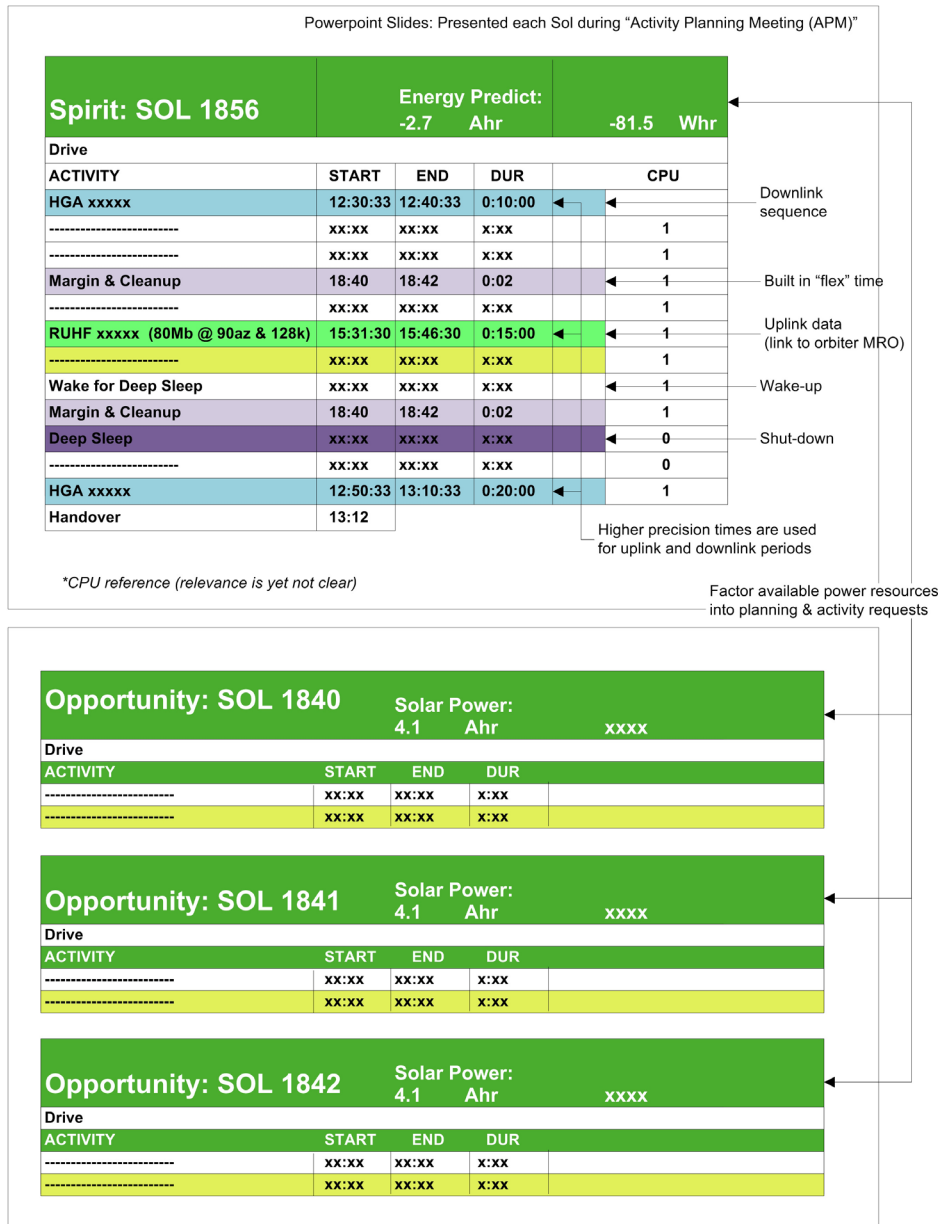
Planning day	PHASE NAME	date	date	date
Planning day of the week				
Tactical Planning sol#	Sol #			
Plans due by AM of:	date			
Restricted Power	watt hours	RESTRICTION		
RA Interaction Limit (ISEs)	1	2		
Sampling Interop	activity name, location (note)			
Surface Imaging				
instruments				
Coordinated Science				
Nighttime Science				
Engineering				
Wake/Sleep Times	hh:mm-hh:mm			
D/L 1st PM Pass	date, hh:mm			

Skeleton Plan

Mars Exploration Rover (MER) mission operations uses a “Skeleton Plan” Excel spreadsheet as a high-level guide for constructing sequences that define the next day of activities for Spirit and Opportunity, a pair of robotic rovers that operate on the surface of Mars.

Examples of these activities include driving to pre-defined destinations, capturing panoramic images and brushing rocks to search for water on the Martian surface.

Each day the Skeleton Plan is introduced during a kick-off meeting. Mission engineers use the schedule as “fence posts” that define fixed deadlines such as “downlinks, wake-up [and] shutdowns” that will occur during the next planning. Engineers fit [their] plan and the resources in between those fence posts.”



APPENDIX D: CONSOLIDATED MODELS

Sol Runner

We analyzed the content of 15 uplink and downlink report documents in Sol Runner find out if there were major formatting and content differences in shift report entries. To analyze style differences, we looked the entries for three different roles over time. We found major differences in the way articles were formatted between roles, within a role, and within a single author over time. In addition, we looked closely at three MECA IDE authors' entries in order to determine if there were major differences in the number of words they used and the size of their entries. We found that the average length of articles within the MECA IDE role varied dramatically between the authors. The first author's wrote two entries and her articles averaged 321 words per entry over 96 lines. The second author wrote three entries. Her articles average 476 words per entry over 130 lines. The third author's entries were much shorter than his colleagues'. He wrote six entries and his articles averaged of 137 words per entry over 43 lines. We conclude that there are major difference in the formatting and length of Sol Runner shift report entries within roles and between roles.

author 1	author 2	author 3
<pre> *AM pass* ----- *ACTIVITIES SEQUENCES UPLINKED* TECP OM/AFM *Expected data info* ----- *SUCCESS* ----- ***1st PM Pass*** ****2nd PM pass**** ****3rd PM pass**** Detailed Notes *EVRS* ----- Expected: Unexpected: TECP details Issues, Concerns and Requests </pre>	<pre> *****AM PASS*** *****ACTIVITIES SEQUENCES***** ----- AFM ----- ----- TECP ----- ----- *****DOWNLINK***** ***1st PM PASS*** MECA Condition: Good No unexpected EVRs. ***2nd PM pass**** MECA Condition: Good No unexpected EVRs. ***3rd PM pass**** MECA Condition: Good No unexpected EVRs. Detailed Notes ****1st PM pass*** </pre>	<pre> ----- TECP ----- ----- Expected EVRs: ----- Detailed Notes Issues, Concerns & Requests Attachments [Add] </pre>
		<p>Breakdowns: Different formatting Varying lengths and different types of information mentioned</p>

Maestro

Maestro is a constraint based, collaborative planning software used to build and refine a (N+1) plan. A Keeper of the Plan (KOP) set constraints from the Skeleton Plan, input from meetings and rough resource predictions generated by the tool.

Skeleton Plan (Excel)

Opportunity: SOL 1842		Energy Predict: -x.x Ahr xx.x Whr		
ACTIVITY	START	END	DUR	CPU
				1
				1
				1
				1
				1
				1
				0
				0
				1

(1) "In the Maestro plan you get say a block of remote sensing that is 30 minutes."



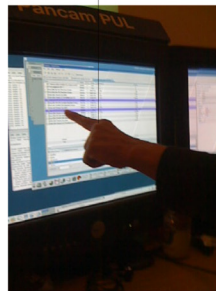
"Hand over plan" (l)

Maestro Plan

(4) "...the keeper of the plan has to go back and forth between the skeleton and the Maestro [plan]"

(3) "So we have a resolution pan that will take about 40 min"

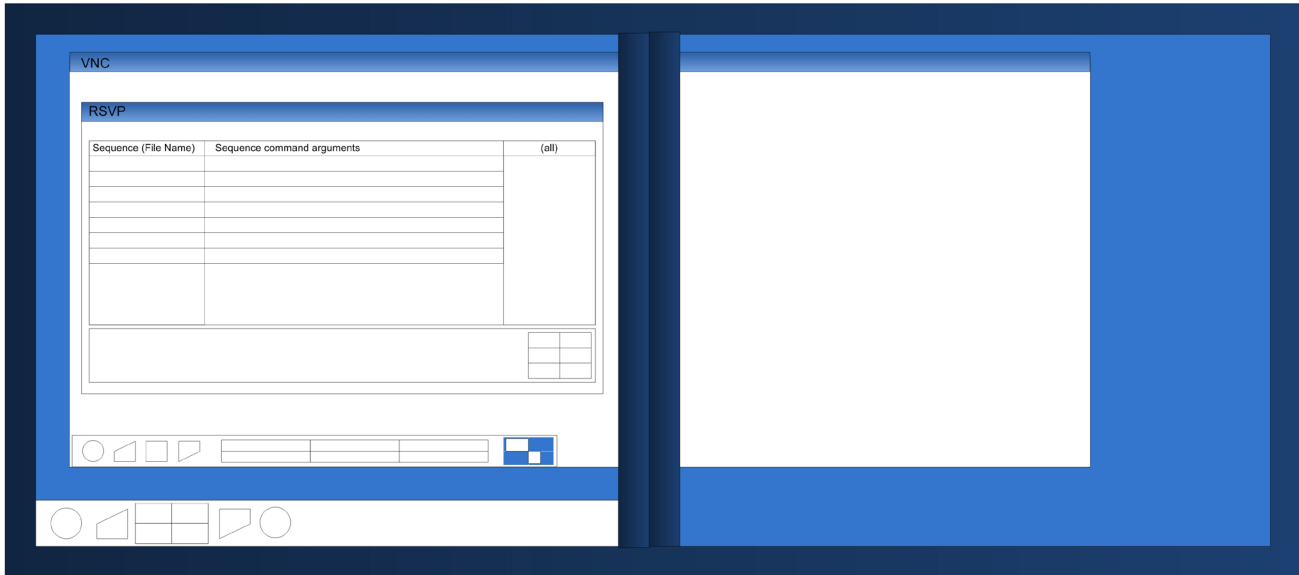
(2) "Maestro calculates the duration and data volume of the activities that you put in."



APPENDIX D: CONSOLIDATED MODELS

RSVP

RSVP, Rover Sequencing and Visualization Program, is software used to construct lower level sequences for robotic rover activities.



```
Command Line (Terminal)
> SeqInfo [number] b
Pancam -----
-----
-----
-----
-----
-----
```

PanSeq

PanSeq is a software tool, created by the MER operations team, for bridging high-level Maestro plans with the lower level sequences produced using RSVP.

SeqGen

SeqGen is a software tool used to produce resources higher resolution resource estimates than those estimated in Maestro.

HyperDrive

HyperDrive is a 3D simulator that provides robot drivers with additional context and assists mission engineers by visualizing shadows that appear on camera images taken at a particular time of day on Mars.

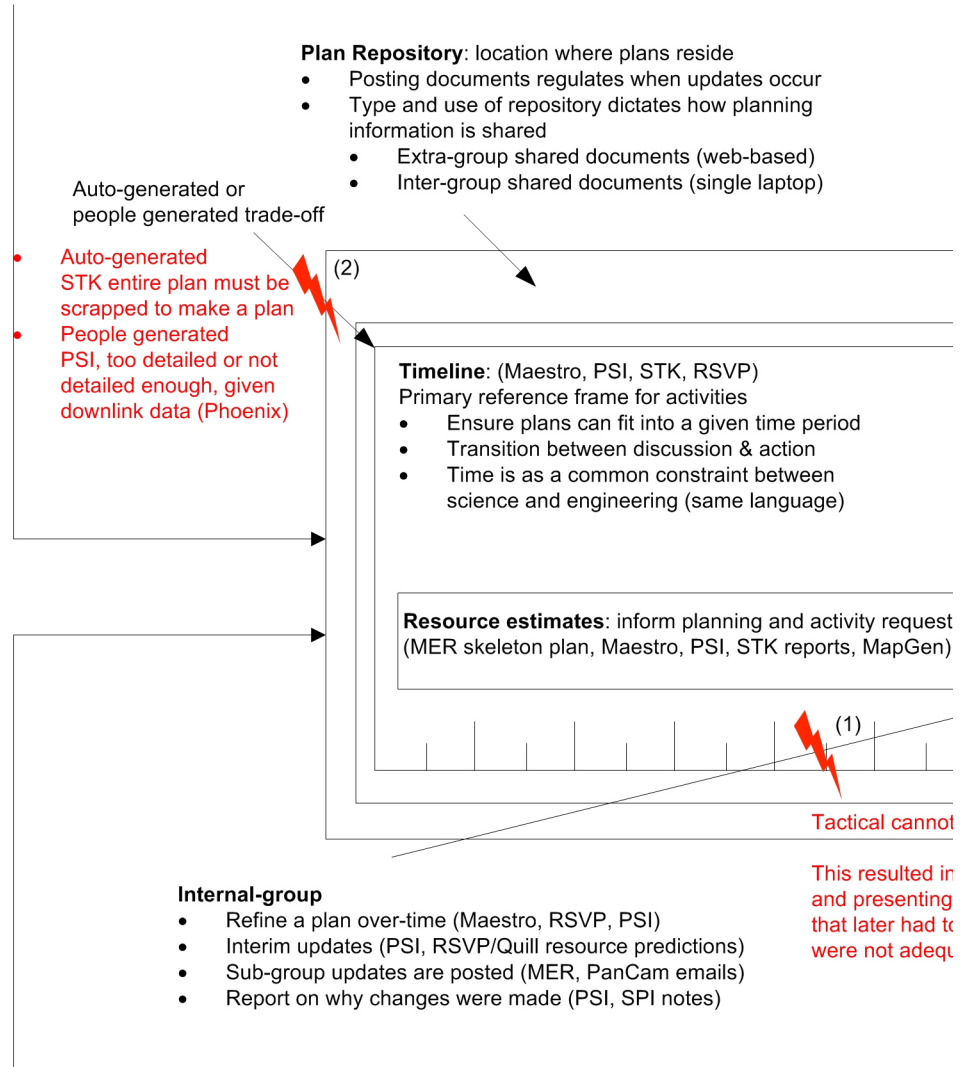
VNC

VNC, Virtual Network Computing, is a desktop screen sharing system. VNC supports the distributed mission by enabling mission engineers at Cornell to operate computers at JPL.

Consolidated Artifact

Presenting a plan to a group: (Global)

- Timeline is **visible, shared** (projected) during meetings and referenced during discussions
- Timeline represents a tangible, **working** consolidation of people's collective input
- **Encourages involvement** by making people's proposals concrete (set in time, common terms)



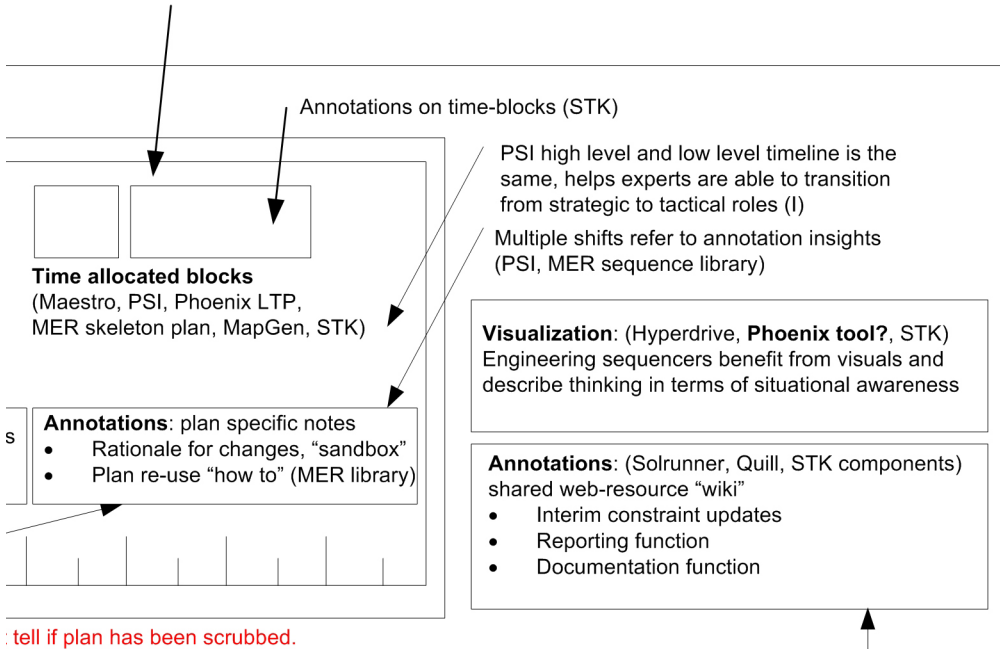
Tool specific levels of fidelity: (Global)

- Each tool serves a specific function during a specific step in the planning process
 - Minute level scheduling (RSVP, Rose, STK)
 - Day level planning (Maestro, PSI)
- "CAD" like assemblies concept is not present

(3) (Global) Tools can be domain specific using language that creates a barrier to entry for collaboration

Modify a plan: (RSVP, PSI, STK)

- Based on downlink data (report or unknown value)
- Based on misunderstanding (miscommunication of intent)
- Based on a preference to balance resources (SSL)
- Based on perceived competence of teammates (SPIs)



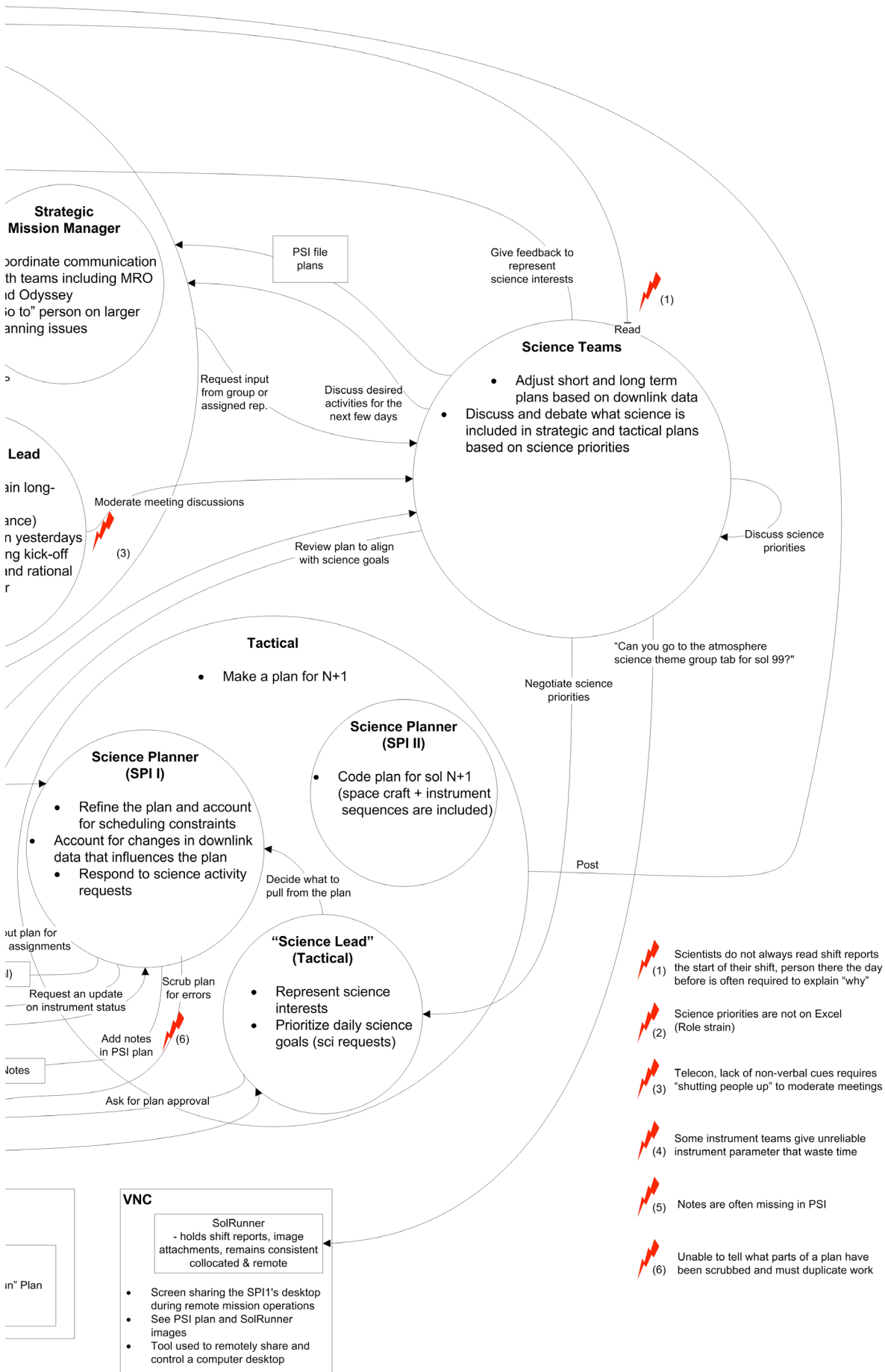
tell if plan has been scrubbed.

occasional duplication of work activities at midpoint meetings be dropped because they are rarely "refined"

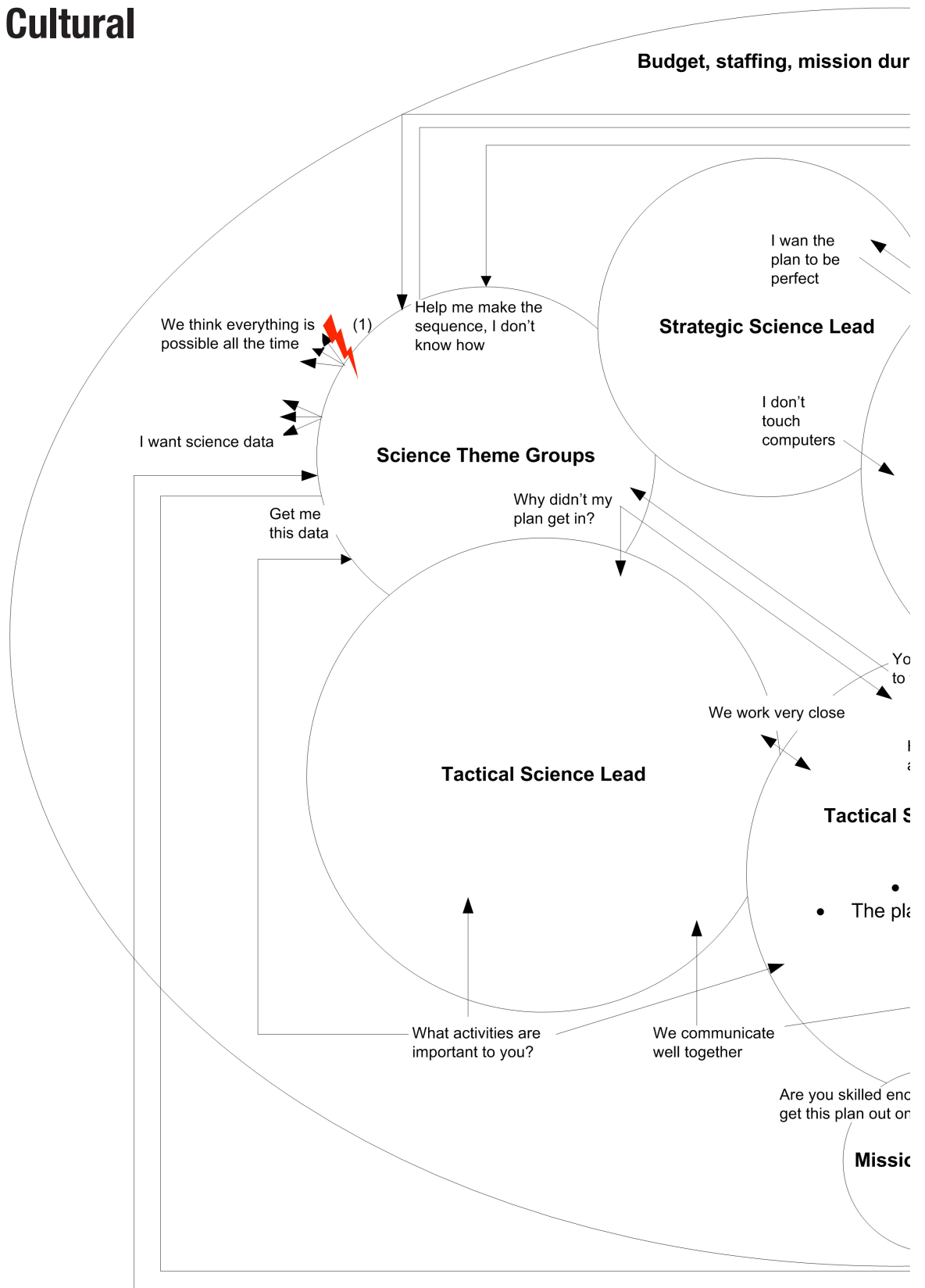
External-group

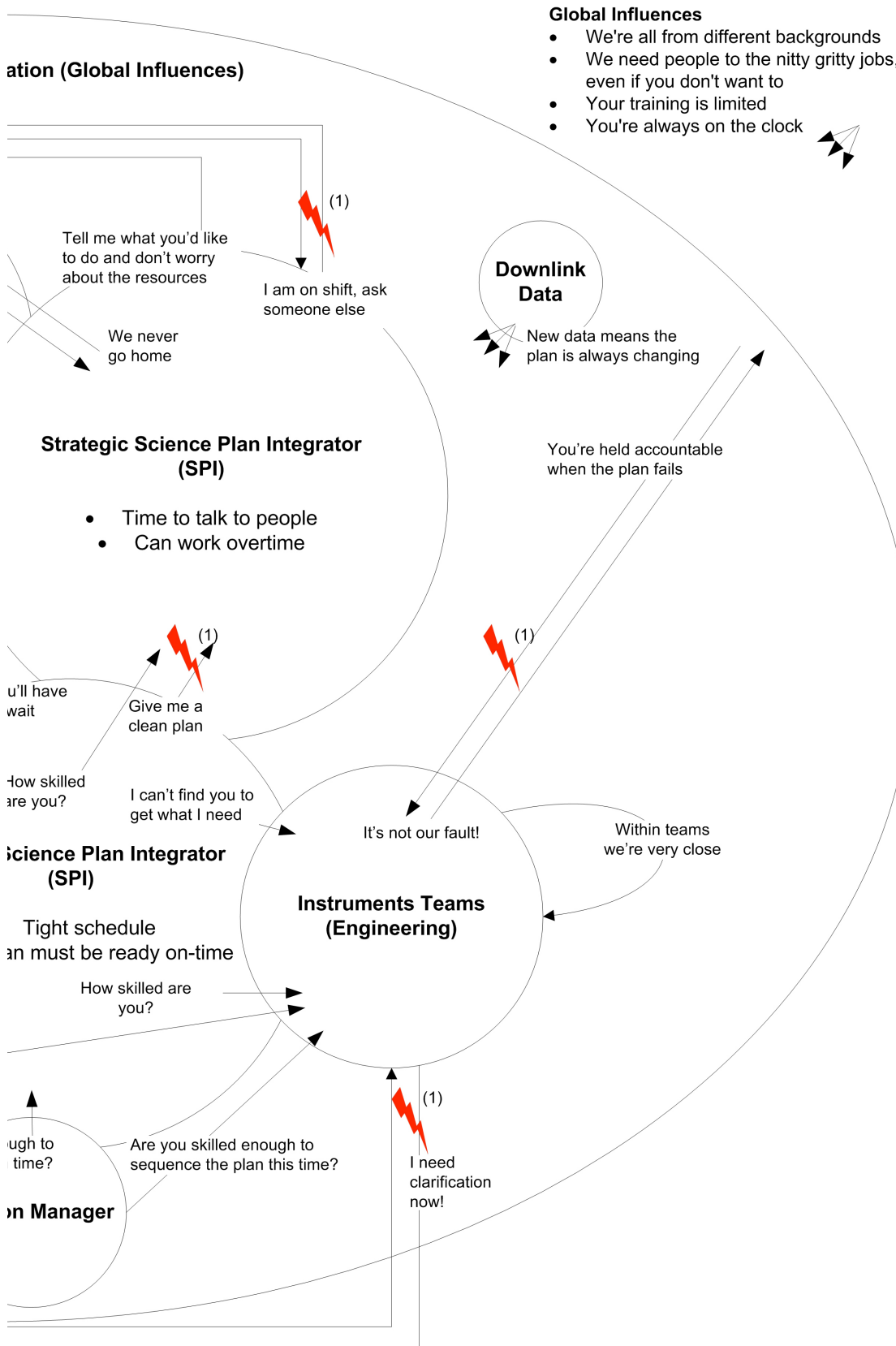
- Reporting on what has been done
 - Strategic Science Lead (SSL) report (Excel LTP)
 - MER (Situation reports for PanCam subgroup)
 - MER Quill (posted picture of planned camera coverage)
- Report on why changes were made (Shift reports)

APPENDIX D: CONSOLIDATED MODELS



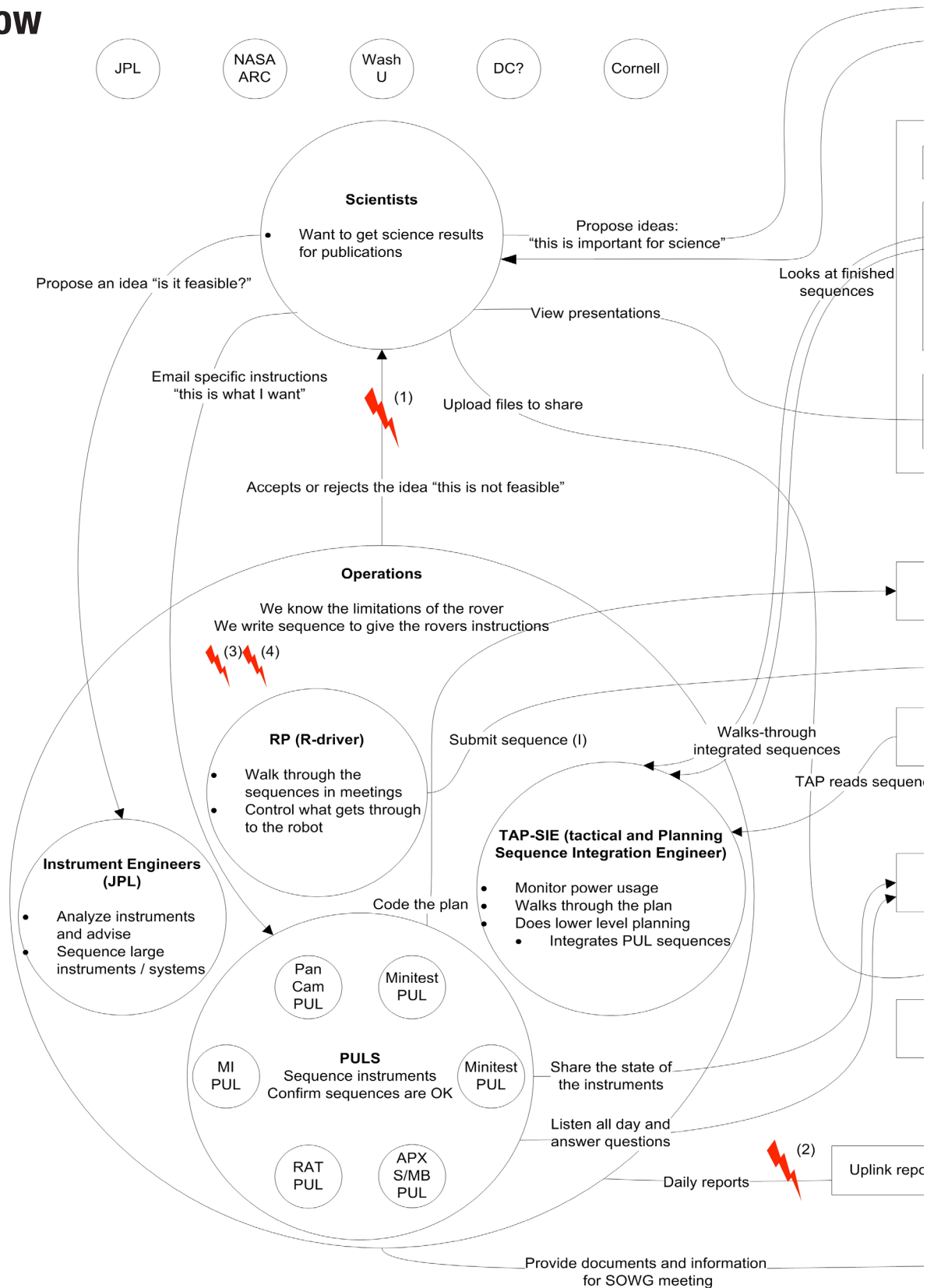
Phoenix Cultural



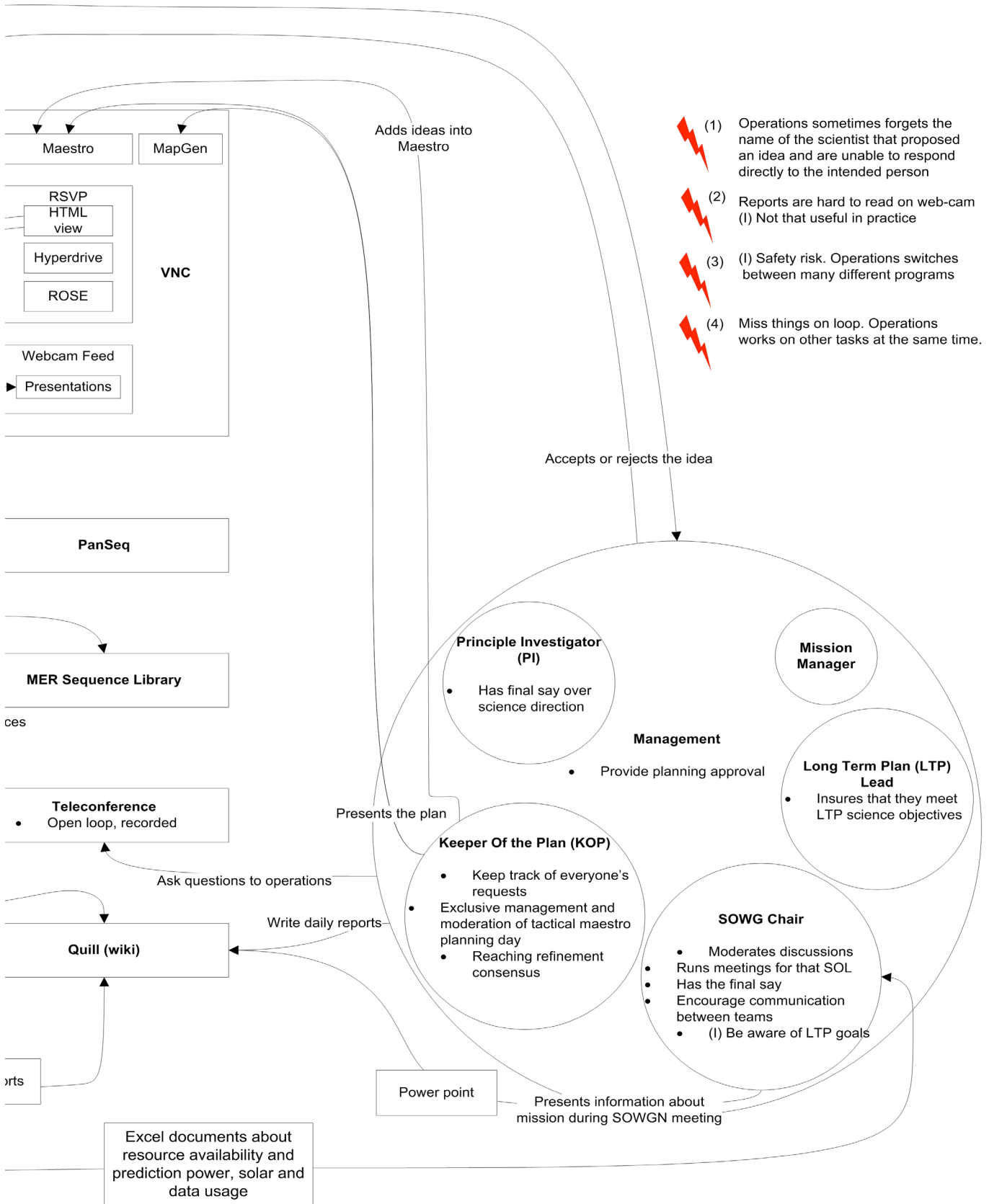


APPENDIX D: CONSOLIDATED MODELS

MER Flow

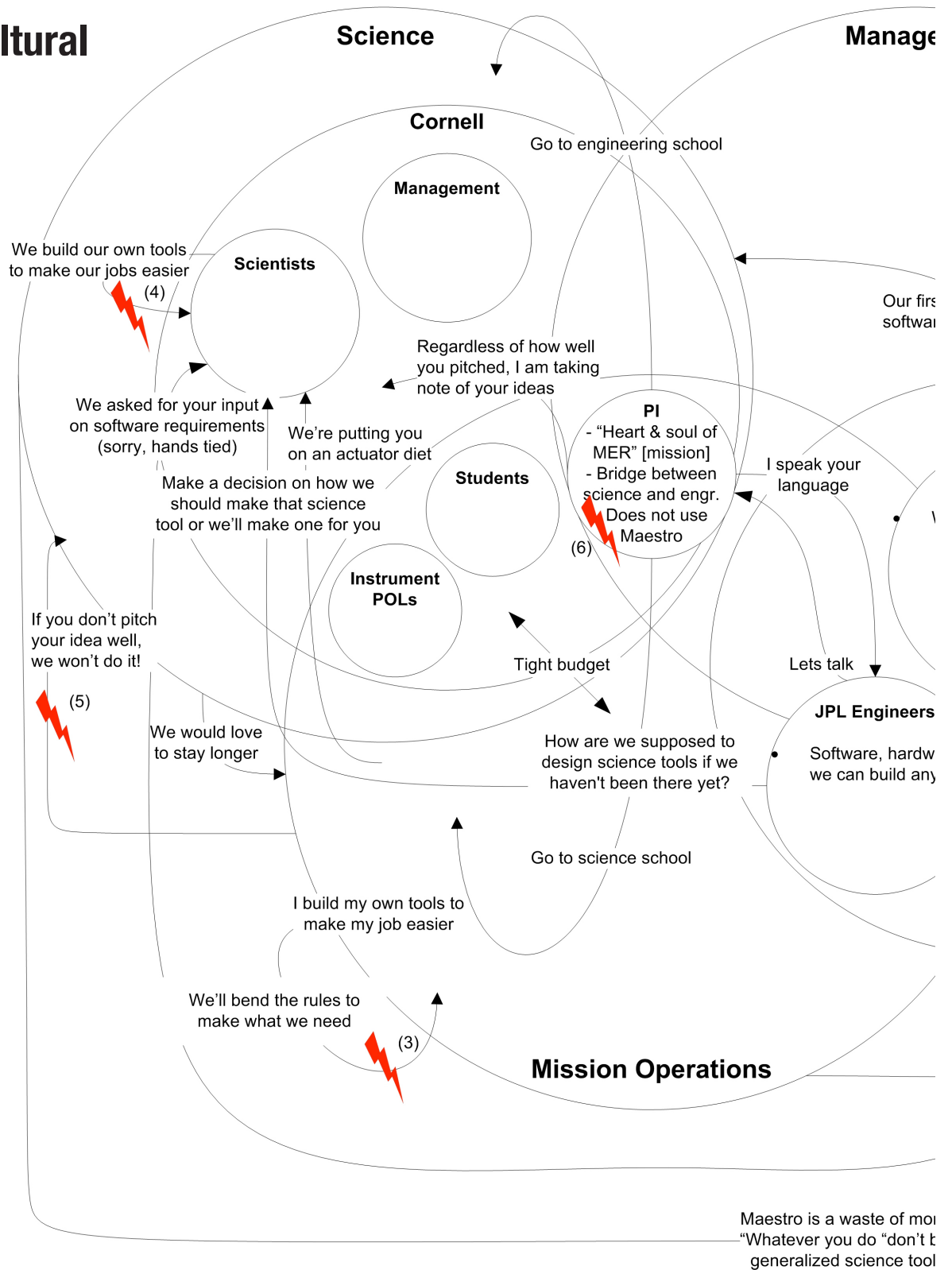


APPENDIX D: CONSOLIDATED MODELS

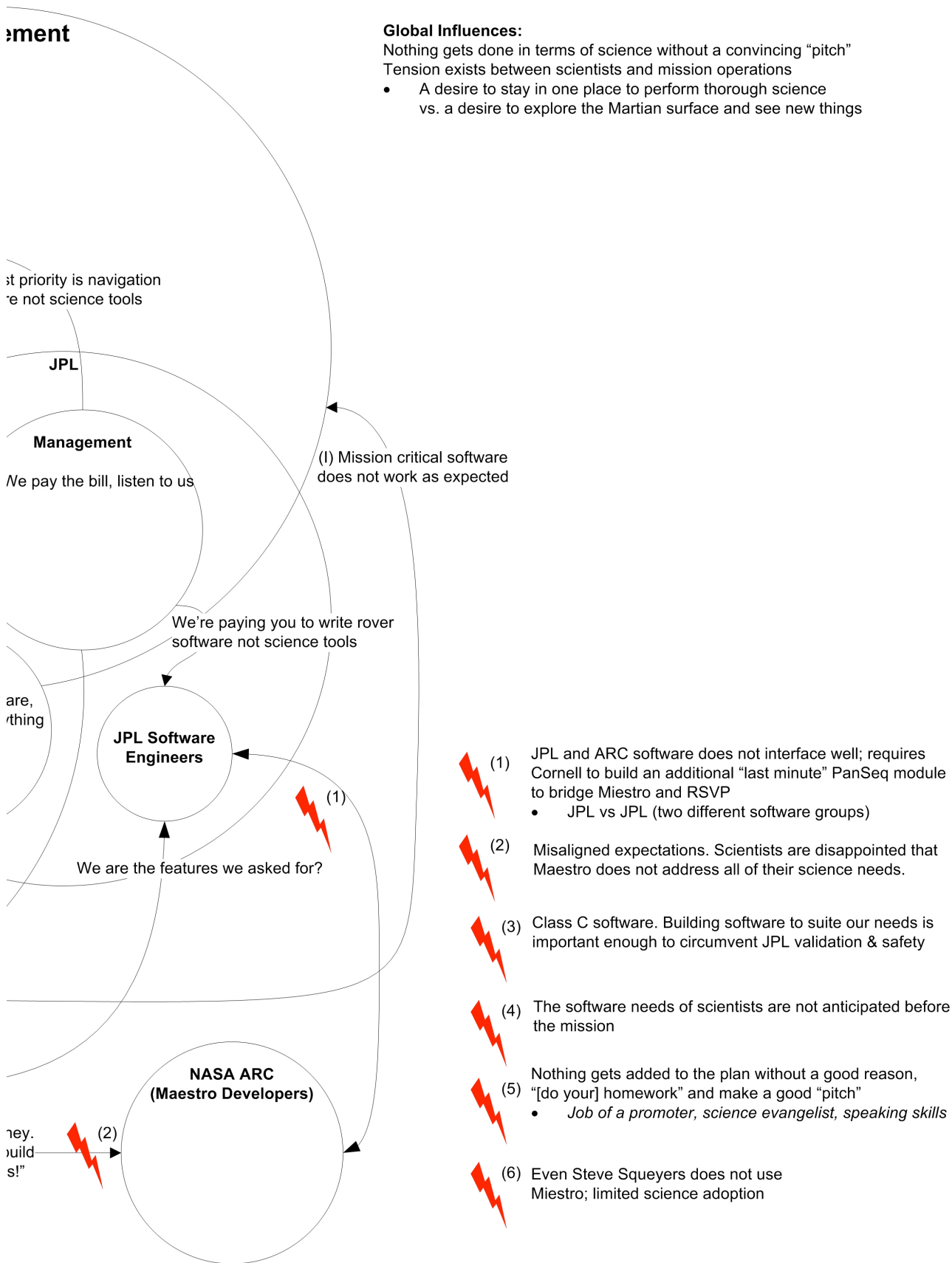


APPENDIX D: CONSOLIDATED MODELS

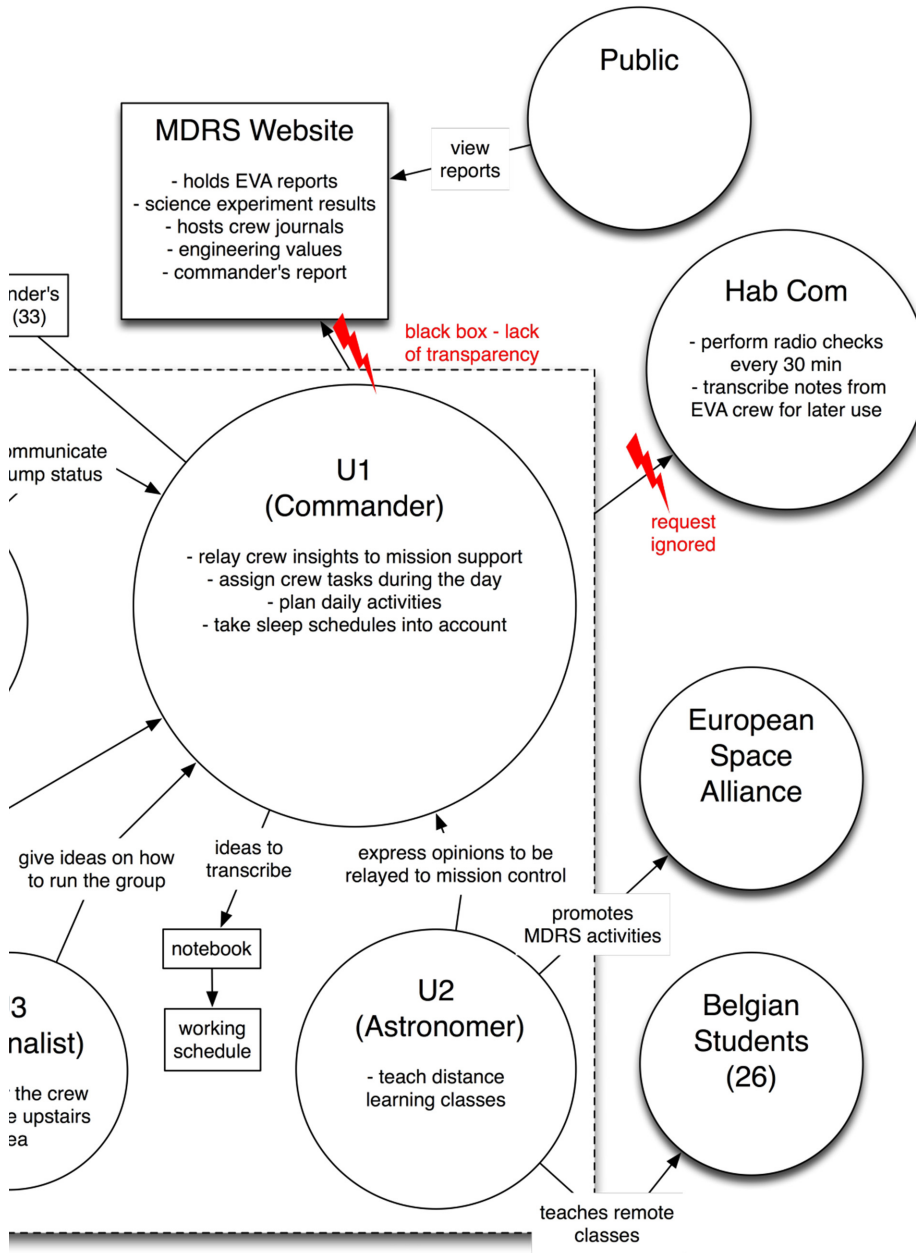
MER Cultural



APPENDIX D: CONSOLIDATED MODELS

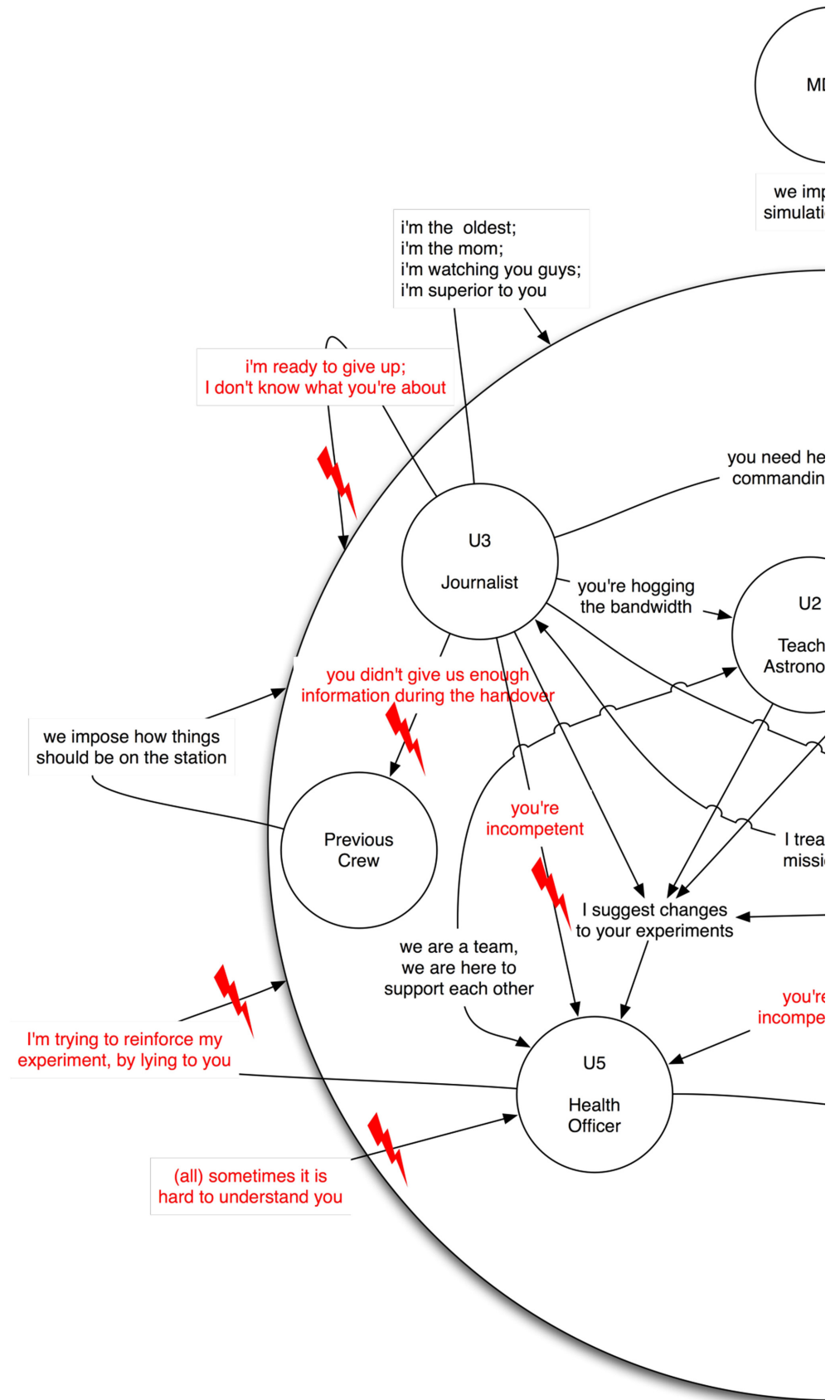


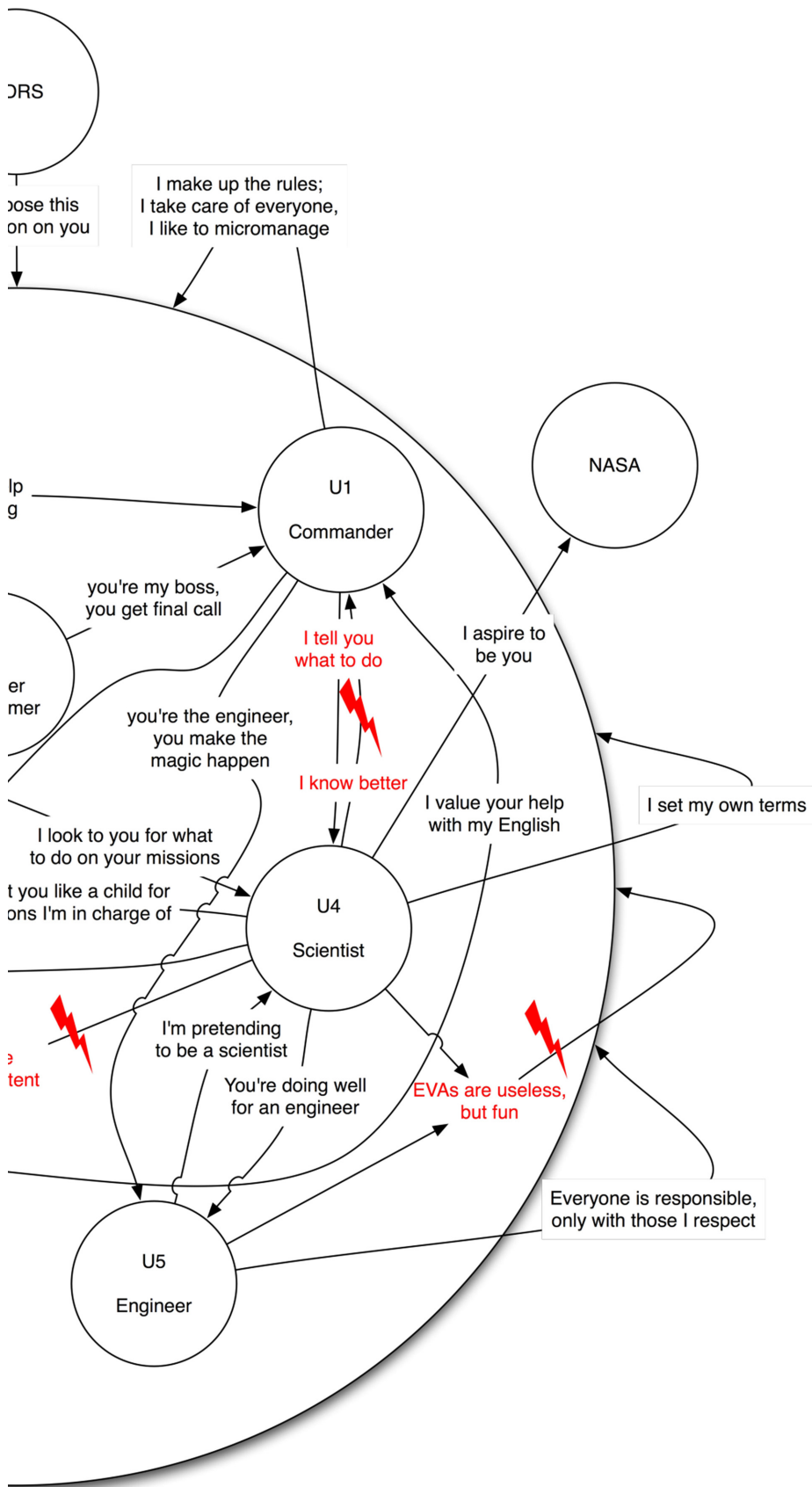
APPENDIX D: CONSOLIDATED MODELS



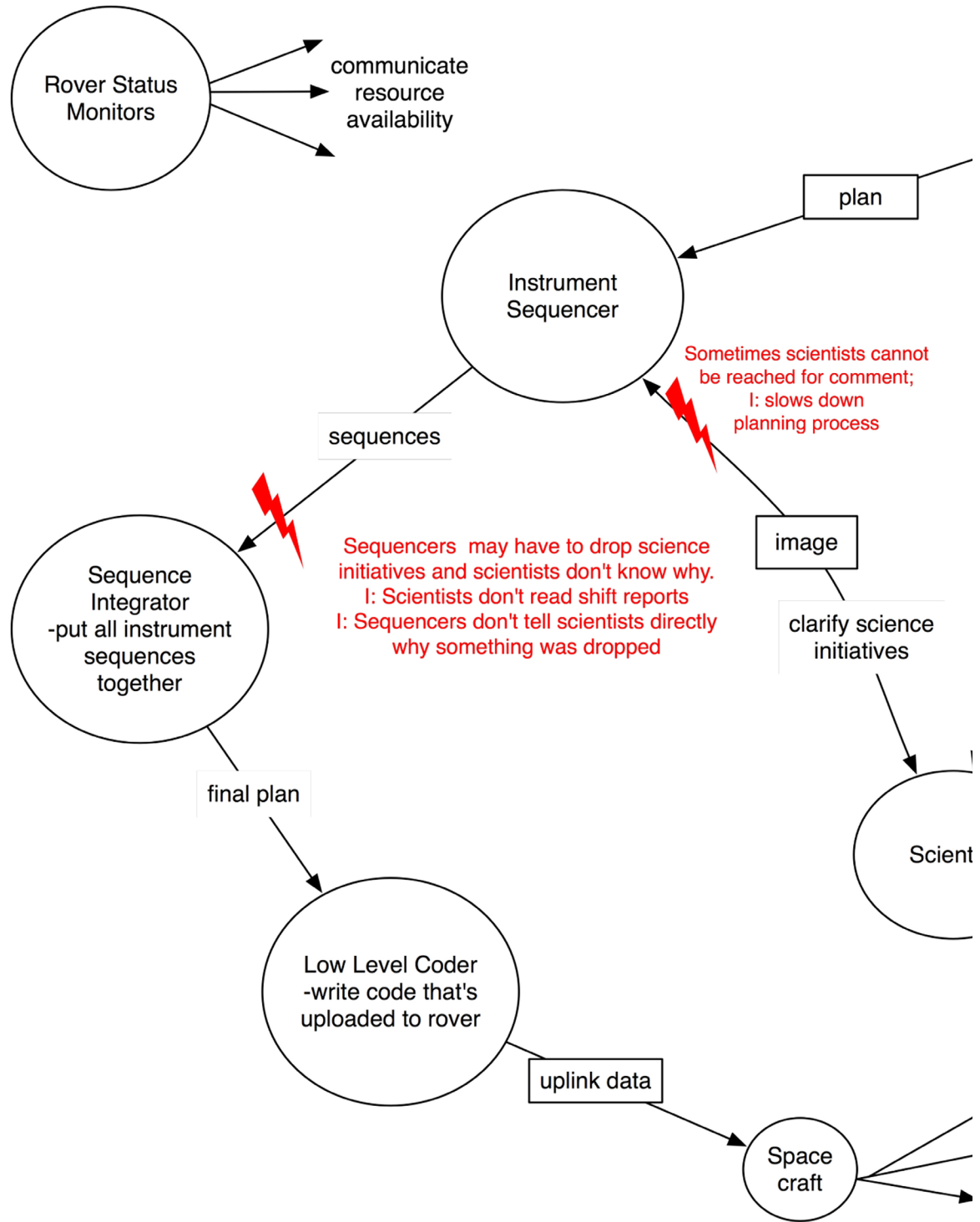
1p

MDRS Cultural





Consolidated Flow



APPENDIX D: CONSOLIDATED MODELS

