conveyance

helping scientists convey their planning goals

Masters of Human Computer Interaction
Final Capstone Project
Summer 2009 Report

M. Azim Ali | Jon Bidwell | Joanna Bresee | Jessa Hafer-Zdral | Steve Hillenius

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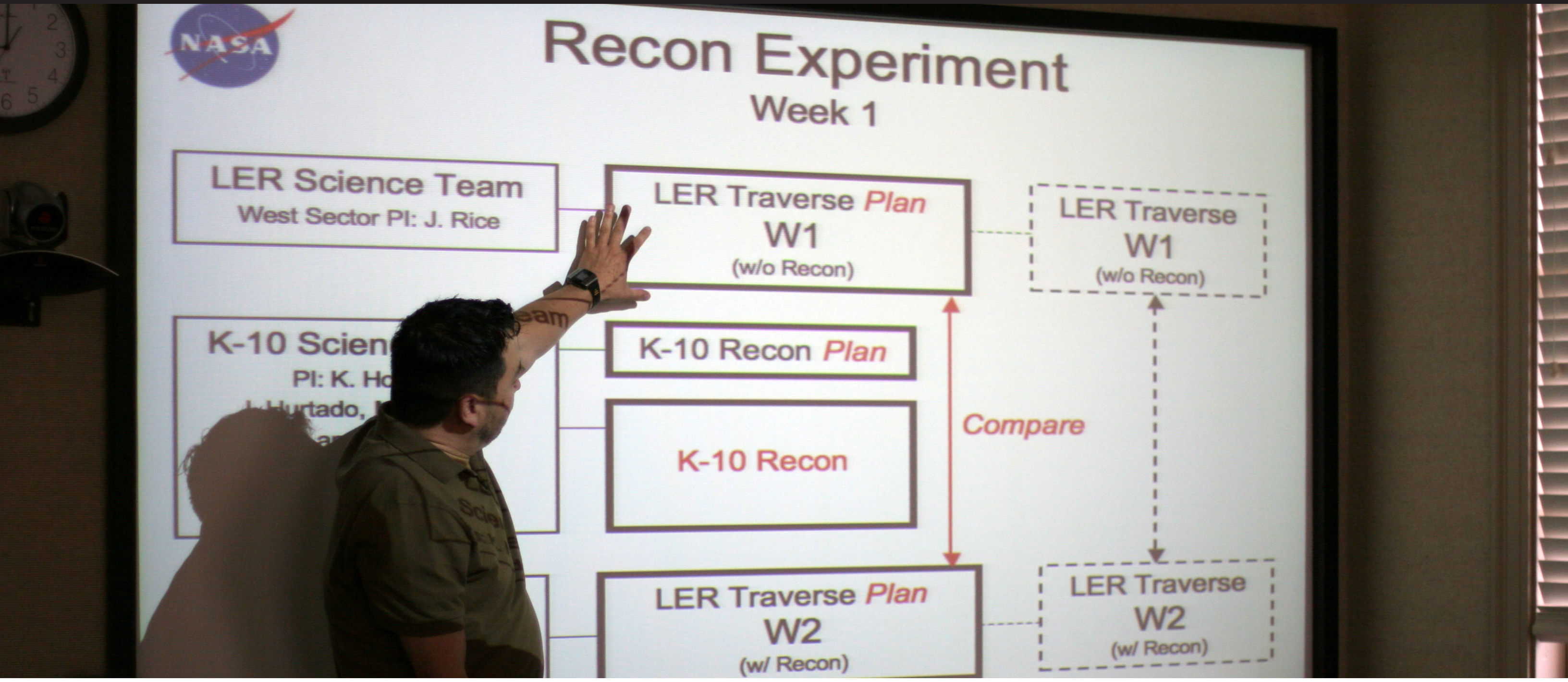


PROJECT INTRODUCTION

Introduction

This spring and summer, our team, comprised of five human-computer interaction masters students, focused on the challenge of planning lunar rover missions. During the spring semester, we researched the Mars rover missions to understand the problem space of rover planning, as well as collaboration between scientists, engineers and operations specialists during the planning process. During the summer semester, we applied our research findings to the domain of lunar robotic reconnaissance, which will support future human exploration of the moon, and designed a tool to help science teams more easily communicate their planning goals to the flight team for execution. Our project culminated in a final "Landing Day" scenario which allowed us to evaluate the success of our tool in meeting our design goals.

Our sponsor is the HCI Group at NASA Ames Research Center. We worked closely with Dr. Alonso Vera, Mike McCurdy, and Mel Ludowise during the spring and summer semesters. The HCI Group engages in a unique combination of applied, mission-critical work and innovative research.

Project Team

Steven Hillenius – Technical Lead

Steve's undergraduate degree from CMU is in Information Systems and HCI. He has experienced internships in both fields, although most recently he was a Usability Analyst at salesforce.com. There, his main project was a competitive analysis using quantitative usability methods.

Jonathan Bidwell – User Research Lead

Jonathan is a graduate of Rensselear Polytechnic Institute with a B.S. in Computer and Systems Engineering. His work includes the development of multiple human robot interfaces that are in use today at NASA, the US Air Force and CMU. Jonathan is currently leading a team to develop an operator interface for CMU's lunar rover entry into the X Prize competition.

M. Azim Ali – Project Manager

Azim earned his B.S. degree in Psychology from CMU in 2006. His research focused on attention, visual perception, and problem solving. Upon graduating, Azim continued his studies in cognitive psychology as a graduate researcher at Florida State University. He utilized protocol analysis to investigate learning and memory, information processing, and expert performance.

Joanna Bresee – Design Lead

Joanna's undergraduate degree from CMU is a joint degree in Anthropology and Art, with an additional major in HCI. She spent a semester studying ethnographic research techniques in Madagascar. She is currently a research assistant for CMU's Usable Privacy and Security lab.

Jennifer (Jessa) Hafer-Zdral – Web/Document Lead

Jessa is a graduate of Reed College with a B.A. in Psychology. Her undergraduate thesis explored voice and face perception. Jessa is drawn to HCI's interdisciplinary approach to problem solving and feels that a lot can be learned from approaching a task from different perspectives.

Executive Summary

With the International Space Station nearing completion, and the space shuttle soon to retire, NASA is setting its sights on 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. NASA will use a process called robotic reconnaissance to support the remainder of the mission.

Robotic reconnaissance uses scout rovers to explore the surface of the moon prior to the crew's arrival. The rovers collect surface data that can help improve science return, improve crew productivity, and reduce operational risk. Managing these rover operations calls for a great deal of research in rover controls, and efficient planning for rover utilization.

For our MHCI capstone project, we sought to contribute to this objective by creating a tool to allow scientists to more efficiently plan for robotic reconnaissance missions and clearly communicate planning goals to flight operations. The project spanned two semesters; the spring semester was spent exploring the domain and conducting user research. The summer semester focused on design, development, and user testing.

Research

We began our research by reviewing related literature and conducted a competitive analysis to expand our understanding of the planning process. The literature review gave us insights into both the human and technological aspects that affect collaboration. The competitive analysis of commercial collaboration tools gave us an overview of which collaboration issues are currently being addressed and how the tools are addressing them. We also conducted eleven interviews and six contextual inquiries on NASA missions including the Phoenix Land and Mars Exploration Rovers (MER). We also investigated domains outside of NASA.

Our research revealed 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. 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.

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

Design

The design phase began with translating our research findings into specific design goals. To test our design concepts we presented ten storyboards to members of the robotic reconnaissance field test to determine scientists' greatest need within the planning process. We then moved into an iterative design process in order to determine the best way to address the scientists' needs and continually refine these features. We tested paper and digital prototypes with seventeen participants to refine the interactions and usability of our software. We then performed three Operational Readiness Tests (ORTs) with six users to test the tool in the context of a planning scenario in preparation for the final "Landing Day" simulation.

Conveyance

Our goal was to create a planning tool that would allow scientists to create a mission plan in a way that easily conveys plan goals to the flight team. This tool, Conveyance, focuses on the data products the scientists want to receive, instead of the instrument specifications required to achieve that data. It has a heavy emphasis on a map, for contextual information, and allows science goals to be conveyed within the plan itself with four key features: a field of view visualization for lidar and panorama images, an activities list, a tool bar, and a notes field. Users can drag observations for the rover to perform directly from the tool bar to the map. In additon the camera field of view and resolution for certain activities is also represented and can be directly manipulated visually on the map, These observations then show up in the activities list, representing the order activities the rover will perform. Users can also add notes to each activities, providing further descriptions of what they are trying to accomplish at each point.

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

A member of the science team planning during a field test simulation

Final Evaluation- Landing Day

The purpose of the simulation was to assess whether or not our planning tool successfully captured the science team's planning intents and conveyed them to the flight team.

We evaluated the success of our tool in a simulated robotic reconaissance field test with six participants. The simulation consisted of a science team, flight team, and rover team. The science team created a rover traverse plan that indicated observations they would like a rover to do and sent the plan to the flight team. The flight team then made adjustments to the science team's plan in response to special constraints that we gave them. Finally, a rover executed the modified plan, collected the data products, and sent the images to the science team.

The purpose of the simulation was to assess whether or not our planning tool successfully captured the science team's planning intents and conveyed them to the flight team. We determined the success of our planning tool by whether or not the flight team understood what the science team wanted to do, and made changes to the plan that were consistent the science team's goals. In ad-dition, we evaluated whether or not the scientists felt that the data products they received from the rover where consistent with the data they requested, in spite of the flight team's adjustments to their plan.

Simulation participants found the interface very straightforward and easy to use, effectively supporting the ability for science team to create plans themselves. The visual aspects of the map and camera field of view representation helped make the interface very intuitive, not only clearly indicating the constraints of the available instruments but also visually communicating the science team's planning goals. The abiltiy to indicate planning goals was also successfully supported by the notes field, which allowed the science team to explicitly communicate what observations the wanted to perform at each point.

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.

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. To acheive this, our focus was to help scientists' clearly convey their planning goals to the mission planners.

Scientists work with mission planners to sequence science initiatives, but often do not know whether the activity was performed as requested.

Robotic Reconnaissance

We applied our research findings toward designing a planning tool for robotic reconnaissance missions. Robotic reconnaissance is the process 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

Science room during the robotic reconnaissance field test

(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.

RESEARCH PROCESS

Introduction

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, as well as retrospective contextual inquiries where interviewees walked us through their daily planning activities, to refine our understanding of mission planning during NASA robotic exploration missions. These accounts provided opportunities to better understand how the roles and responsibilities involved in mission planning changed over time and allowed us to get an understanding of domains that would otherwise be 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 as unmanned Mars missions. Operating rooms must coordinate limited hospital resources (such as an Magnetic Resonance Imaging machine) with patient health and surgeon availability in order to reduce downtime.

The research revealed both problems with collaboration, potential solutions for those problems, as well as 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 identify cross-cutting collaboration issues and compare how each tool addressed such issues using specific features of the software. To better understand the purpose of each software tool, 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. For example, we found in our CIs that Phoenix scientists annotated images on paper to convey their exact analysis needs to engineers. While easy to do on paper, current commercial tools poorly support in-situ contextual information exchange. Overall we found that the commercial collaboration tools ranged widely between the features they supported and were too generic for use in distributed planning.

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

Interviews

We performed eleven interviews over the course of the spring semester to learn about mission planning during two of NASA's Mars exploration missions, Phoenix and MER. The objective of these intereviews was to identify successful strategies for planning in enviroments that share similarities with robotic reconassance field testing, where people from different backgrounds must work together to create a plan based on constantly changing information.

Finding appropriate CIs proved difficult. Missions such as Phoenix are no longer running, ruling out the option of conducting CIs in this environment. For this reasons, these interviews and retrospective CIs proved to be extremely valuable for gaining contexual information needed to better understand current limitations and challanges faced during mission planning. 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 performed 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.

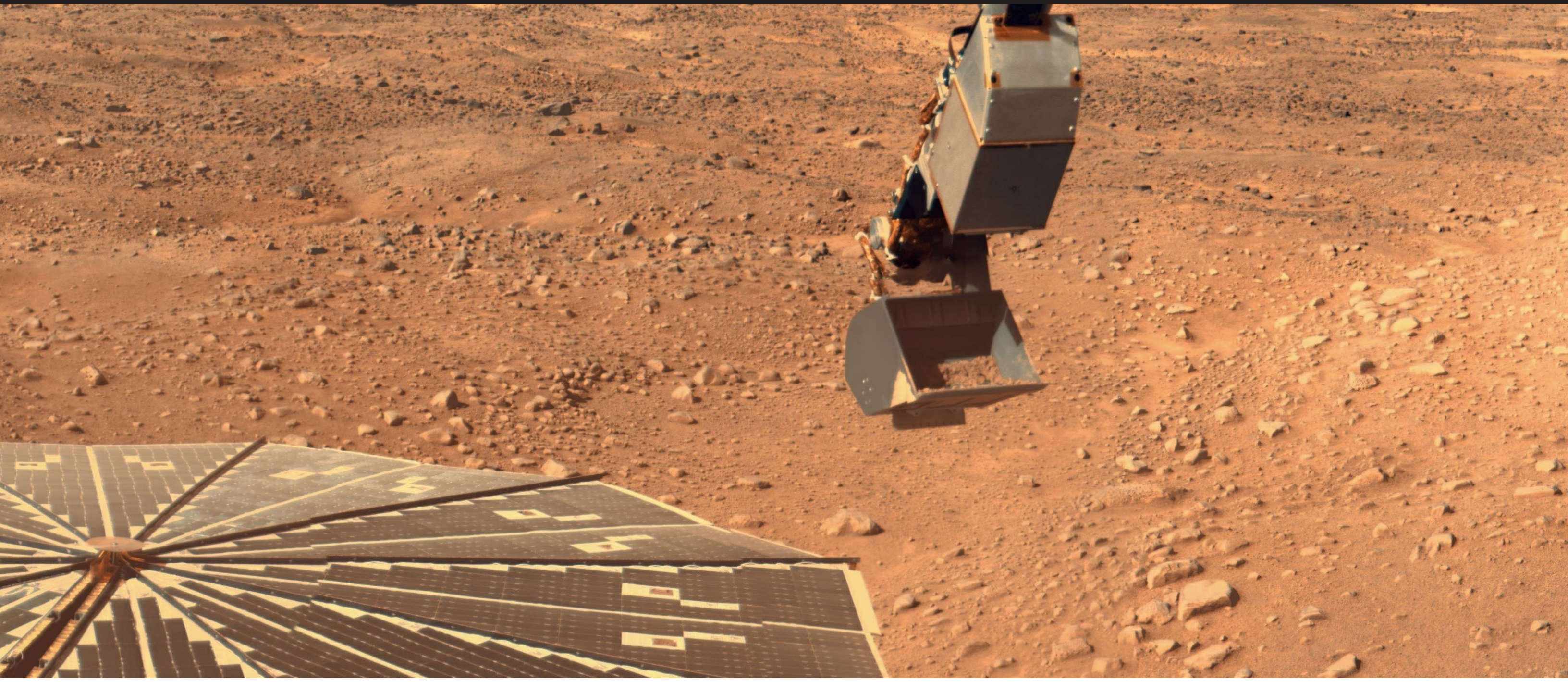
Mars Exploration Rover (MER)

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 constrasted 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.



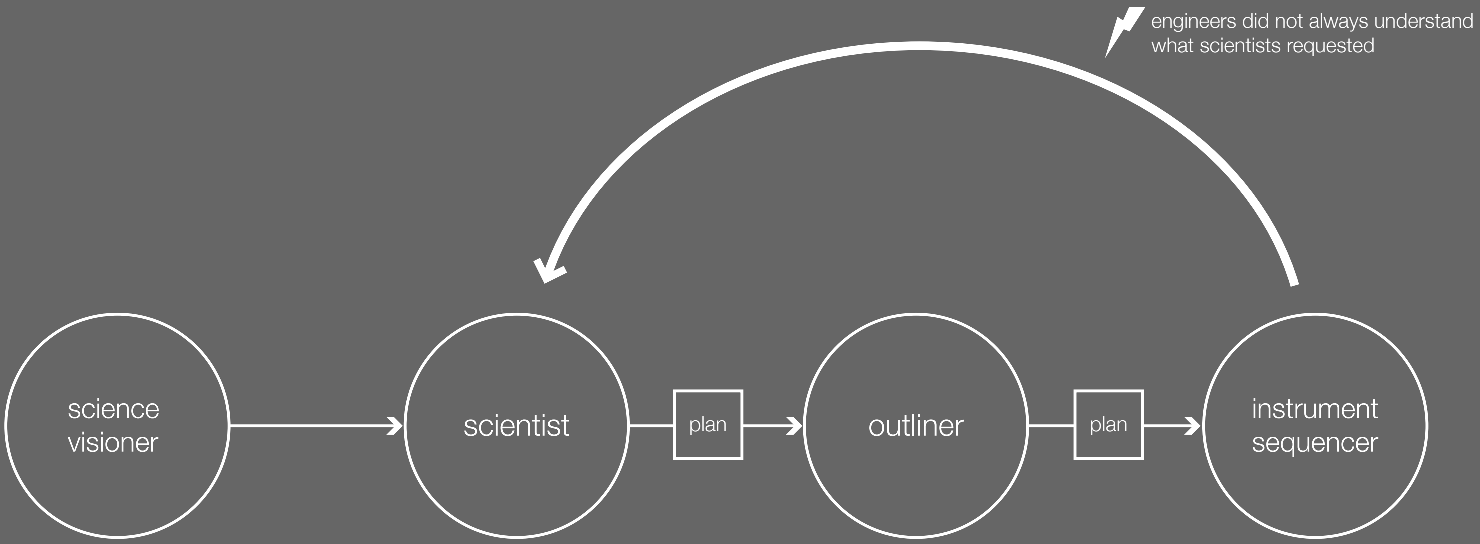
FINDINGS AND CONCLUSIONS

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



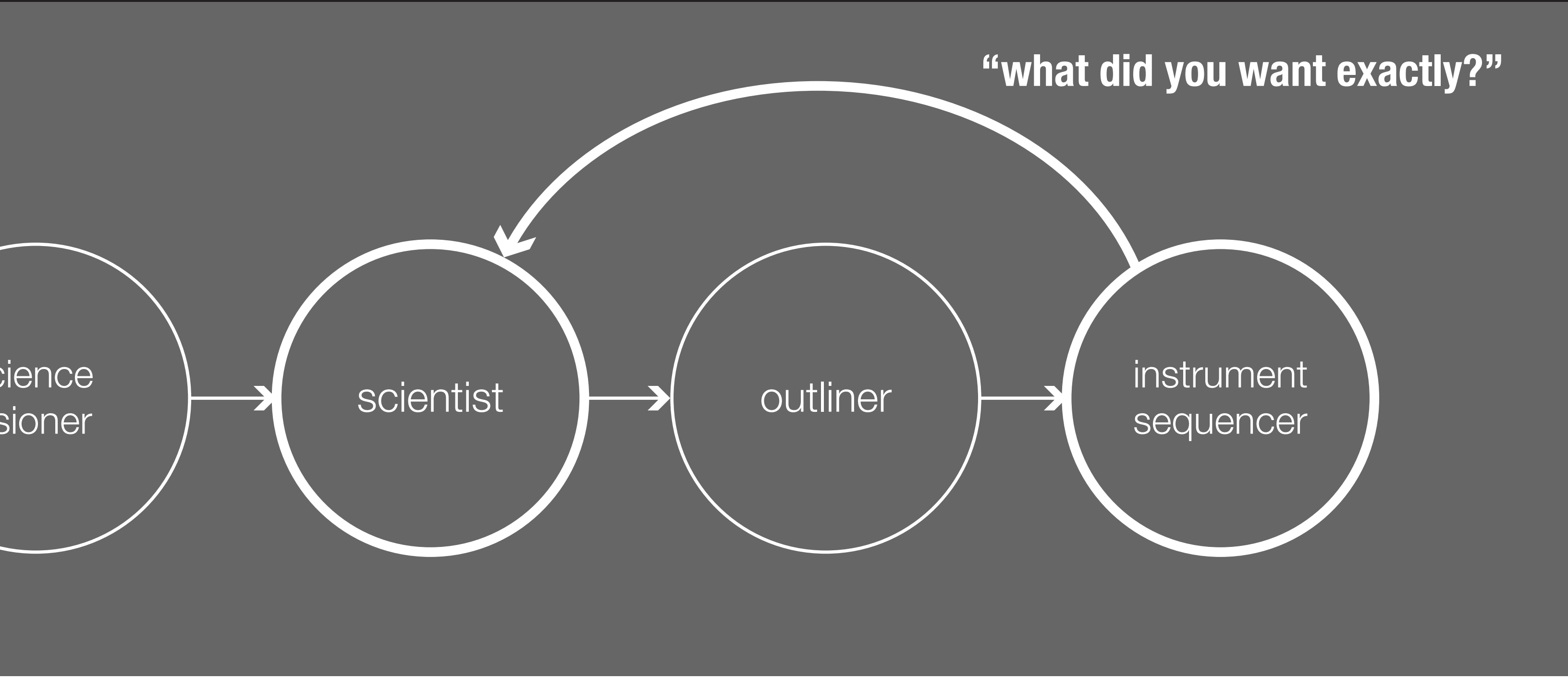
“Scientists think that everything is possible all the time” -Lead Tactical SPI

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.”

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

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



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."

"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

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.

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

-Instrument Sequence Engineer

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.

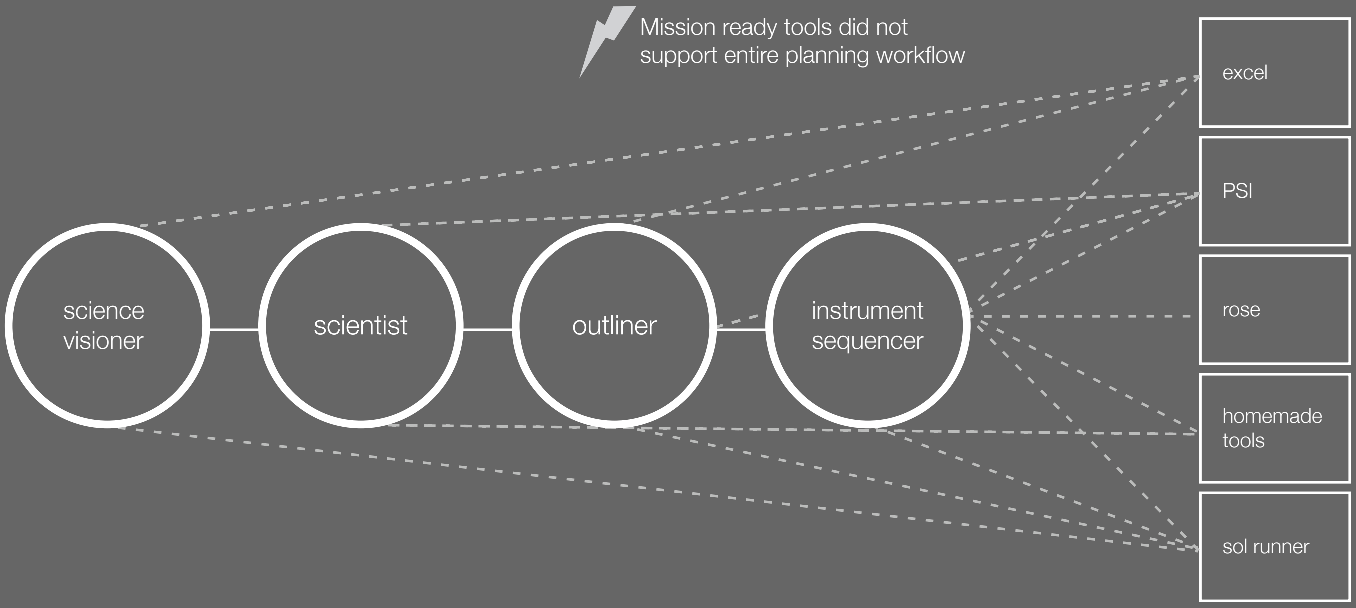
Education also assisted the planning process at Carnegie Mellon’s rapid prototyping lab, where a machinist took orders from students who did not understand the operational constraints of his machines. The plans that students gave him were at various stages of fidelity and students often asked him to 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.”

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

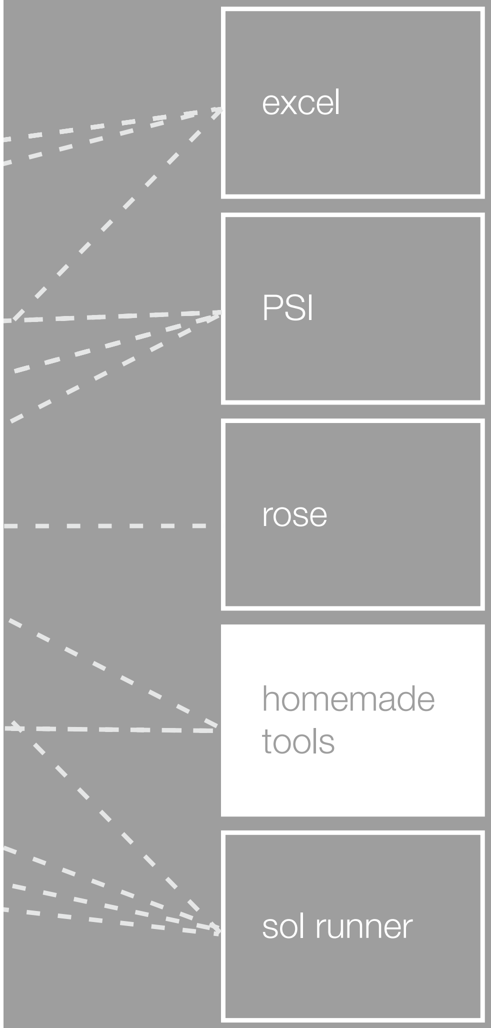


Across many of the missions, we observed that several domain-specific tools were used throughout the planning process. These specific tools only addressed one part of the mission planning process. For instance, RSVP was used on the MER mission for writing rover sequences but the issues such as resource 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.

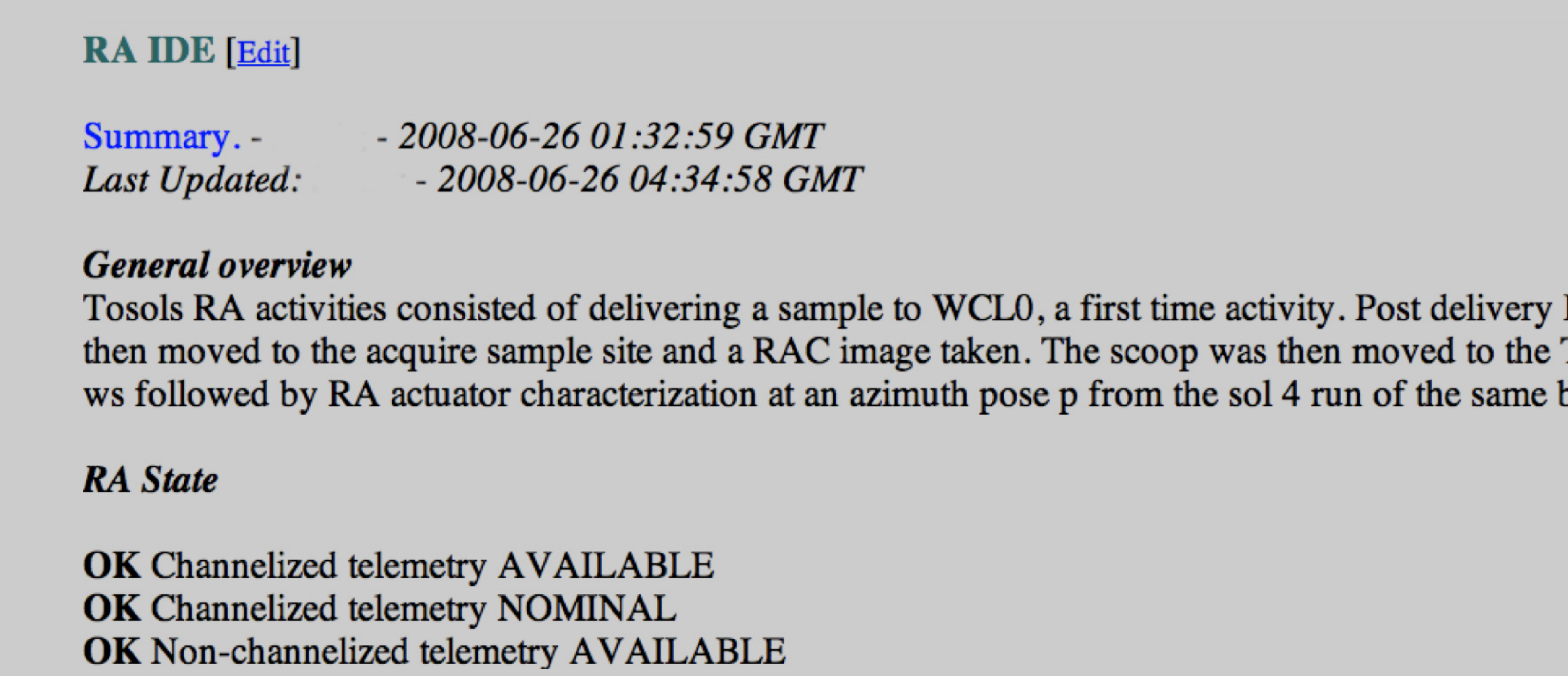
This gap between domain-specific tools was prevalent in both the Phoenix and MER missions. On Phoenix, an engineering group created a homemade tool to predict where shadows may occur in images to aid in the rover sequences they wrote. In a similar vein, a MER engineer created a tool named Panseq to aid 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



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
ws followed by RA actuator characterization at an azimuth pose p from the sol 4 run of the same

RA State

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

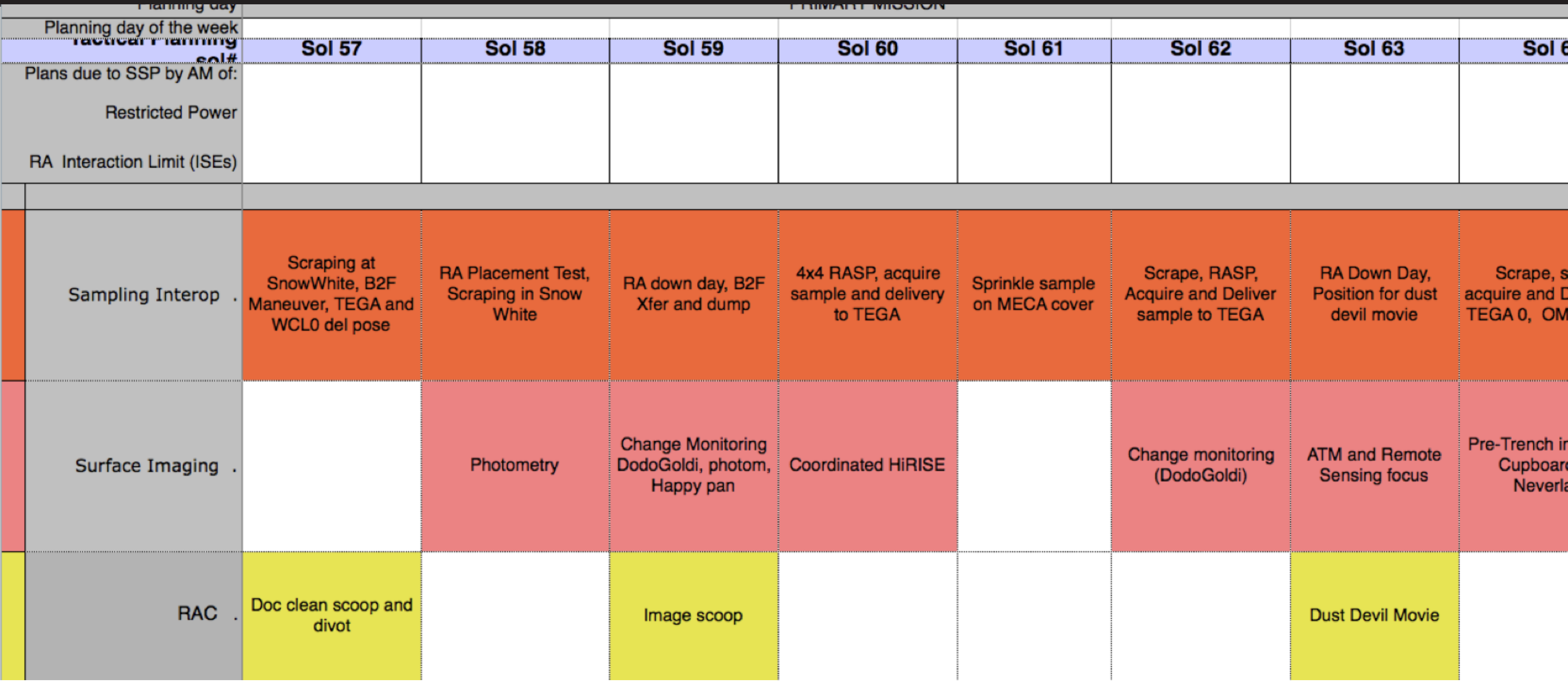
Sol Runner shift report entry for Phoenix

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.

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.

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.



Tactical Planning sol#	Sol 57	Sol 58	Sol 59	Sol 60	Sol 61	Sol 62	Sol 63	Sol 6
Planning day of the week								
Plans due to SSP by AM of: Restricted Power RA Interaction Limit (ISEs)								
Sampling Interop	Scraping at SnowWhite, B2F Maneuver, TEGA and WCL0 del pose	RA Placement Test, Scraping in Snow White	RA down day, B2F Xfer and dump	4x4 RASP, acquire sample and delivery to TEGA	Sprinkle sample on MECA cover	Scrape, RASP, Acquire and Deliver sample to TEGA	RA Down Day, Position for dust devil movie	Scrape, s acquire and D TEGA 0, OM
Surface Imaging		Photometry	Change Monitoring DodoGoldi, photom, Happy pan	Coordinated HiRISE		Change monitoring (DodoGoldi)	ATM and Remote Sensing focus	Pre-Trench i Cupboar Neverla
RAC	Doc clean scoop and divot		Image scoop				Dust Devil Movie	

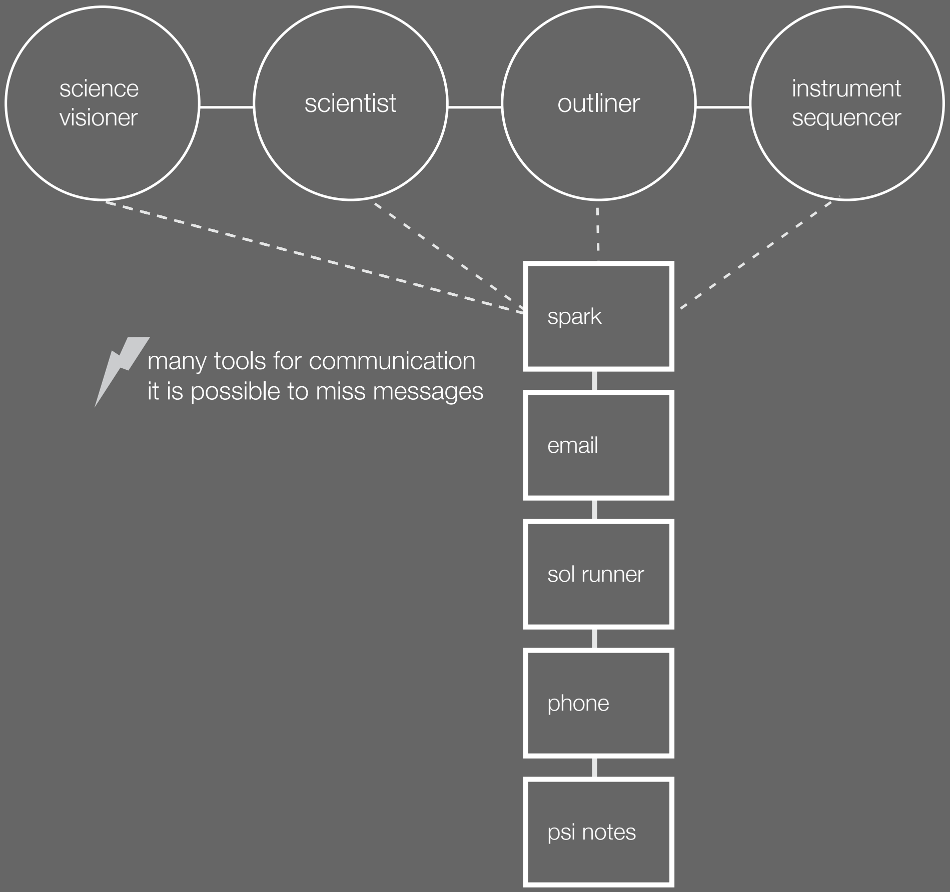
Long-term planning excel spreadsheet for Phoenix

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

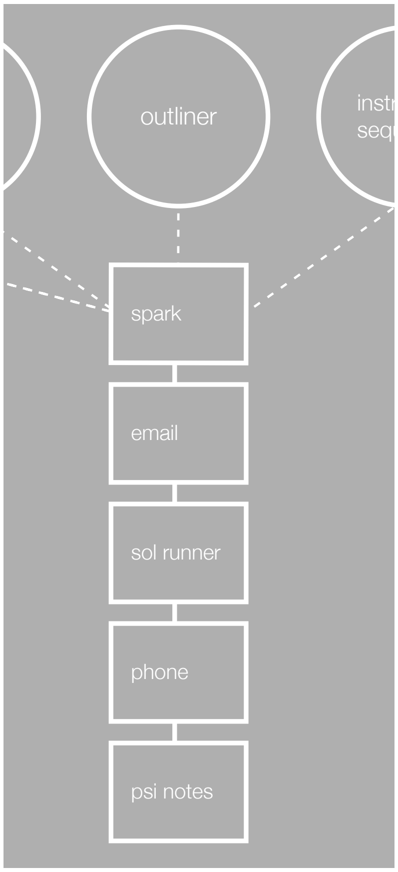


> **“It was frustrating because you knew there was someone who could answer your question right away, but they weren’t available.”**
>
> **-Sequence Engineer**

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.”

From our research findings, we developed the following process design recommendations:

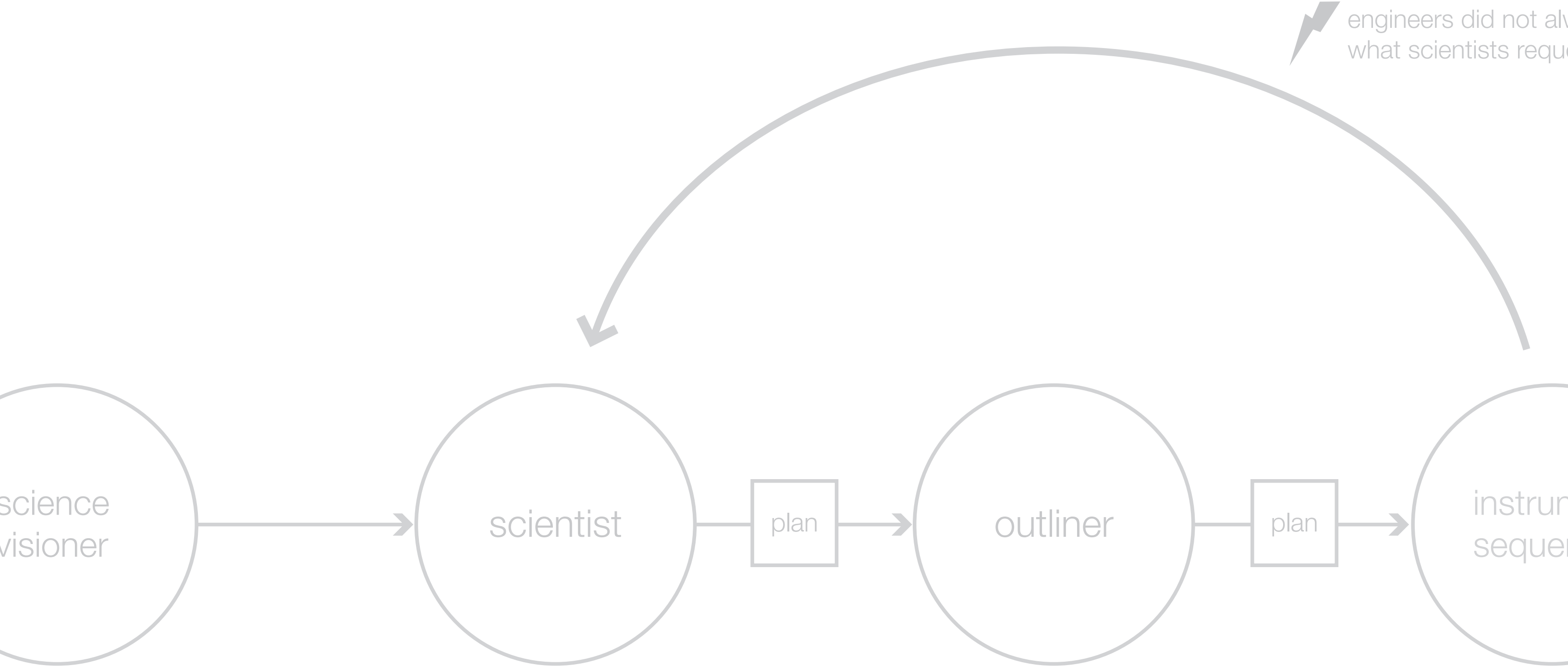
Design recommendations

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.

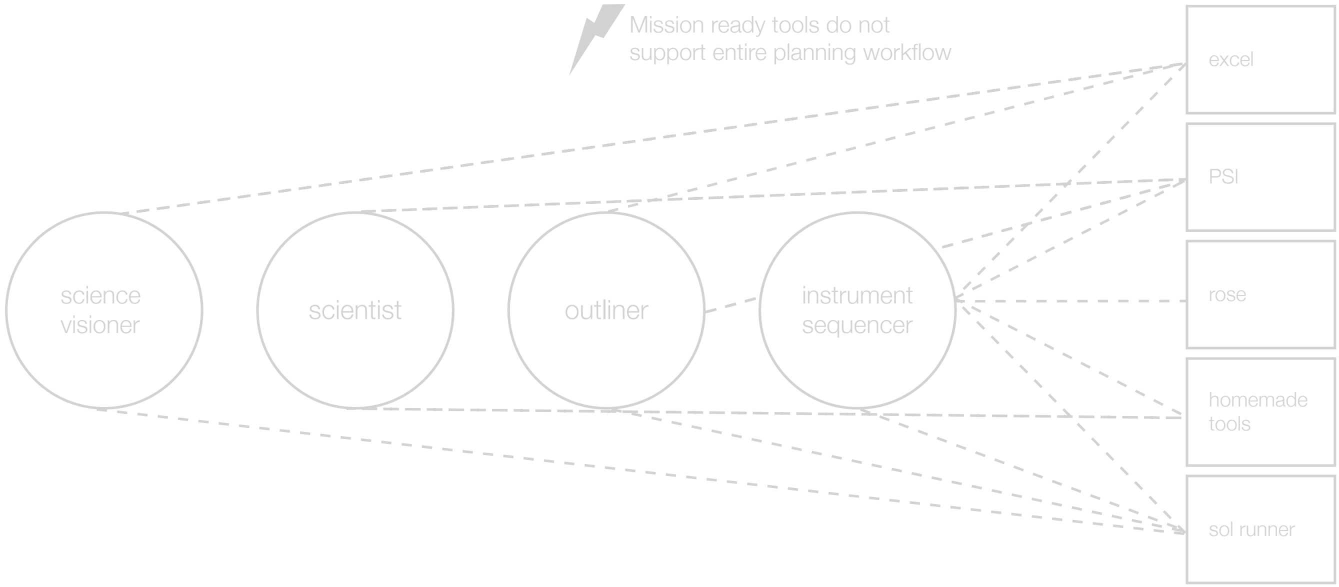


Support common, extensible mission tools to enable planning software to evolve with the mission

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.

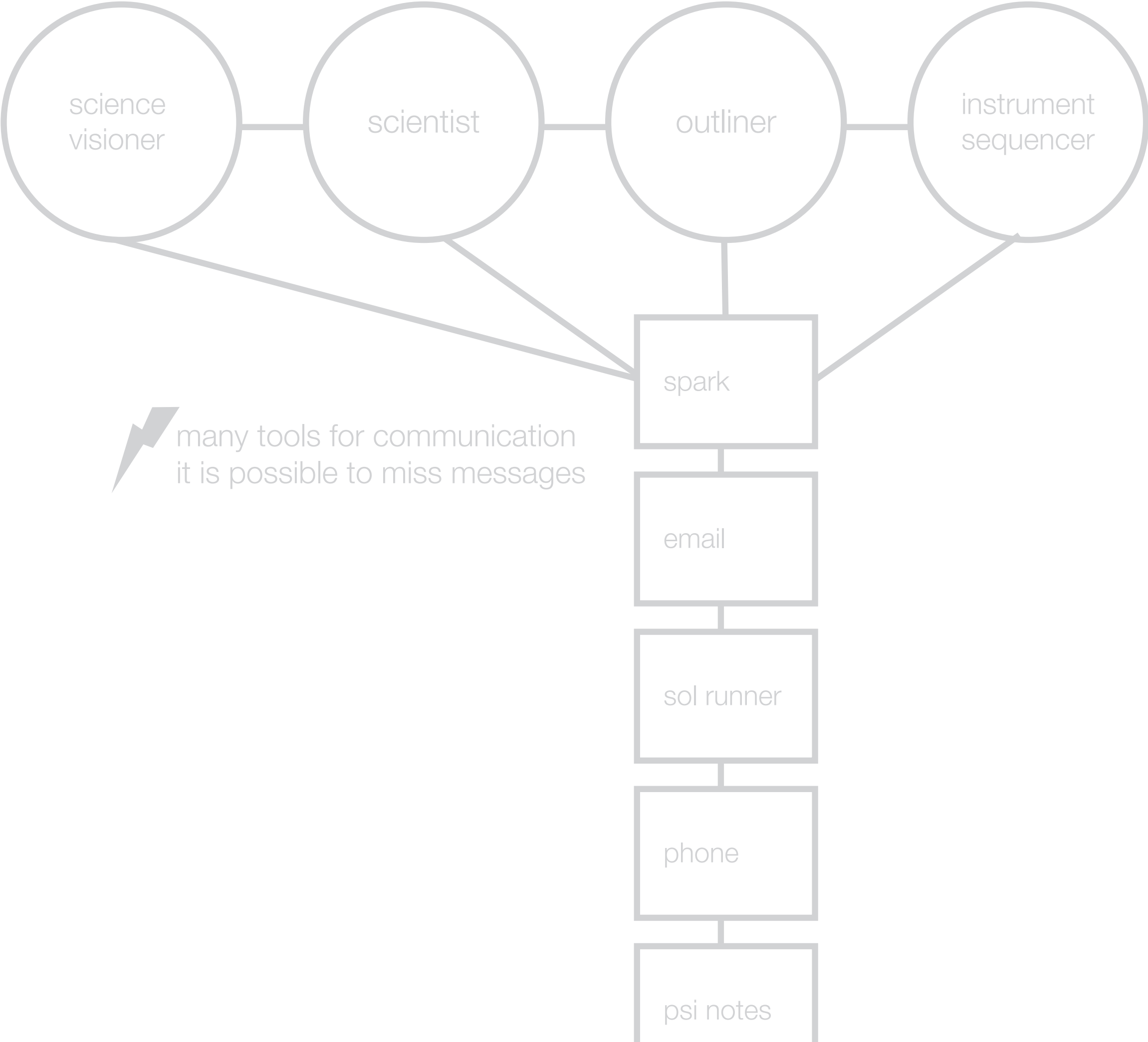
We found that both planners and scientists created homemade tools to bridge the gap between specialized tools, as well as tools that filled specific needs. One scientist on MER revealed his concern about “one-size-fits-all” planning tools. He urged: “Don’t make generic science tools!” We propose creating 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 Microsoft Excel, used for 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.



DESIGN PROCESS

We followed an iterative design process involving many rounds of brainstorming, rapid prototyping and user testing in order to continually refine the interface's functionality and feature set.

We began by translating our research findings into specific needs within robotic reconnaissance planning, and generating ideas based on those needs. To test our design concepts, we created ten storyboards and presented them to users and stakeholders. We then created low-fidelity paper prototypes and performed think aloud studies to evaluate the success of the interactions. Next, we created a digital prototype, and performed additional think aloud studies to assess the tool's usability and refine the interaction for each feature. Finally, we tested the digital prototype in more formal scenarios called Operational Readiness Tests (ORTs) in order to prepare for the final "Landing Day" simulation.

Needs Validation

To determine our users' planning needs during the Robotic Reconnaissance Field Test, we created ten storyboards of our design concepts (Appendix F). Storyboards are sequences of three or four illustrations that show a concept in context. We proceeded with a method for needs validation called "speed dating" , where we showed the storyboards to twelve potential users and domain experts to see how they reacted to the perceived need and proposed solution in each scenario. We showed our designs to the team members of the robotic reconnaissance field tests, including a flight director, science/flight liaison, and technical support.

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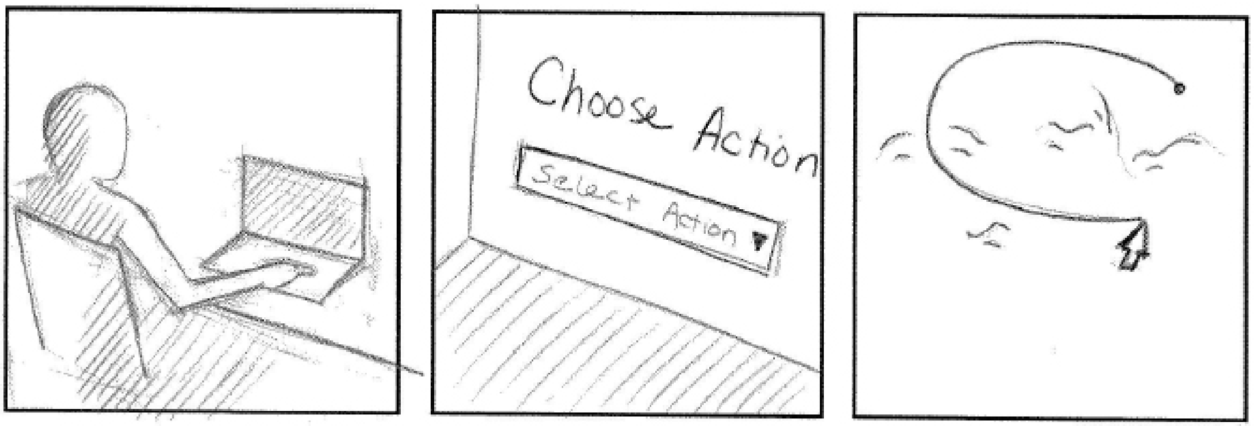

storyboard for needs validation testing

science room in the robotic reconaissance field test

Over a two-week period, we had the opportunity to observe the flight and science rooms in the robotic reconnaissance field test, which was carried out with groups at NASA Ames and at Black Point Lava Flow in Arizona. There were seven geologists on the science team and they were tasked with scouting out portions of the lava flow for interesting geological discoveries as well as dangerous or unknown terrain. The Flight Team consisted of operations experts and robot controllers who were in charge of keeping K10 on track to execute the daily missions. We observed the science team discussing exactly what it was they wanted the rover to do and watched how this information was conveyed to the flight team. We presented our concepts to the scientists and the flight personnel and they told us whether or not our ideas were addressing real communication needs in the planning process.

We documented all elements of the process and noted issues, both good and bad, which arose during planning. Detailed findings from the field test can be found in Appendix E. The field test allowed us to refine our storyboards based on needs we observed and feedback from science and flight team members. We then created an affinity diagram with our observations from the field test, and compared these with previous planning research and design needs generated thus far. The complete list of final design ideas can be found in Appendix G. After discussions with our client, we refined our focus to helping the science team clearly communicate their plan intent to the flight team.

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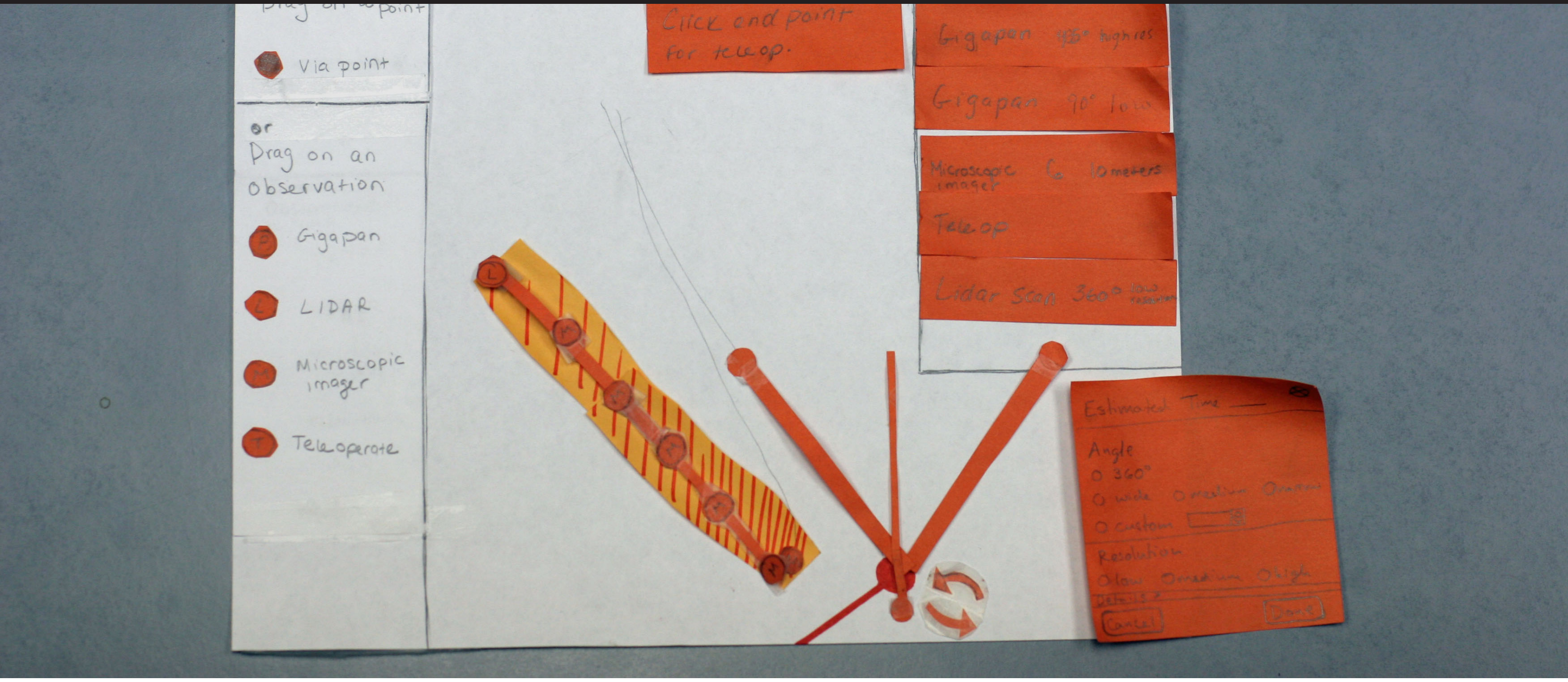

paper prototype

Design Goals

During needs validation, it became apparent that while scientists were not currently creating the plans on their own, they could do so with the right tool. Scientists were thinking about the plan in terms of the data product they wanted back, not necessarily considering the instrument settings required in order to receive that data. We also observed the scientists relying heavily on the satellite imagery for contextual information while planning.

Our goal was to create a planning tool that would allow scientists to create a mission plan in a way that easily conveys plan goals to the flight team. This tool would focus on the data products the scientists want to receive, instead of the instrument specifications required to achieve that data. It would have a heavy emphasis on a map, for contextual information, and would allow science goals to be conveyed within the plan itself.

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Paper Prototyping

Our initial designs were tested using paper prototypes with eight participants. These low-fidelity prototypes, consisting mainly of paper cutouts, sticky notes, and pipe cleaners, allowed us to make many changes to the design early on. We performed needs

checking out the lower ledge area. want to determine which way

Lat 37.416447058410846
Long -122.06559026016426

Waypoint 2 Type PANO

digital prototype think aloud testing

validation with two geologists from the robotic reconnaissance field test by walking through the paper prototypes and asking questions to assess whether the features we had incorporated were addressing current science needs. We also performed "think-aloud" tests with a geologist and three engineers from the robotic reconnaissance field test, as well as four members of the NASA Ames HCI group. During think-aloud testing we created a testing script and defined scenarios and tasks for the users to complete. Users were asked to explore specified areas on the map with the instruments available to them, voicing their thought processes as they performed these tasks. These tests allowed us to assess the usability of the system with unfamiliar users, and also to narrow in and iterate on the ideal interaction for each feature. In addition, the paper prototypes allowed us to rapidly narrow in on the ideal interaction for each feature from a broader concept.

We also performed "think-aloud" tests with a geologist and three engineers from the robotic reconnaissance field test, as well as four members of the NASA Ames HCI group.

Digital Prototyping

Once we had determined the most appropriate design for each feature through paper prototypes, we moved into digital prototyping, enabling us to refine the more complex functionality and user interaction that was not possible to do with low-fidelity prototypes. Because development occurred in parallel to user testing, in many cases we were able to test what would eventually become our final prototype with various stages of functionality. In some cases, we also created mid-fidelity Adobe Flash prototypes of individual features--such as viewing notes in the task list, and creating a microscopic imager sequence--in order to quickly test their functionality before fully implementing them. We performed think-aloud testing with three geologists from San José State University, giving them the goal of locating scientific points of interest and traverse hazards, much like the geologists' goal at the robotic reconnaissance field test. We also performed think-aloud tests with four NASA Ames summer interns, giving them step-by-step instructions in order to test specific aspects of usability. These tests helped us refine the tool's usability, isolate unexpected bugs in the program, as well as refine the ideal interaction for each feature. In addition, digital prototypes allowed us to test the system as a whole, instead of focusing on each individual feature. The high fidelity digital prototypes allowed us to see when and how users moved between each feature in the system and how they worked together in one application.

We performed think-aloud testing with three geologists from San José State University, giving them the goal of locating scientific points of interest and traverse hazards, much like the geologists' goal at the robotic reconnaissance field test.

Final Concept

Our observations of the robotic reconnaissance field test this summer contributed greatly to our final design. We observed that during planning operations, scientists discussed the plan for the rover traverse among themselves while an individual with technical expertise of the planning software generates a plan for them. This disconnect between the scientists and plan creation caused two problems. First, scientists did not communicate in a manner that provided useful inputs for the planning tool, and engineers needed time to interpret their requests. For example, scientists would often gesture with their hands the desired field of view for a panoramic image. Scientists would then wait while the person creating the plan translated this into specific camera settings including angle and resolution.

The second problem with not having a scientist create the plan was that the planning person would influence the points that were laid down. We witnessed the planner accidentally laying down points in the wrong location, and scientists would frequently correct the person. There were also times when the person was not able to generate the plan at all because they were working on other tasks.

Our final design concept starts with a major process change from

Scientist gesturing to indicate the desired field of view

what we observed during the field test. We propose having a geologist actually create the plan so they can accurately represent their planning goals. This will give them the ability to indicate the rationale behind each point they add to the map so this intent is included in the plan itself. Not only will this help the flight team to interpret the plan during execution, but this will also allow the science team to refer back to such information during data analysis. The interface contains four core features designed to allow scientists create plans themselves:

1. Tool bar
2. Activities list
3. Notes field
4. Field of view visualization

Scientists would often gesture with their hands the desired field of view for a panoramic image.

Final Concept Testing- Landing Day

The Conveyance mission planning tool was evaluated in the context of a simulated robotic reconaissance field test. This field test served to evaluate how well the tool supported scientists ability to convey their planning goals. The following section describes the testing process and evaluation methods that was used.

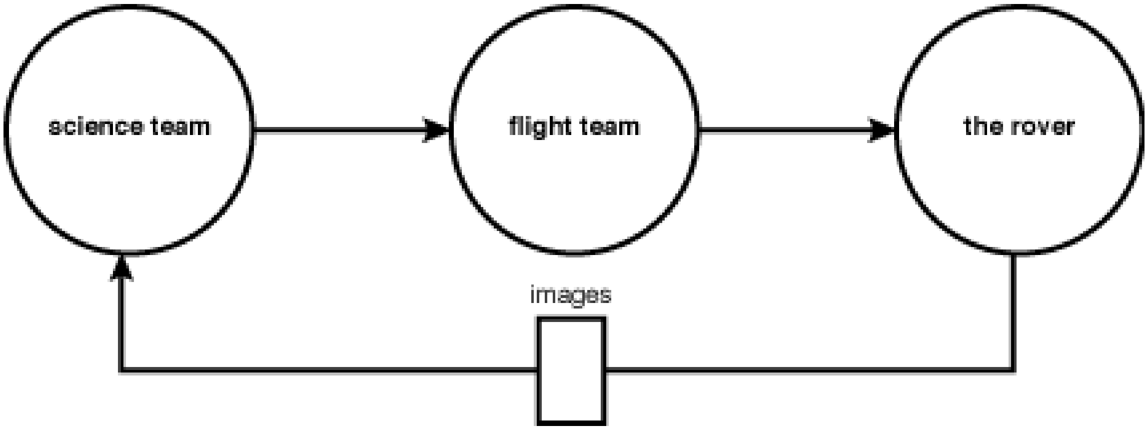
Robot Team executing the plan during a simulation

During our simulation we placed the teams in different locations and elimated the all forms of communication with the science team, which allowed us to isolate our tool and determine how well it helped scientists communicate their intent.

The simulated robotic reconaissance field test consisted of three teams: a science team, flight team and rover team. Each team was composed of one or two partcipants, and we recruited users from NASA Ames and local Universities. In order to refine our scenario and evaluation procedures, we conducted three practice simulations with a total of six partcipants, called Operation Readiness Tests (ORTs). We conducted the final "Landing Day" evaluation of our interface with six participants.

During a normal robotic reconaissance field test, the three teams would be in constant contact with one another over a voice loop. However, during our simulation we placed the teams in different locations and elimated all forms of communication with the science team, which allowed us to isolate our tool and determine how well it helped scientists communicate their intent.

The simulation consisted of three stages. First, we showed the science team a satallite image of the Mars Yard at NASA Ames, and asked them to create a plan which evaluated the traversability of the region and explored areas of scientific interest. They were able to request microscopic imager (MI) and panorama images. They used Convayance to indicate where they would like the rover to go and what observations they would like it to do at those locations. Second, the plan was sent to the flight team for review.



Model of simulation test process

We introduced several constraints to the flight team which forced them to makes changes to the science team's plan. By introducing constraints, we hoped to test how well the flight team understood what the science team wanted to do, and was able to stay true to the scientists' planning goals despite the need to make slight adjustments to the plan. For instance, we indicated areas on the Mars Yard that were unsafe for the rover to go. The flight team needed to adjust the plan slightly in order to move the rover away from unsafe areas. Finally, the revised plan was sent to the rover team for execution. The rover for this simulation was a human-powered cart on the Mars Yard, equipped with two digital cameras to act as the MI and panoramic camera, a GPS, and a compass so the rover could move to the correct location.

To evaluate the simulation, we asked the science team and flight team qualitative questions thoughout day. First, we asked the flight team how well they understood the intent of the scientists' plan. Second, we asked the science team how they felt about the changes that the flight team made to their plan and if they believed that the adjustments still capture the original intent of their plan. When the data products came back, we reviewed each data product with the science team and asked them if the data they got back was what they asked for. At the end of the day, science and flight teams were brought together to discuss what worked well, what did not, and any breakdowns in communicating the intents and changes that may have occurred.

We asked the science team how they felt about the changes that flight made to their plan and if they believed that the adjustments still capture the original intent of their plan

1 V 30 min add note
2 L 10 min add note
3 P 20 min add note
4 M 10 min add note
5 P 20 min add note

science: Professor, Metamorphic petrology, geochemistry, and metamorphic rocks and thermobarometry.

flight: investigated how river channels process large pulses of sediment via field and experimental work.

6 L 20 min add note
7 P 20 min add note

total time 84 minutes

THE INTERFACE

The system, at its core, is written in Adobe Flex and uses the Google Maps Flex API, Degrafa graphics library, and BlazeDS server, to provide an interactive, collaborative web environment to capture and communicate plan intent. The science team members are often selected on short notice for field tests. As a result these teams often consist of a fresh group of scientists that are new to the mission planning software. With that in mind, we made a walk-up-and-use software interface that requires little to no training. The main features of this interface are the ability to select instrument icons from a tool bar, visualize activities as a list, enter notes about observations in a text field, and visualize and manipulate a camera field of view.

Tool Bar

Keeping with the minimal, walk-up-and-use design, the tool bar contains a clear list of the toolset available to the science team. The tool bar includes a via point, a panoramic camera, a microscopic imager (MI), and a 3D lidar scan. Each tool can be dragged directly to a location on the map, and is added to the activities list where users can input the reason behind using the instrument and see the settings available for the instrument.

Supporting Data

On the Mars missions and the field test, scientists did not interact directly with the planning tool because the tools were very complex and required extensive training. In order to allow scientists to communicate exactly what they want through a planning tool, common tools and settings need to be easily accessible so many different people can learn the planning tool quickly. The minimalist tool list design streamlines the method to add new points and supports the walk-up-and-use design.

Testing

The first version of the tool list required users to drag out a via point first, then add observations to it if they chose. In addition to our final list of four tools, the tool list included options for a "hypothetical" waypoint, a teleoperation waypoint, a microscopic image sequence, and a 360-degree lidar.

After our first round of user tests on the paper prototype, we revised the design so that users could begin by dragging out any observation they chose, not necessarily a via point, reducing the

drag a point to the map

V

via point

P

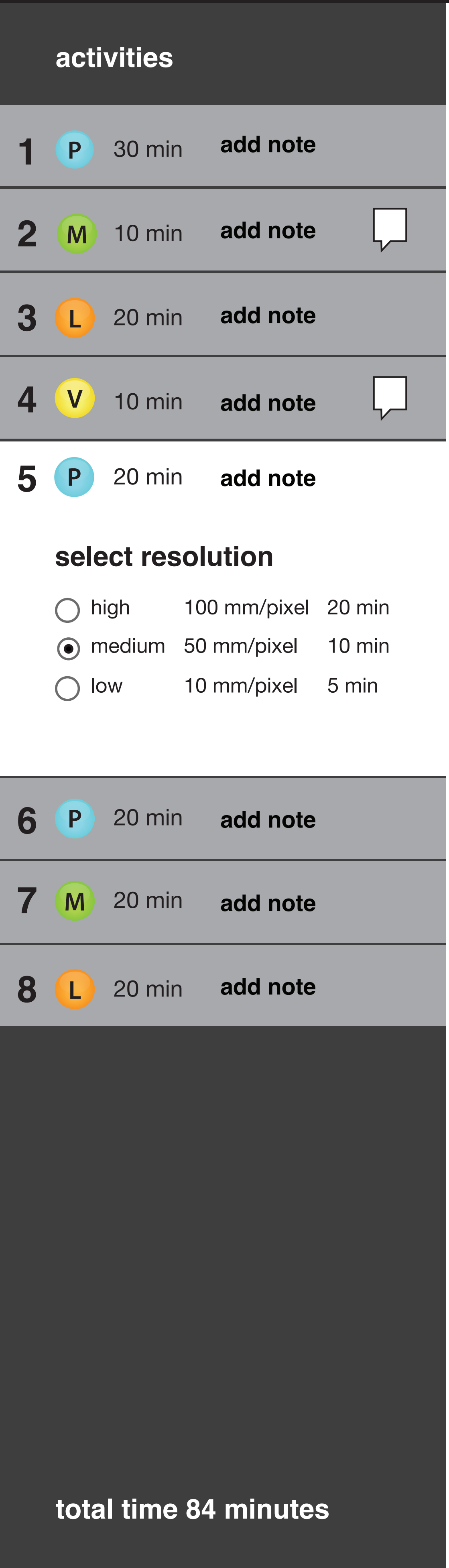
panorama

M

microsopic imager

L

lidar



activities

1 P 30 min add note
2 M 10 min add note
3 L 20 min add note
4 V 10 min add note
5 P 20 min add note

select resolution

○ high 100 mm/pixel 20 min
● medium 50 mm/pixel 10 min
○ low 10 mm/pixel 5 min

6 P 20 min add note
7 M 20 min add note
8 L 20 min add note

total time 84 minutes

number of steps needed to get observations into the plan. In addition, the "hypothetical" waypoint was removed because we decided that hypothetical plans were outside the scope of our focus. The teleoperation waypoint was also removed because we determined that the choice of whether to teleoperate or not should should be left up to the flight team rather than the science team.

The 360-degree lidar was removed from the tool list after several rounds of user testing with the digital prototype. Users consistently did not see the option when asked to place a 360-degree lidar scan, instead using the regular lidar tool and setting it by hand to 360-degrees. Similarly, users rarely noticed the MI sequence option, instead laying out points by hand. In addition, the MI sequence felt out of place on the tool bar since it laid out multiple points while the other tools laid out a single point. The tool's concept however, received very positive feed back, so while it was removed from the tool bar, we redesigned it to be an option within the single MI. Users would place a single MI, then have the option of setting it to a multipoint series which would unlock the options for number of points and interval. Unfortunately due to time constraints this redesign did not make it into the final Landing Day evaluation, but since this tool received very positive feedback during user tests we felt it really addressed the goal of visualizing planning, so we made an effort to include the concept in the final implementation.

Activities List

The activities list shows sequentially all of the observations added to a plan. It is a centralized location for adding and removing waypoints, adding and removing observations to these waypoints, collecting the rationale for all observations, and manipulating instrument settings. Having the entire plan represented in one list allows for a clear understanding of which instruments are being used at each observation. This list is directly linked to the waypoints placed on the map and scientists can choose to edit the plan in either location. The connection allows the two plan representations to complement each other and provide easy access to contextual information as well as plan intent information.

Supporting Data

During the robotic reconaissance field test, we observed on several occasions that it was difficult for the science team to determine the order in which activities would occur. When multiple activities occurred at the same point, the person in charge of the plan would have to scroll over the point to see what all the activities were. On several occassions, we observed that the flight team was also confused over what order the waypoint would be occurring. The activities lists provides a space to clearly list out the order of observations, and allows for easy reordering and removal.

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Testing

Initially, the activities list was simply a list of points and activities. The settings and notes panels would pop up next to a point once it was placed on the map. However, during user tests with paper prototypes we discovered that, because it was a pop-up, users seemed to think that this was where they were supposed to change the settings and did not realize that in some cases they could also be changed in the map. The pop-up also took up a great deal of screen real-estate.

The settings and notes panels were eventually incorporated as drop-downs within the activities list, saving screen real-estate and putting emphasis on the map interactions. However, during user tests with the digital prototype there were times when users did not seem to notice that there were settings other than those presented visually on the map. Subsequent versions of the prototype highlight the appropriate observation in the task list when a point on the map is clicked, and vice versa, to better link the two different plan views.

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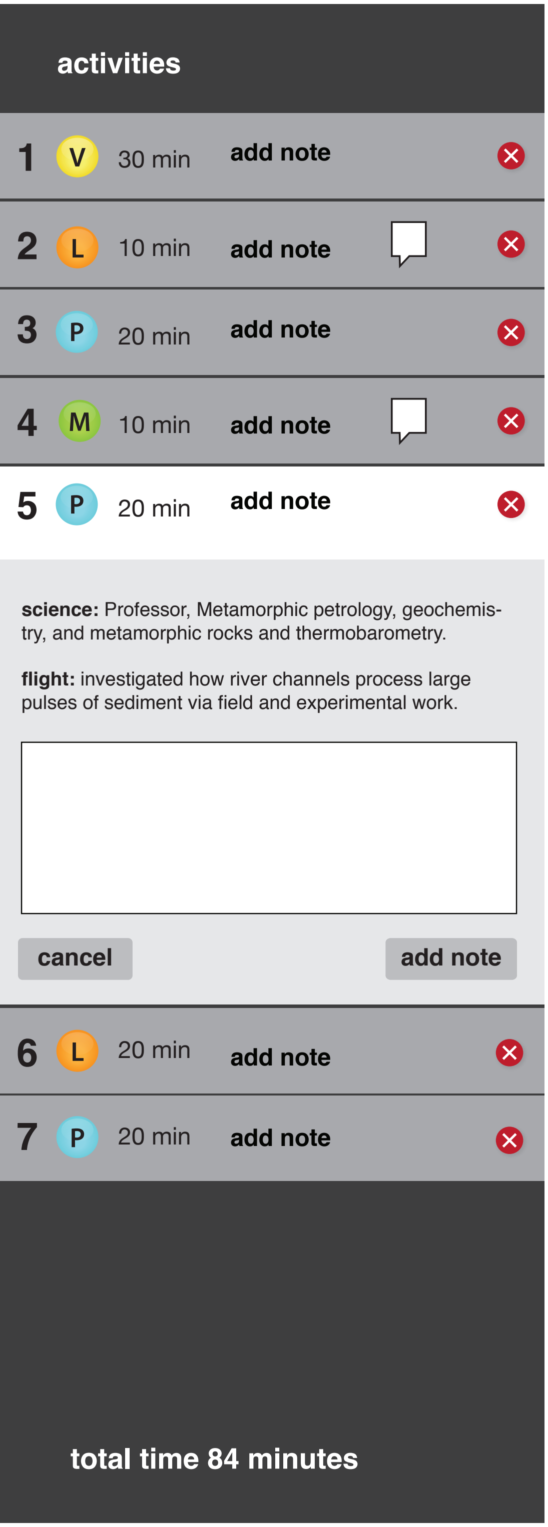
Notes Field

While generating waypoints in a plan, scientists are prompted to enter the rationale behind the request. This gives the science team a place to capture some of the discussion that took place when considering possible waypoints. The flight team can use this information to interpret exactly what the science team is trying to accomplish at each waypoint. In addition, the science team can use this information during data analysis to help direct them to the specific reason an image was requested.

Supporting Data

The main goal of our design is to give scientists the ability to



science: Professor, Metamorphic petrology, geochemistry, and metamorphic rocks and thermobarometry.

flight: investigated how river channels process large pulses of sediment via field and experimental work.

clearly communicate the intent of their plan to the flight team. This goal was derived not only from research during the spring semester, but also supported by our observations of the robotic reconnaissance field test. On the MER and Phoenix missions, there were many instances where instrument engineers would have to clarify with the scientists exactly what sort of data they were trying to get and why. Similarly on the field test, the flight team asked the science team questions to make sure they were interpreting their plan correctly. The notes field will not only facilitate this understanding, but also allow the science team to look back and remember their own reasons and discussions behind past plans.

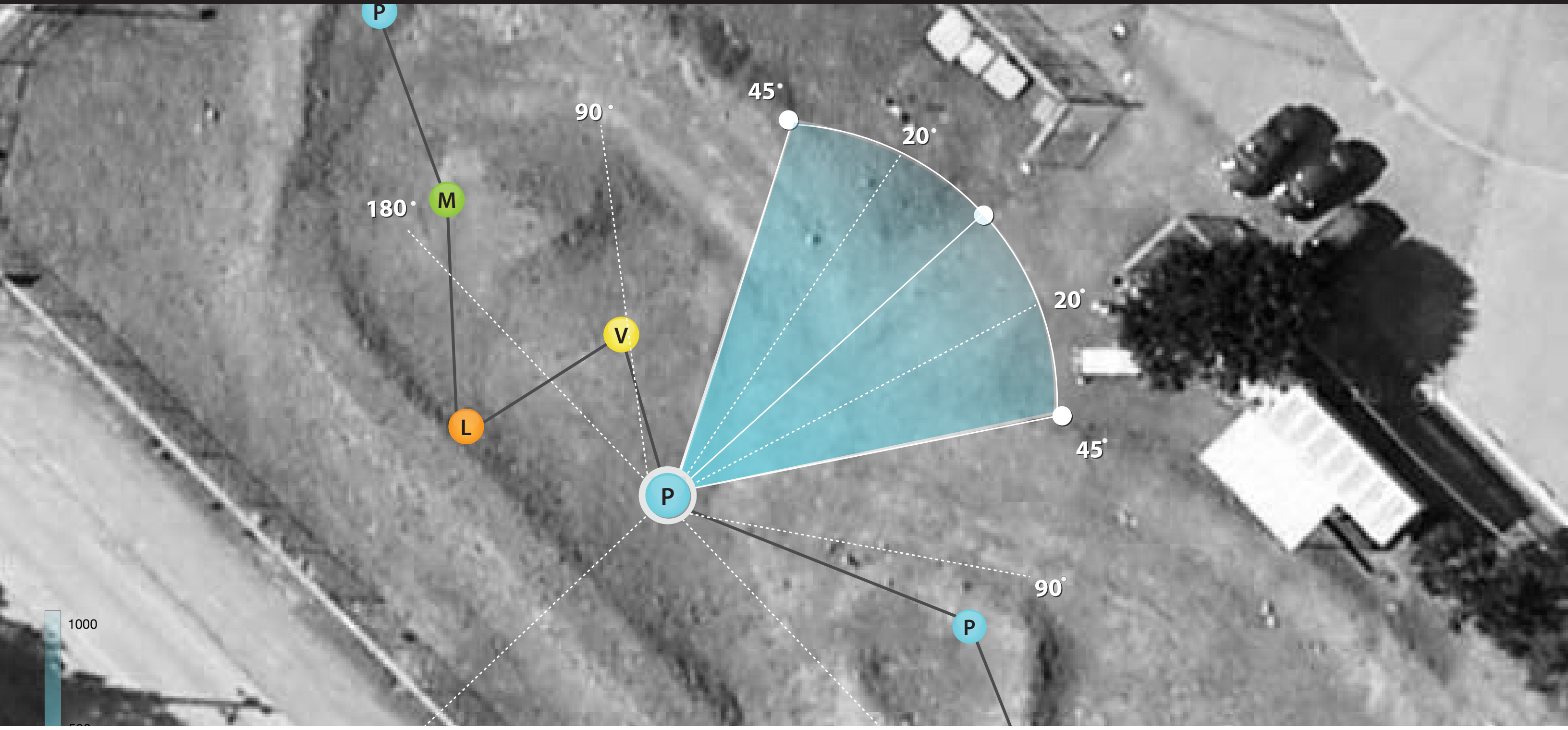
Testing

Like the settings panel, the notes field initially started as a popup that would appear when the user clicked on a point and selected an option to “add intent”. The notes field was soon moved to the activities list both to save screen real-estate and to make it more easily accessible with the ever present “add note” button.

Users responded positively to the note icon and the ability to preview the note to by rolling over it with the mouse. However, there were some cases where users did not seem to notice the “add intent” button below the text box that would save their note, resulting in many lost notes. This was later iterated on by having the intent save as soon as text was entered in the field, however this resulted in saving notes the user was not necessarily ready to save.

Testing our tool during the ORTs inspired some important changes in preparation for the final simulation. In the ORTs both the flight team and science team added notes to the points: science would describe the rationale behind the point, and flight would describe any changes made. Initially, flight would append their comments to the same comment box as flight, but we observed that sometimes it was difficult to tell where a new note was added, and occasionally prior notes would be accidentally deleted or altered.

We addressed these issues by designing the notes field more around a “conversation”. When a note is added, it would be appended to the conversation with the appropriate “Flight” or “Science” label and can no longer be edited.



Field of View Visualization

The field of view visualization allows the science team to specify exactly what type of image they would like to capture and manipulate angle and resolution settings directly on the map. Scientists are able to drag the central bar to a specific area of interest, which shows flight the intended target of the photograph. We then provide them with a estimate of the image quality at the target for low, medium or high resolution. In addition scientists can preview the image quality at any point in the field of view through a gradient visualization. Higher opacity color in the gradient indicates a lower number of millimeters per pixel. The tool also illustrates the limitations of the cameras to help the scientists plan within constraints. For instance, the cameras can only take images of a certain angle, and the scientists can select from one of the available settings by manupulating the field of view on the map In addition, the science team can see which areas of the map are already being captured, so they do not collect duplicate data unnecessarily.

Scientists can preview the image quality at any point in the field of view through a gradient visualization. Higher opacity color in the gradient indicates a lower number of millimeters per pixel.

Supporting Data

The field of view visualization was in response to research that showed that visuals can help scientists explain their plan intent to engineers. During our interviews with members of the MER and Phoenix teams, engineers reported that the most useful information they could get from a scientist was an image annotated and circled with exactly what camera view the scientist wanted. Similarly on the field test, the science team was concerned with what information the data product would contain, not necessarily the settings required to obtain the data. The principle investigator would hold his hands in a V-shape up on the map, indicating exactly the view he wanted to see, and leaving the decision of what settings would get that view to the engineers. In addition, scientists at the field test were frustrated that there was no method to preview the millimeters per pixel at their target. The field of view visualization is a direct translation of these observations, clearly indicating to scientists what view they will be getting back, and clearly indicating to the flight team what the science team wants to see.

Testing

The interaction for manipulating field of view changed little over the evolution of our prototype. It was inspired directly from our observations of principal investigator's gestures during the field test, and during both paper prototyping and digital prototyping users found the interaction very intuitive.

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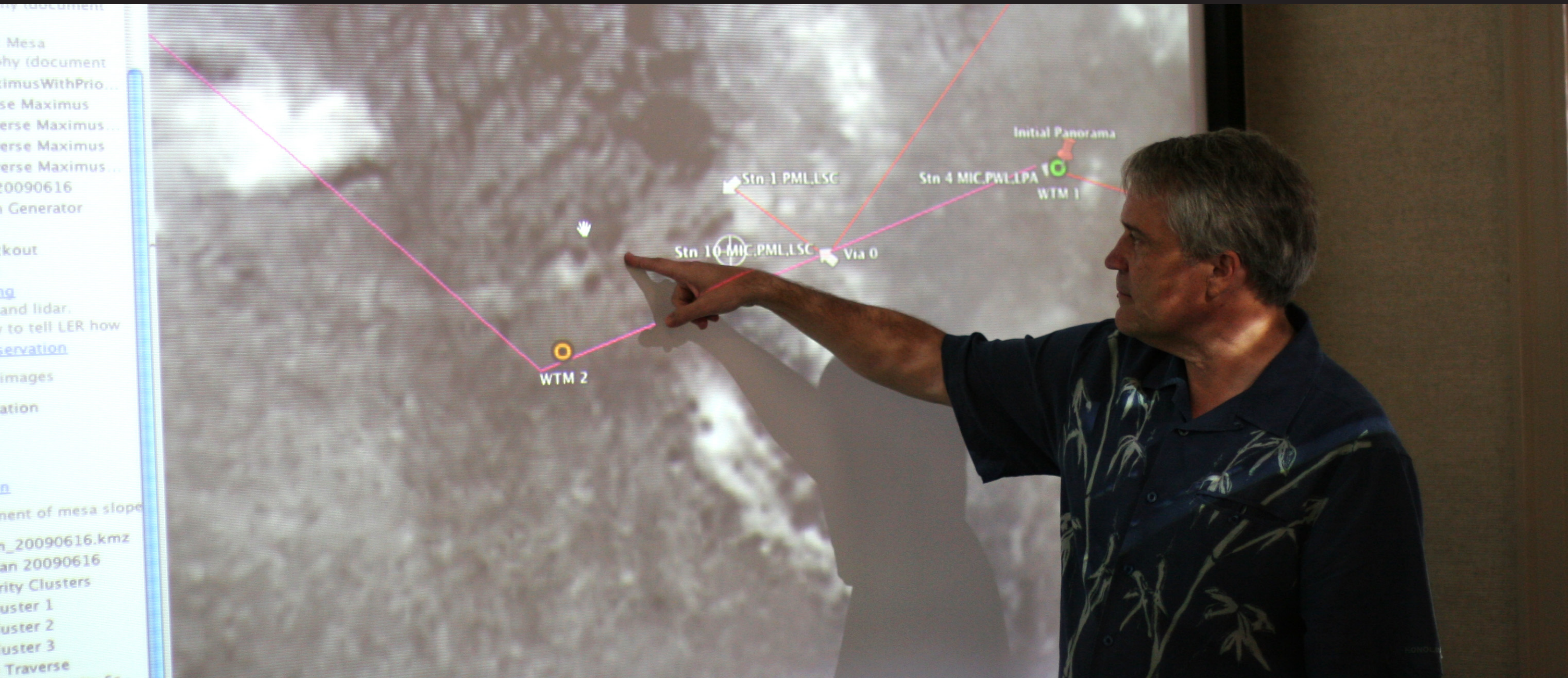
Determining the best way to represent the options for camera resolution proved to be much more of a challenge. We originally had the central bar represent resolution, extending further out for higher resolution, and closer in for lower resolution. However we found that attempting to represent resolution with distance to be a confusing analogy.

We revised our design by replacing resolution with the concept of quality. The user would drag the central bar to their target of interest and select the desired image quality. Depending on the distance, the qualities would represent different resolutions. For example for a very close target, a high quality image could be achieved with a lower resolution, while a high quality image of a distant target would require high resolution.

The opportunity to talk with the geologists on field test revealed that, while they do not necessarily care about fine grained tool specifications, the separation of image quality versus resolution was a step too far removed. We found that the scientists cared about resolution insofar as to determine the scale of objects in the image. For example, a high resolution image would contain more millimeters per pixel for distant object than a lower resolution image. Thus, our final design fills the panorama frustum with a gradient representing approximately the millimeters per pixel at any given distance. For a lower resolution, the gradient dissipates quickly, while for a higher resolution the gradient extends much further.



CONCLUSIONS

We focused on improving communication between scientists and engineers to assist with mission planning during robotic reconnaissance missions. The team created a collaborative software prototype designed to help scientists better accomplish their science objectives. By using visual planning tools that link intent with instrument settings, this software allows scientists to more easily convey their scientific goals to the flight team.

The following is a discussion of the success of our prototype in meeting this goal during our final Landing Day simulation (July 24, 2009), and recommendations for future work based on our research and observations throughout the spring and summer.

Change in Workflow

Our final design involves a major change in workflow. We propose having a geologist actually create the plan so they can accurately represent their planning goals, instead of dictating what they want to an engineer who lays out the plan for them. In order to allow scientists to make their own plan, we strived to make our tool very straightforward and approchable. During the “Landing Day” scenario, users found the tool intuitive and easy to use. One user commented that many tools get more complex with more features, but he found our tool to be very simple straightforward. We found that all users with whom we tested the tool, whether they had planning experience or not, were able to start laying out a plan right away.

Visual Planning

In order to help scientists create a plan themselves, we also provided a visual way to understand instrument settings and easily indicate what sort of observations the scientist wants. Conveyance enables scientists to lay down waypoints directly onto a satellite image and indicate roughly what scale the scientist can expect to see in the image.

Everyone who participated in the Landing Day scenario responded very positively to the field of view interface. Scientists understood intuitively how to interact with the tool and were able to easily plan within the constraints of the rover. In addition, scientist were pleased that they could preview the millimeters per pixel at a given distance. All of our partcipiants, even those from a non-scientific background, understood that the gradient was an indication of what quality image they would get at a given distance.

Capturing Intents

The main purpose of our tool was to clearly capture the intent of the scientists' plan so that it can be interpreted by the flight team. This is done both visually on the map and in the activities list's "notes" field. The notes field successfully helped scientists communicate their planning goals. There were only a couple of instances where the science team was not happy with the flight team's changes. However, these were mainly instances where there was no way flight could adjust the plan to account for both the science goals and the constraints. In this case a voice loop would have been appropriate to discuss contingency plans, but it was necessary to restrict communication for the purpose of our evaluation. Even though many users said they would have liked to have some sort of verbal communication, they were still able to get across the goal of each observation and flight was able to interpret their intent. Users liked the simplicity of the note field. A NASA planetary geologist who participated in our final evaluation commented that the MER mission made an attempt to incorporate notes, but scientists stopped using them because the could not figure out what information was supposed to go where. The ability to simply write out what the goals are, and have it stored directly in the plan proved very successful.

Directions for Future Work

Unfortunately due to time constraints we were unable to implement all of the functionality that we had hoped. The prototype presented here focuses on a narrow set of use-cases, but the tool has the potential to address a number of other issues.

Activities list

In the tool's current state, only one type of observation can be associated with each waypoint. While this was sufficient to test the goal of our tool, users should ideally be able to perform multiple observations at a location before moving on. These observations would then be listed hierarchically under each waypoint in the activities list. In addition, the ability to insert a point between two points on the map, or reorder points and observations in the activities list would be very useful.

Highlight areas of interest

In our simulation, we gave the science team a map with areas of interest already circled and labeled, but ideally the users should have the ability to draw directly onto the map. This allows scientists to refer to specific areas in their notes, as well as express interest in a large range rather than a single point.

Undo

The request for an undo button came up numerous times throughout our user tests, but unfortunately was more involved than we had time to implement in our prototype. In a fully functioning tool, the ability to undo is essential to help users recover from errors.

Other Design Directions

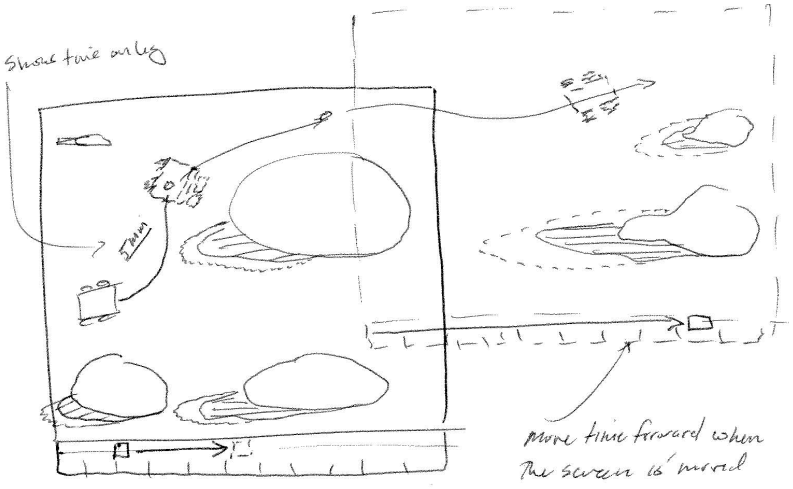
Our prototype only addresses one of the many possible directions we considered focusing on in the planning process. The following is a list of recommendations for future work based on our research and user-testing over the past eight months.

Hypothetical planning

In both our spring research on the various Mars missions, as well as in the robotic reconnaissance field test we observed during the summer, there were many instances where moving forward with a plan was dependent on the data received from the previous plan. In the field test, the scientists worked around this issue by sometimes creating multiple plans, the execution of which would depend on the data received at the “bifurcation point”. However, there was little support for these hypothetical plans in both their visualization on the map and the structuring of the planning tool. Supporting hypothetical plans would help scientists make more efficient use of their time, particularly in real-time planning scenarios where time is spent waiting for the rover to execute or data to downlink could instead be spent outlining new plans.

Data context and analysis

During the robotic reconnaissance field test, we observed several occasions where scientists had difficulty associating the downlinked data with the corresponding waypoint on the map. In addition, for some observations, such as microscopic images and



A design idea for visualizing sun glare in the future

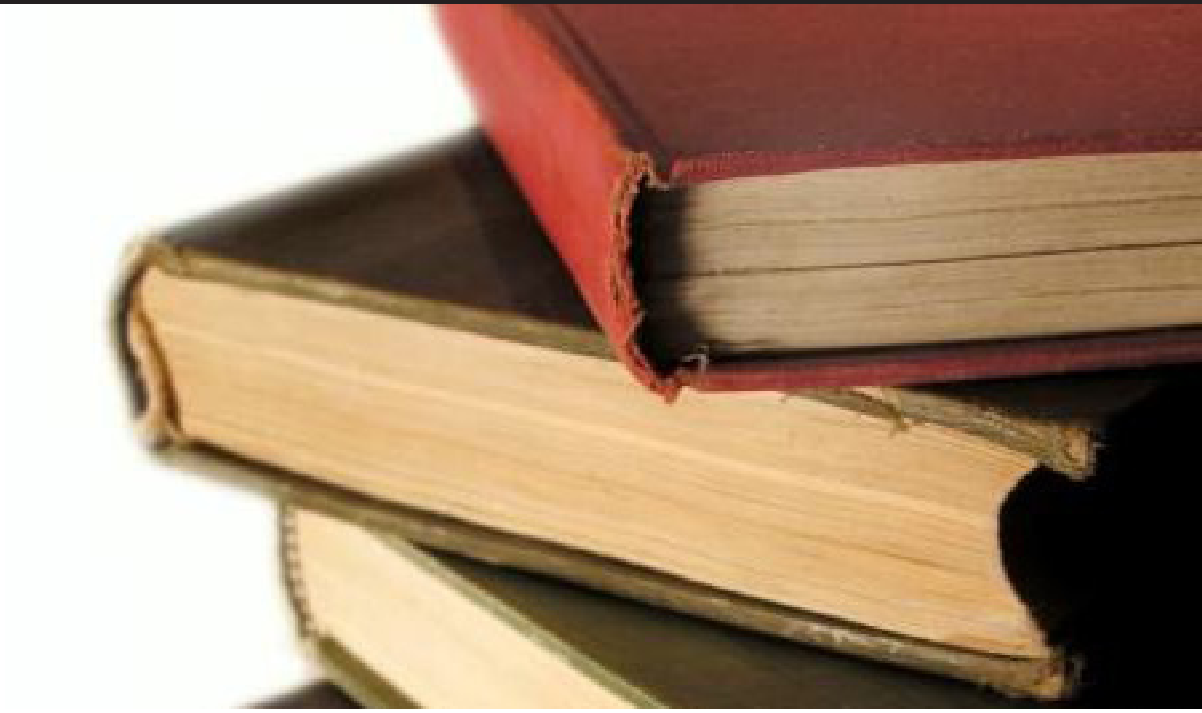
panoramas it was difficult to determine exactly which way the rover was facing and which features in the images corresponded to those on the map. Integration of the data and planning tools would help inform scientists of the rovers context and give them a better understanding of the surrounding environment.

Time management

In both “Mars-style” missions and real-time missions, such as the field test, time is an important factor. Constraints such as execution time, downlink time, drive time, data analysis time (for real-time missions) as well as the rover’s resources and changes in the sun’s angle must all be taken into account when creating a plan. In the field test, we observed that the flight team was often waiting on the science team to analyze the data and create the next plan, while the science team was often waiting for the rover to execute and for the data to downlink. An investigation of the best ways to visualize and manage such time constraints would help in more efficient use of the available time and resources.

Collaborative decision making

During the field test, while the principle investigator had the final call, the science team often had lively discussions concerning where to send the rover next and what observations to do, as well as the interpretation of the incoming data. Because the plans and data were projected on a large screen for all to see, we observed that it was sometimes difficult to tell exactly what part of the image or map an individual would be referring to. In some cases the whole science team would all crowd around one person’s laptop to see exactly what they were seeing. Investigation into methods of group discussion and decision making would help facilitate these important discussions.



APPENDIX A: RELATED LITERATURE

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

Herbsleb at 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 instability. 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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APPENDIX B: INTERVIEW SUMMARIES

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 cul-tural 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 differ-ent 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.

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

-Sequence Engineer

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.

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 comunicate with scientists and SPIs.

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.

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

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’ 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.”

> **“some people didn’t get [low level planning] and just didn’t want to.”**
>
> **-Lead Tactical SPI**

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.

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.

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

-Strategic SPI

As a strategic SPI, the interviewee was in charge of taking top-level mission re-quirements 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 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 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 conduced 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 cientists 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 per-sonalities in effectively communicating ideas and values.

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

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, 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.

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 encouraged 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 mis-sion'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.

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

-MER geologist

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 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.

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

-MER geologist

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 organiza-tions. 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.

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

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.

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 work place, 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.

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

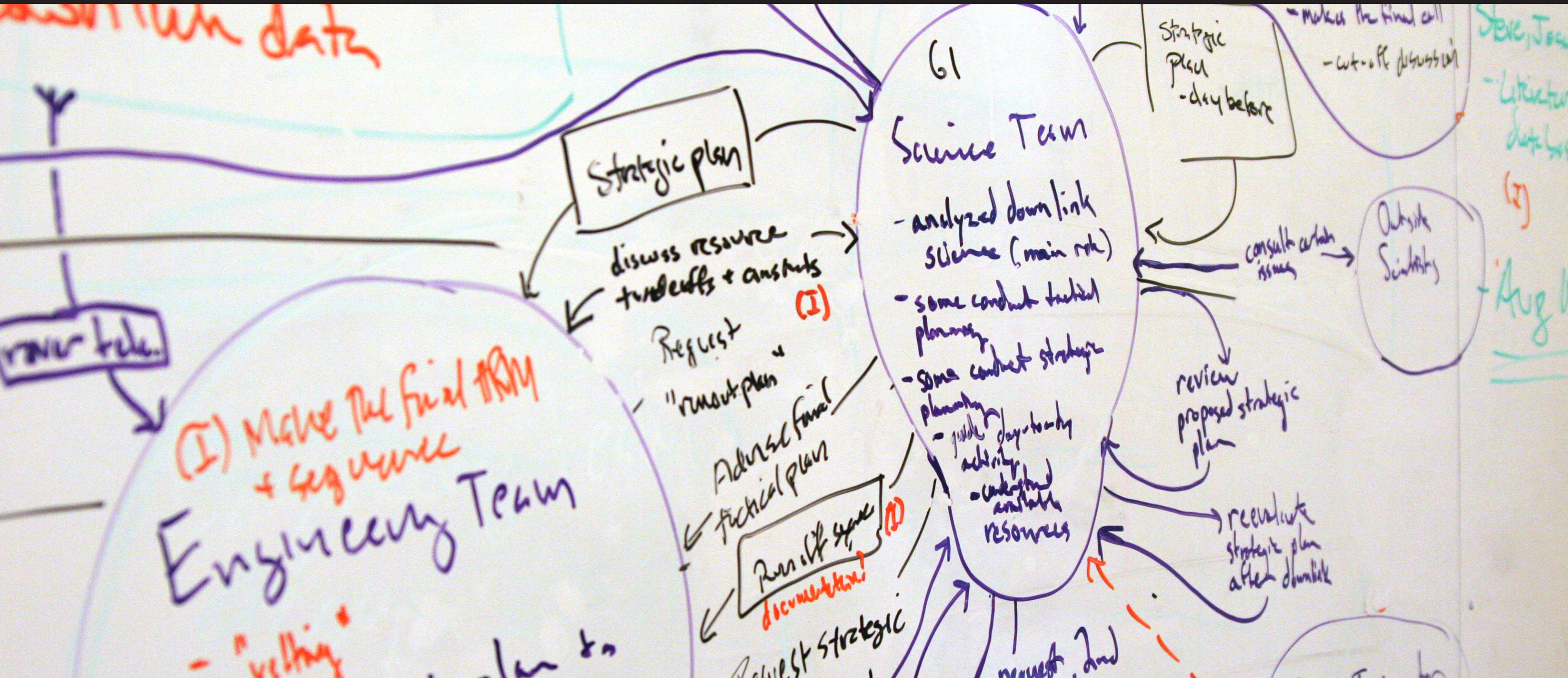
The customers do not always know exactly what they want. Often, they know the end goal, but are not aware of the part that may be needed to achieve that goal, or the process involved to make the part. The foreman must interact with a range of customers, from those with no machining, drafting, or design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

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	✓	✓				✓			

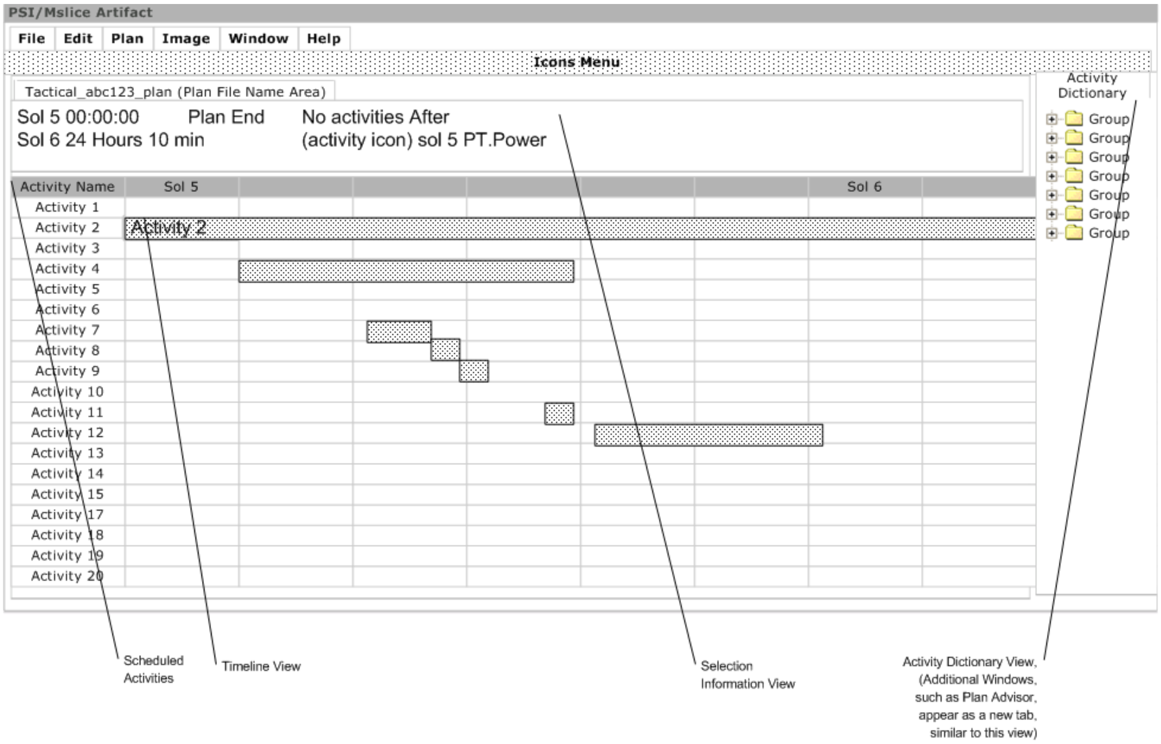


APPENDIX D: CONSOLIDATED MODELS

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 of 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 direc-tions (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 compli-cated constraints. All noted functionality in PSI appeared to be present in MSlice.



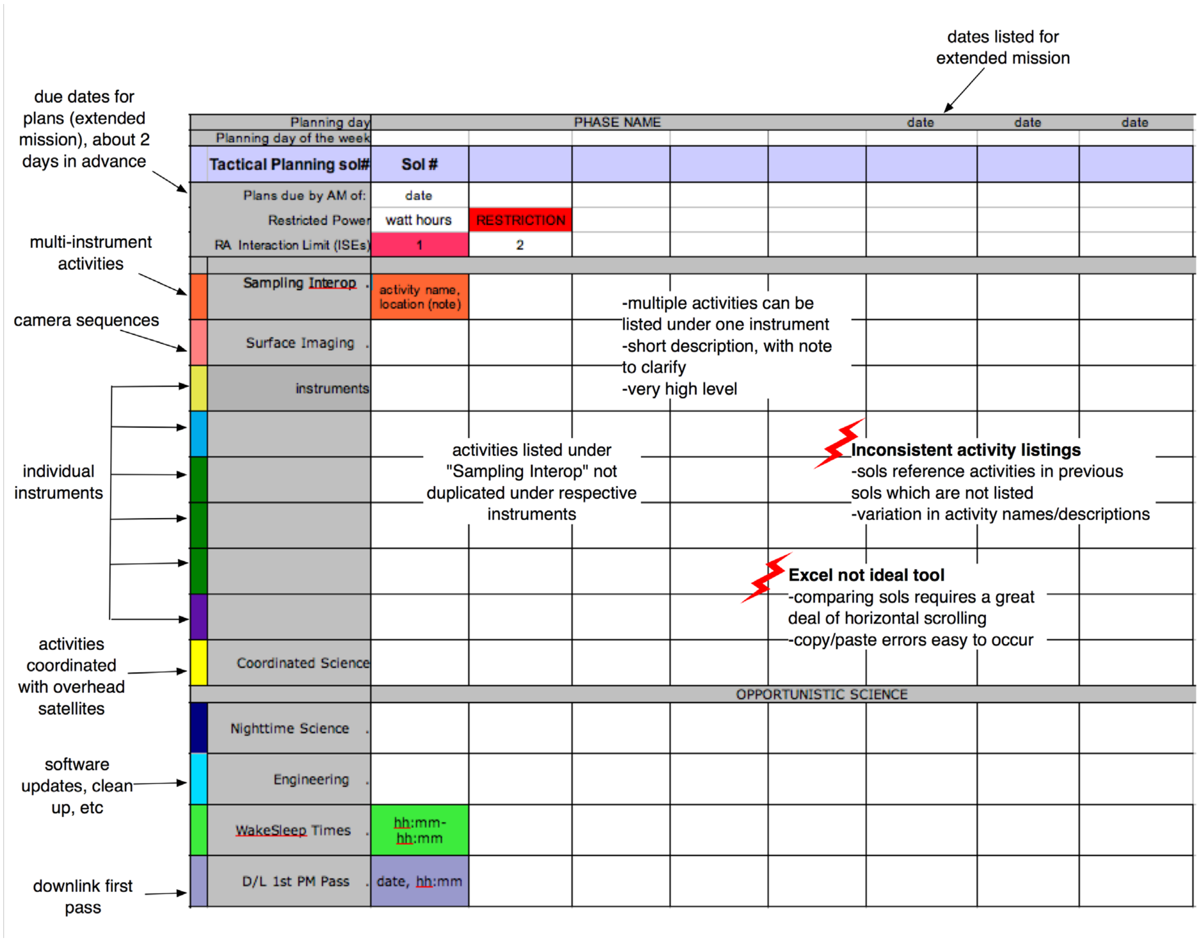
Sol 5 00:00:00 Plan End No activities After
Sol 6 24 Hours 10 min (activity icon) sol 5 PT.Power

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.



dates listed for extended mission

due dates for plans (extended mission), about 2 days in advance

multi-instrument activities

camera sequences

individual instruments

activities coordinated with overhead satellites

software updates, clean up, etc

downlink first pass

-multiple activities can be listed under one instrument
-short description, with note to clarify
-very high level

activities listed under "Sampling Interop" not duplicated under respective instruments

Inconsistent activity listings
-sols reference activities in previous sols which are not listed
-variation in activity names/descriptions

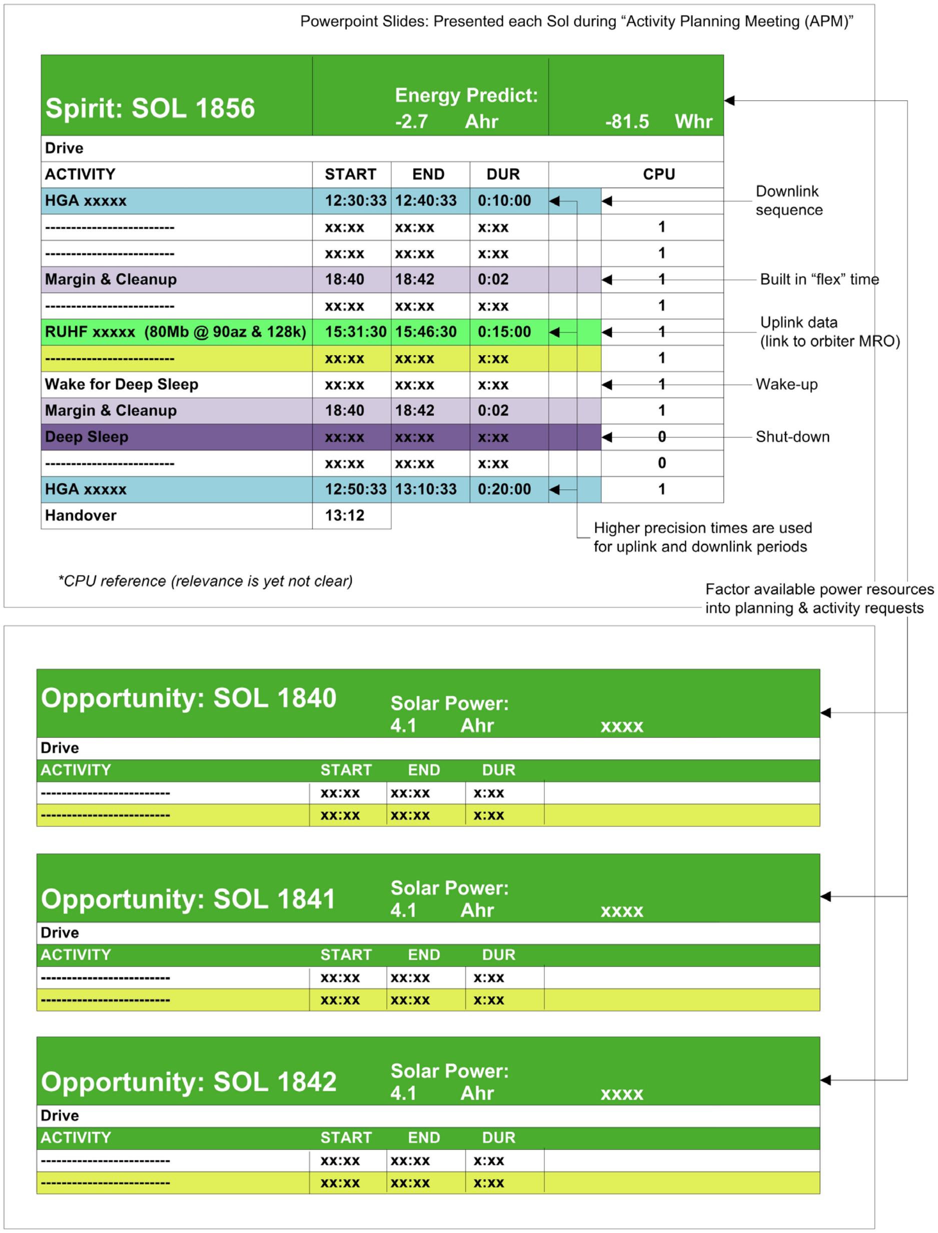
Excel not ideal tool
-comparing sols requires a great deal of horizontal scrolling
-copy/paste errors easy to occur

Skeleton Plan

Mars Exploration Rover (MER) mission operations uses a “Skeleton Plan” Excel spread-sheet 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.”



Powerpoint Slides: Presented each Sol during “Activity Planning Meeting (APM)”

Spirit: SOL 1856 Energy Predict: -2.7 Ahr -81.5 Whr

Drive

ACTIVITY	START	END	DUR	CPU
HGA xxxxx	12:30:33	12:40:33	0:10:00	
------------------------	xx:xx	xx:xx	x:xx	1
------------------------	xx:xx	xx:xx	x:xx	1
Margin & Cleanup	18:40	18:42	0:02	1
------------------------	xx:xx	xx:xx	x:xx	1
RUHF xxxxx (80Mb @ 90az & 128k)	15:31:30	15:46:30	0:15:00	1
------------------------	xx:xx	xx:xx	x:xx	1
Wake for Deep Sleep	xx:xx	xx:xx	x:xx	1
Margin & Cleanup	18:40	18:42	0:02	1
Deep Sleep	xx:xx	xx:xx	x:xx	0
------------------------	xx:xx	xx:xx	x:xx	0
HGA xxxxx	12:50:33	13:10:33	0:20:00	1
Handover	13:12			

Downlink sequence

Built in “flex” time

Uplink data (link to orbiter MRO)

Wake-up

Shut-down

Higher precision times are used for uplink and downlink periods

*CPU reference (relevance is yet not clear)

Factor available power resources into planning & activity requests

Opportunity: SOL 1840 Solar Power: 4.1 Ahr xxxx

Drive

ACTIVITY	START	END	DUR
------------------------	xx:xx	xx:xx	x:xx
------------------------	xx:xx	xx:xx	x:xx

Opportunity: SOL 1841 Solar Power: 4.1 Ahr xxxx

Drive

ACTIVITY	START	END	DUR
------------------------	xx:xx	xx:xx	x:xx
------------------------	xx:xx	xx:xx	x:xx

Opportunity: SOL 1842 Solar Power: 4.1 Ahr xxxx

Drive

ACTIVITY	START	END	DUR
------------------------	xx:xx	xx:xx	x:xx
------------------------	xx:xx	xx:xx	x:xx

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

```
*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
```

author 2

```
*****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***
```

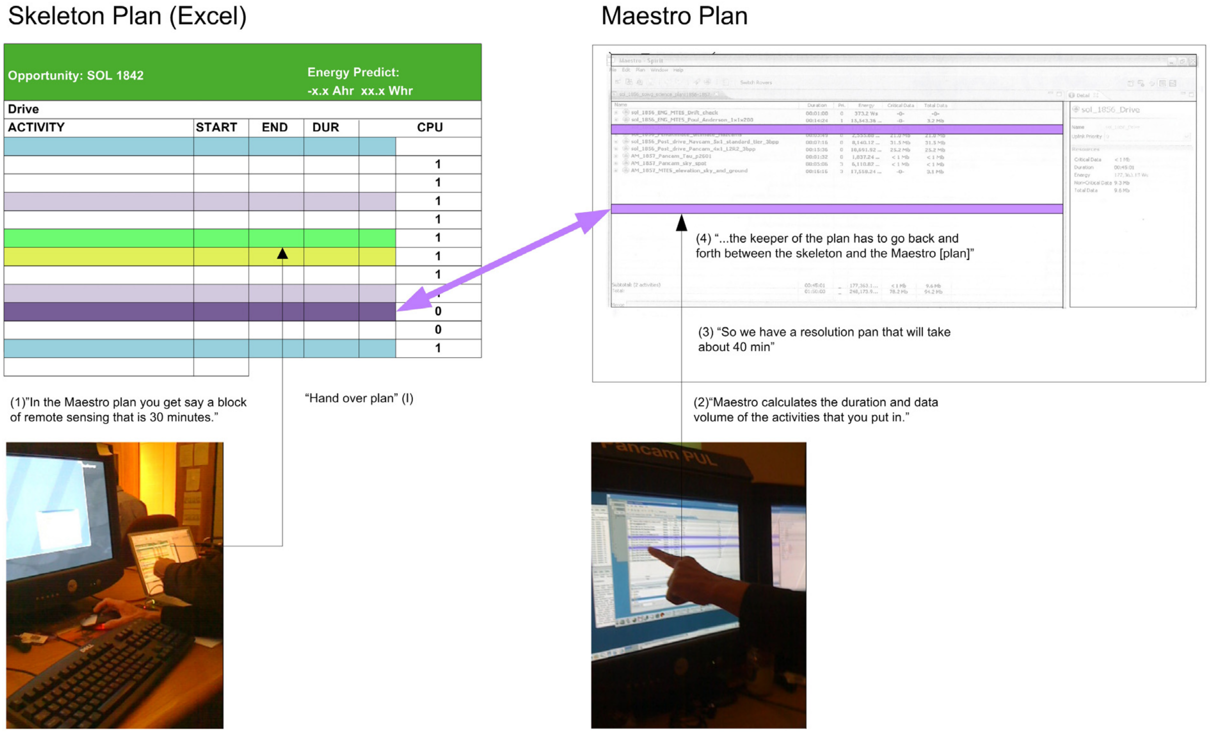
author 3

```
------------------------------------------------------
TECP
------------------------------------------------------

------------------------------------------------------
Expected EVRs:
------------------------------------------------------


Detailed Notes



Issues, Concerns & Requests

Attachments [Add]
```

Breakdowns:
Different formatting
Varrying lengths and
different types of
information mentioned

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		
Drive					
ACTIVITY	START	END	DUR		CPU
					1
					1
					1
					1
					1
					1
					1
					1
					0
					0
					1

Maestro Plan

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

“Hand over plan” (I)

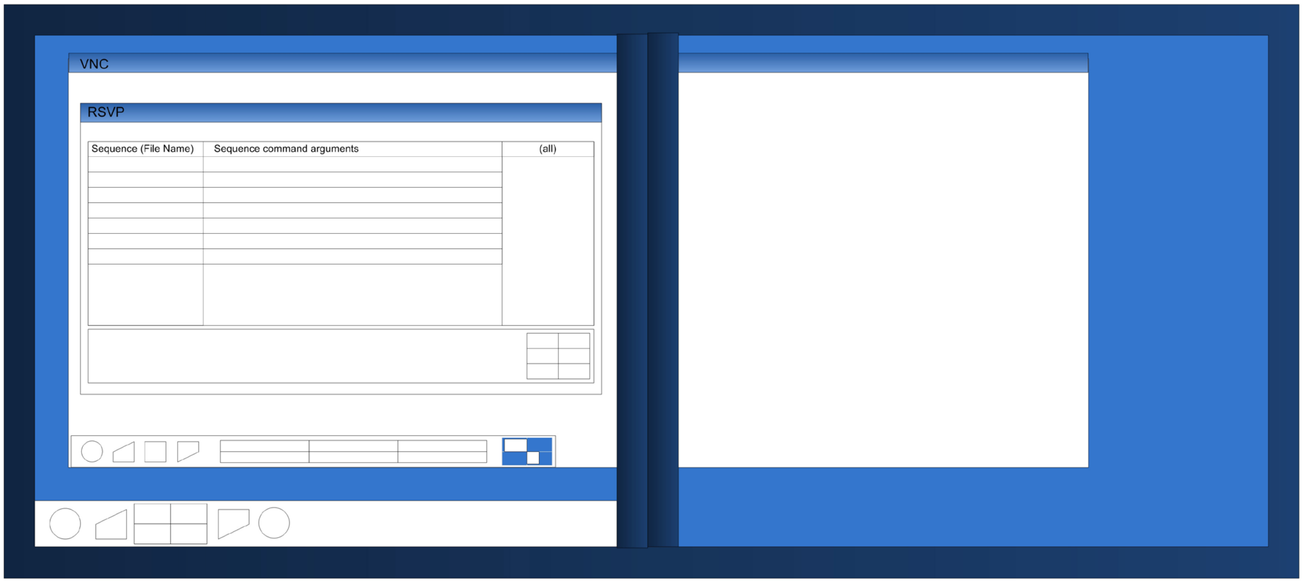
(2)“Maestro calculates the duration and data volume of the activities that you put in.”

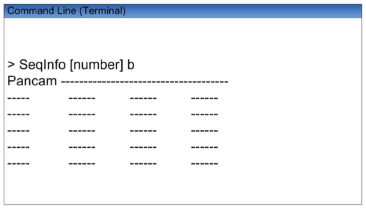
(3) “So we have a resolution pan that will take about 40 min”

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

RSVP

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





```
> 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.

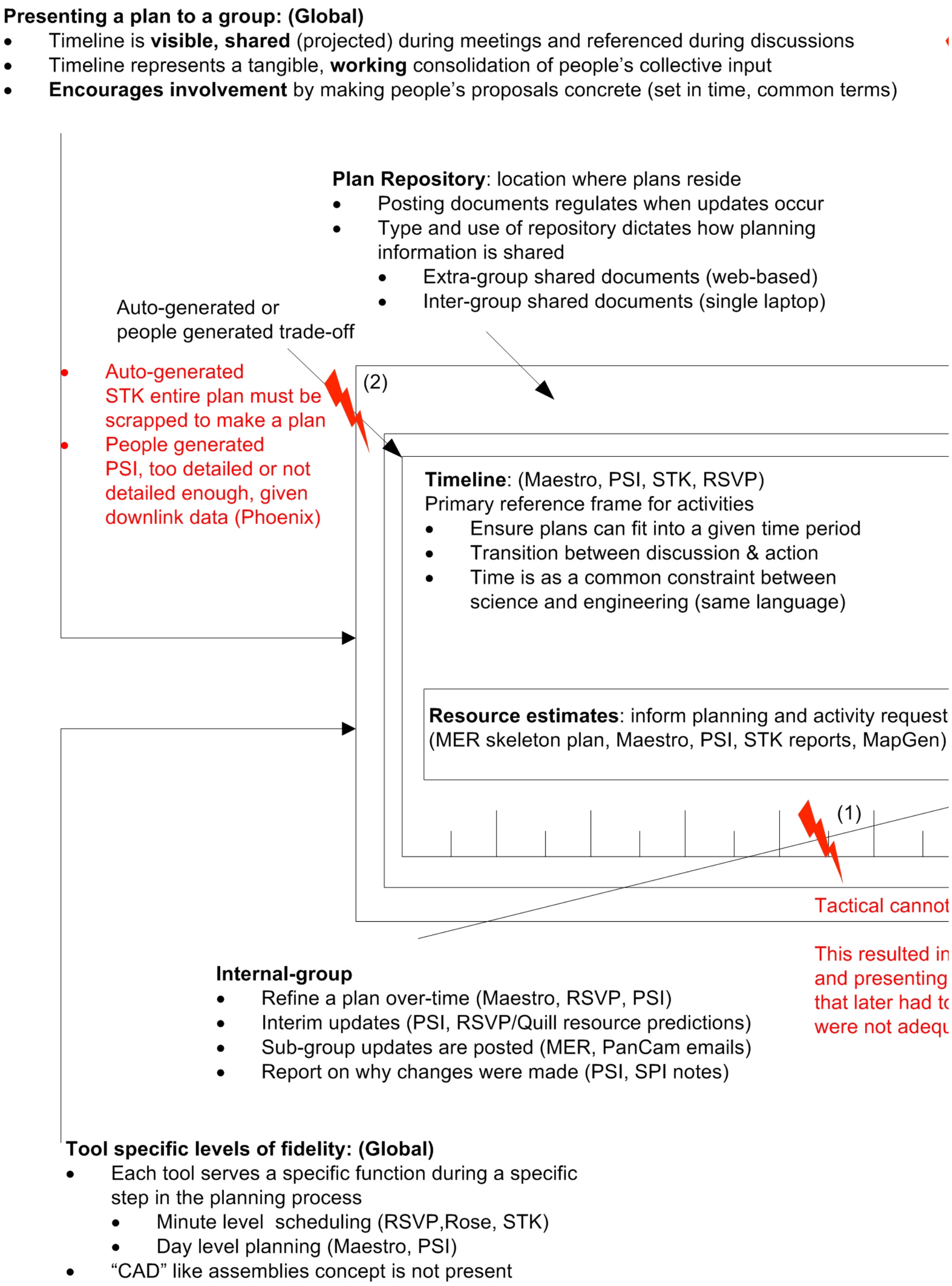
HyperDrive

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)

Plan Repository: location where plans reside
- Posting documents regulates when updates occur
- Type and use of repository dictates how planning information is shared
  - Extra-group shared documents (web-based)
  - Inter-group shared documents (single laptop)

Auto-generated or people generated trade-off

- Auto-generated STK entire plan must be scrapped to make a plan
- People generated PSI, too detailed or not detailed enough, given downlink data (Phoenix)

(2)

Timeline: (Maestro, PSI, STK, RSVP)
Primary reference frame for activities
- Ensure plans can fit into a given time period
- Transition between discussion & action
- Time is as a common constraint between science and engineering (same language)

Resource estimates: inform planning and activity request
(MER skeleton plan, Maestro, PSI, STK reports, MapGen)

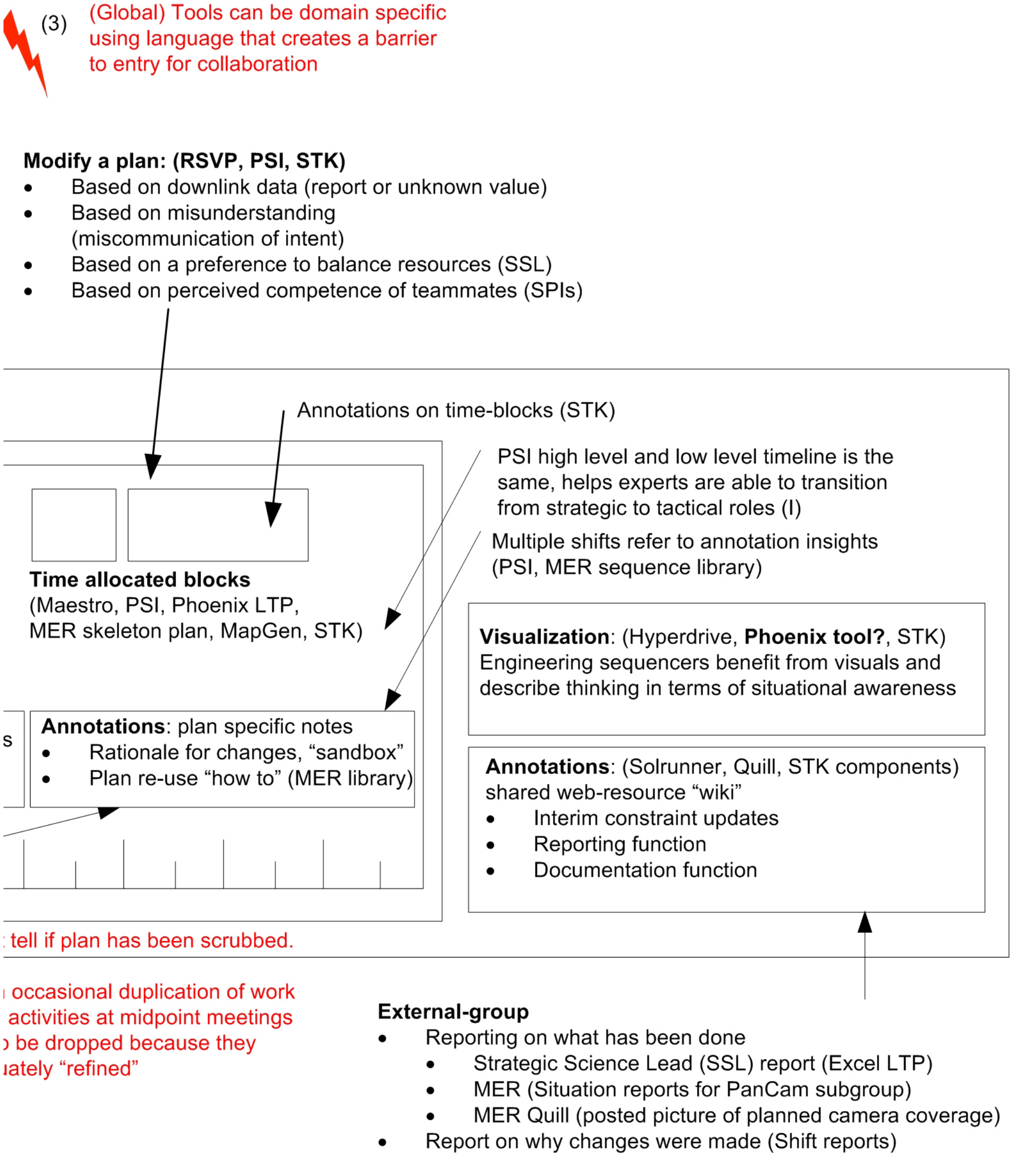
(1)

Tactical cannot

This resulted i
and presenting
that later had t
were not adequ

Internal-group
- Refine a plan over-time (Maestro, RSVP, PSI)
- Interim updates (PSI, RSVP/Quill resource predictions)
- Sub-group updates are posted (MER, PanCam emails)
- Report on why changes were made (PSI, SPI notes)

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)

Annotations on time-blocks (STK)

PSI high level and low level timeline is the same, helps experts are able to transition from strategic to tactical roles (I)

Multiple shifts refer to annotation insights (PSI, MER sequence library)

Time allocated blocks
(Maestro, PSI, Phoenix LTP,
MER skeleton plan, MapGen, STK)

Visualization: (Hyperdrive, **Phoenix tool?**, STK)
Engineering sequencers benefit from visuals and describe thinking in terms of situational awareness

s

Annotations: plan specific notes
- Rationale for changes, “sandbox”
- Plan re-use “how to” (MER library)

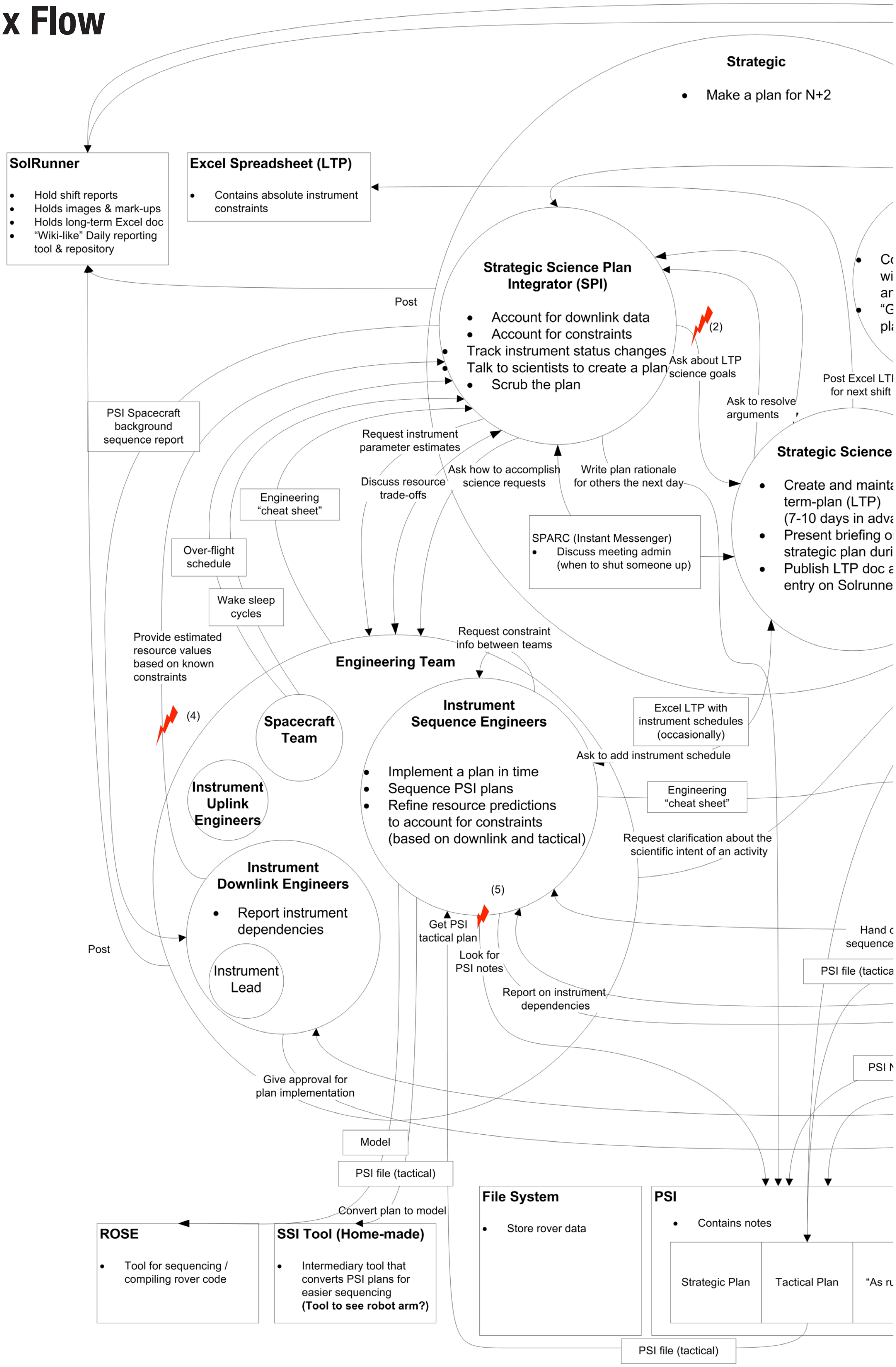
Annotations: (Solrunner, Quill, STK components)
shared web-resource “wiki”
- Interim constraint updates
- Reporting function
- Documentation function

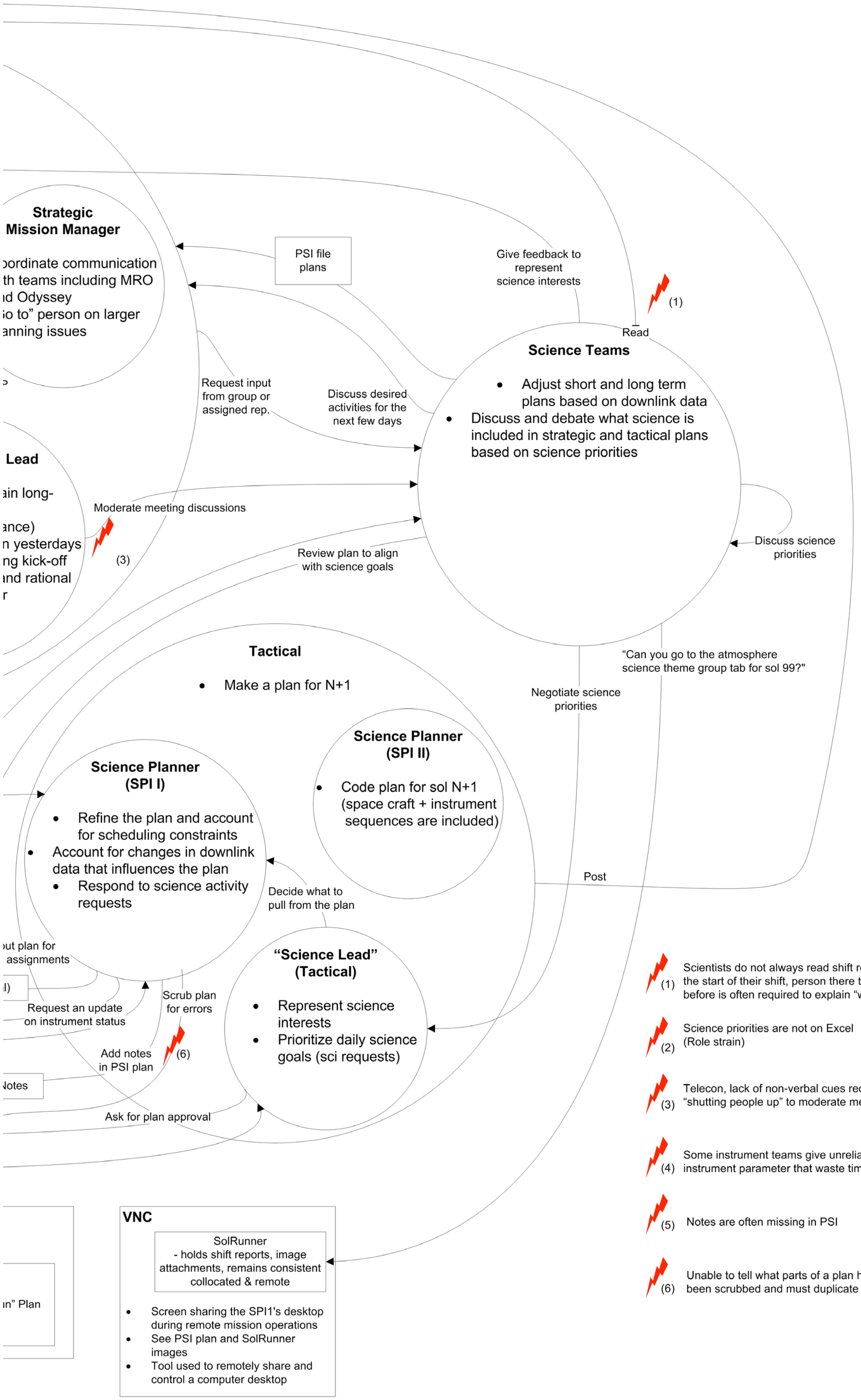
tell if plan has been scrubbed.

occasional duplication of work
activities at midpoint meetings
be dropped because they
ately “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)

Phoenix Flow





(1) Scientists do not always read shift reports the start of their shift, person there the day before is often required to explain "why"

(2) Science priorities are not on Excel (Role strain)

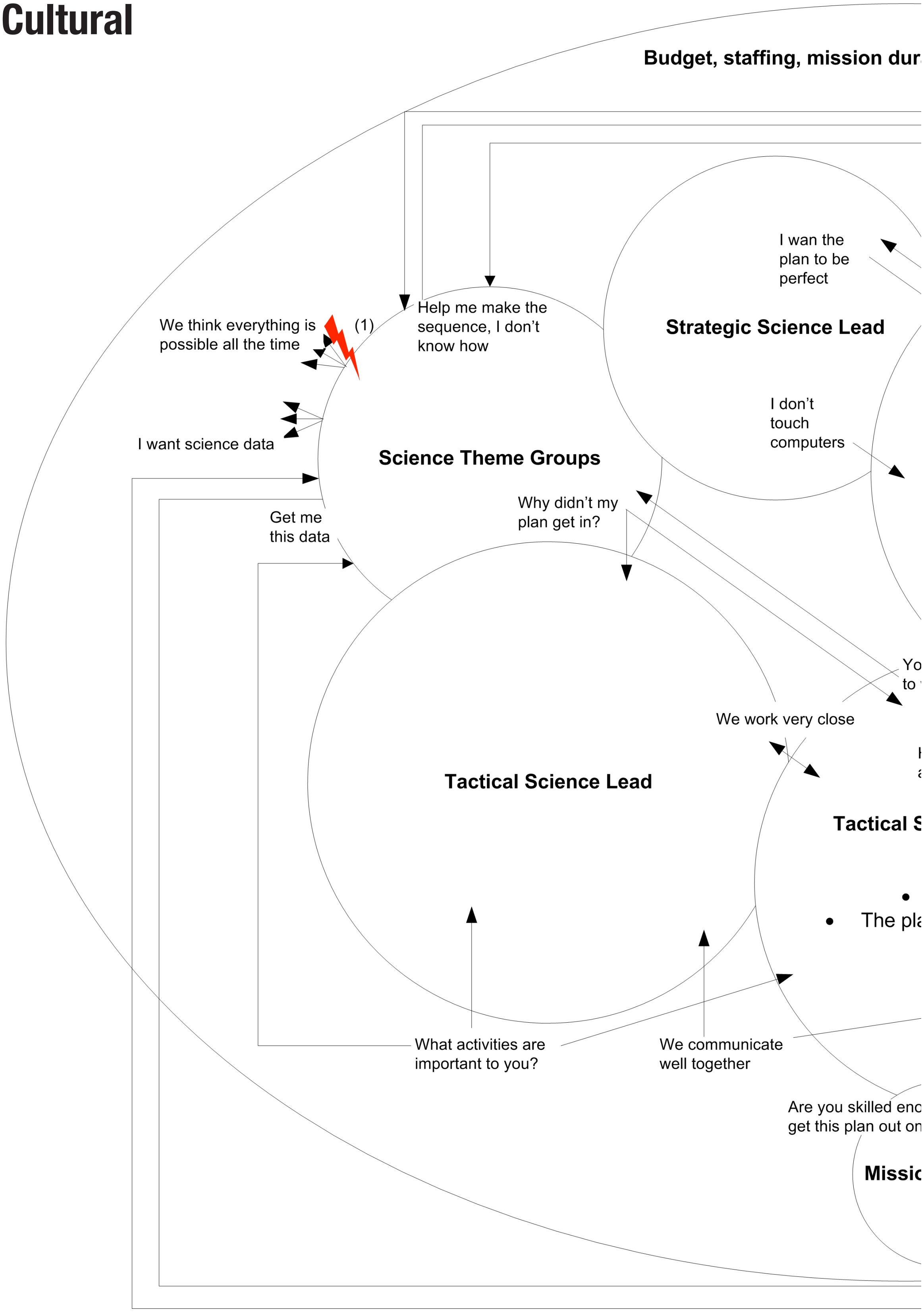
(3) Telecon, lack of non-verbal cues requires "shutting people up" to moderate meetings

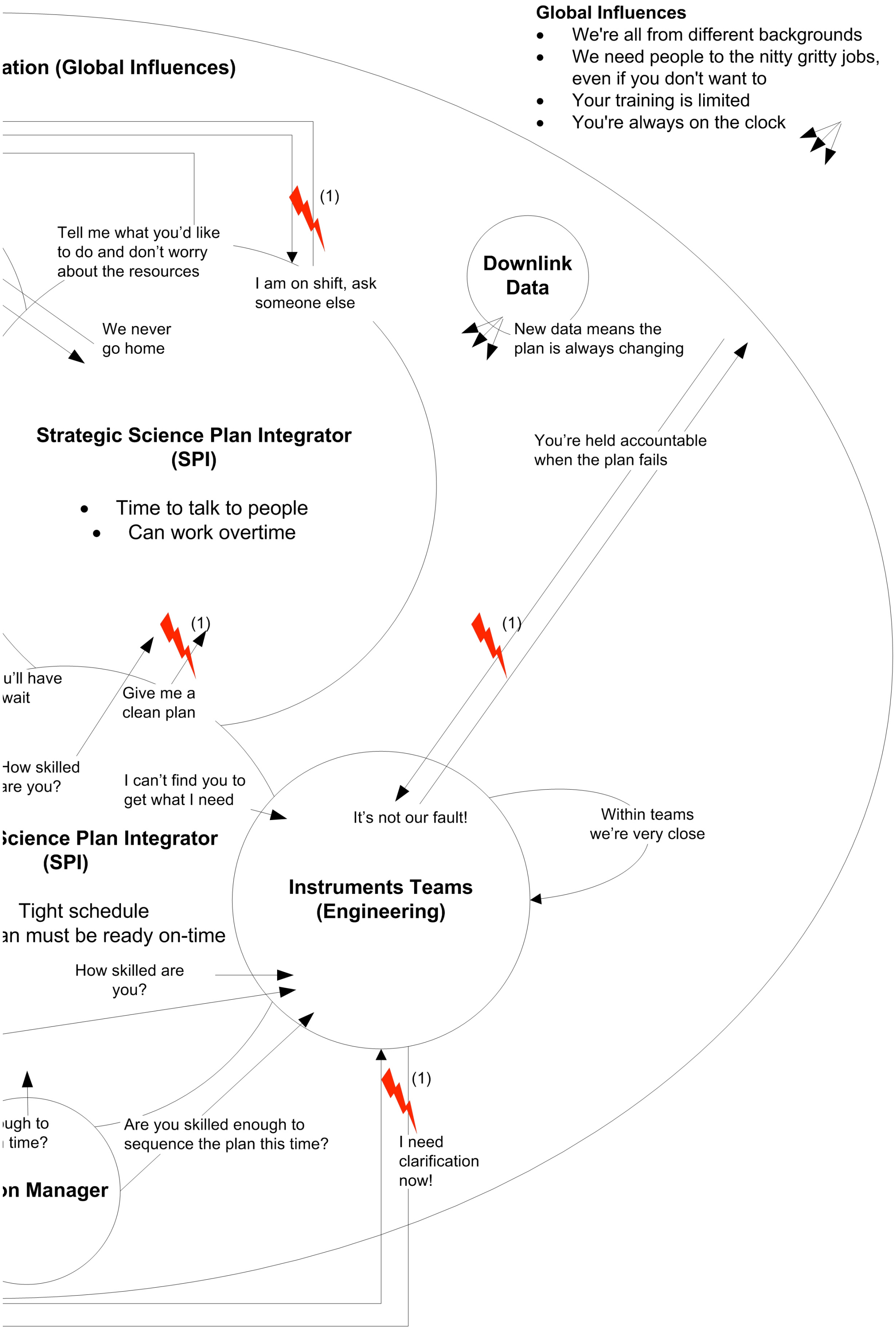
(4) Some instrument teams give unreliable instrument parameter that waste time

(5) Notes are often missing in PSI

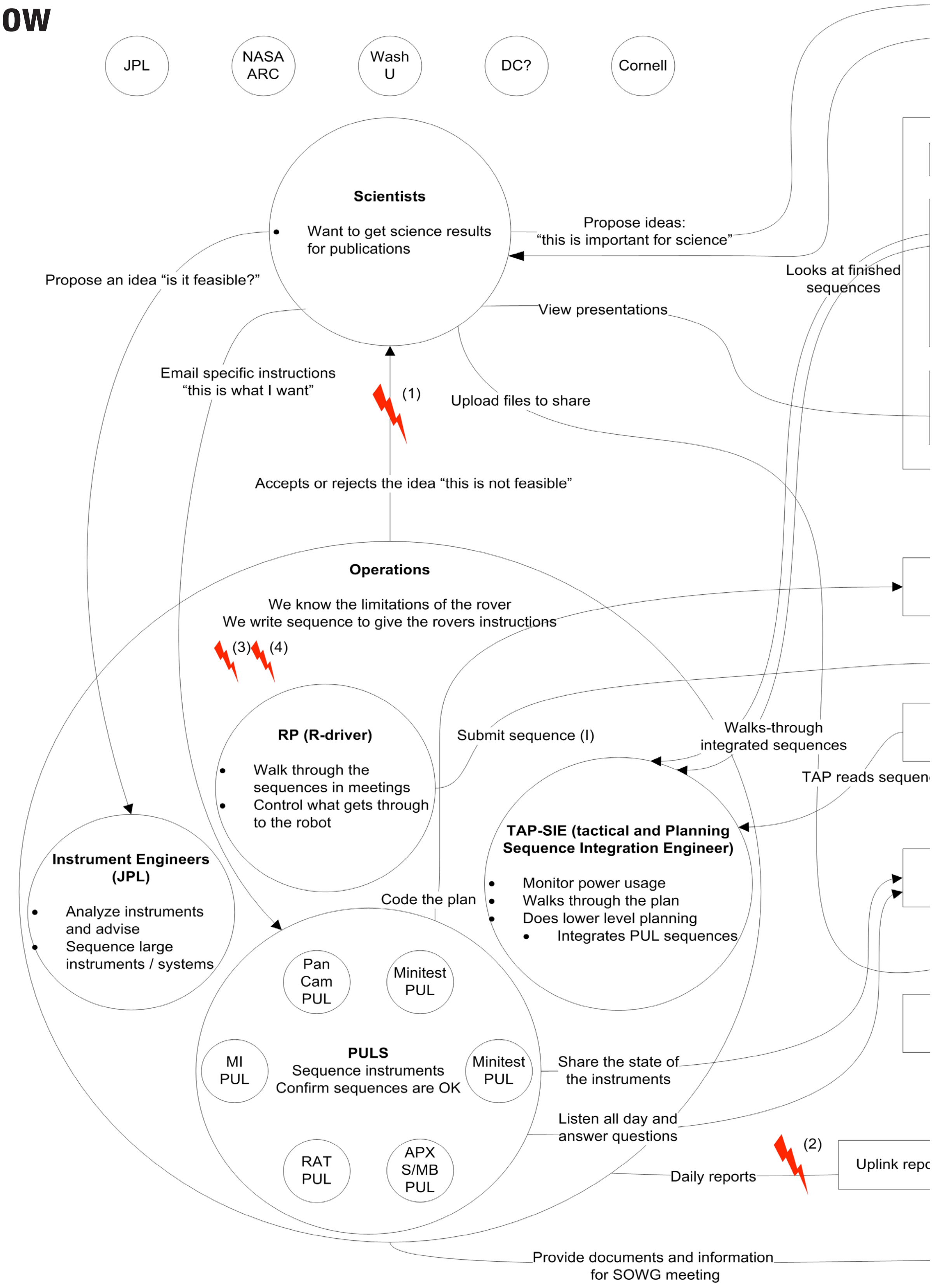
(6) Unable to tell what parts of a plan have been scrubbed and must duplicate work

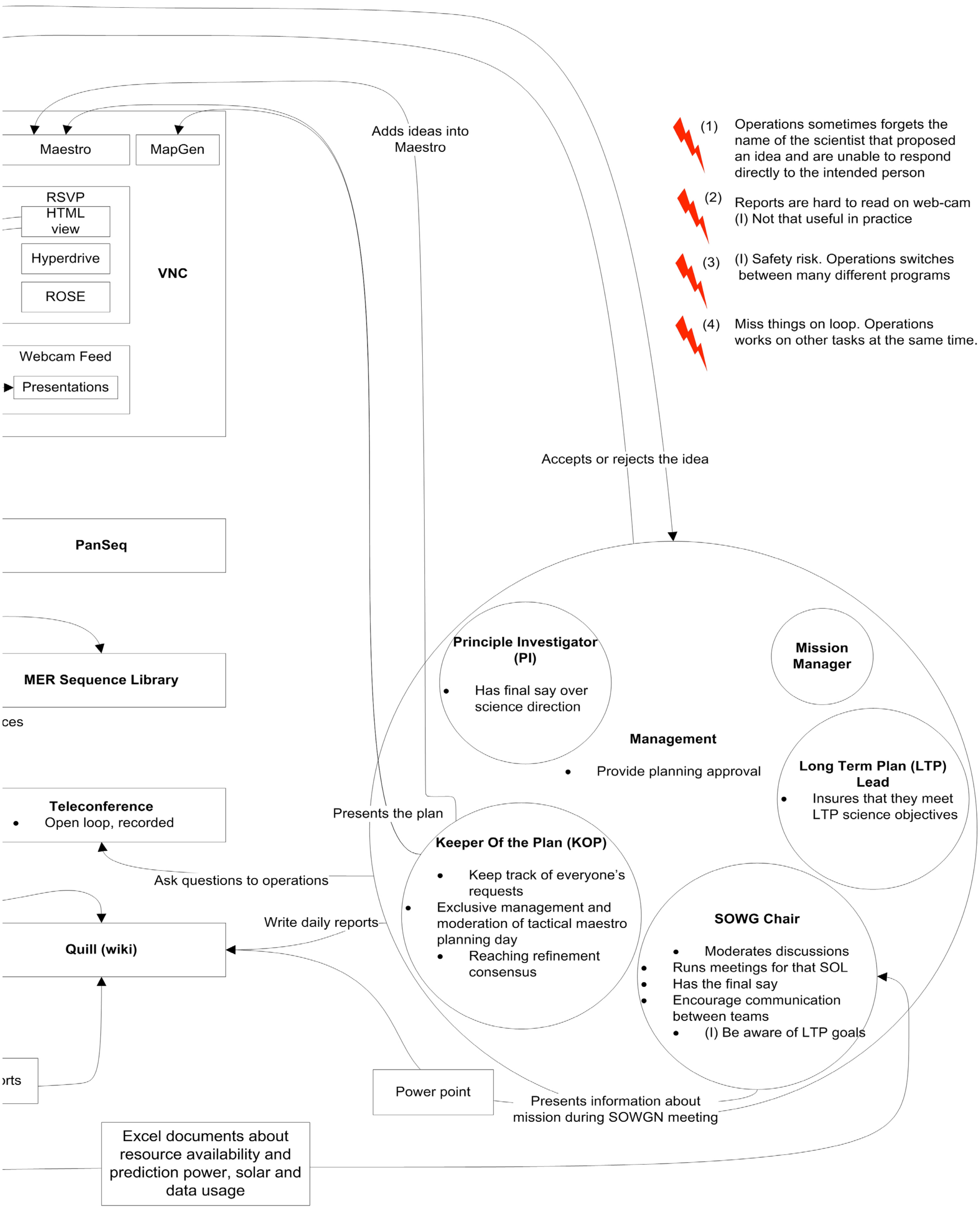
Phoenix Cultural



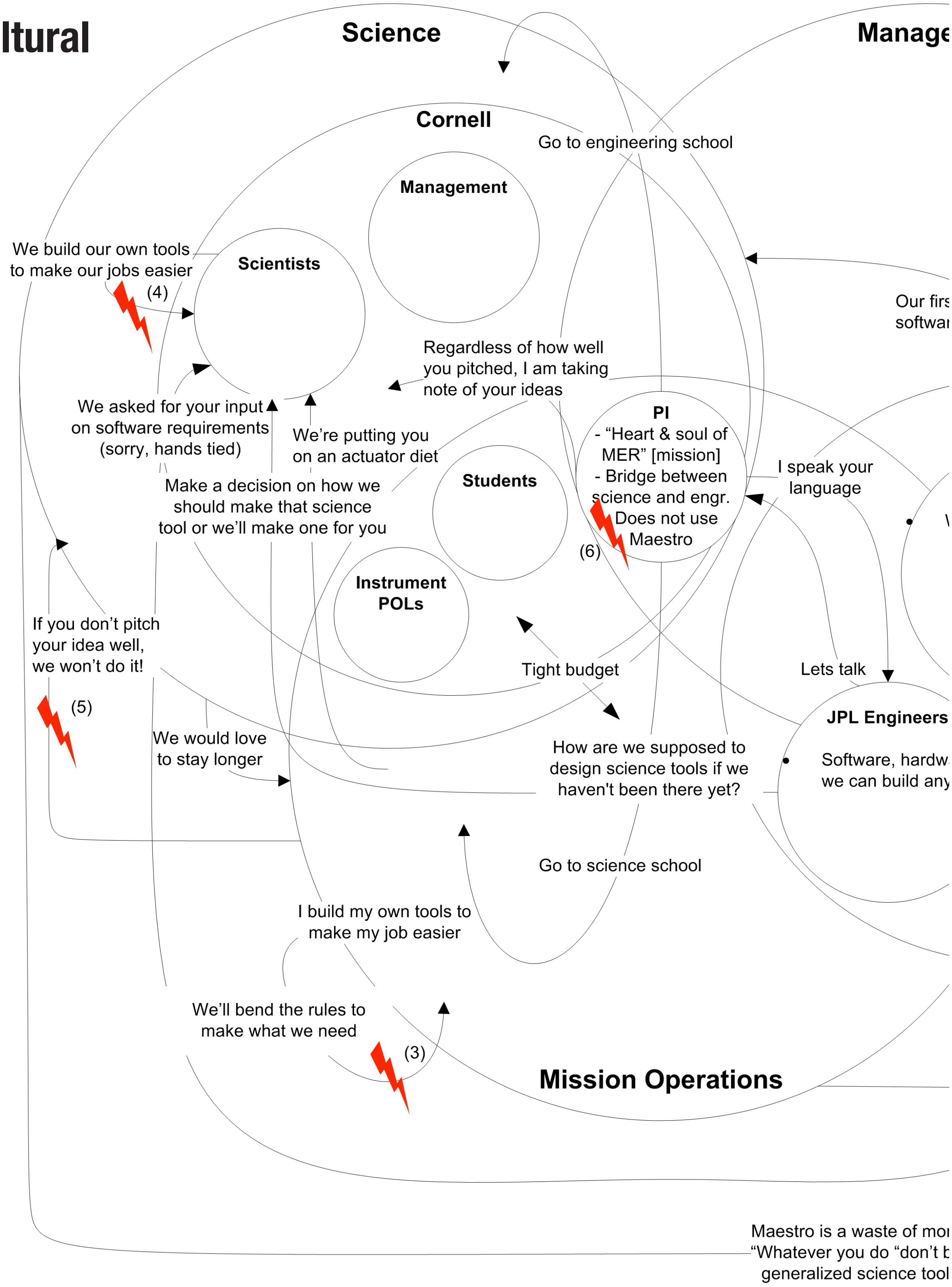

Global Influences
We're all from different backgrounds
We need people to the nitty gritty jobs, even if you don't want to
Your training is limited
You're always on the clock
ation (Global Influences)
(1)
Tell me what you'd like to do and don't worry about the resources
I am on shift, ask someone else
We never go home
Downlink Data
New data means the plan is always changing
Strategic Science Plan Integrator (SPI)
Time to talk to people
Can work overtime
You're held accountable when the plan fails
(1)
(1)
u'll have wait
Give me a clean plan
How skilled are you?
I can't find you to get what I need
It's not our fault!
Within teams we're very close
Science Plan Integrator (SPI)
Tight schedule
an must be ready on-time
Instruments Teams (Engineering)
How skilled are you?
(1)
ugh to time?
Are you skilled enough to sequence the plan this time?
I need clarification now!
on Manager

MER Flow


JPL
NASA ARC
Wash U
DC?
Cornell
Scientists
Want to get science results for publications
Propose ideas: "this is important for science"
Looks at finished sequences
View presentations
Propose an idea "is it feasible?"
Email specific instructions "this is what I want"
(1)
Upload files to share
Accepts or rejects the idea "this is not feasible"
Operations
We know the limitations of the rover
We write sequence to give the rovers instructions
(3)
(4)
RP (R-driver)
Walk through the sequences in meetings
Control what gets through to the robot
Submit sequence (I)
Walks-through integrated sequences
TAP reads sequen
TAP-SIE (tactical and Planning Sequence Integration Engineer)
Monitor power usage
Walks through the plan
Does lower level planning
Integrates PUL sequences
Instrument Engineers (JPL)
Analyze instruments and advise
Sequence large instruments / systems
Code the plan
Pan Cam PUL
Minitest PUL
MI PUL
PULS
Sequence instruments
Confirm sequences are OK
Minitest PUL
RAT PUL
APX S/MB PUL
Share the state of the instruments
Listen all day and answer questions
(2)
Uplink repo
Daily reports
Provide documents and information for SOWG meeting

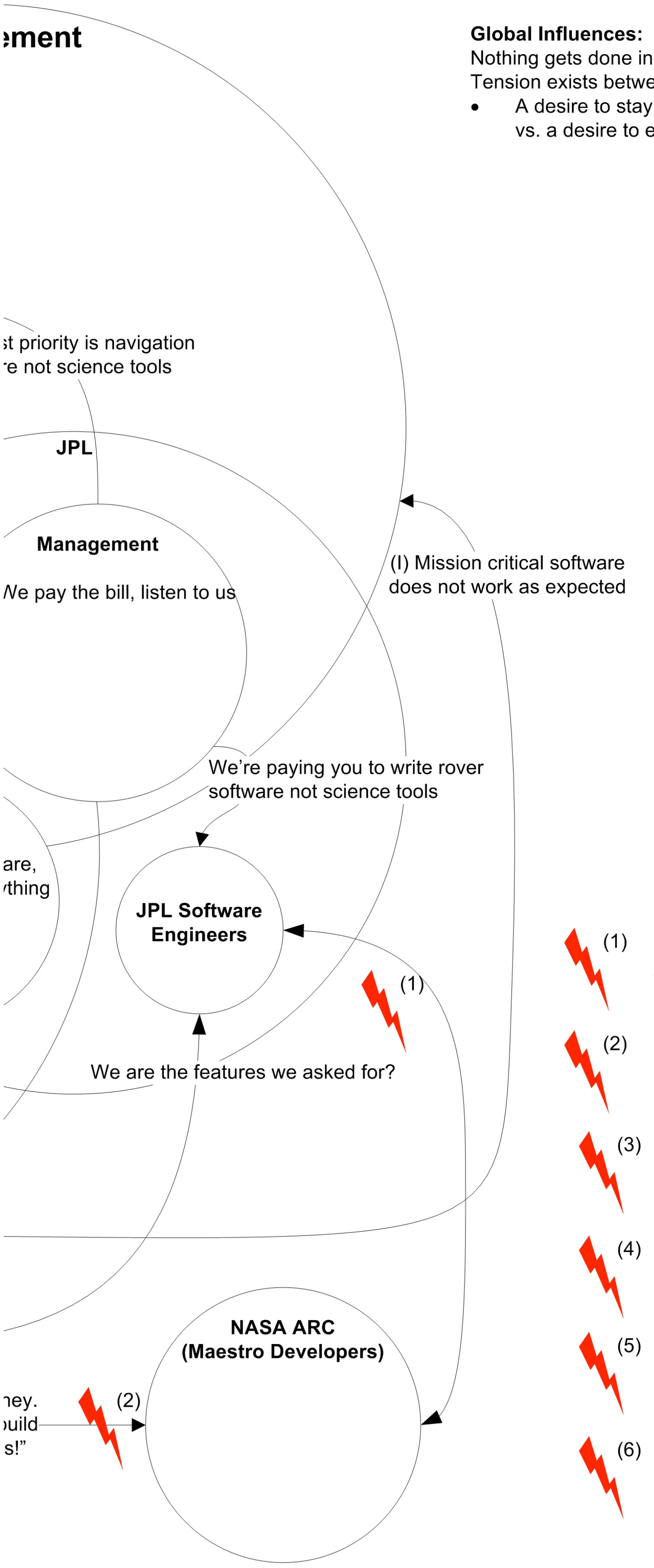

Maestro
MapGen
RSVP
HTML view
Hyperdrive
ROSE
VNC
Webcam Feed
Presentations
Adds ideas into Maestro
(1) Operations sometimes forgets the name of the scientist that proposed an idea and are unable to respond directly to the intended person
(2) Reports are hard to read on web-cam
(I) Not that useful in practice
(3) (I) Safety risk. Operations switches between many different programs
(4) Miss things on loop. Operations works on other tasks at the same time.
Accepts or rejects the idea
PanSeq
MER Sequence Library
ces
Principle Investigator (PI)
Has final say over science direction
Mission Manager
Management
Provide planning approval
Long Term Plan (LTP) Lead
Insures that they meet LTP science objectives
Teleconference
Open loop, recorded
Presents the plan
Keeper Of the Plan (KOP)
Keep track of everyone's requests
Exclusive management and moderation of tactical maestro planning day
Reaching refinement consensus
Ask questions to operations
Write daily reports
Quill (wiki)
SOWG Chair
Moderates discussions
Runs meetings for that SOL
Has the final say
Encourage communication between teams
(I) Be aware of LTP goals
rts
Power point
Presents information about mission during SOWGN meeting
Excel documents about resource availability and prediction power, solar and data usage

MER Cultural



Global Influences:
Nothing gets done in terms of science without a convincing “pitch”
Tension exists between scientists and mission operations

- A desire to stay in one place to perform thorough science vs. a desire to explore the Martian surface and see new things



(1) JPL and ARC software does not interface well; requires Cornell to build an additional “last minute” PanSeq module to bridge Miestro and RSVP

- JPL vs JPL (two different software groups)

(2) Misaligned expectations. Scientists are disappointed that Maestro does not address all of their science needs.

(3) Class C software. Building software to suite our needs is important enough to circumvent JPL validation & safety

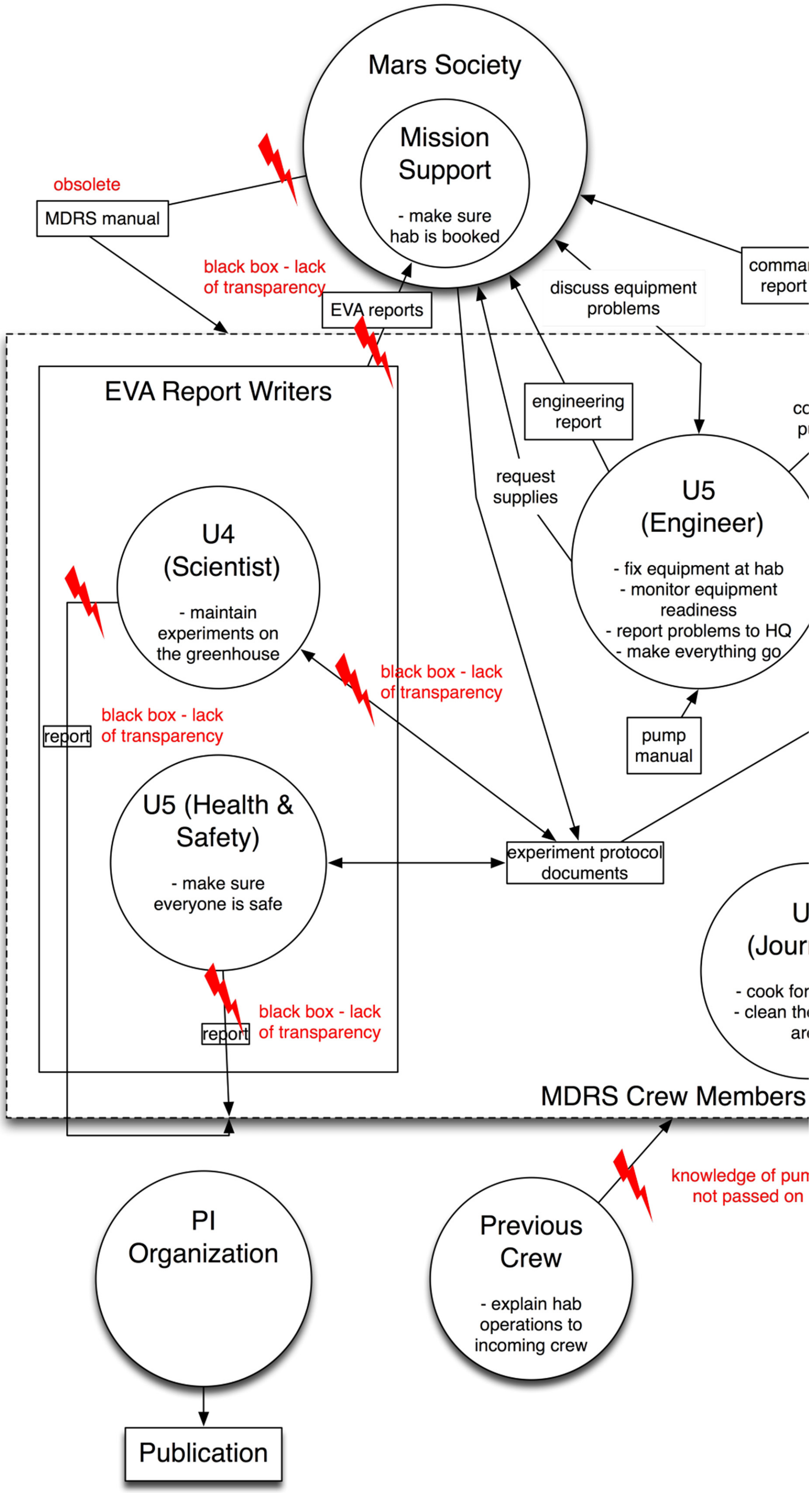
(4) The software needs of scientists are not anticipated before the mission

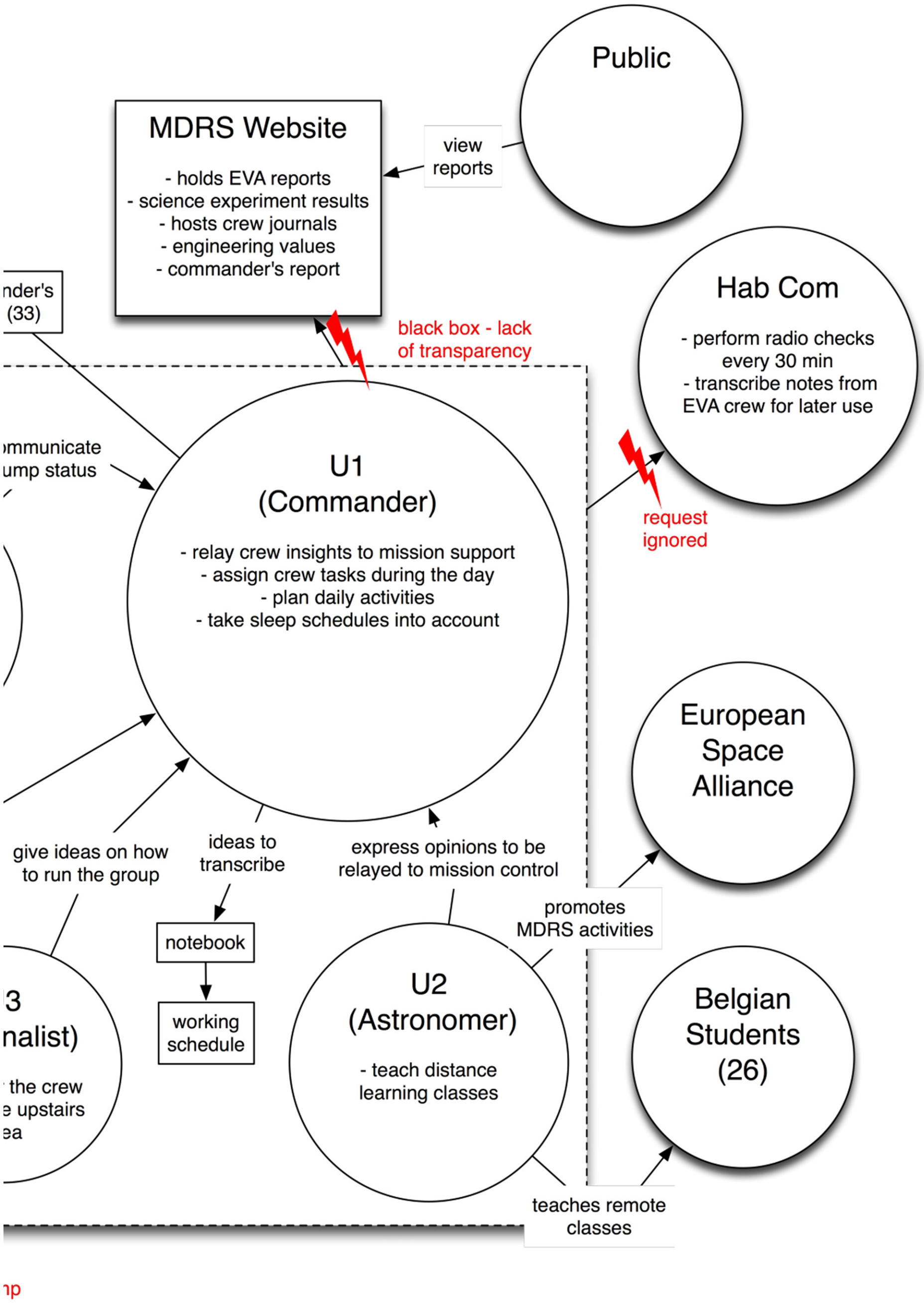
(5) Nothing gets added to the plan without a good reason, “[do your] homework” and make a good “pitch”

- *Job of a promoter, science evangelist, speaking skills*

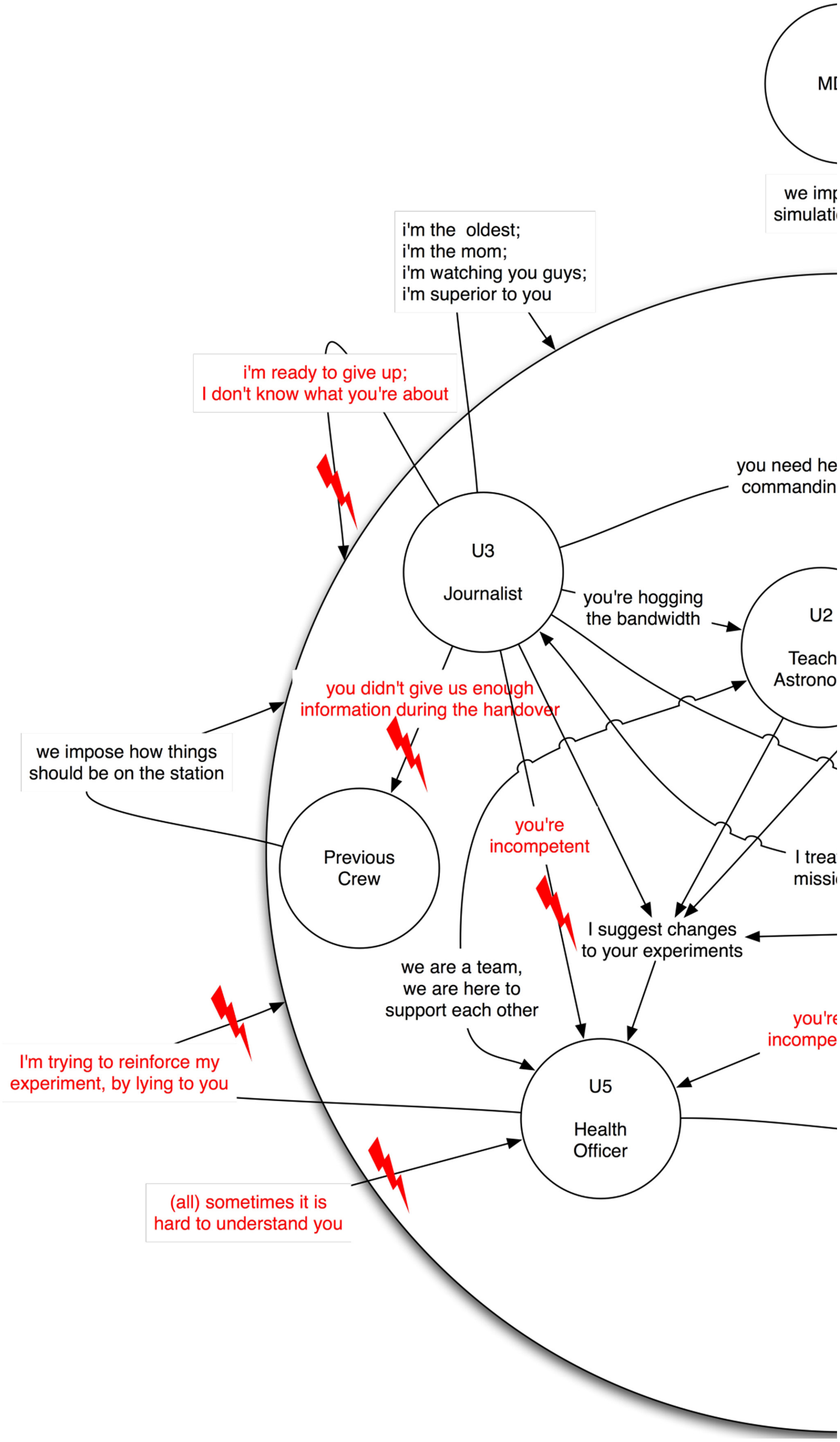
(6) Even Steve Squeyers does not use Miestro; limited science adoption

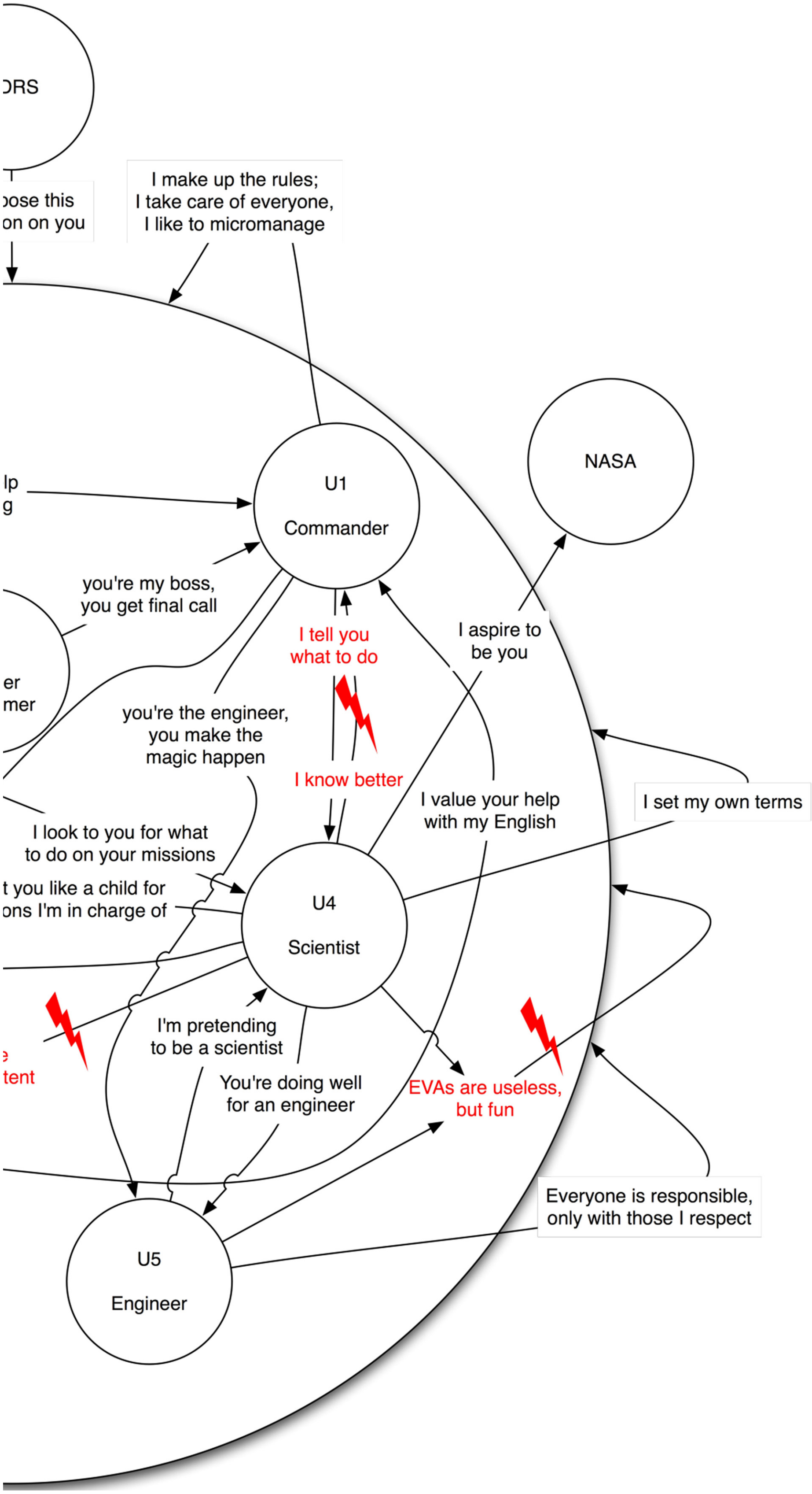
MDRS Flow


Mars Society
Mission Support
- make sure hab is booked
obsolete
MDRS manual
black box - lack of transparency
EVA reports
comma report
discuss equipment problems
EVA Report Writers
engineering report
request supplies
co p
U4 (Scientist)
- maintain experiments on the greenhouse
U5 (Engineer)
- fix equipment at hab
- monitor equipment readiness
- report problems to HQ
- make everything go
black box - lack of transparency
report
black box - lack of transparency
pump manual
U5 (Health & Safety)
- make sure everyone is safe
experiment protocol documents
U (Jour
- cook for
- clean th ar
report
black box - lack of transparency
MDRS Crew Members
knowledge of pun not passed on
PI Organization
Previous Crew
- explain hab operations to incoming crew
Publication

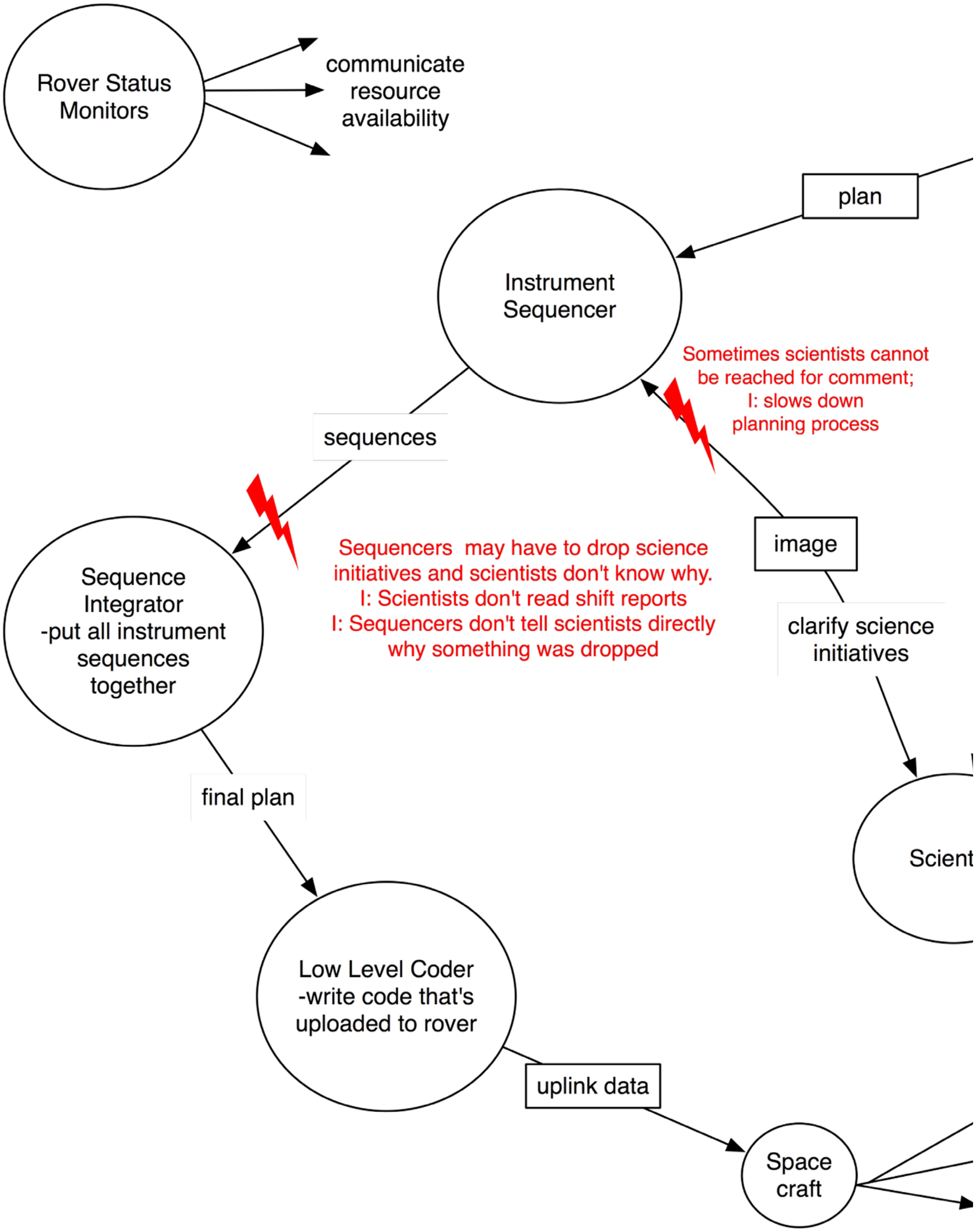

Public
view reports
MDRS Website
- holds EVA reports
- science experiment results
- hosts crew journals
- engineering values
- commander's report
nder's
(33)
black box - lack of transparency
Hab Com
- perform radio checks every 30 min
- transcribe notes from EVA crew for later use
request ignored
mmunicate
ump status
U1
(Commander)
- relay crew insights to mission support
- assign crew tasks during the day
- plan daily activities
- take sleep schedules into account
European Space Alliance
give ideas on how to run the group
ideas to transcribe
express opinions to be relayed to mission control
promotes MDRS activities
notebook
working schedule
3
nalist)
the crew
e upstairs
ea
U2
(Astronomer)
- teach distance learning classes
Belgian Students (26)
teaches remote classes
np

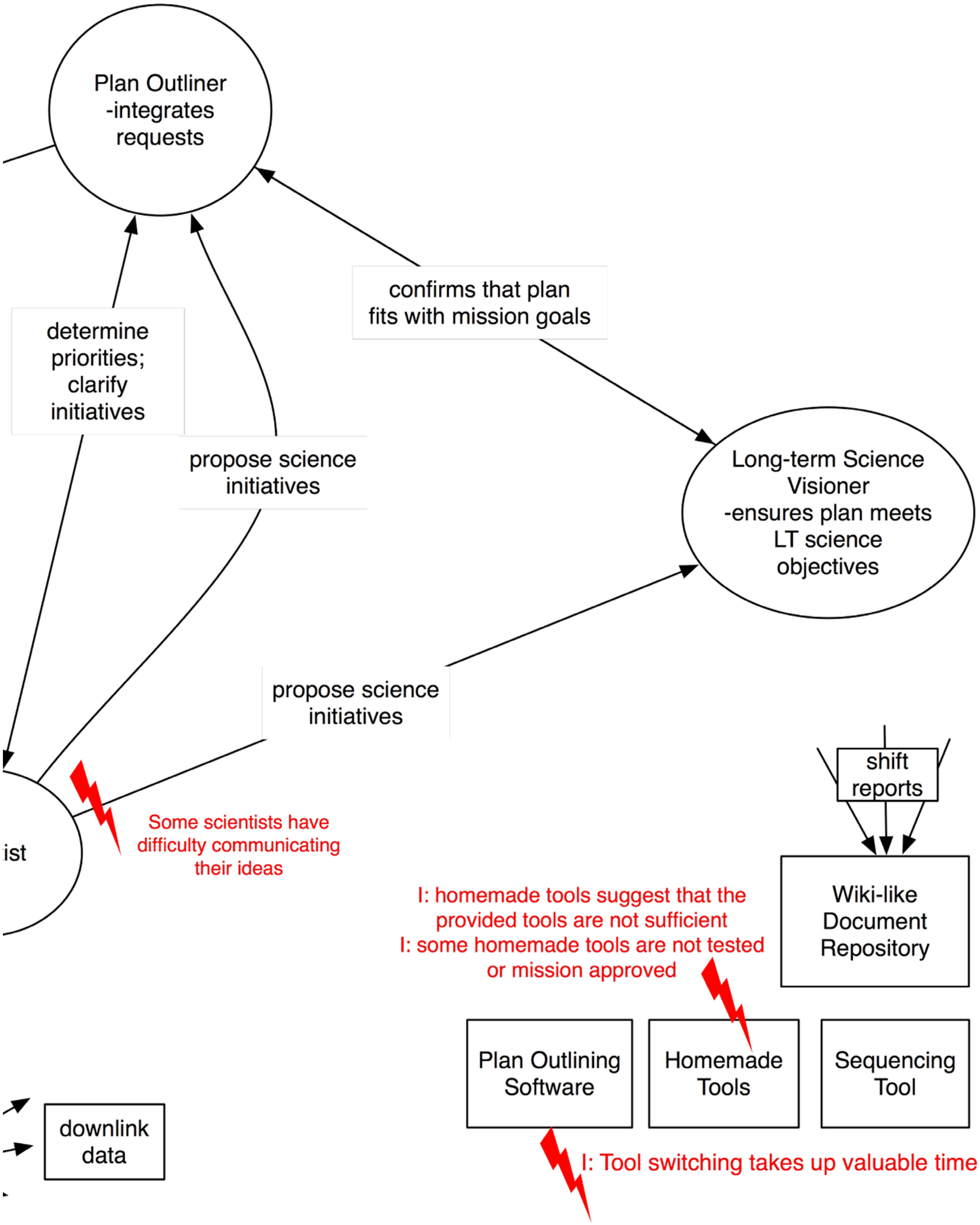
MDRS Cultural



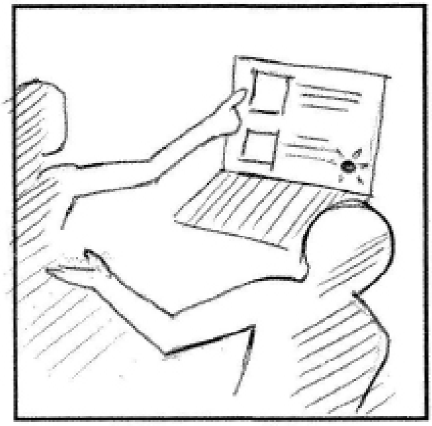

RS
ose this
on on you
I make up the rules;
I take care of everyone,
I like to micromanage
lp
g
U1
Commander
NASA
you're my boss,
you get final call
I tell you
what to do
I aspire to
be you
er
mer
you're the engineer,
you make the
magic happen
I know better
I value your help
with my English
I set my own terms
I look to you for what
to do on your missions
t you like a child for
ons I'm in charge of
U4
Scientist
I'm pretending
to be a scientist
tent
You're doing well
for an engineer
EVAs are useless,
but fun
Everyone is responsible,
only with those I respect
U5
Engineer

Consolidated Flow

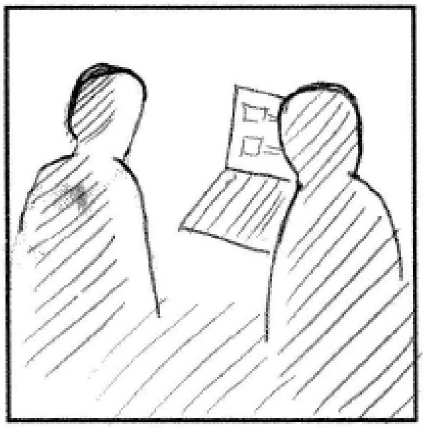



Plan Outliner
-integrates
requests
determine
priorities;
clarify
initiatives
propose science
initiatives
confirms that plan
fits with mission goals
Long-term Science
Visioner
-ensures plan meets
LT science
objectives
propose science
initiatives
ist
Some scientists have
difficulty communicating
their ideas
shift
reports
Wiki-like
Document
Repository
I: homemade tools suggest that the
provided tools are not sufficient
I: some homemade tools are not tested
or mission approved
Plan Outlining
Software
Homemade
Tools
Sequencing
Tool
downlink
data
I: Tool switching takes up valuable time

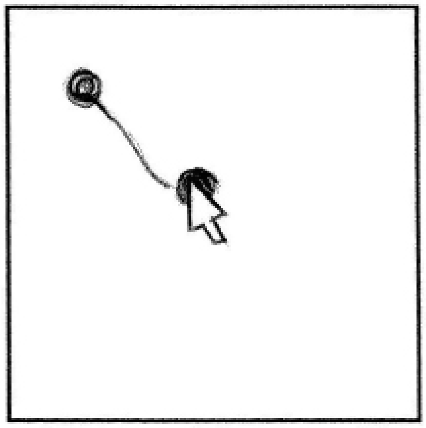
APPENDIX E: STORYBOARDS FOR NEEDS VALIDATION



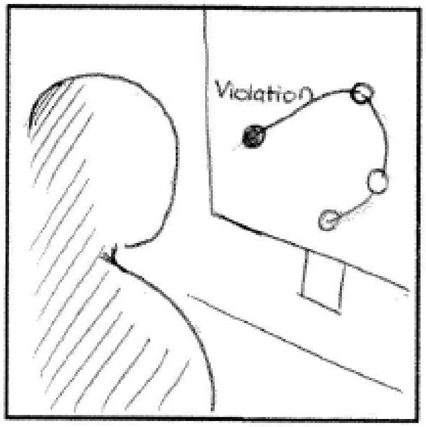
Two scientists are having a lively debate about the data when an indicator reminds them that they are running aout of planning time.



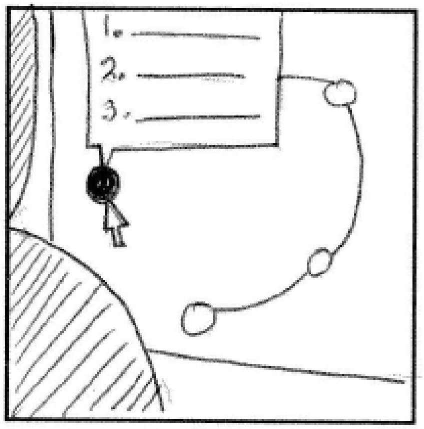
They quickly refocus and wrap up their discussion.



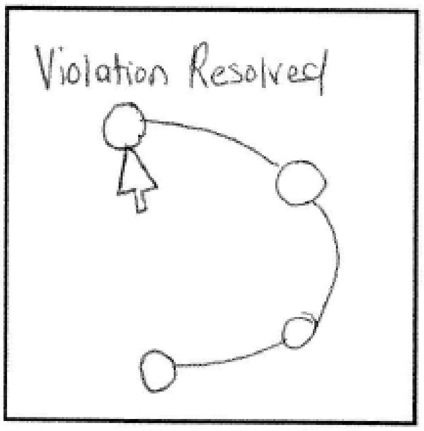
And begin on the next plan.



Joe, on the science team, started creating the next plan and the plan automatically indicated that there was a constraint violation.

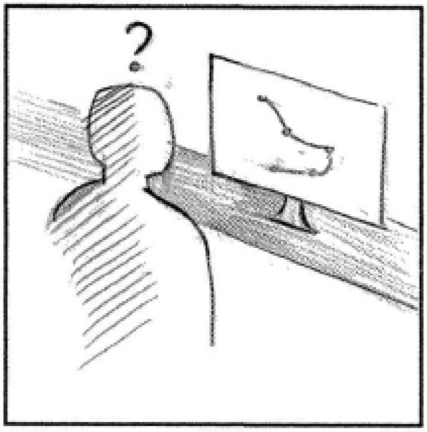


He clicked on the point and recieved step by step instructions on how to fix the probelm.

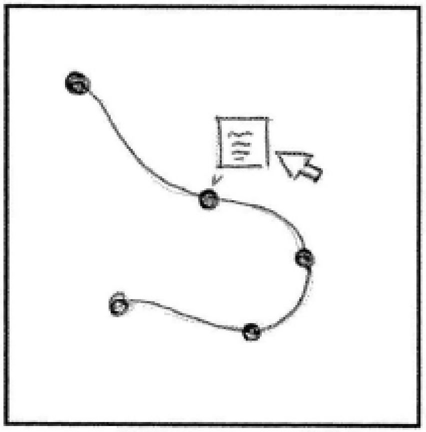


And he succesfully resolved the issue.

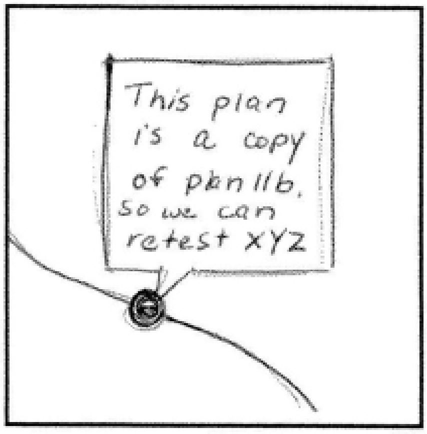
APPENDIX E: STORYBOARDS FOR NEEDS VALIDATION



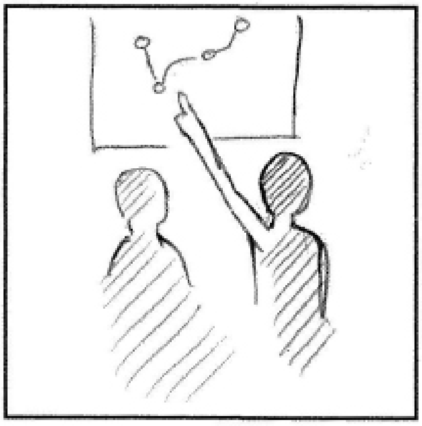
Jack on the flight team is unsure why this new plan is exactly the same as one they just ran a little bit ago.



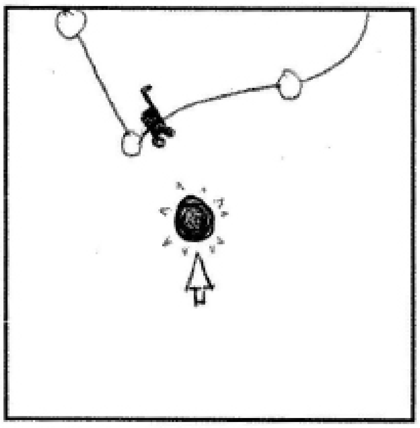
Instead of having to relay his question through the chain of command, he can check the plan description.



A notes/description field can quickly display a high level description of the plan's rationale, reducing the number of questions that need to be asked.

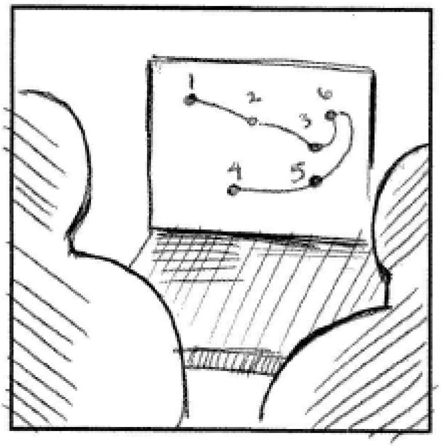


The rover is in the middle of executing a plan when the science team notices something. interesting

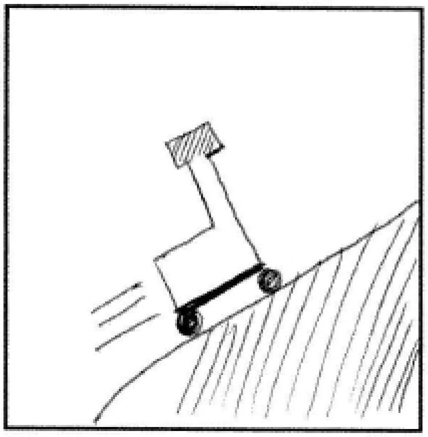


The science team clicks on the area that looks promising...

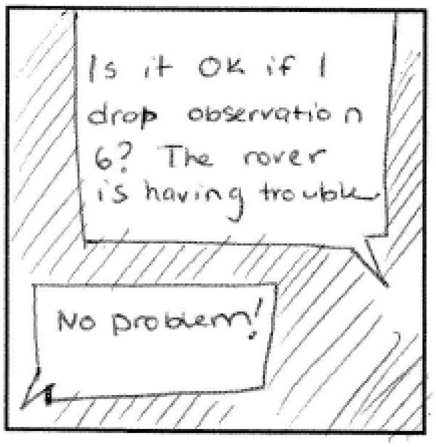
...and the rover's plan automatically adjusts to include the new waypoint.



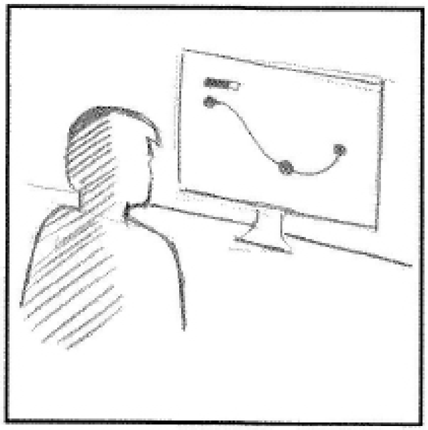
The science team prioritizes the waypoints before sending the plan to flight ops.



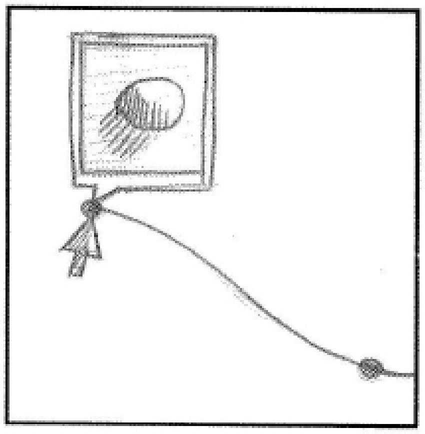
The rover is running short on time becasue it took longer than expected to get to way point 3.



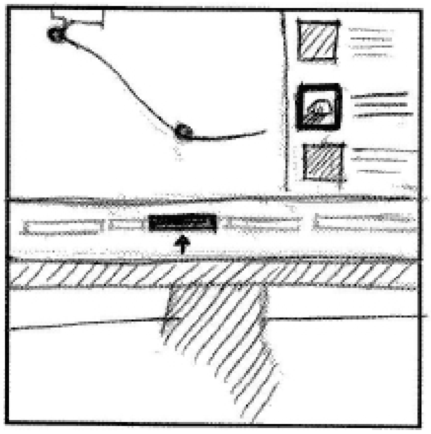
Flight ops notice that waypoint six is low priority, and ask the science team if it's ok to drop it. The science team agrees right away.



Joe, on the science team, checks the download progress bar to see when the data is ready.

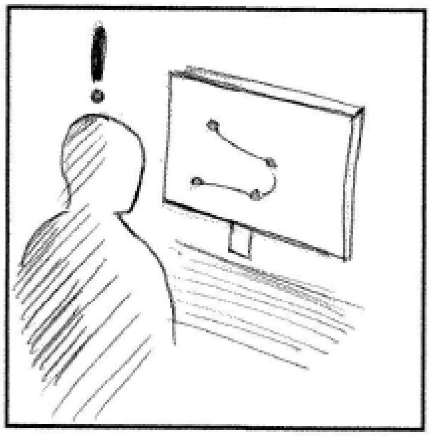


He then clicks on the waypoint to see a small version of the associated data.

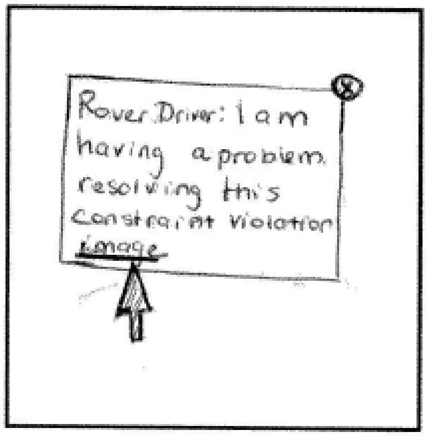


When he double clicks on the waypoint he can highlight that data in all the possible views, including the map, timeline, and image gallery for easy reference.

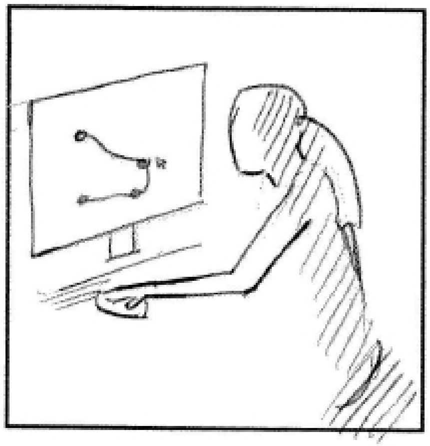
APPENDIX E: STORYBOARDS FOR NEEDS VALIDATION



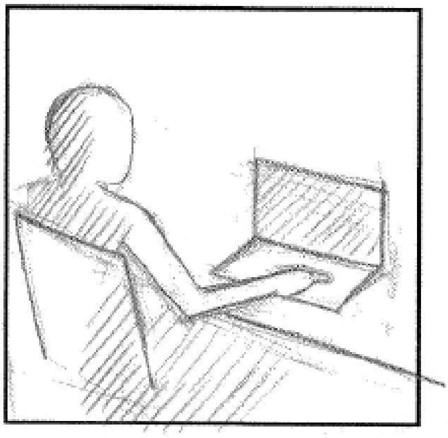
A scientist is having some trouble fixing constraint violations in the plan.



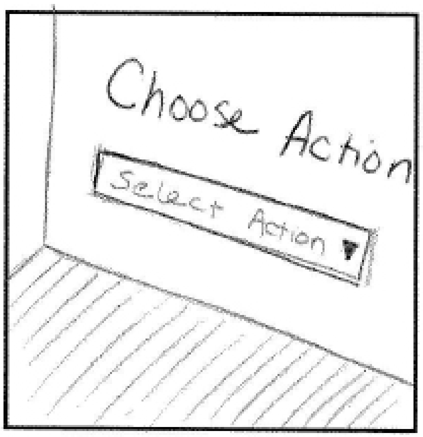
He IMs the rover driver, including a link to screen share exactly where he is having the problem.



He IMs the rover driver, including a link to screen share exactly where he is having the problem.



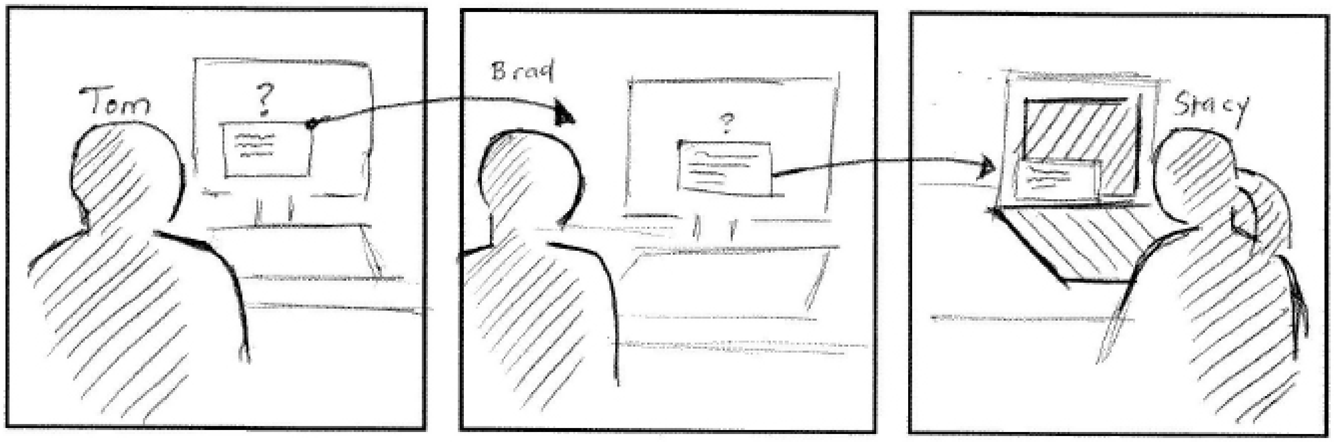
Rob, the science lead, decides they should do a perimeter survey of the area.



He selects the action from the action template.

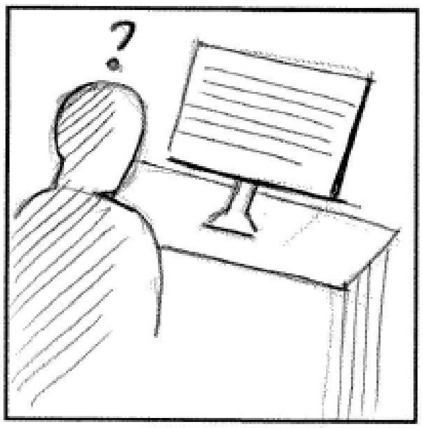
He then selects the area on the map he wants to survey and the program automatically sets the points to carry out the action.

APPENDIX E: STORYBOARDS FOR NEEDS VALIDATION

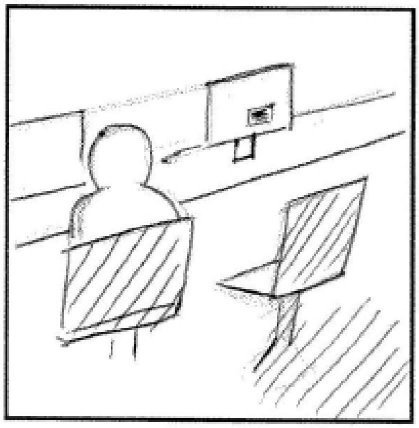


Tom, the rover lead, sends a question to Brad the science liaison over IM.

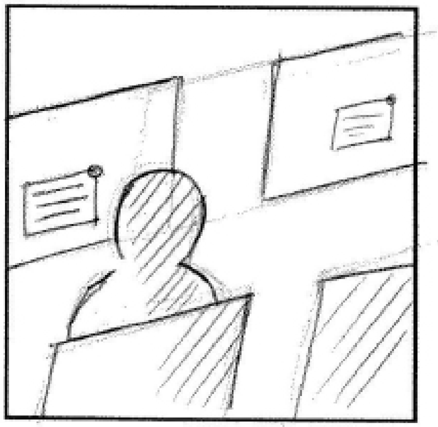
Stacy, the flight director, can view the communication as she works on other things.



Stan, on the science team, has a question for the rover driver so he sends him an IM.



However the rover driver is away from his desk.



After a couple of minutes, the system sends the question to Jack, also in Flight Ops, who is also able to answer Stan's question.

APPENDIX F: FIELD TEST FINDINGS

Process Issues

Possible Process Issues

- Person creating the plan makes suggestions to the science PI, but the science PI knows exactly what he wants
- Person creating the plan is not a geologist, but they influence the waypoints that are added to the plan
- No one knows who is controlling which projector screen; Have to physically switch video cables in order to change control of large shared screens

Excel not Linked; Slow

- Data analysis of MI image is verbal; Needs to be dictated and added to Excel, which is not linked to the data product
- Excel plan is not integrated with the map view
- Excel sheet is created on-the-fly; columns are forgot and added later, losing context for information
- Estimating time took hours and was not accurate

System Status Awareness

Hard to Tell What is Executing and What Activities are at Each Waypoint

- Cannot tell at a glance what observations are happening at what waypoints
- Flight Director could not tell which activity the rover was executing
- Only noticed LIDAR problems by watching the clock

Hard to Compare Hypothetical Plans

- Mutual dependencies between waypoints are unknown, so it is hard and slow to make changes
- No way to compare time/distance for “conditional” plans
- No distinctions between alternate paths; No way to set apart the ‘decision point’
- No way to visualize the plans that have been created vs executed vs saved as hypothetical

Specifying clearly what you want

No Field of View

- LIDAR shows panoramic view, but pancam images do not
- Panorama icons only show direction
- No tilt control on images
- Scientists use their hands to indicate camera angle

Technical Specifications Do Not Translate Easily into Data Output

- Scientists do not know optimal LIDAR height to minimize footprint and shadows
- Scientists verbally suggest image settings, but this is not captured in the plan (angle, resolution, etc)
- Gigapan sizes are not intuitive (medium/low, etc)
- No place to indicate LIDAR resolution in the plan
- Confusion over LIDAR resolution values

Scientists Desire to Express Intent, not Technical Specifications

- Scientists are not sure how to safely approach a ledge to look over
- Scientists do not care about specific image settings, they just want to gain situational awareness
- No way to indicate fine-tuned (tele-op) control in the planning tool
- Science team verbally explains what they want: “Low res pan, 135 degrees straight, then turn left 135 degrees, do a low res pan”
- Science/flight liaison and rover driver do not know what each other are looking at on the screen as they discuss a complex handoff
- Scientists want to say “take a picture of that nearest boulder” and have Flight Ops figure out how to do it

No MI Series Template

- Series of MI images needed to be placed by hand and with estimated distances

Difficult to Lay Down Waypoints

- Scientists try to plan specific points only; Not always concerned with how to get between the points

- Scientists request something verbally, then have to wait for the technical people to figure out how to implement the request before moving on
- Technical people creating the plan do not always place waypoints the way scientists want (“No, that’s not right”)
- Takes a long time to add/change/remove a waypoint
- Can only place points in the middle of the screen

No Area to Capture Intents

- No place, within the planning tool, for writing intents
- Live discussion during planning is lost
- (LER Traverse) Waypoints do not indicate exactly where to collect the observation (“Make sure they grab a sample over there on the right. They will have direct line of sight”)
- No centralized place for notes
- Reason for taking an image is not linked with the image
- Scientists gesture at the projector screen, but this is not captured in the plan

Hard to Understand Context of Images

Hard to View Context and Intents of Images

- No context of rover position when looking at data products
- No information regarding why this image was taken when looking at the data products
- “It’s much easier to look at [images] in Google Earth than in Gallery”
- Science team was looking at pancam image from the wrong waypoint
- Have to refer to the map in GEOps in order to gain context for the images in Gallery

Hard to Compare Images

- No way to view multiple images together for comparison
- Gallery is completely disconnected from everything else
- No context for images
- No way to group sets of images

Problems Measuring Distance

Google Earth Problems

- Shaded ‘priority’ regions look like ‘keep-out’ danger-zones
- K10 knows the position of the sun; Does GEOps?
- Tilting the viewing angle is useless when there is no height data

No Easy Way to Measure Distance

- Had to use the ruler tool to measure traverse distances; time-consuming and not accurate
- Scientists try to measure distances using the scale at the bottom of the screen; Hold up their hands and move to where they want to check
- Individual creating the plan could not tell how far apart things were (“I’m trying to guess what a meter is”)
- Measuring distance between points has to be done manually
- No distance context in pancam images

Awareness of Time for Plan, Instruments

No Time Estimates

- Time estimates are done by hand (in excel); mistakes were made
- No way to see how long a plan is in terms of distance or time
- No way to see time for plan creation + execution + downlink + data processing

Cannot Tell When Data Will Come Back

- No status on downlink times
- Technical person pulls up the images, not a scientist
- Scientists are not aware when data is ready for viewing (“Oh look, we got the panorama back; I wasn’t paying attention”)
- Verve says an activity is executing, while GEOps indicates ‘Success’
- Flight Ops does not know what data Sci Ops has received
- Data products come back, but scientists have to wait for someone to put images up on the projector screens

Shared Awareness Between Groups

No Shared View Between Flight Ops and Science Room

- Science team was sending screenshots of the timeline to Flight Ops
- Alternate plans are stored in the science teams' heads, as opposed to on the map
- -"I am not sure that I am seeing the same view as you"
- Flight Ops does not have access to the LIDAR data
- No shared view of the map
- (During shift brief) Science officer suggests looking at a pancam image while Flight and Science are in the same room so they can discuss things in context; Suggests problems communicating this information over the loops
- Flight Ops takes breaks that Science is not aware of
- -Flight suggests alternative routes to the Science team, but Science has already discussed and rejected these ideas
- Science does not know when K10 will start moving again

Who is Controlling the Rover?

- Need to submit a whole new plan, even when micro-managing tele-operation
- "Shouldn't we just tell them where to click?"
- What is Flight Ops' role if Science has more accurate visualizations?

Supporting Discussion Within Science Team

Scientists Cannot Control Zoom of Large Screen

- Person controlling the projector screen doesn't always move to the correct place or zoom to the correct level; Not always paying attention
- Zooming the large screen does not zoom on everyone's individual screens

Scientists Have No Ability to Make Marks on the Map

- Lots of people cluster around one person's laptop so they can all see the same thing
- Scientists point at the screen from far away, or use laser pointers

- Not sure who is controlling which screen
- Gesturing toward the screen is not captured or conveyed across voice loops
- “Let’s put a point there (pointing)”
- Scientists want to discuss areas on the map that may be hazardous, but they cannot annotate the map and have no control over GEOps
- No ability to collaboratively mark up a map
- When pointing at the screen, and someone moves or zooms the map, you are no longer pointing at the same spot
- SciOps is trying to gesture to points on the screen for remote rover team

APPENDIX G: DESIGN CONCEPTS

Initial Ideas (*=concepts/needs that carried forward)

Concept	Need
Timeline estimates both execution and analysis time for each action.	The rover is often idle because the rover executes the plan faster than the science team can analyze.
*The ability to prioritize waypoints at the plan creation.	*If an activity needs to be dropped, flight must discuss with science what activity is lower priority and can be removed.
Activity template to fill rover idle time.	The rover is often idle because the rover executes the plan faster than the science team can analyze.
One plan that can be modified dynamically.	Currently each plan contains a few way points and is uplinked separately, which takes time and are hard to change on the fly.
*Action templates based on science intents.	*Reduce the time needed to figure out how to do something by just having the science team select what they want to do where.
A place to indicate notes/rationale for a given plan.	The flight team often wants to know the purpose/rationale behind certain activities.
IM a role rather than a specific person.	Roles change each day, making it difficult to remember who to contact for a specific question.
*Viral IM finds the next available person if the recipient is not available	*Questions are sometimes missed over IM if the recipient is not at their desk.
*Give flight director access to all IMs.	*Most communication needs to go through the flight director, but IMs are only point to point.
Selecting a point highlights associated data and timeline location.	*Scientists want to see the data in context, but need to go to a separate program to view the images.
Status bar for each waypoint shows download status of associated data.	Scientists can’t tell when their data will be done downloading.

Concept	Need
“Progress” option shows details listing with times and current status of the rover.	It is difficult for the science team to tell exactly what the rover is doing when.
Rollover a portion of the plan to see who created it.	Facilitate problem solving by directing questions to the right person.
“Egg timer” to give scientists a deadline of when the plan needs to be completed by.	The flight team often waits for the science team to finish a plan.
Class critique 1 slide 24	
Plan “history”; visualize who made what changes to a plan	Facilitate problem solving by directing questions to the right person.
Screen sharing between a scientists and engineer.	Science and flight often discuss the plan, but have no way to see exactly what the other is looking at.
“Fog of war” show what has and hasn’t been explored.	Facilitate awareness of the surrounding terrane.
Two second “event history” leading up to the picture being seen.	Show the context of the rover at each waypoint.
Waypoint gives thumbnail of associated images.	*Scientists want to see the data in context, but need to go to a separate program to view the images.
Construct a ready-to-go optimized plan from the most promising analysis results.	Reduce the time needed to plan or replan after data analysis.
All information regarding waypoint is available at once.	Facilitating contextual awareness in planning.
Show a thumbnail preview of motion leading up to a captured image.	Show the context of each image.
Ability to vote waypoints up or down.	Help speed up the discussion/planning process.
Split up data for individual analysis, then discuss most promising results as a group.	Help speed up the discussion/planning process.
Display analysis status of waypoints.	Scientists can’t tell when their data will be done downloading.

APPENDIX G: DESIGN CONCEPTS

Concept	Need
Prioritize waypoints as a list based on science analysis.	*If an activity needs to be dropped, flight must discuss with science what activity is lower priority and can be removed.
Support setting waypoints with specific arrival times; spatial constraints.	Constraint visualization
Suggest solutions for terrain navigation.	*Reduce the need for the flight team to vet the plan submitted by science for any constraint violations.
Plan “health bar” indicate constraint violations.	*Reduce the need for the flight team to vet the plan submitted by science for any constraint violations.
*A step by step guide for resolving constraint violations	*Reduce the need for the flight team to vet the plan submitted by science for any constraint violations.
Drag and drop with terrain constraint indication.	*Reduce the need for the flight team to vet the plan submitted by science for any constraint violations.
Auto-generated alternate routs to avoid constraint violations.	*Reduce the need for the flight team to vet the plan submitted by science for any constraint violations.
Visualize sun position to estimate shadows and sun-glare at a point based on estimated time of arrival	*Reduce the need for the flight team to vet the plan submitted by science for any constraint violations.

Needs Validation 1

Concept	Need
An indicator light to notify scientists they are running out of planning time	The flight team often waits for the science team to finish a plan
A step by step guide for resolving constraint violations	The flight team must vet the plan submitted by science to make sure none of the rovers constraints are violated
A place to indicate notes/rationale for a given plan.	The flight team often wants to know the purpose/rationale behind certain activities.
The ability to pause and edit a currently running plan.	Scientists often want to stop the rover to investigate something unexpected, but must submit a whole new plan and discuss it with flight ops.
The ability to prioritize waypoints at the plan creation.	If an activity needs to be dropped, flight must discuss with science what activity is lower priority and can be removed.
Linking the images with the map and timeline.	Scientists want to see the data in context, but need to go to a separate program to view the images.
Screen sharing through IM.	Science and flight often discuss the plan, but have no way to see exactly what the other is looking at.
Action templates based on science intents.	Reduce the time needed to figure out how to do something by just having the science team select what they want to do where.
Give flight director access to all IMs.	Most communication needs to go through the flight director, but IMs are only point to point.
Viral IM finds the next available person if the recipient is not available	Questions are sometimes missed over IM if the recipient is not at their desk.

Needs Validation 2 (*=concepts/needs from previous iterations)

Concept	Need
Screen sharing between science and flight when science wants to change a plan.	There is a lot of verbal discussion, but no easy way to see what the other is looking at.
Timeline updates estimated duration during plan execution.	It is difficult to tell how long a plan will take, or if an activity needs to be dropped.
Scientists selects area of interest and system suggests possible waypoints.	*Reduce the time needed to figure out how to do something by just having the science team select what they want to do where.
System indicates dangerous areas on the map and suggests nearby locations that are safer, or a teleoperation option	Sometimes scientists want to go into areas that might be unsafe for the rover.
*A place to indicate notes/rationale for a given plan.	*The flight team often wants to know the purpose/rationale behind certain activities.
*An indicator light to notify scientists they are running out of planning time	*The flight team often waits for the science team to finish a plan
*Linking the images with the map and timeline.	*Scientists want to see the data in context, but need to go to a separate program to view the images.
*Screen sharing through IM.	*Science and flight often discuss the plan, but have no way to see exactly what the other is looking at.
*Give flight director access to all IMs.	*Most communication needs to go through the flight director, but IMs are only point to point.
*The ability to prioritize waypoints at the plan creation.	*If an activity needs to be dropped, flight must discuss with science what activity is lower priority and can be removed.

Post-Recon brainstorming (*=concepts/needs from previous iterations)

Concept	Need
Visualize gigapan field of view with data	*Scientists want to see the data in context, but need to go to a separate program to view the images.
Manipulate field of view for gigapan directly on the map	Scientists would gesture on the screen to show exactly the view they wanted.
Support hypothetical planning	Scientists have no way to indicate which plan is hypothetical
*Highlighting specific features	Scientists can only label a point in Google Earth but are often interested in large areas.
Task list	It is difficult to tell the order activities are supposed to occur
Smart board	Allow the PI to interact directly with the large screen for all to see.
*Screen sharing	*Science and flight often discuss the plan, but have no way to see exactly what the other is looking at.
Rollover distance/time measurement	It is cumbersome to measure the total distance between points, and difficult to estimate how long it will take to traverse.
*Template library	Reduce the need to lay down individual waypoints for a multi-point activity (i.e. MI sequence)
*Field to Indicate intents	*The flight team often wants to know the purpose/rationale behind certain activities.
Voice record science team discussion and link to associated waypoints.	Scientists have detailed discussions about what to do and why that the flight team is unaware of.
Tools to request teleop action	Scientists cannot directly indicate when the rover should be teleoperated

Final feature list

Concept	Need
Task list	It is difficult to tell the order activities are supposed to occur
Field to Indicate intents	The flight team often wants to know the purpose/rationale behind certain activities.
Visualize gigapan field of view with data	Scientists want to see the data in context, but need to go to a separate program to view the images.
Manipulate field of view for gigapan directly on the map	Scientists would gesture on the screen to show exactly the view they wanted.
Common actions / Tool list	Reduce the need to lay down individual waypoints for a multi-point activity (i.e. MI sequence)