CLOSEST APPROACH

DESIGN RESEARCH REPORT

TEAM

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SPONSOR

NASA JPL

CLASS

MHCI+D Capstone 2018

EXECUTIVE SUMMARY

The Europa Clipper mission, set to launch in the 2020s, will place a spacecraft in orbit around Jupiter in order to determine whether or not conditions could be suitable for life on its icy moon Europa. Nine instruments have been selected to conduct science discoveries but the plans and trajectories are still being laid out as the mission is in its early planning stages. This is a lengthy and detailed process because of complex sociotechnical constraints.

Past missions have relied on heavy human resource and fragmented tools to support uplink operations. The Europa Clipper mission has a requirement to support 1:1 uplink operations. This means scientists and engineers can only use as much time to develop and upload sequences as it takes for the spacecraft to execute the commands. Other space orbiters in the past, such as Cassini, took much longer to develop commands (4:1 on Cassini). NASA's Jet Propulsion Laboratory has tasked us with designing a solution that helps instrument scientists and their partners, science planners, plan and schedule activities for their instruments faster and more efficiently than in prior missions.

After comprehensive literature review and 13 interviews with instrument scientists, planners, designers, and automation researchers, we have gained a high-level understanding of mission planning and operations, as well as identified numerous difficulties and opportunities to address the problems of instrument scientists and related stakeholders during planning and scheduling. Our research has enabled us to draw insights from various missions besides Europa, and because Europa is still so early in its planning phases, we will be targeting our solution towards problems prevalent across missions. The biggest challenge will be navigating the complexity of the diverse needs of scientists, which differ greatly based on the type of science they investigate, in order to solve problems shared by all scientists across various orbiter missions.

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INTRODUCTION

Unmanned missions require careful planning, modeling, and simulation years before launch and while in orbit. At the highest level, every mission establishes science objectives that act as ultimate guides throughout the planning, execution, and wrap up of a mission. They ensure that scientists and engineers work cohesively and collaboratively to meet the same goals. Through years of execution and reflection, software and processes have evolved greatly. However, improving uplink efficiency is a problem that is consistently evaluated. As time is a precious resource on any mission, reducing the time it takes to respond to spacecraft data is especially valuable. We have been brought on by NASA-JPL to design a solution to assist instrument scientists and engineers in speeding up decision making processes in planning and scheduling.

Europa has learned many lessons from past missions on the engineering of the spacecraft, processes, software, and even data ownership. Through the words of Participant 2, Clipper Project Scientist, Bob Pappalardo, wants “data to belong to everyone”. In order to achieve this, teams need to share data, discoveries, and be aware of each other’s objectives at the very least. We learned through 13 interviews that many conflicts arise during operations because planning and scheduling are still quite fragmented across teams. Yet instruments are highly dependent on collaborating with one another on shared resources. To facilitate the negotiation of resources such as power, data storage, and pointing, teams go through a long winded negotiation process that starts within teams and might involve high level roles such as project scientists. This back and forth, human intensive communication takes a lot of time and can cause significant misunderstanding and frustration.

In order to better understand our problem space, we conducted both secondary and primary research over 12 weeks. Due to the sensitive nature of working with a government organization, there was a lot more to be uncovered and learned through our conversations with participants rather than through published research. Our secondary research helped us shape the questions we asked our participants and provided a basic understanding of each topic-orbiter missions, Cassini planning and sequencing, automation, publications for attempt to solve similar problems, etc. We have concealed the identity of our participants throughout this report and our subsequent presentations. All the quotes, findings, and insights will not have identifying information.

From our research, we have identified four potential directions:

- A collaborative platform for stakeholders to make efficient science decisions
- An easy way for scientists to realize how their changes impact other instruments to promote collaboration
- Visualizing resource usage and allocation to alleviate negotiations
- Checking validity against models to increase sequencing speed

It should be noted that our research participant pool was greatly limited due to current state of the mission. As the mission is in its early planning process, the full team has not been established and any confirmed personnel are only on Europa part-time. As such, we drew from Cassini and Mars missions to help inform our knowledge of Europa. However, we were able to speak to a few participants who have worked on both missions and able to identify differences and similarities. All but one of our user interviews were conducted remotely via Skype or phone call, which also introduced significant restrictions on the research process. Despite this, the insights gained from our generous participants assure us that we will reach a solution that leverages existing planning and scheduling software capabilities while upholding the needs and autonomy of scientists and other mission personnel. Below is outlined the method to our process, competitive analysis, insights, and the design principles that will guide us through the next phase of this project.

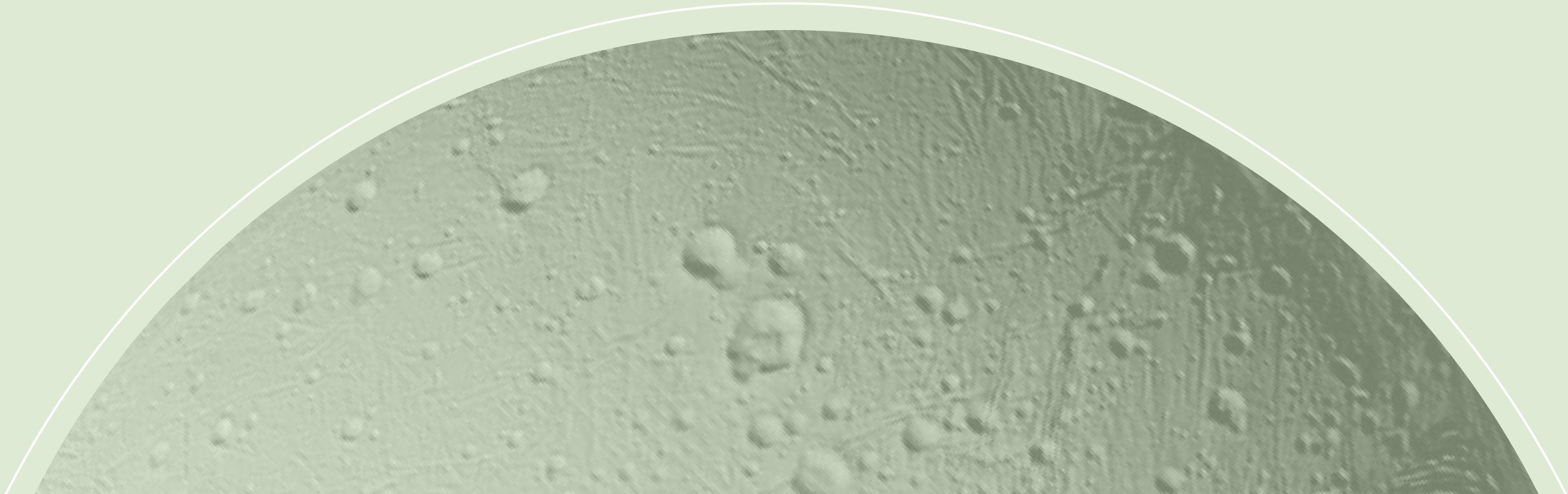
BACKGROUND

SECONDARY RESEARCH

Our team began our secondary research process by watching a lecture series presented by Bob Pappalardo to gain a holistic understanding of the Europa Clipper mission, it's complexities, and its current stage. The goal of our literature review was to prepare us for a basic understanding of domain terminology and research interests/areas of our participants so that we might be able to have tailored and productive conversations with each participant since backgrounds vary extensively.

We also wanted to familiarize ourselves with tried practices in planning and scheduling as there were more published papers in this area than any other area. We then used the articles to ask follow up questions with our participants so that we could build rapport and trust with our participants in the areas of research they care most deeply about.

Scientists and engineers also do not like to be asked questions that can be found in open research.



LITERATURE REVIEW

Because the Europa Clipper mission is still in its early stages, not much can be said conclusively about how operations will be structured and subsequently unfold. However, Clipper is ultimately of the orbiter class, one of the many classes of missions from flybys to rovers to tours, and within each class, missions share similarities in design and operational structure that enable one to speculate about what Europa Clipper will be like [1].

Europa vs. Other Missions

Cassini-Huygens, which studied the Saturnian system from 2004-2017, is one such similar mission. Although as a touring mission, Cassini explored an entire planetary system (whereas Clipper will mainly study one moon [2]), operations surrounding investigation of Saturn's moon Titan closely mirror the nature of Clipper's exploration of Jupiter's moon Europa. That is, both involve repeated flybys, a relatively short data collection period, and time between flybys to plan exactly what science will be collected and at which times [3][4].

Operations

Much of this is planned far in advance - Europa is already in its early planning stages and it will not launch for at least another 4-5 years [2][3]. However, no plan can be perfect and changes must occur during operations to keep the spacecraft healthy and on track and to respond to new discoveries [3][5][6]. This is what makes operations so complex. The process of collecting data is a "deeply social task," [7] one that involves negotiations among scientists and between scientists and engineers, and ultimately one that is grounded in constraints on what the spacecraft can do [5].

Managing Complexity

Missions have various methods for managing this complexity, from organizational structure to spacecraft design to software assistance, and they are always adapting [3][4][5]. Though each can be improved, software assistance in planning and scheduling is a unique challenge because such software must navigate and mediate complex social networks and the strong political nature of NASA missions.

Planning & Scheduling Software

There has been significant success in utilizing planning and scheduling software during mission operations, but improvements can still be made as far as reducing conflict and gaining the trust of scientists [8]. Some of the oldest automated planning and scheduling software is still being adapted for mission use today [9][10][11][12]. Despite successes though, none of this software is capable of doing what mission personnel do because of the complexity of constraints involved and the knowledge and experience of scientists and engineers [13]. As such, automated software's greatest strength in improving the efficiency of planning and scheduling is in providing scientists and engineers with possible outcomes to analyze and debate over [13][14]. The challenge perhaps then is how to best incorporate such software into operations in such a way that efficiency is improved and scientists' autonomy is respected and preserved.

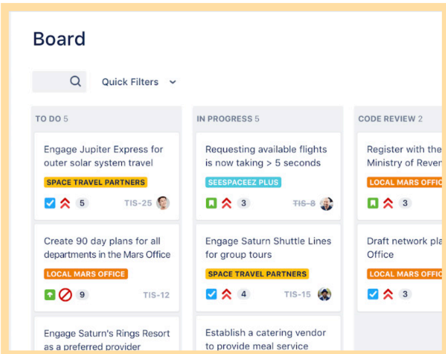
COMPETITIVE ANALYSIS

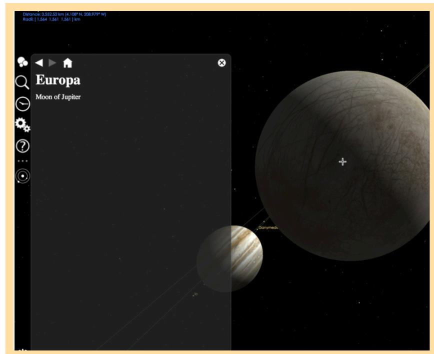
We began our competitive assessment by identifying mainstream tools and products that fit our areas of interest: planning, project management/collaboration, visualizing, and merge conflict. We also attempted industry tools such as EUROPA, SPIFe, Cosmographia, and ILOG but ran into implementation and code issues that hindered us from fully assessing them (except Cosmographia). However, in doing so, we gained a lens into our users mental model and were able to experience a few of the pain points our participants mentioned in interviews.

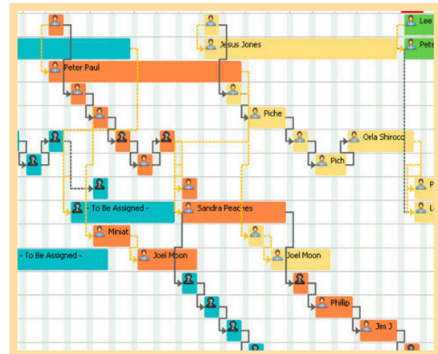
It was interesting to see industry applications with functionality we could imagine being applied to a specialized context such as JPL operations. While many of the tools we analyzed were only tangentially related to our problem space, there were many lessons to be learned about visualization of time, errors, system status, and error handling which are critical elements to consider in our design. On the other hand, there were applications that were examples of easy-to-learn interfaces that will serve as a model for us as we move forward.

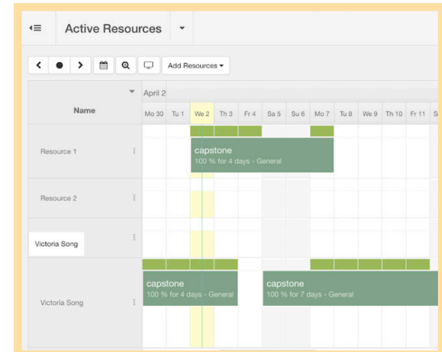
While conducting assessments, we paid special attention to features that related to the needs of our users, which generated a lot of ideas about how we might go about tackling our problem space. We know that we must consider actionability in every feature. If we provide a visualization, the user should be able to interact with it either by pressing in to “see more” or to filter down to less information. We also need to bear in mind familiar interaction patterns when designing. Our users have likely been in the industry for a long period of time and have become accustomed to the home grown tools developed by each time. While these tools might seem clunky to an outsider, there are interaction patterns we should respect as they fit the mental model of our users. On the other hand, we want to avoid resorting to external help on the interface. A trend with industry tools is oversimplification to keep a clean interface. As a result, many tools require users to access help pages or hover tips for confusing icons or features. P12 shared, “I would have to be constantly referring to the wiki or asking my colleagues” as a pain point when discussing planning software she has used in the past.

ANALYZED PRODUCTS









JIRA

A project management tool for agile software development. Plan, track, and see statuses on the entire product development and support pipeline.

COSMOGRAPHIA

A general solar system simulator and visualization tool. Paired with SPICE, it becomes a way to model observational geometry for planetary missions.

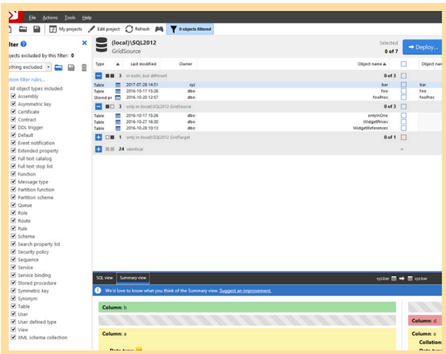
VISUAL PLANNING

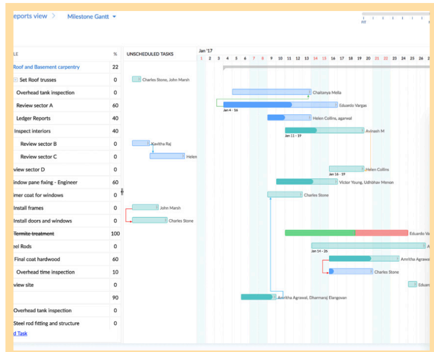
Visual Planning is a resource management and scheduling application thats share schedules with colleagues and work together more efficiently.

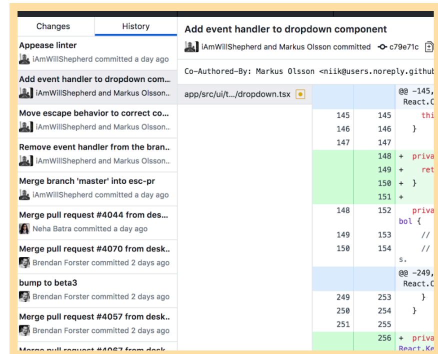
HUB PLANNER

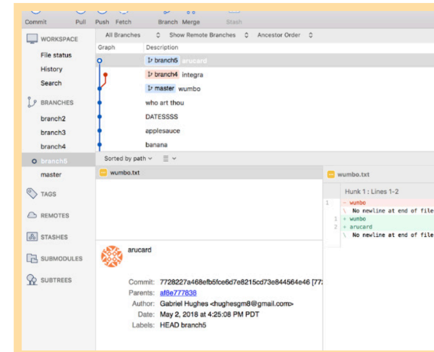
HUB Planning is a resource scheduling, time track and project management software.

ANALYZED PRODUCTS









SQL COMPARE

Comparing SQL Server schema changes from dev, to test, to production. Error free deployment script in minutes.

ZOHO PROJECTS

Project management tool that serves two different purposes: traditional project management and to manage sprints for agile teams. The tool can be used to plan, track, and collaborate.

GITHUB DESKTOP

It is an interface for project management that uses git to manage and track changes to files and allows collaboration through branching and merging.

SOURCE TREE

Sourcetree is an interface for project management that uses git to manage and track changes to files and allows collaboration through branching and merging.

EVALUATION CRITERIA

- Error Discovery
- Memory Load
- Flexibility
- Visibility of System Status
- Recommendations
- Timelines
- Other Notable Visualizations
- Zoom
- Filter
- Save for Later
- Learnability and Help

DESIGN RECOMMENDATIONS

Actionable visualizations

Many systems utilized 3 column grids or something similar to help organize the information but also gave clear break-points to make the tool also responsive on multiple devices.

Flat Vector Shape Overlays

Using flat vector shapes are useful as callouts to illustrate important characteristics of a complex visualization.

Familiar interaction patterns

Know your user well enough to know what software they use and model interaction patterns to fit what they already know. This saves on the need to teach users new interaction patterns that might cause confusion.

IMPLEMENTATIONS TO AVOID

External help

Having an external help center can be used to fill in the gaps for usability problems. Ideally, we should make any help needed contained in the interface being used.

Oversimplification

Some systems oversimplified their UI as a result it’s hard to discover additional features without going through external documentation or tutorial help from external users.

Icons with no labels

Some systems have entirely too many icons to memorize. Too many icons obfuscate what affordances are available and require the user to memorize what each each symbol means.

RESEARCH

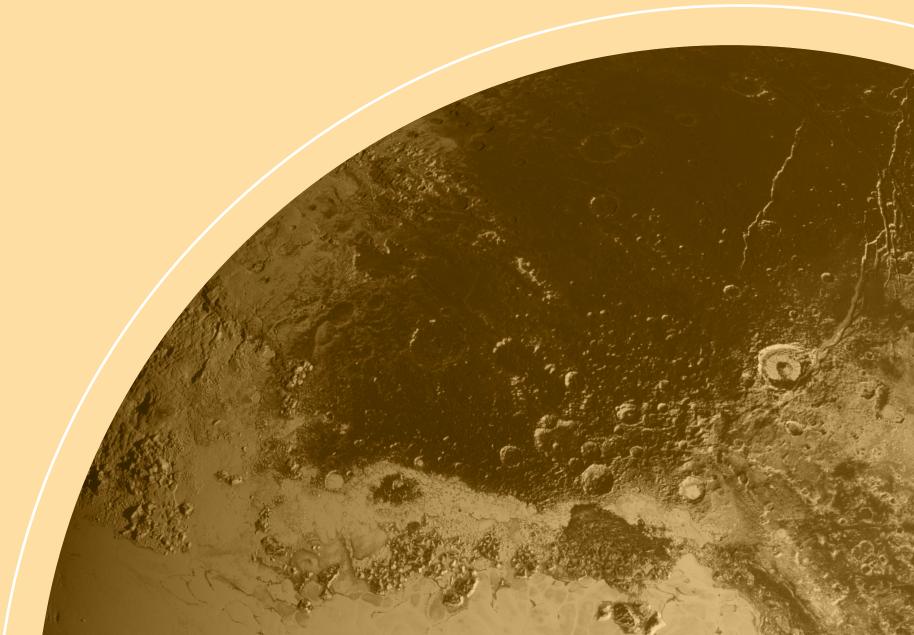
RESEARCH GOALS

To help guide our research we established the following research goals:

1. **Make sense of the organizational structure within JPL and the flow of interactions that define operations for orbiter missions**
   Because so few resources were available publicly to help us understand mission, we needed to speak to participants to learn about internal team structures- how teams are formed and how decisions are made. We also needed to get a high level understanding of the chain of power as well as checks and balances within the Clipper team.

2. **Learn about the intricacies of planning, scheduling, and sequencing involved in uplink operations**
   Planning, scheduling, and sequencing is a iterative and complex process. We needed to understand what goes on within the process as well as decision points and how they affect the overall process. Our diagram on page (insert page number) shows what we learned about the process.

3. **Understand perspectives on how software has been used on past missions to aid in planning and scheduling**
   We know that similar software has always been used as aids for scientists and engineers on each mission. We wanted to learn about the pain points and short-comings of legacy tooling to help us identify a problem space.



RESEARCH QUESTION

HOW MIGHT WE PROMOTE COHESION ACROSS INSTRUMENT TEAMS TO DECREASE TIME SPENT ON NEGOTIATION AND CONFLICT RESOLUTION?

POTENTIAL TARGET USERS

PRIMARY STAKEHOLDERS

Instrument Scientist and Leads

Instrument scientists on each instrument as well as their group leads are primarily responsible for developing detailed plans for their instrument's data collection (and their instrument's only). Instrument teams can be scattered across the country or across the world, depending on the mission, and are often solely concerned with their science and the health of their instruments. This focus in isolation necessitates the attention of intermediary roles to communicate within the instrument team, between the team and other scientists and engineers, and between the team and project management.

Science Planners

Science planners are heavily involved throughout pre-launch mission planning and subsequent operations. They may hold other titles, but as science planners they are responsible for ensuring instrument teams' plans stay on track with mission objectives. They, like systems engineers, also integrate plans across science teams to find conflicts but are not as involved with engineering as systems engineers.

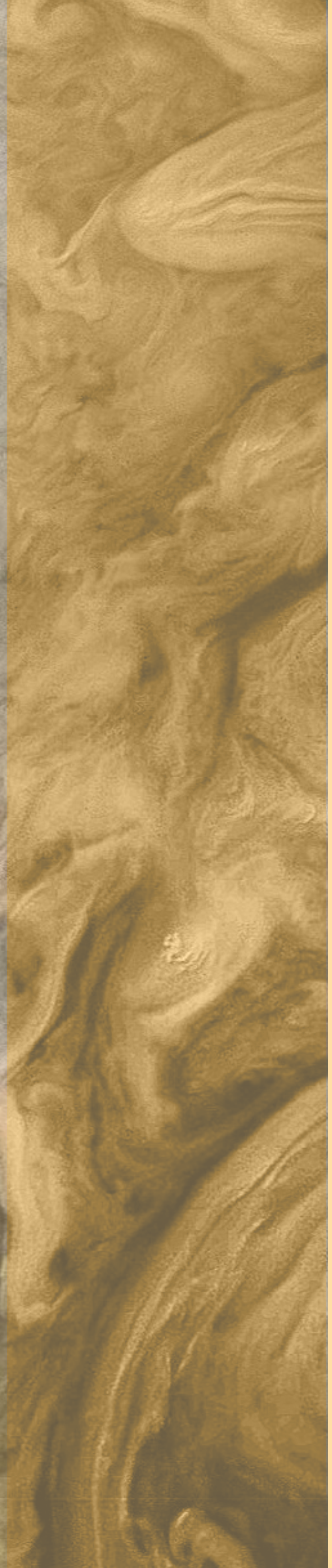
SECONDARY STAKEHOLDERS

Investigation Scientists

These roles act as a liaison between management at JPL, instrument science teams, and engineers responsible for calculating trajectories and maintaining the health of the spacecraft. They represent their instrument team's needs during negotiations and help ground scientists' desires within the reality of spacecraft constraints.

System Engineers

Systems engineers are active in the mission from the start, as they help design the structure of the mission and the software to be used in planning and operations. This is a fluid role that is generally responsible for coordinating among teams of scientists and engineers. Many are primarily responsible for integrating the plans of scientists and engineers, iteratively modeling them to find conflicts, and eventually sequencing commands that get uplinked to the spacecraft. However, specific roles depend on the systems engineer's background, so someone familiar with science might be more involved with instrument teams, while someone with an engineering background might be more involved with software planning and execution.



METHODS

THE FOLLOWING METHODS HELPED INFORM OUR INSIGHTS AS WELL AS PRIME US FOR INTERVIEWS:

LITERATURE REVIEW

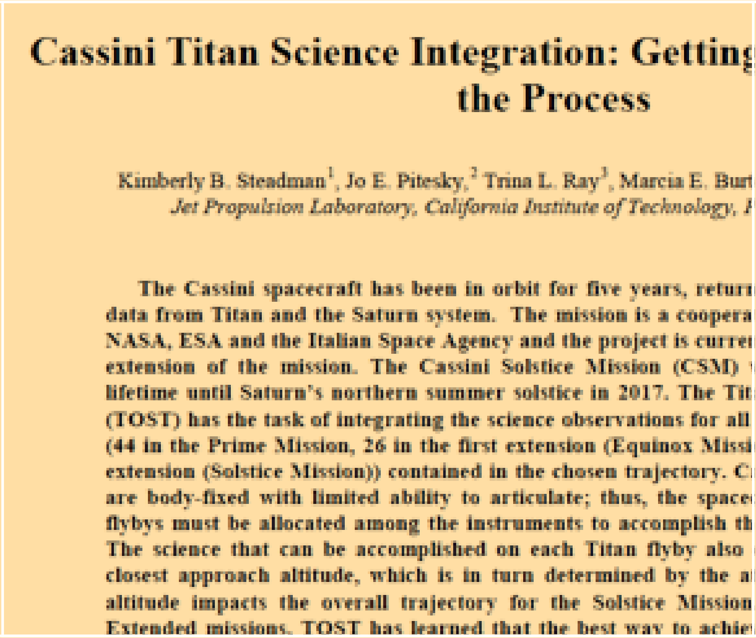
Synthesis of existing research helps understand similar technology and how planning and automation work in the astronomical data field. It helped inform our primary research questions.

SEMI-STRUCTURED INTERVIEW

The bulk of our time was spent here. we wanted to better understand the mental model of our participants, especially around planning, scheduling, and sequencing. This involved negotiation, decision making, and the steps that go in between.

ITERATIVE DIAGRAMMING

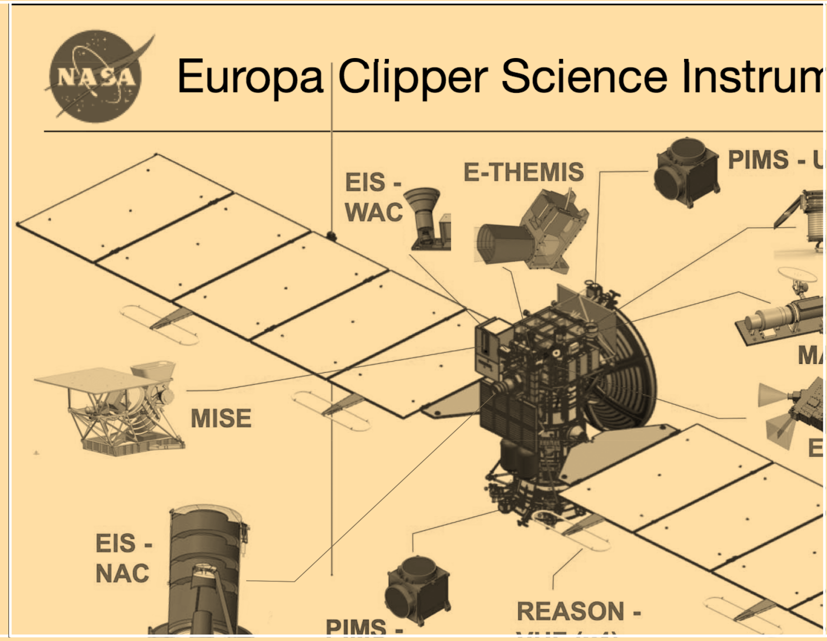
Visual diagram to show our current understanding of scheduling activities. participants were asked a series of questions to correct misunderstanding and further develop our insights. The diagram evolved over time.



**Cassini Titan Science Integration: Getting
the Process**

Kimberly B. Steadman[1], Jo E. Pitesky,[2] Trina L. Ray[3], Marcia E. Burt
Jet Propulsion Laboratory, California Institute of Technology, P

The Cassini spacecraft has been in orbit for five years, returni
data from Titan and the Saturn system. The mission is a coopera
NASA, ESA and the Italian Space Agency and the project is curre
extension of the mission. The Cassini Solstice Mission (CSM)
lifetime until Saturn's northern summer solstice in 2017. The Tit
(TOST) has the task of integrating the science observations for all
(44 in the Prime Mission, 26 in the first extension (Equinox Missi
extension (Solstice Mission)) contained in the chosen trajectory. C
are body-fixed with limited ability to articulate; thus, the space
flybys must be allocated among the instruments to accomplish th
The science that can be accomplished on each Titan flyby also
closest approach altitude, which is in turn determined by the a
altitude impacts the overall trajectory for the Solstice Mission
Extended missions. TOST has learned that the best way to achie



LITERATURE REVIEW

PROCESS

Before each interview we would read relevant and recent work written by the participant. The notes of what we read became the beginnings of the interview guide for each participant.

GOALS

Understand Detailed Processes that would be difficult to discuss in conversation.

Look for examples of software used (images of interface, pain points and successes discussed)

Learn the language of our participant to allow for a more seamless discussion.

SEMI-STRUCTURED INTERVIEWS

PROCESS

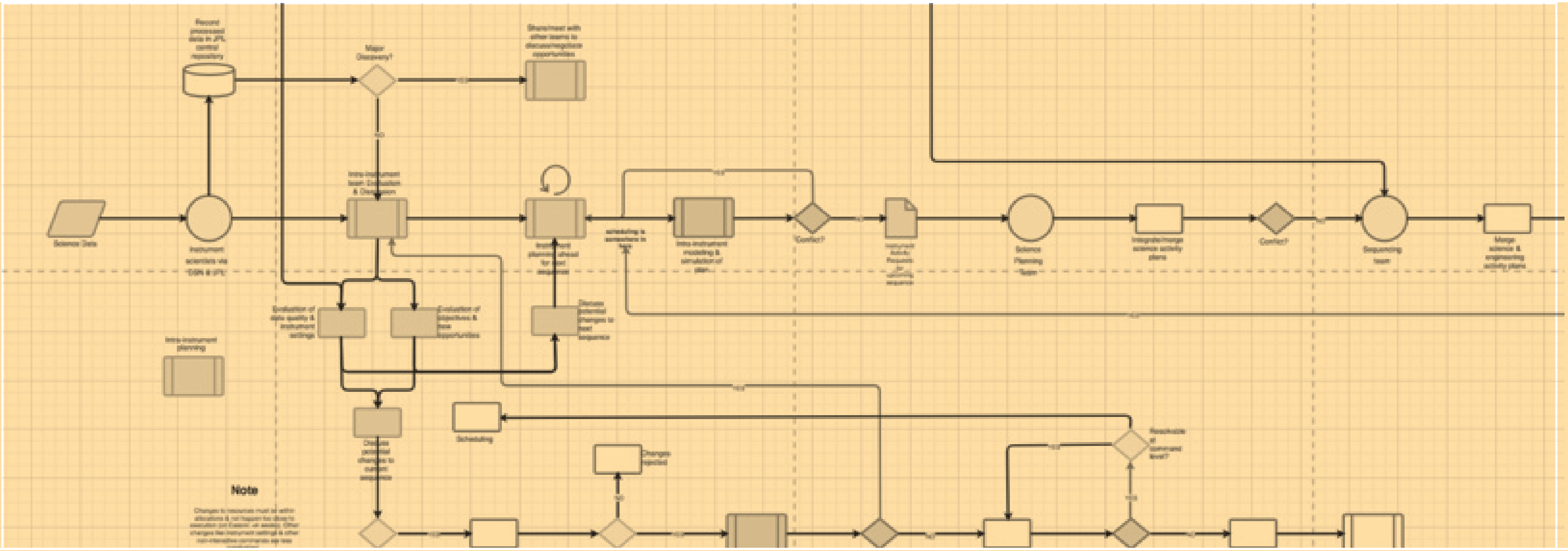
Ask experts from NASA a predetermined open questions to understand their current planning process Be open to let interviewees further explore and share topics relevant to our problem space.

GOALS

Understand what it is like to work on past orbiter missions.

Find how Europa Clipper and new missions might be different.

Learn about employee interactions both remote and in-person.



ITERATIVE DIAGRAMMING

PROCESS

In order to better understand stakeholders' mental model on priority of different orbiter data, we will use visual diagram to show our current understanding on scheduling activities. Then participants are asked a series of questions to correct misunderstanding and further develop our knowledge scope. As we iterate on getting feedback from different participants on diagrams, the diagram will be consolidated and evolved over time.

GOAL

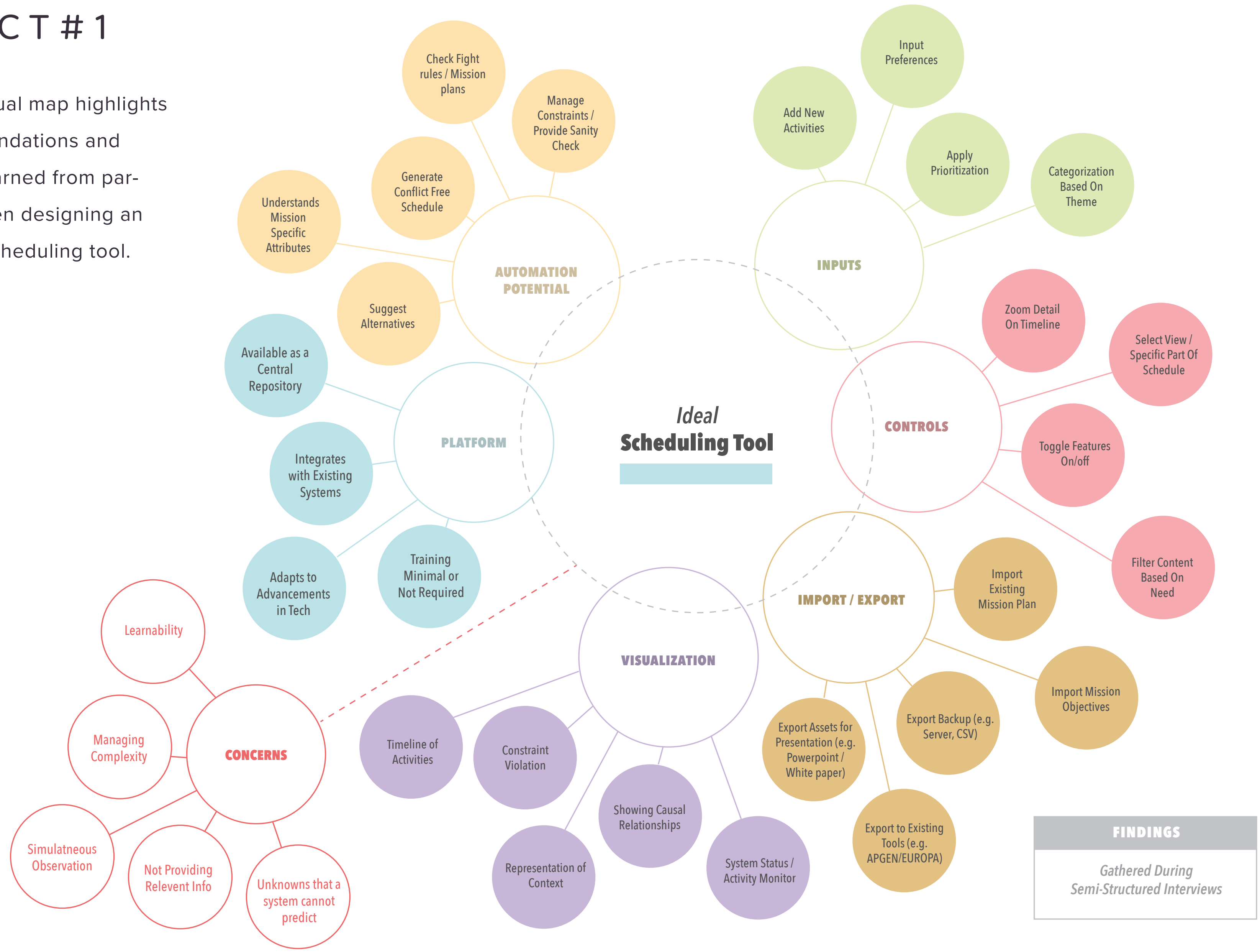
Understand the activity schedule and mission phases in a temporal way. Personal experience and comments on improvement in different phases will be collected by iterative diagramming method.

How different phases are transit and how personnel are communicated.

RESULTS

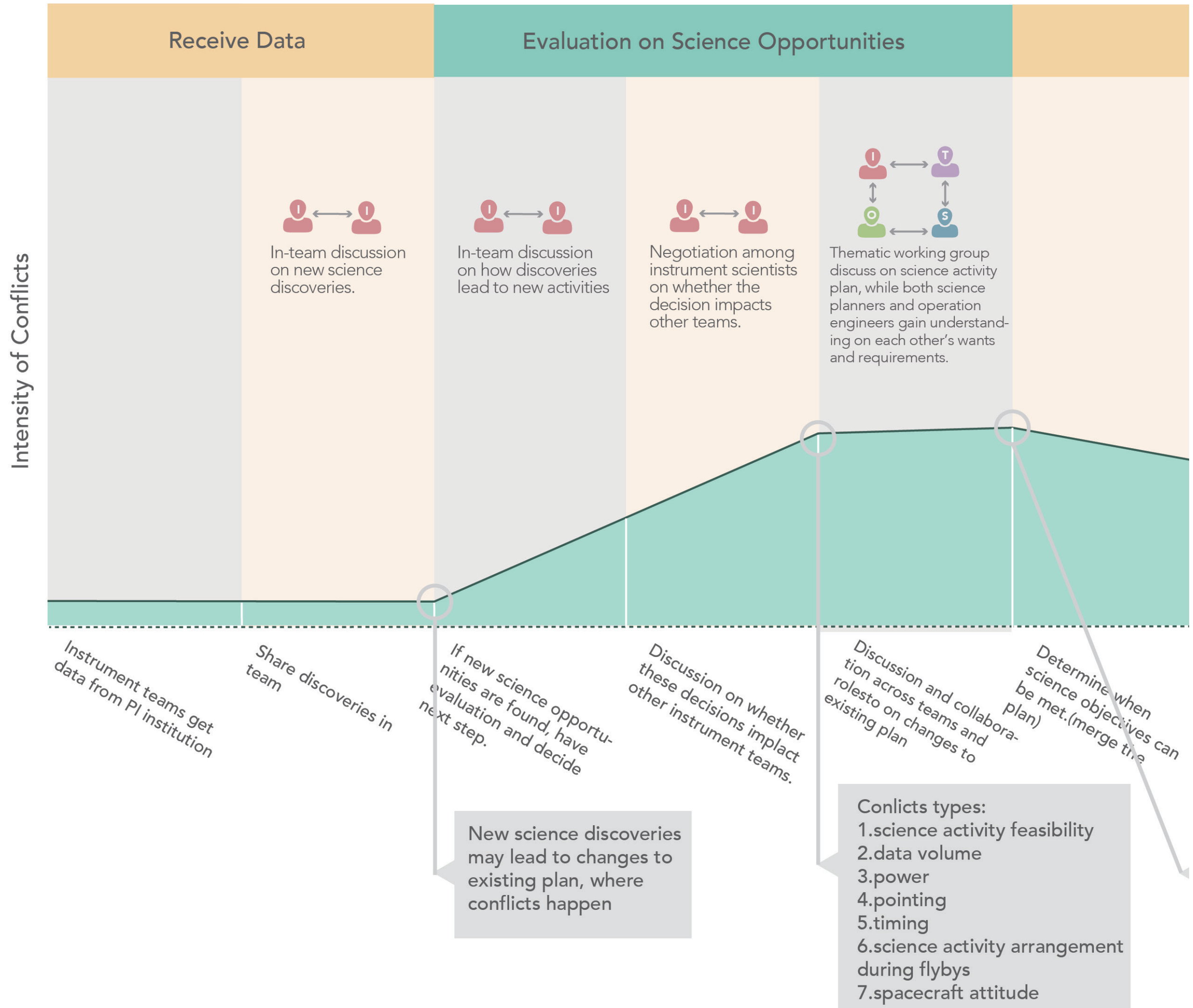
ARTIFACT #1

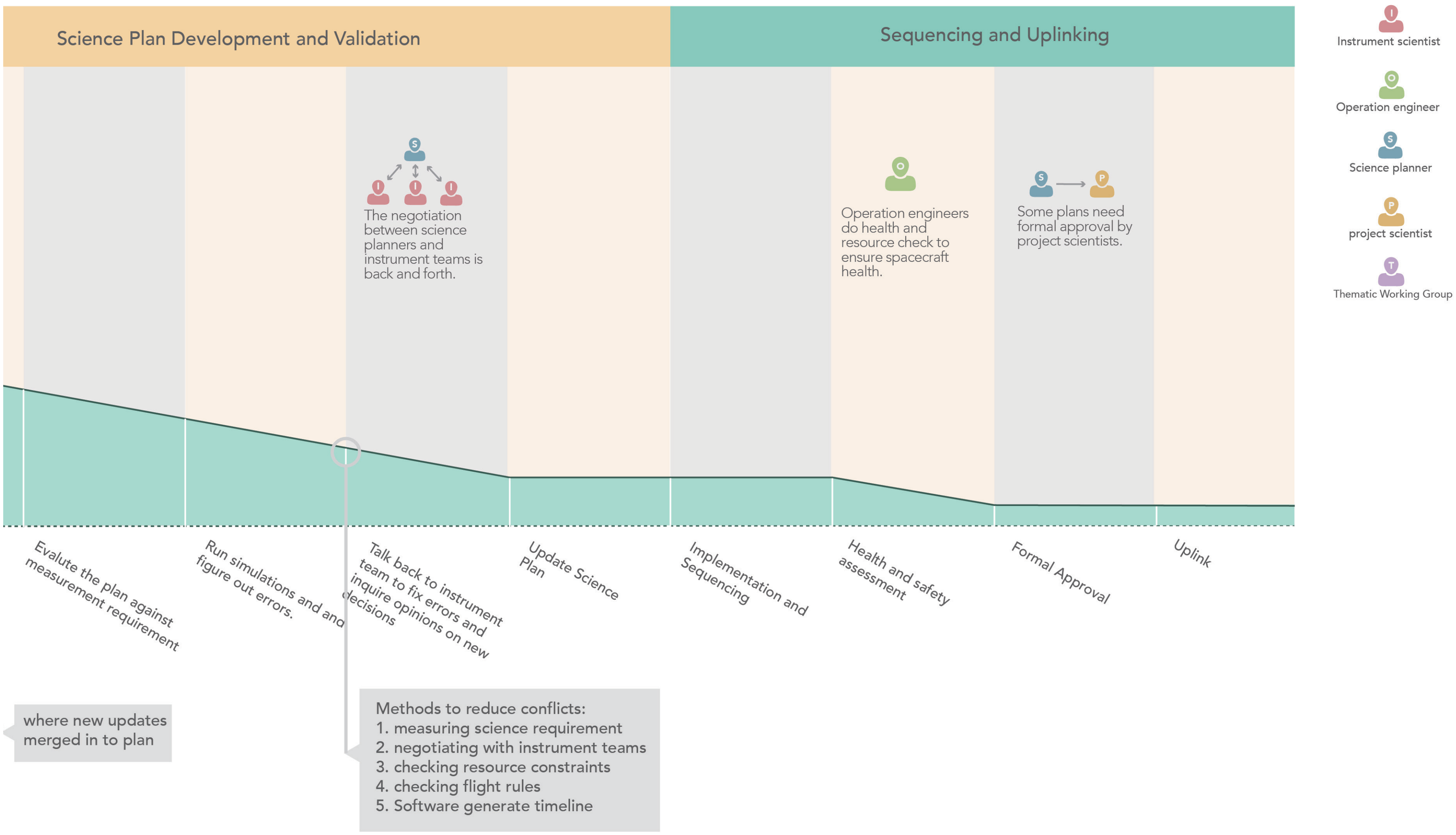
This conceptual map highlights the recommendations and pitfalls we learned from participants, when designing an automated scheduling tool.



ARTIFACT#2

- Understand the general decision making process from data downlink to uplink
- Understand how different roles involve in negotiation and collaboration in different phases.
- Understand how scheduling conflicts happen.

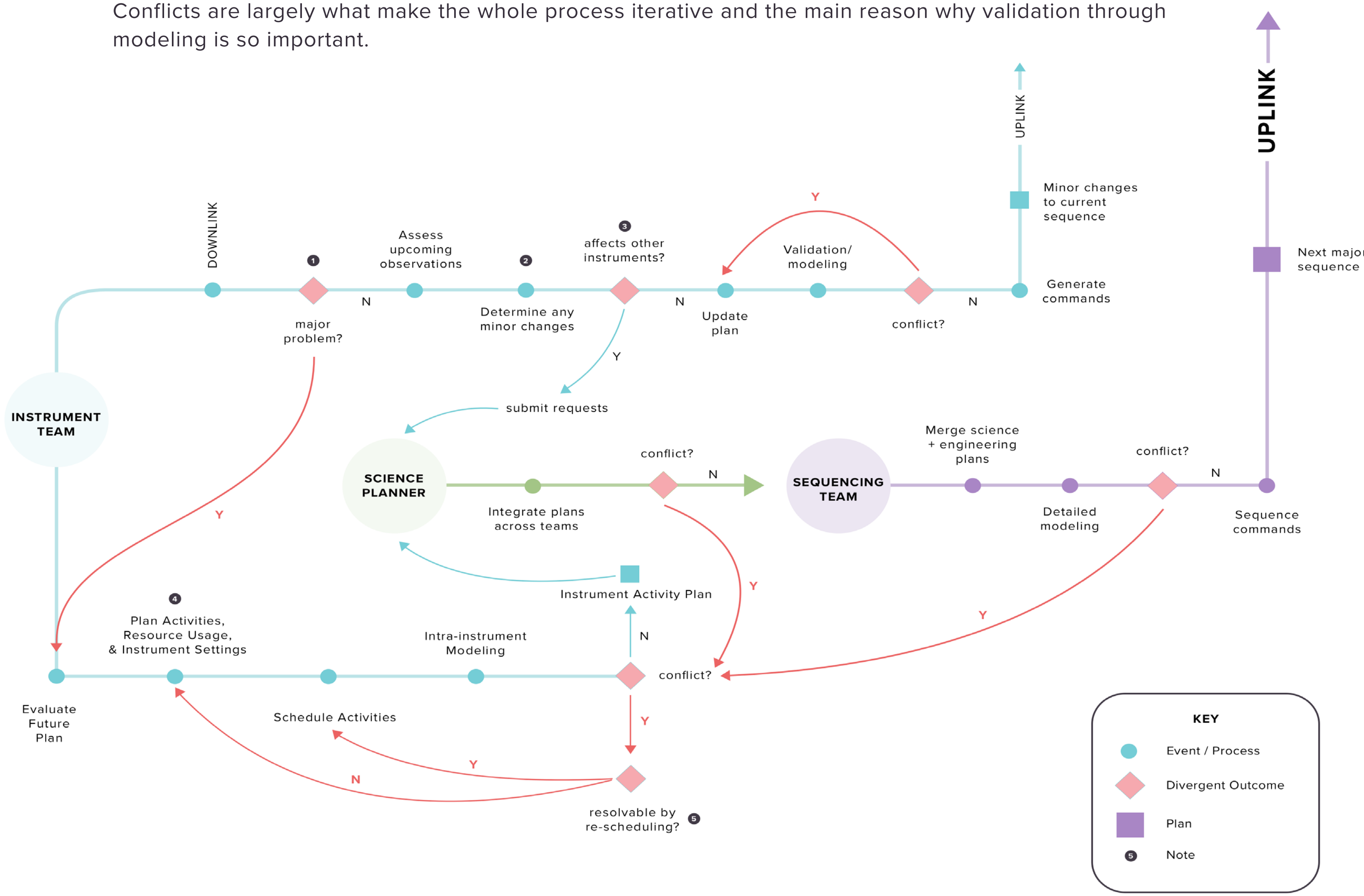



Science Plan Development and Validation
Sequencing and Uplinking
The negotiation between science planners and instrument teams is back and forth.
Operation engineers do health and resource check to ensure spacecraft health.
Some plans need formal approval by project scientists.
Evalute the plan against measurement requirement
Run simulations and and figure out errors.
Talk back to instrument team to fix errors and inquire opinions on new decisions
Update Science Plan
Implementation and Sequencing
Health and safety assessment
Formal Approval
Uplink
where new updates merged in to plan
Methods to reduce conflicts:
1. measuring science requirement
2. negotiating with instrument teams
3. checking resource constraints
4. checking flight rules
5. Software generate timeline
Instrument scientist
Operation engineer
Science planner
project scientist
Thematic Working Group

ARTIFACT #3

Orbiter missions generally uplink a month or more worth of commands to ensure the spacecraft continues to function in the event of a communication failure. Because of this, scientists and other mission personnel are constantly responding to incoming data while planning for the next month-long sequence. This diagram illustrates the differences between the two, mainly from the perspective of instrument science teams, and how they play out in conjunction. Specifically called out (in pink) are the effect that conflicts have on the process. Conflicts are largely what make the whole process iterative and the main reason why validation through modeling is so important.

1. Major problems include spacecraft malfunction or instrument failures, either of which requires instrument teams to thoroughly re-evaluate their plans.
2. Minor changes permitted to the current sequence include instrument settings - anything that doesn't require validation by the sequencing team.
3. Changes that don't affect other instruments - called non-interactive commands - are rare, but easy to implement as instrument teams can execute them independently.
4. Though a plan is already in place, more detail needs to be added - scientists need to decide how exactly they will use their observation opportunities & how much resources are required.
5. Note the difference between planning - what will happen - and scheduling - when it will happen. Some conflicts cannot be resolved by adjusting schedules & require rethinking the plan.



INSIGHTS

- Missions are planned and simulated in as much detail as possible before launch to optimize the cost and efficiency of operations, but they are also flexible enough to account for anomalies.

- Measures are taken at every level of mission design - from organizational structure to spacecraft engineering to software design - to maximize flexibility, efficiency, and science return.

- Science rules the mission, but because it can be put at risk by any problems with the spacecraft or its instruments, ensuring the health and safety of the spacecraft is paramount.

- Mission operations are always adapting, learning from problems both in past missions and ongoing ones.

- Fragmentation of software tools across teams contributes significantly to conflict-related inefficiency because team-specific tools don't account for (changes made by other teams during planning and scheduling / the activity of other teams)

- Cross-pollination across diverse teams facilitates healthy collaboration and cohesion across disciplines because it ensures that no team's individual needs dominate.

- Data return is emotionally charged because careers are at stake.

- While automation is welcomed if scientists and engineers understand how and why decisions are made, it is still crucial that humans remain the arbiters in all aspects of decision-making.

Insight 1

Missions are planned and simulated in as much detail as possible before launch to optimize the cost and efficiency of operations, but they are also flexible enough to account for anomalies.

Orbiter and flyby missions have the advantage of a stable environment, unlike rover missions, and so can be planned in detail in advance (sometimes up to a decade in advance). Once operations begin, responding to new data and changes becomes relatively efficient (compared to planning from scratch) and low cost because the team has narrowed down possible courses of action at every step, giving everyone a better idea of what needs to be done. Scientists know roughly when they'll be collecting data and if they want to change something, it will be relatively easy for someone, like a science planner, to tell them it's not possible because the tour design and engineering constraints dictate that only these things can happen during this time. All this advance planning happens so that time isn't wasted during operations calculating possibilities and negotiating among teams as opposed to collecting valuable data, all of which serves to increase the value of the mission by requiring less workforce and maximizing time spent on data collection and analysis. Moreover, if anomalies like spacecraft errors or new discoveries happen, all that advance planning contributes to flexible response. Expertise spread out across teams of scientists and engineers allows them to come up with creative workarounds to restructure the plan in the least disruptive ways possible.

"Science planning starts several [7-8] weeks before execution." P7

"You can make later updates to [the plan] but it was planned quite far out" P1

"Lots uncertainty on the surface of Europa...there will be adjustments" P7

Insight 2

Scientists' needs are grounded in instrument constraints, thus the more complex the constraints are, the more contentious negotiations of instrument and resource usage will be.

Spacecraft have limited resources that teams have to account for and a vast number of engineering constraints on everything from how long an instrument can be powered on to which activities can occur simultaneously, all of which affect what science can be collected. Because all the constraints in place limit what each instrument can do and at what times, scientists cannot be idealistic about what data they want to collect. Even things they consider realistic might turn out to be unrealistic when compared against other activities already in place. Some instruments have an easier time than others at getting the data they need because, for example, they might require less data volume to record their data so they can schedule more recordings during a single flyby than an instrument like a camera that requires a lot of data volume. These constraints can have wide-ranging effects that reveal themselves during negotiations. A single observation with high data volume requirements might be replaced with multiple observations with lower requirements if the latter have equal or greater science return. Instrument teams are also allocated a certain amount of resources that they have to stay within, which might be especially challenging for instruments with greater resource requirements.

The Saturn Working Group "had a lot more ... heated discussion from what I've heard because they're the instruments that take photos of Saturn [so] they use a lot more data." P12

"We have to constrain the amount of data we record far below [what] we could record to make sure to get data back." P7

"The mission planning team takes all those inputs and looks for first order conflicts...you then get into discussion with teams that sometimes involve executive decisions" P11

Insight 3

Science rules the mission, but because it can be put at risk by any problems with the spacecraft or its instruments, ensuring the health and safety of the spacecraft is paramount.

The primary role of all engineers on missions is to support the collection of science by ensuring that the spacecraft is functioning and that no proposed activities will cause problems. Therefore, scientists constantly have to check with engineers that their plans are valid, which is also why everything that goes up to the spacecraft is carefully modeled. Though a complete spacecraft malfunction almost never happens and even minor malfunction is rare, problems do happen that put science at risk. For example, “sick” events happen when an instrument or one of its subsystems, e.g., data storage, malfunctions. These are responded to rapidly and usually don’t cause major havoc, but relevant instrument teams do need to re-evaluate their plans in these scenarios. Losing even a single observation can affect a team’s progress towards their objectives, so when a “sick” event happens, teams need to make sure they’re still achieving their goals and re-plan and reschedule accordingly. To prevent these problems from happening, the spacecraft downlinks data to Earth as often as possible - for Europa it’s planned at every other 8 hours - so that engineering teams can evaluate its position and status and make necessary adjustments.

“There’s a huge amount of pressure not to declare the whole mission a failure - for political... for a lot of reasons.” Engineers will do everything possible to get the spacecraft functioning. P11

“Scientists can “really get off into the weeds” discussing possibilities. Engineers are there “to keep sanity.” P2

“In there there are resource checks, health checks, make sure you’re not going to break things.” P4

Insight 4

Mission operations are always adapting, learning from problems both in past missions and ongoing ones.

There is evidence enough for this in the number of academic papers output by NASA personnel about “lessons learned” from completed and even ongoing missions. It’s especially clear how Europa Clipper is learning from past missions like Cassini. One of the biggest problems on Cassini was that the spacecraft design significantly hindered operations and data collection. The Clipper spacecraft is being designed explicitly to avoid those failures. Within Cassini, its mission extensions were planned much more efficiently than its Prime Mission, using different planning methods and organizational structures like Target Working Teams (sometimes called Thematic Working Groups). And it’s not just planning processes that change - sometimes new functionalities are discovered during the mission that change how teams collect data.

“They [Clipper team] are building the spacecraft very smartly.” P2

“We’re building models very early. We build models that run simulations and simulations help us discover if there might be opps or problems in our tour design. Then the model that is created will be continually updated during the mission... We’ll be able to put a plan in, run it against the planning tool and see if it makes sense.” P13

“I know in the past a lot of things have been tried at JPL” P1

Insight 5

Fragmentation of software tools across teams poses a challenge to science collaboration and contributes significantly to conflict.

Naturally, with the vast amount of considerations each instrument team needs to take into account when planning and scheduling, it's impossible to also be concerned with everything that other teams are doing. However, one of the biggest contributors to inefficiency in operations is the conflicts that arise from merging the plans of different teams together. This can be mediated if instrument teams know better in advance how their plans affect other teams. JPL is learning how to accomplish this. The Europa Clipper team is designing a complete suite of software tools to assist in planning, scheduling, and sequencing that will be used across teams. In the past, there have been central repositories at JPL, like the Cassini Information Management System, where teams could see the status of all activities, e.g., planned and approved or requested and not approved. However, there was nothing ensuring all instrument teams knew what others were doing, and software was not provided by JPL so teams developed their own software for modeling and analysis based on their needs.

"Instrument teams are not always aware of what other instruments are planning." P6

"It was a combination of JPL not taking the right path in developing tools... they wanted to develop something for the uplink process but what we needed was a rudimentary planning tool that gave you a high level planning of your planning process." P1

"A bunch of tools that people have developed on their own" P1

Insight 6

Cross-pollination across diverse teams facilitates healthy collaboration and cohesion across disciplines because it ensures that no team's individual needs dominate.

The way missions are structured and the presence of mediating roles, i.e., roles with the responsibility of communicating between scientists and engineers, is indicative in itself of an organization that depends on healthy collaboration. These structures have been arrived at over time. For example, Cassini was one of the first missions to utilize "Thematic Working Groups," in which representatives from distinct instrument science and engineering teams work together to optimize the achievement of mission objectives. The overall mission objectives cannot be accomplished without all the instruments working together, and some instruments even rely on others' data to make discoveries. Engineers are there to keep discussions grounded in the reality of spacecraft constraints, and interdisciplinary scientists are present to reason around the diverse scientific perspectives being thrown around. Problems with collaboration still exist though. Despite the existence of mediating roles being a sign of healthy collaboration, the number of roles responsible for representing science and engineering to each other suggests collaboration can still be improved.

"It's a good thing in my opinion to have scientists who are orthogonal: member of an instrument team and a Thematic Working Group." P2

"The investigation scientists ... would know what spacecraft things affect their instruments." P1

"I already had experience with flight projects and working on missions and being on call." P12

Insight 7

Data return is emotionally charged because careers are at stake.

Reaching decisions that fulfill mission objectives is not only difficult because of technical constraints and organizational challenges. The personal importance of scientists' academic goals also complicates decision-making during negotiations. Because of how long it takes to plan and execute these missions, scientists can spend the majority of their career on one mission, so when the time comes to collect data, analyze it, and produce papers for publishing in academic journals, scientists want as much data as possible. This makes it difficult when deciding which instrument gets to collect data at a certain time, and what data that instrument should be obtaining. A lot of the time when negotiating who gets an observation, decisions are made based on how scientists prioritize certain observation opportunities. But as a few of our interviewees noted, no one is going to prioritize an opportunity as low if it means collecting valuable data, even if they know another instrument could potentially make better use of that opportunity. For this reason, negotiations can get intense and occasionally have to involve executive decisions from the Project Science Group, which oversees all science and progress towards objectives.

"People get emotionally attached to the work, the more time you work on something the more upset you get when someone comes in and says we're going to do something different." P4

"There is the managing of the emotional and the work ebb and flow." P4

"There is the managing of the emotional and the work ebb and flow." P7

Insight 8

While automation is welcomed if scientists and engineers understand how and why decisions are made, it is still crucial that humans remain the arbiters in all aspects of decision-making.

Automated software has been used on JPL and other NASA missions for a long time. Rover missions are a testament to its necessity and success - because there is much more to respond to on the surface of a planet than in the void of space, rovers occasionally need to make decisions autonomously, without the direct guidance of personnel at JPL. Moreover, automation has been incorporated into planning and scheduling software (e.g., MAPGEN) to solve the same type of problem we are addressing. The caveat here is that this type of software is generally mixed-initiative, so humans are always closely involved, supervising and making decisions along with the computer. This is because there is so much information about scientists' preferences that can't be captured in a piece of software - they are qualitative, uncertain, and ever-changing. Software can model constraints and quantifiable objectives, but no scientist is going to trust it to autonomously make mission-critical decisions that involve fluid goals and preferences. However, decisions made based on constraints and other quantifiable, determinate information are trustworthy as long as they are explained adequately enough that scientists can understand how they affect the goals and preferences they hold in their heads.

"One of the reasons why the automated planning & scheduling wasn't entirely successful was because it did not have the ability to accept the kind of preference information scientists wanted." P5

"That's why it [encoding of science objectives into software] typically hasn't been done, and I'm not sure the scientists would give that up. They'd rather do it themselves." P6

"Let the user ask why is this here, why is this before that." P5

DESIGN PRINCIPLES

Frame individual needs within the bigger picture

Because all science must contribute to the overall mission objectives, the design should ground the user's desires within bigger-picture objectives.

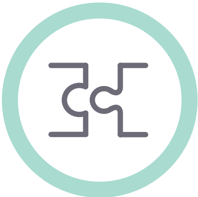
Encourage collaboration & cohesion

To encourage data shared across teams and roles, the design should provide a shared platform for all stakeholders to collaborate on mission-critical decisions. Facilitating communication and awareness across teams builds trust and cohesion.

Minimize cognitive load to allow users to focus on their objectives

Allow stakeholders to focus primarily on their objectives by minimizing or easing the burden of menial tasks. Minimizing cognitive load enables scientists to focus on theirs and the mission's goals.

DESIGN PRINCIPLES

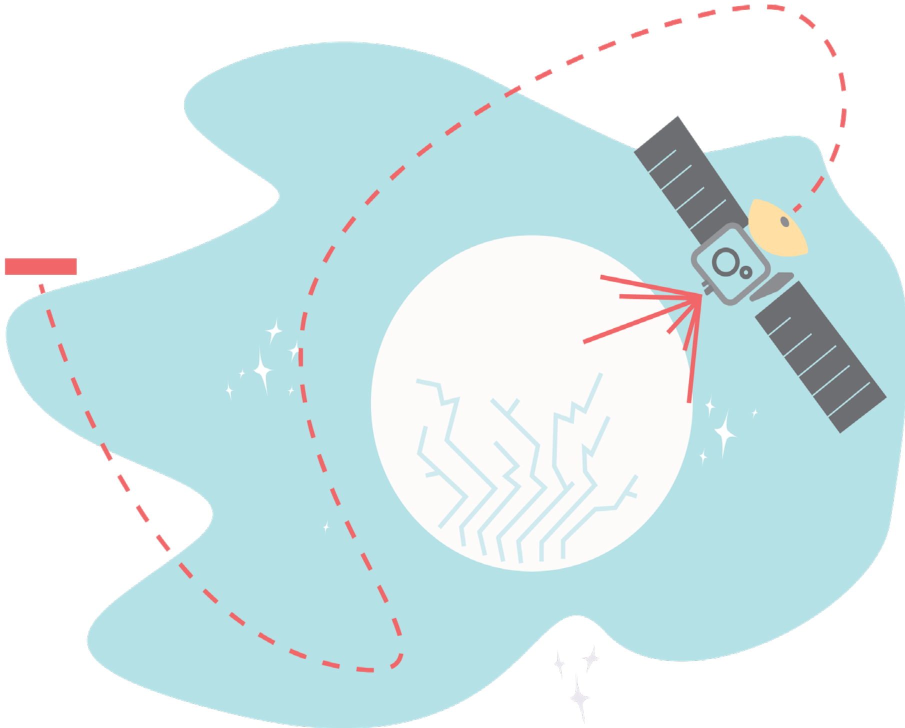


Be adaptable to new and old

JPL personnel move from mission to mission throughout their careers, bringing legacy tooling and experiences with them to the next mission. Our design should consider what scientists and engineers are used to doing when designing something new.

Encourage collaboration & cohesion

The design should explain constraints and possible consequences of stakeholder's actions explicitly to encourage trust in a system's outcomes. Scientists and engineers are accustomed to rigorous process and testing.



DISCUSSIONS

OPPORTUNITIES

A collaborative platform for stakeholders to make efficient science decisions.

Responding to data downlink and new discoveries is a large part of the mission process. Teams are not always co-located which extends the time for decision making. Clipper is aiming for a 1:1 uplink operations. How might we help stakeholders decrease the time it takes to make science decisions?

An easy way for scientists to realize how their changes impact other instruments to promote collaboration

Resource negotiation is a contentious process often because instrument teams don't understand or realize how their tweaks- big or small, affect other teams. How might we help instruments collaborate with one another when collecting data so that they work together rather than get in the way of each other?

OPPORTUNITIES

Visualizing resource usage and allocation to alleviate negotiations

While pointing is less of an issue on Clipper, other resources like power, data, etc. are still resources to be negotiated. How might we use the power of data visualization to help teams better see their resource usage and impact on other teams? Teams don't usually negotiate because they want to use more resources than others but rather because they don't understand why other teams are doing what they're doing.

Checking validity against models to increase sequencing speed

Modeling and simulation happens every step of the way, pre launch and post launch. A set of interactive commands have been identified by the planning, execution, and sequencing team to decrease human decision making. How might we increase sequencing speed by helping decision makers quickly understand levels of risk when validating models?

APPENDIX

APPENDIX CONTENTS

REFERENCES

[1] Doody, D. (2017, February). Basics of Spce Flight. Retrieved from https://solarsystem.nasa.gov/basics/

[2] NASA Jet Propulsion Laboratory Caltech. February 11, 2016. The von Kármán Lecture Series: The Europa Mission. https://www.jpl.nasa.gov/events/lectures_archive.php?year=2016&month=2

[3] Paczkowski, B. G., & Ray, T. L. (2004, May). Cassini science planning process. In Space OPS 2004 Conference (p. 339).

[4] Steadman, K., Pitesky, J., Ray, T., Burton, M., & Alonge, N. (2010, April). Cassini Titan Science Integration: Getting a" Jumpstart" on the Process. In SpaceOps 2010 Conference Delivering on the Dream Hosted by NASA Marshall Space Flight Center and Organized by AIAA (p. 2126).

[5] Paczkowski, B. G., Larsen, B., & Ray, T. (2009, March). Managing complexity to maximize science return: Science planning lessons learned from Cassini. In Aerospace conference, 2009 IEEE (pp. 1-14). IEEE.

[6] Bresina, J., Dearden, R., Meuleau, N., Ramakrishnan, S., & Smith, D. (2002, August). Planning under continuous time and resource uncertainty: A challenge for AI. In Proceedings of the Eighteenth conference on Uncertainty in artificial intelligence (pp. 77-84). Morgan Kaufmann Publishers Inc..

[7] Vertesi, J., & Dourish, P. (2011, March). The value of data: considering the context of production in data economies. In Proceedings of the ACM 2011 conference on Computer supported cooperative work (pp. 533-542). ACM.

[8] Lyons, J. B., Koltai, K. S., Ho, N. T., Johnson, W. B., Smith, D. E., & Shively, R. J. (2016). Engineering trust in complex automated systems. ergonomics in design, 24(1), 13-17.

[9] Chein, S., Rabideau, G., Knight, R., Sherwood, R., Engelhardt, B., Mutz, D., ... & Stebbins, G. (2000). ASPEN-Automated Planning and Scheduling for Space Mission Operation. Retrieved from https://trs.jpl.nasa.gov/bitstream/handle/2014/14437/00-0874.pdf?sequence=1

[10] Bresina, J. L., Jónsson, A. K., Morris, P. H., & Rajan, K. (2005). Mixed-initiative planning in MAPGEN: Capabilities and shortcomings. Retrieved from https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20050184145.pdf

[11] Aghevli, A., Bencomo, A., & McCurdy, M. (2011). Scheduling and planning interface for exploration (spife). ICAPS 2011, 54.

[12] Bresina, J. L. (2015, January). Activity Planning for a Lunar Orbital Mission. In AAAI (pp. 3887-3895)

[13] Ray, T. L., Knight, R., & Mohr, D. (2014). Automated scheduling of science activities for Titan encounters by Cassini. In SpaceOps 2014 Conference (p. 1892).

[14] Troesch, M., Chien, S., & Ferguson, E. (2017). Using Automated Scheduling to Assess Coverage for Europa Clipper and Jupiter Icy moons Explorer. Retrieved from https://ai.jpl.nasa.gov/public/

Europa + the Machine

Research Plan + Study Guide

Introduction & Background:

Our sponsor NASA's Jet Propulsion Laboratory "JPL" is in the planning phase of an orbiter mission to Jupiter's moon Europa set to launch in the 2020's. Nine scientific instruments have been selected that include team members from diverse locations. The internal JPL planning teams are starting to create "Thematic Working Groups" who need to collaborate across different locations. Multiple stakeholders including Working Groups have to agree upon a set of flyby's before the spacecraft even launches, but most likely will make corrections once they start to collect information from both simulations and actual downlinked information from the spacecraft in orbit. We are still unsure of the exact process these teams come to agreement and to what extent all teams need to agree to make a decision.

Our challenge is to decrease the amount of time it takes for workgroups to come to consensus and make uplink corrections to the spacecraft currently in orbit. From our initial secondary research this process can be quite complicated and for those involved the stakes are very high. On previous missions, such as the Cassini Huygens orbital mission to Saturn, instruments had requirements that caused conflicts with other instruments. While Europa Clipper is very different in spacecraft design, there may be other constraints that require compromise amongst team members. We know that many teams collaborate remotely and make decisions over teleconference calls, for some teams in person meetings with other teams can be rare. We also know that some form of automation is already used for scheduling mission flybys.

Through a series of research activities we hope to learn as much as possible about how those involved with the Europa Clipper mission make decisions that affect the orbiter during uplink operations. We also are looking to measure attitudes in regards to automation and artificial intelligence, and how best to utilize these tools while keeping a high level of trust in the decisions made.

References

Paczkowski, B. G., & Ray, T. L. (2004, May). Cassini science planning process. In *Space OPS 2004 Conference* (p. 339).

Paczkowski, B. G., Larsen, B., & Ray, T. (2009, March). Managing complexity to maximize science return: Science planning lessons learned from Cassini. In *Aerospace conference, 2009 IEEE* (pp. 1-14). IEEE.

Ray, T. L., Knight, R., & Mohr, D. (2014). Automated scheduling of science activities for Titan encounters by Cassini. In *SpaceOps 2014 Conference* (p. 1892).

Rabideau, G., Chien, S., & Ferguson, E. (2010). Using Automated Scheduling for Mission Analysis and a Case Study Using the Europa Clipper Mission Concept. *coordinates*, *30*(30), 0.

Steadman, K., Pitesky, J., Ray, T., Burton, M., & Alonge, N. (2010, April). Cassini Titan Science Integration: Getting a" Jumpstart" on the Process. In *SpaceOps 2010 Conference Delivering on the Dream Hosted by NASA Marshall Space Flight Center and Organized by AIAA* (p. 2126).

Vertesi, J. (2012). Seeing like a Rover: Visualization, embodiment, and interaction on the Mars Exploration Rover Mission. *Social Studies of Science*, *42*(3), 393-414.

Vertesi, J., & Dourish, P. (2008). *The Social Life of Spacecraft*. LUCI Technical Reports, LUCI-2008-09.

Vertesi, J., & Dourish, P. (2011, March). The value of data: considering the context of production in data economies. In *Proceedings of the ACM 2011 conference on Computer supported cooperative work* (pp. 533-542). ACM.

Design Question

- How might we help incorporate automation into mission planning processes to improve decision making in such a way that both minimizes cost and maximizes the collection of crucial scientific data?

- How might we improve decision making during the mission planning process by providing teams with crucial scientific data

Research Goals

- *To further our understanding of organizational structure within JPL and the flow of interactions that define planning and decision-making, including interactions with teams outside JPL, in order to identify possible points of intervention*

- The work division of current work teams
- The quantity of people in each team
- How roles are switched and its effects
- The workflow of current planning process
- How scientists and engineers communicate and collaborate with each other?
    - In the planning phase
    - During the mission
    - When things don't go as planned and need to pivot
- How scientists prioritize plans in their teams
- The process of final decision sequence making

- *To understand how data is collected, interpreted, and communicated among teams and what kinds of information influence or constrain decision making*
    - types of instruments that are used
    - types of data that are collected and shared
    - the process of data synthesis
    - How data is shared across teams
- *To gather perceptions and opinions about how decision-making can be improved, including the potential for automated assistance*
    - What are some examples of problems that typically occur during missions that are most concerning to participants?
    - Do participants think of any form of automation to improve decisions made during the mission?
    - What concerns do participants have about automation being used to speed up uplink operations?

Participant Profiles

The profiles of our participants will become clearer as we learn more about the roles involved in planning and decision-making processes, but really our stakeholders could be any mission personnel. Likely we will be interviewing mostly scientists and engineers, ideally those with more say in the planning process, such as **investigation scientists and engineers**. These roles act as a liaison between management at JPL, instrument science teams (i.e., the people collecting data from each of the spacecraft's 9 instruments), and engineers responsible for calculating trajectories and maintaining the health of the spacecraft. We will likely not get much chance to interview anyone higher up than investigation scientists and engineers, such as project scientists and project managers. Whatever form our final design takes, it will need to consider data from all science teams as well as engineering teams, overarching mission objectives, and conform to the recommendations of leadership roles such as mission planners and project managers.

Recruiting Strategy

Due to the sensitive nature of the project, all of our interview participants will be pre screened by our sponsors at NASA-JPL. We will begin our process by generating a list of participants, from there, our sponsors will give us a green light for people who we can reach out to. In some cases, an introduction from the sponsor will be made to the contact. In other cases, we will email the participant referencing our status as UW MHCI+D graduate students working on our capstone project. Suggestions for people to talk to from email or conversations with participants will also be confirmed with our sponsor before reaching out.

Email example to recruit experts:

- Address participant by title and last name
- Reference how we got their contact information (if no introduction)
- Reference their research and work in email
- Provide our purpose for interview and how the participant can help us

{

Dear Ms. XXXXX,

We're a team of graduate students in the University of Washington's Human-Computer Interaction + Design program working with NASA-JPL on our Capstone project. Our focus is to research and design an automated scheduler for the upcoming Europa Clipper mission. Because the mission is still in the early stages of planning, we're looking to understand the intricacies of planning other, similar missions such as Cassini, and how that can inform planning for future missions. We believe you would offer an essential perspective on how the ac-

quisition of scientific data affects decision making. Would you be willing to chat with us via video about the project and how it relates to your work on previous missions?

We're in the early stages of the research process, and as such, learning anything about how scientists collaborate with engineers to optimize data collection and how this compares to other JPL-led missions would be greatly valuable to us. We look forward to hearing from you.

Thanks,

UW Capstone Team (Daphne Liang, Gabriel Hughes, Will Oberleitner, Victoria Song)

}

The majority of our interviews during our research phase will be expert semi structured interviews. As such, we will not be providing them compensation for their time. We will instead send a thank you email and handwritten card post interview.

We will also be recruiting software engineers who have experience with managing merge conflicts and/or distributed development environments. These participants will be recruited through University of Washington CSE department and/or personal network. We will provide them with $25 gift cards for compensation.

Study Activities

Secondary research

- Synthesis of existing research helps us understand similar technology and give us a general sense how planning automation work in astronomical data field.
- Help us understand how previous and current NASA missions work in general and generate primary research questions

Semi-structured interview

(Time Estimate: 30-45 min)

- Ask experts from NASA a pre-determined open questions to understand their current planning process
- Be open to let interviewees further explore and share topics relevant to our problem space

Iterative Diagraming

(Time Estimate: 15-20 min)

- In order to better understand stakeholders' mental model on priority of different orbiter data, we will use visual diagram to show our current understanding on scheduling activities. Then participants are asked a series of questions to correct misunderstanding and further develop our knowledge scope. As we iterate on getting feedback from different participants on diagrams, the diagram will be consolidated and evolved over time.

- **Users:** Scientists, engineers,investigation scientists and project scientists

- **Goal**: understand the activity schedule and mission phases in a temporal way. Personal experience and comments on improvement in different phases will be collected by iterative diagramming method. Also, how different phases are transit and how personnel are communicated.

- **Scenarios**: Uplink development timeline & uplink process flow

Open Card Sort

(Time Estimate: 30-45 min)

- **Description:** Open card sorting allows us to have a participant generate their own terms alongside some we create, giving them the ability to provide terms and natural groupings for their use in the mission. We will describe a scenario and have the participant begin to sort cards we previously created, they can create and edit new cards based on their requirements. By using "think out loud protocol" we will have the participants elaborate on why these terms are used, and the reasoning for the groupings. Once we have a set of cards the participant is happy with, we will also ask them to arrange them in a hierarchy for prioritization, also having them describe why they made these decisions.

After each session we plan to document each configuration. As we start to build enough evidence we will compare terms and hierarchies, looking for similarities and differences. Because of the small amount of overall participants, and the importance of each individual we interact with, if we notice "corner cases" we will look to follow up with participants asking why their responses were different from the others.

- **Participants:** Project Scientists, Engineers, Investigation Scientists, Mission Planners (Others we learn about who have requirements that affect spacecraft sequencing)

- **Goal:** To understand the language used when describing their data, the requirements needed for decision making, and the priority of the terms they describe for key scenarios. By keeping the card sort open we encourage creativity and the possibility for the participants to use terms they naturally use.

- **Scenarios:** Routine Flyby, Possible Problems & Troubleshooting, Big Discoveries That Change Science Goals.

- **Card & Category Labels:** These terms will come from our first interviews and may change per participant as we learn more about their requirements. From our secondary research possible terms seem to varied to make assumptions without interviewing those who make decisions.

Interview Guide

Note: *Due to the variety of roles we expect to interview throughout our research process, and the unfamiliarity of the problem space, we will be generating unique interview guides for each of our participants. This guide serves as a template for structuring future guides and aligning them with our research objectives. We have included as many pertinent high level questions as we can think of, and have color coded questions that relate to specific categories of personnel: scientists, engineers, and leadership.*

Scientist Engineer Leadership

Introduction

Hi, [Participant Name]! Thank you so much for taking the time to talk with us.

Just to give you a little more context, our team is working with JPL's Ops Lab to improve the efficiency of uplink operations for the Europa Clipper mission, potentially using assistive software. Through interviews with experts like you, we hope to learn as much as possible about all the variables involved in decision-making in orbiter missions, including the people involved and how scientific and spacecraft data informs uplink commands. Although our research and future design implementation is focused on the Clipper mission, we greatly value any input specific to other, similar missions, as our solution could potentially be applied to future operations.

The format of today's chat will be an approximately 60-minute interview [which will include one activity; we will share details about this about halfway through the interview.

We'll be sharing your responses anonymously between our UW research team and our advisors at JPL.

Do you have any questions so far?

Before we get started today, we also want you to know that we would like to audio record our interview with you as a full transcription of your responses will be greatly valuable for the purposes of analysis. Is it ok with you if we record this interview?

[If YES] Thanks so much for your cooperation. We're starting the recording now.

[If NO] Not a problem. We'll continue without recording.

Background

Goal: To learn more about the participant's background, their current role, and, if on the Clipper mission, their motivations for their work on the mission.

Can you tell me a little bit about your role as a [ROLE] at [LOCATION]?

- IF WORKING ON ORBITER MISSION:
    - How do your day-to-day operations change from the planning phase to post-launch? (probably less of a background question & more operations)

What other projects or missions have you worked on?

- How is Europa different? [if NASA/JPL]

What excites you about working on the Europa Clipper mission? [if relevant]

Organizational

Goal: To further our understanding of organizational structure and the flow of interactions that define planning and decision-making in order to identify possible points of intervention

What kinds of people or roles do you work with?

- Who do you report to? / Who reports to you?
- What other important roles are you aware of that you may not work with directly?
- Do you work with a team or more independently? How is that?
- If you communicate with anyone remotely, how is that experience different from working with people within your organization?

How is working with [scientists / engineers]?

- How often do you meet with them directly?
- Can you recall a specific experience?
    - How would you describe this experience? Was it typical, would you say, or unique?

Can you give me an example of a difficult decision you had to make in a previous mission (or project)?

- What made it difficult? Was it the number of people involved or simply the nature of the problem?
- How was it resolved?

Data Collection, Analysis, and Decision Making

Goal: To understand how data is collected, interpreted, and communicated among teams and what kinds of information influence or constrain decision making

How are decisions made among members of your team?

- What kinds of information (or previous decisions) influences those decisions, and what's the influence of that decision once it's made? Who makes decisions based off of yours?

How are science objectives created?

- Can you give an example of a formal science objective and how it affected trajectory design?

What kinds of data are most important to you?

- What kinds of data do you want to see? What kinds of data do you not want to see?
- What kinds of data are crucial to your research objectives and would lead to a request to change trajectory or attitude?
  - Can you give an example?
- What are some constraints on collecting data from [INSTRUMENT]? E.g., engineering constraints
- What types of data typically lead to changes in the spacecraft's attitude and/or trajectory?
- What types of requests do you typically accept, and which do you tend to deny? What are some typical changes that need to be made, if there is anything typical about this?
  - Can you give an example?
- How common have changes happened in past missions you have worked on?
  - Can you give an example?

Imagine Clipper is orbiting Europa now. Can you walk me through how you would acquire data from the spacecraft?

- What's the timeline for this process, considering Clipper only has around 8 hours to collect data from Europa?
- What do you do with the data when you get it?
- What does the data look like when you get it?
- How do you determine the quality of the data?
  - What makes it usable and actionable or not?
- Are there other datasets that are important to your research (outside your instrument team)?

What kinds of tools do you use to analyze your data? What kinds of tools do you use to share or communicate your data to others both within your team and outside it?

- Specifically, are there any valuable tools you use to visualize data?

What are data sharing practices like?

- Do instrument teams share data among themselves? If so, to what extent?
- How much scientific data is shared with engineers? How much of this data is important to engineers?
- How is data shared with personnel outside JPL?

Do you know what role mission personnel outside JPL have in the planning and decision-making process? (if at JPL)

Automation / Assistive Software

Goal: To get an idea of perceptions surrounding automation / assistive software at JPL and, in general, in similar high-stakes scenarios

To our knowledge, in past orbiter missions the ratio of operations to spacecraft execution has been at a minimum 4:1. Do you think assistive/auxiliary software has potential to improve uplink operations?

- If so, how? We can picture two different scenarios for use of assistive software with our limited knowledge. One would be presenting the team with options. For example, if the magnetometer (ICEMAG) team wanted to collect more data, the system could present them with potential changes to the schedule, with visualizations of how this affects other activities, resources, and data collected. Another use is conflict resolution. For example, an unexpected obstacle causes a change in trajectory or unexpected use of some resource, and the system quickly presents the team with options for rescheduling activities.
    - Is there anything in particular you'd want to make sure such a system would take into consideration, or anything that's especially important to visualize?

What concerns do you have about assistive/auxiliary software being used to speed up uplink operations?

Check-list

After participant confirms interview

- Send calendar invite to all members of team + participant
- Send Skype or Google Hangouts contact request depending interviewee preference
- Book an on campus meeting space to conduct the interview. The room should be booked for a minimum of 30 minutes before and after interview to allow for preparation and flexibility

Day before

- Send a reminder email to participant
- Confirm location with all team members

Day of

- Meet 30 minutes prior to scheduled interview to set up and prepare

After interview

- Send thank you interview or card to participant. Include any follow up questions. Take note if participant is interested in a project update on a later date.

Equipment needed

- 2x computer
- 2x phones, 1 for audio recording and the other for picture taking when necessary
- Chargers, both phone and computer, converters if necessary
- 1x whiteboard + markers if needed
- Notebook + pen if taking notes by hand

Software needed

- Skype or Google Hangouts
- Recording software

- Camera
- Google Docs for note taking

Documents needed

- 2x printed interview guide
- 1x printed gratuity release (when appropriate)
- 1x printed consent form (for in person interview)
- Notebook paper or blank paper (for in person interview)

Consent Form

In person

I agree to participate in this research project conducted by University of Washington Master's of Human Computer Interaction + Design graduate students Daphne Liang, Gabriel Hughes, Jialing (Victoria) Song, and William Oberleitner. I understand that my participation in this research project is voluntary and that I may withdraw and end the session at anytime without penalty. If I feel uncomfortable in any way during the interview session or activity, I have the right to decline to answer any question or to end the interview.

Participation involves being interviewed by any person on the team. Notes will be taken during the interview, photos may also be taken. An audio recording of the interview will also be recorded. I give my consent for all of the above.

I understand that the team will not identify me by name in any reports using information obtained from this interview, and that my confidentiality as a participant in this study will remain secure. Subsequent uses of records and data will be subject to standard use policies which protect the anonymity of individuals and institutions.

I have read and understand the explanation provided to me. I have had all my questions answered to my satisfaction, and I voluntarily agree to participate in this study.

____

Name

____

Signature

____

Date

Verbal Consent

To participant:

You understand that your participation in this research project is voluntary and that you may withdraw and end participation at anytime without penalty. Notes will be taken during the session, and photos might also be taken. An audio recording of the interview will also be recorded. The research team will not identify you by name in any reports using the information obtained from this interview/test, and your confidentiality as a participant will remain secure. Subsequent uses of records and data will be subject to standard data use policies which protect the anonymity of individuals and institutions. If you understand all of the above and agree to participate in this study please say, “I agree”.

From participant: “I agree”

Participant 1 Interview Guide

Scientist

Profile: P1

Roles:

- Cassini Science Planning and Sequencing Team
    - **Magnetospheric and Plasma Science** (MAPS) **Investigation Scientist** or IS
    - **Science Integration Engineer** (TOST, MAPS)
- **Cassini Titan Orbiter Science Team Co-chair**

Research interests:

- **Planetary magnetic field modeling**, including modeling of Saturn's internal magnetic field based on inversion of magnetic field data and modeling Earth's magnetic field derived from paleomagnetic data over the Holocene

Introduction

Hi, [Participant 1]! Thank you so much for taking the time to talk with us.

Just to give you a little more context, our team is working with JPL's Ops Lab to improve the efficiency of uplink operations for the Europa Clipper mission, potentially using assistive software. Through interviews with experts like you, we hope to learn as much as possible about all the variables involved in decision-making in orbiter missions, including the people involved and how scientific and spacecraft data informs uplink commands. Although our research and future design implementation is focused on the Clipper mission, we greatly value any input specific to other, similar missions, as our solution could potentially be applied to future operations.

The format of today's chat will be an approximately 60-minute interview [which will include one activity; we will share details about this about halfway through the interview.

We'll be sharing your responses anonymously between our UW research team and our advisors at JPL.

Do you have any questions so far?

Before we get started today, we also want you to know that we would like to audio record our interview with you as a full transcription of your responses will be greatly valuable for the purposes of analysis. Is it ok with you if we record this interview?

[If YES] Thanks so much for your cooperation. We're starting the recording now.
[If NO] Not a problem. We'll continue without recording.

Background

Goal: To learn more about the participant's background, their current role, and, if on the Clipper mission, their motivations for their work on the mission.

Can you tell me a little bit about your roles as an investigation scientist and science integration engineer at JPL?

- *Goal here is to probe for follow-up questions regarding organizational structure and workflow to be asked in the "Organizational" section*
- How is the investigation scientist's role different from that of a scientist working on an instrument team, for example the PI of an instrument?

We've seen from reading some of your publications that you're also the Titan Orbiter Science Team (TOST) Co-chair. What does this role entail?

- How did it complement your roles as an IS and IE?
- How did it conflict? Did you experience any significant challenges balancing those roles?

What phases of the Cassini mission did you work on? Pre-launch planning, full mission, or just extensions...

What other projects or missions have you worked on?

- How is Europa different?

Organizational

Goal: To further our understanding of organizational structure and the flow of interactions that define planning and decision-making in order to identify possible points of intervention

What kinds of people or roles did you work with on Cassini?

- Who did you report to? / Who reported to you?

- What other important roles are you aware of that you may not have worked with directly?
- Did you work with a team or relatively independently?
- If you communicate with anyone remotely, how is that experience different from working with people within your organization?

Being an investigation engineer, what was the nature of your relationship with the engineers on the mission?
- How closely did you work with them?

IF ON TEAM FOR FULL MISSION: How did your day-to-day operations change from the planning phase to post-launch?
- IF NOT: What role do investigation scientists and engineers have before the mission launches, compared to after it launches?

Data Collection, Analysis, and Decision Making

Goal: To understand how data is collected, interpreted, and communicated among teams and what kinds of information influence or constrain decision making

How are science objectives created?
- Can you give an example of a formal science objective and how it affected trajectory design?

Can you give me an example of a difficult decision you had to make in a previous mission (or project)?
- What made it difficult? Was it the number of people involved or simply the nature of the problem?
- How was it resolved?

How are decisions made?
- What kinds of information (or previous decisions) influences those decisions, and what's the influence of that decision once it's made?

What kinds of data are most important to you?
- What kinds of data do you want to see? What kinds of data do you not want to see?
- What kinds of data are crucial to your research objectives and would lead to a request to change trajectory or attitude?
    - Can you give an example?
- What are some constraints on collecting data from [INSTRUMENT]? E.g., engineer-

ing constraints
- What types of data typically lead to changes in the spacecraft's attitude and/or trajectory?
- What types of requests do you typically accept, and which do you tend to deny? What are some typical changes that need to be made, if there is anything typical about this?
    - Can you give an example?
- How common have changes happened in past missions you have worked on?
    - Can you give an example?

Can you walk me through how you would acquire data from the spacecraft?
- What's the timeline for this process?
- What do you do with the data when you get it?
- What does the data look like when you get it?
- How do you determine the quality of the data?
    - What makes it usable and actionable or not?
- Are there other datasets that are important to your research (outside your instrument team)?

What kinds of tools do you use to analyze your data? What kinds of tools do you use to share or communicate your data to others both within your team and outside it?
- Specifically, are there any valuable tools you use to visualize data?

What are data sharing practices like?
- Do instrument teams share data among themselves? If so, to what extent?
- How much scientific data is shared with engineers? How much of this data is important to engineers?
- How is data shared with personnel outside JPL? (is this important?)

Do you know what role mission personnel outside JPL have in the planning and decision-making process?

Can you think of any specific ways in which missions like Cassini inform the planning and design of future missions? Were there any major concerns you had about operations that you would change for Europa?

Automation / Assistive Software

Goal: To get an idea of perceptions surrounding automation / assistive software at JPL and, in general, in similar high-stakes scenarios

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To our knowledge, for the Cassini mission the ratio of operations to spacecraft execution was around 4:1. Do you think assistive software has potential to improve uplink operations?

- If so, how? We can picture two different scenarios for use of assistive software with our limited knowledge. One would be presenting the team with options. For example, if the magnetometer (MAG) team wanted to collect more data, the system could present them with potential changes to the schedule, with visualizations of how this affects other activities, resources, and data collected. Another use is conflict resolution. For example, an unexpected obstacle causes a change in trajectory or unexpected use of some resource, and the system quickly presents the team with options for rescheduling activities.
    - Is there anything in particular you'd want to make sure such a system would take into consideration, or anything that's especially important to visualize?

Were you involved at all with any discussions about ASPEN, the Automated Scheduling and Planning Environment? We know that it was used experimentally during Cassini to resolve conflicts, such as changes to trajectory or a failed instrument, and generate new plans quickly. The new plans were compared to those generated by TOST to see how weighing science objectives differently led to different schedules.

NOTES

Introduction

Consent given

Notes begin:

Who are you working with at JPL?

- Marijke and Nat from the Human Interfaces group

So we looked up a little about you. Can you tell you tell us your role as an IS and _____ JPL

- In that role, it was primarily the past roles in the past decade on the mission
- Half the payload was magnetometer, detector, that type of stuff
    - Work with them to see that they got their observations into their overall science goal

- I've worked on other space missions but they weren't as complex as cassini and involve a science process

What phases were you involved in? Beginning to end?

- I started pretty early, early 90s, around 92. I started working with the mag and the dust then as time went on i started working all the instruments, 6 of them on the spacecraft. Development through the end of the mission, I've been around a while.

What are the main differences between investigation scientists and engineer? I guess the engineering role tries to integrate science objectives into spacecraft commands?

- As an integration engineer you don't have to have any science knowledge. You would just have to figure out the processes and engineering things that would affect your things. You wouldn't need science knowledge. The investigation engineer has more science knowledge, space knowledge. They would know how things would affect each other. It's more science backed. One of our ops engineers is an English major but she's really efficient but she doesn't have a science background?
- Most of them come from a systems background engineering, and generally their background. I think even that it's probably not essential for that role. You just have to be smart and organized.

We're trying to get a picture of how the organization is structured. We know that you were the correspondent for a few science teams but can you tell us a few of who you worked with. Who were you representing and who did you have to report to? Were you in charge of those instrument teams or were you representing them when you were reporting to someone else

- The way cassini is organized, we have 12 science teams distributed around the world
- England and Germany PI teams
- Often it was representing their instruments
- The responsibility contractually was given to the PI institutions so i would never be able to damage the instruments. But i certainly could inform the project there were activities that would affect one of the science instruments. An ex, we defined certain power modes, to keep ops simple. We decide that this set up instruments can be operating in this mode or power mode. One of the modes didn't work with one power. I would go to negotiations and tell them this would not be a good mode to use. It's not that I could represent the instrument. I would represent their scientific interest when there was an engineering spacecraft activity that would affect them in any way.

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I'm wondering how are some science objectives? We heard from a little from our advisor? Does each instrument team get approved or? We're not sure about how works

- I think the project has evolved so how we did it on Cassini is not how they do it on current missions
- The process to define a traceability matrix. This is the guiding document that leads to all the capabilities. The Europa Clipper has one, you should get your hands on it. It defines the high level science objectives and allows you to trace where you associate an objective to a science. This is the guiding document on how things get implemented on a spacecraft. If you're working on clipper, this is where you should start. For Cassini, back in the day, when people said to go to Saturn there was the AO. I would know, this was before my time. Talk to someone on clipper to find out how it's done now.

We've heard a little about the different levels of objectives. Why are they given these distinctions?

- I think I'm going to suggest you talk to Clipper so talk to someone there. It's evolved over time so I'm not sure how it works now.

Back to team structure. How was communicating with remote instrument teams? It sounds like most of them external to JPL in the US or even in Europe? What were the logistics of that, were there any challenges?

- In the beginning that was hard and challenging but that was the early 90s. And i talk to people who worked on Galileo which went to Jupiter so they had to fax things around. In the beginning we didn't even have the internet to rely on to share documents and communication. I think now it's a piece of cake. You can talk to anybody from any time zone. The only thing we had to keep in mind was scheduling meetings because our colleagues in Europe were going to bed when we were getting up. We had to schedule important meetings early in the morning if we want to talk face to face. In the beginning, we had mac/pc issues we had to deal with. It was so archaic. But none of that is even relevant now.

So what happened then during the mission when the orbiter was near Saturn. What happened if there was error or obstacle? And it was night time in Europe for example. How did you make decisions in those cases and were there any?

- So, is my video on? I can see you but I don't know. If it was something that one of the science instruments. The operations team lead for each instrument (the individual responsible for the health and safety of the instrument) had to get notified and get up in the middle of the night to respond. If they went on vacation it needed to be delegated. If it didn't affect their instrument and was just an anomaly then the ground tea here. This happened very rarely. Some of the instruments had instrument anomalies, but there were very spacecraft events (Safe-ing events) There were very few of those that happened throughout the course of the mission. Less than 5.

This is another general question. Since you worked on the planning before the mission and were also involved during and after the mission. How did your day to day operations change from the planning phase to post launch? How much did things change when the orbiter was already near Saturn. How often new decisions need to be made or new schedules created?

- The way Cassini operated is that we would come up with the science plan and that would be planned well in advance and uplinked (months in advance) and there was a very detailed process which you can talk to some other people about it and there was a way to update it when new knowledge was gained or something changed or some error was found. So you can make later updates to that but it was planned quite far out. Once they got into tour, out 20 days, it was a steady stream of things you would have to monitor, respond to new science discoveries. It wasn't intense because it was a flagship mission so it had a lot of resource but it was a heavy stream of activity. A bunch of scientists fighting over what you were going to do so we had to share the pointing and a lot of negotiating and which science operation should be integrated. That was a more contentious process of course because everyone wants their own science. Once you decide rhythm of implementation then it becomes more routine and negotiation.

What was the process like after the data is collected and downlinked? Does each time have access to their respective instrument data and what happens to that? Are you seeing that data first or does each instrument report to you? I don't know if this is the same for Cassini but some centralized repo for data. Like who had access to that how did inform future decisions?

- The data gets downloaded from DSN through some central server then goes directly to the science team. The science i do is related to the magnetometer and the data comes down through JPL. IT quickly gets taken over to imperial college in london and they do this then stage it on the server. All the info is on the PI institutions. There are other facility instruments data telemetry streams was handled through JPL. I would get my data through PI institution, through the server, through imperial college. You'd go through your PI team to get your day. Each team had a SOXY (a special computer hooked up to JPL) that had all the software hooked up to the telemetry and allowed you to process your data but it all went through the PI.

Can you give us an example where the data collection didn't go to plan or when the trajectory needs to be changed. How did the process differ when there was some anomaly?

- I'm trying to think if i ever falling off the trajectory in any major way. I'll have to think about that some more. My mind is like a sieve. [P2] is very good at remembering all these things. I know she's on your list but she has events from 10 years ago at the tip of her tongue. We would have instrument anomalies but I don't think we ever fell off the trajectory. We had times
- What did you ask me?
-

Anytime it differed from the master time?

- The largest changes we had to respond to were new science discoveries so when the scientists would come to do this and we had to change the plan. That was the most disruptive. I don't think we ever fell of the trajectory.
- One of the recent ones were that we saw red stripes and didn't know what they were. The imaging team came back and it was a weird color stuff. They came back in and changed all the observations to change all the process and stuff. That required a lot of negotiations and reinsert observations in different parts of the timeline in order to get the geometry they need. Science discoveries were the most disruptive, late changes.

IF something did need to be changed, was it relatively easily if a different instrument team wanted to make an observation at? Was it easy to rearrange?

- It was kind of a messy situation. It wasn't. All the things are coaligned so they're all looking at the same place. But all the instruments I was looking at were body fixed and very limited space to articulate. Their articulation degraded over time and they had really limited FOV. Most challenging thing was integrating and changing- we would rely on any spacecraft attitude we could get on whatever spacecraft that was planned and take what we got and it might not be optimal. A plasma instrument wants to look in the instrument that a plasma was looking into. Some of the instruments just had 35, 45 FOV. The cameras wanted to look somewhere else and we wouldn't put for FOV. And we would take a hit and negotiate for prime pointing so it would be considered to be the most observation. But anytime obs were changed late in the process, we were subject to losing out and we had to negotiate pointing that would work for our obs view. It was a disjointed conversation but it was the biggest thing Cassini had to grapple with the fact that we had all these disciplines on this spacecraft and limited space to grapple with. It really reduced the science return to a significant extend 26:30-27:10. We were trying to summarize the mission and it's kind of unanimous it was the biggest thing Cassini got wrong- not being able to articulate the instruments in certain ways.

How did the negotiation occur? How did one team justify that they needed that slot in the schedule?

- It's too painful to even recall. Hahaha, just kidding. It evolved over time. When the mission started out, all the fly bys, people with huge egos, fighting over with every time of observing time. It got more relaxed and time went on but the general process was that you had to argue for your obs and it would be trade off. One team would get this and another team would get that. If an agreement couldn't get reached, it was go the PS to get resolved. Later in the process (prime mission, extension, etc.), the process changed over time. We divided the timelines into the different disciplines. So the magnetosphere would get a certain amount of time. Saturn people would get a different amount time. We allocated the time equally for each team. It evolved over team.

When you say people had to argue for observations? Was it mainly PIs or did you have to argue?

- With Titan, all the PIs showed up to negotiations and people got more confident they would get more data. This was related for that 30:00. Towards the end of the mission when we were doing close orbits to Saturn, the PI got involved again since it was prime real estate. But, generally, it got more relaxed over time

The structure is different for Europa but I'm just wondering how communication happened between instrument teams and how decisions were made considering how things were over time? How were decision made for things like that? Magnetosphere, etc. thematic working groups that help achieve science objectives. Did that happen on Cassini or were you in charge of negotiating among research teams of similar research objectives?

- There are discipline working groups similar to Europa. We had the MAPs group, the lead of the group was more of a theory group so that he wasn't involved in the day to day. He was called in to weigh in on bigger issues. With some of the their chairs were active so they were participate regularly. For MAPS, those teams worked pretty well together and they get along and share data it's quite conducive to doing joint synergistic science. They tried to coaligned with their ____ side as much as possible. Their requirements would be similar if they had them. In general, magnetospheric science is a very instrument discipline. On Cassini it was the magnetospheric instrument that led to the discovery of the plume. I think we weren't proactive enough to request prime time. When you're pitted against beautiful images rather than esoteric images, it's hard to get time for that. But we should have.

Can you talk about the importance of Magnetospheric and .... Mission?

- On Cassini we looked at the magnetic field and we found that the field lines were

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bent in a certain way and it was in the south pole. So that it led to a huge discovery of a volcano. Then mass loads the mass loads ~35:00. It was an important an important discipline. With clipper, and the galileo mission. That's how they are getting a handle on the motion. They're able to determine the induction period of the interior so it's important to determine interior properties and it's what both of those projects have. With the particle instruments. It was able to determine...they were able to. You can infer a lot of information about the interior and interior processes with field and particles instruments. But those are the kind of things that the MAPS instruments were studying. CDA, the dust measured the dust. Another thing the magnetometer does is measures the interior ring of Saturn, we haven't solved this after Cassini. It tends to be underappreciated because we don't have pretty pictures.

What was it that was unsolved in regard to Saturn and why wasn't it resolved. That's an interesting question. We don't how fast Saturn rotates. The rings rotate at different rates and so we don't know. With Saturn so we don't see the wobble. We don't see the final orbits of Cassini we still haven't figured it out. We thought we would get enough data and we don't get it out. When we get closer to the planet we don't have to do. We're going to a workshop next week but it's really the biggest mystery of Saturn that we still have no solved/

Something you said there made me think that how who are elsewhere in JPL who are responsible for synthesizing interdisciplinary data and team?

- We have interdisciplinary scientists and they would share the info, there are 5 but they are not JPL people. Each one is at different location. They are scientists at different institutions. There is no one at JPL who has got that role. I ended up working with all the field and particles instruments and that's got a long way on how that happened. That's really the person at the UM who is the discipline scientist.

Going back to the instruments can you give us an example on some constraints on any one of the instruments you're working on? A magnetometer for ex? What types of things help it collect data and how are those considered in the plan?

- Things like data rate, data capacity. This is one of the shared resources that we negotiated a lot. People who wanted as much data as we could get. Later in the mission as power got degraded, we had to negotiate for power in the negotiation and we had to do sharing of the power because we couldn't have everyone.
- Pointing, data rate, power. Those are the types of things we had to negotiate and share over.

We're looking at the possibility for having software to assist in decision making? What kind of tools were used to visualize a plan and what science data was collected? Was that all visible in one place? Could people see different examples of scheduling and how that would affect how data was returned? We're trying to get a picture of software tools that are being used at JPL among the different science teams

- So you're talking about after we had an integrated plan and the phase we're trying to plan what we're trying to do.
- JPL didn't do an excellent job providing the science community with planning tools in the beginning. That has a long history but the science teams had developed their own home grown tools. There is one i use quite frequently, java based tools, it shows the fields of view and direction all the relevant vectors for fields and participles. Orientation of the magnetic field, where the plasma is coming from, it had all those relevant. It's probably publicly available. It made high level planning possible. The MAP science team so everyone just developed the home-grown thing but I'm holding a coffee mug that has a depiction of the spacecraft and people would use this mug XY axis and they would hold this thing up and figure out how to do their pointing. This gives you an idea of how pathetic it was. It was a combination JPL not taking the right path in developing tools and they wanted to develop something for the uplink process but we needed was a rudimentary planning tool that gave you a high level of your planning process. Tool is called JCSN. It's really cool, i think it developed by the MEME? team at APL. It was just what we needed and didn't have. It's worth looking at even for clipper I think, it's very slick.

I'm guessing, there was such a need for this kind of planning software that you guys had an idea of what that was useful for? Can you tell us anything that might be crucial capability for this type of planning software to have? What kind of things does it need to consider and how are people i inputting, I don't know, input their desire for a plan and help visualize what each team wants, that kind of thing?

- The way of it work work for F&P science instruments is, often times, we would just rely on whatever instrument was controlling the attitude of the spacecraft. They would get the prime pointing, the cameras are looking at Titan. You have flex on what the secondary is doing. So it would allow us to point for ex: -X to North pole and that would get me my science. This tool allowed me to look at the plan and specify the secondary and see if we could get good access to that. We need prime spacecraft. The camera wants to look at Europa but Mass Spectrometer wants to look at particles. For this type of stuff, it would make it easier for us to do simultaneous observation to do different types of science.

We were looking at what that would look at for different types of knowledge. Providing the team with options? If something needed to be changed? It would give a few options on what a changed plan would look like and how that changes the data that can be

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collected. Another example app we've talked about is more of a conflict resolution. If anything happened during the tour and something needed to be rescheduled it could automatically rearrange things and show the time how the changes would differ from the master plan. So do either of those application sound better than the other and what other things should such a software visualize?

- I don't have much current knowledge about clipper knowledge. Are the instruments are body fixed is there a scan platform, i don't know. Someone like [P2] has current knowledge have spacecraft design so she would have better way to weighed in. I know in the past a lot of things have been tried at JPL. Have you talked to people about it?

It was experimentally used in Cassini to compare the plans generated by the science team to the plans it automatically generated. They didn't use it to make decisions but they were doing a study on how prioritizing different things changed the things generated. I can't remember the exact results but the plans were pretty similar but there were some things the software wasn't taking into account. Which is why they didn't use it during the mission. Do you know anything about ASPEN being used? We know that research came out of the AI group at JPL so it was more of an experiment.

- Nemong Lee. I'll ask around to see if that'd be a good contact for you guys?

Are there are other tools that were being used?

- IDIGIT, it was written by a mission planner at JPL. Jay Seal. It's very cool but there is some issue about availability to the public.
- A bunch of tools that people have developed on their own.
- Allowed you visualize Saturn and the moon. People used for planning all the time.
- There is another thing call Cosmographia (remote sensing). It's a NASA system for archiving all the trajectory information and tools

How were these teams talking to each other when they were using home grown?

- Use it for high level science planning to see if it would work and it would accomplish different types of science at once
- When the actual observations were planned, there was a JPL provided software tool that was planning everything. "PDT" further along the process. Detailed observation design, at the very end of the process when you send the sequence to the spacecraft. Someone on Europa.

Shortcomings?

- None, they were adequate for me cus I only did high level planning. Others might have it?

Did you have to use developers to set up or onboard onto a tool like this?

- The online tools that I used on an everyday basis, they were extremely easily to use. The developer is really amazing, he did such a good job. IDIGIT is really quite intuitive, no learning curve. PDT is in particular, when doing detail, that's challenging but i didn't have to do that.

Participant 2 Interview Guide

Engineer   Scientist

Profile

[Participant 2] is currently working on wrapping up the Cassini-Huygens mission at NASA's Jet Propulsion Laboratory, where she maintains her roles as the senior Science Systems Engineer for the Project Scientist and the Titan Orbiter Science Team (TOST) co-chair. These were her most recent roles during the final phase of the mission (the Solstice extension), during which she was also appointed as Deputy of the Science Planning and Sequencing Team, where she was responsible for coordinating science objectives and uplinking the final sequences to the Cassini-Huygens spacecraft during the Grand Finale. These roles were just a subset of the many she played on Cassini. She's been a part of the team since the mission was proposed in the early 90s. She started as the Instrument Operations Engineer for the Radio Science Team and quickly moved her way up to the role of Distributed Operations Engineer, responsible for coordinating all 12 of the spacecraft's science instruments.

She started her career at NASA working on the Voyager Neptune Encounter in 1989, and is currently also playing a role in planning for the Europa Clipper Mission. Certainly one of the most accomplished people at JPL, she receives high praise from her colleagues, has won numerous awards, including the NASA medal for Exceptional Service, and is an active public speaker for NASA.

Introduction

Hi, [Participant 2 Name]! Thank you so much for taking the time to talk with us.

Just to give you a little more context, our team is working with JPL's Ops Lab to improve the efficiency of uplink operations for the Europa Clipper mission, potentially using assistive software. Through interviews with experts like you, we hope to learn as much as possible about all the variables involved in decision-making in orbiter missions, including the people involved and how scientific and spacecraft data informs uplink commands. Although our research and future design implementation is focused on the Clipper mission, we greatly value any input specific to other, similar missions, as our solution could potentially be applied to future operations.

We'll be sharing your responses anonymously between our UW research team and our advisors at JPL.

Do you have any questions so far?

Before we get started today, we also want you to know that we would like to record our interview with you as a full transcription of your responses will be greatly valuable for the purposes of analysis. Is it ok with you if we record this interview?

[If YES] Thanks so much for your cooperation. We're starting the recording now.
[If NO] Not a problem. We'll continue without recording.

Background

Goal: To learn more about the participant's background, their current role, and, if on the Cassini mission, their motivations for their work on the mission.

So we know you've had a variety of roles on the Cassini mission, from an instrument operations lead to Titan Orbiter Science Team co-chair. Can you tell us a little bit about these roles and how they differ?
Goal here is to probe for follow-up questions regarding organizational structure and workflow to be asked in the "Organizational" section

- We're still trying to understand how all these different roles and titles fit with each other on a large scale project like this. Would you mind elaborating a bit more on the overall structure of the Cassini planning team?

What other projects or missions have you worked on?

- Are you familiar at all with Europa Clipper and how it differs?

Organizational

Goal: To further our understanding of organizational structure and the flow of interactions that define planning and decision-making in order to identify possible points of intervention

What were your responsibilities as ...

- ROLES:
    - an instrument operations lead for the Radio Science team
    - a part of the Science Planning Team
        - Can you tell us a little bit about what Titan integration and sequence development entails?
    - the Science System Engineer for the Project Scientist
        - What's the role of the Project Scientist and how did your roles complement each other?
        - We've been hearing about a lot of different titles that make up mission structure. For example, another author on the paper you sent us - Barbara Larsen - is the Mission Operations System Engineer. How does that role differ?
            - What's the nature of your communication with other engineers?
            - What are your objectives when you engage in discussion?
    - The Titan Orbiter Science Team (TOST) co-chair
        - What does TOST do, and how does its function change before and after launch, and now that the orbiter is defunct?
- Who did you work with most closely in each of these roles?
- Am I correct in assuming that you worked as an instrument operations lead and as part of the Science Planning Team before launch and as an engineer and TOST co-chair after launch?
    - Does mission structure then change from pre- to post-launch? How or why did you transition roles?
    - How was the atmosphere different?

It sounds like you've worked closely with both scientists and engineers. How do these relationships differ?

Data Collection, Analysis, and Decision Making

Goal: To understand how data is collected, interpreted, and communicated among teams and what kinds of information influence or constrain decision making

How are science objectives created?
- Can you give an example of a formal science objective and how it affected trajectory design?

We understand through our reading that there are phases during the SOP (Science Operations Plan) process, can you describe the processes for each? (Segmentation, Integration, Implementation)

- After integration and implementation are done, what is the process of Aftermarket? How do scientists make adjustments to existing plan?

What kinds of data are crucial to research objectives and would lead to a request to change trajectory or attitude?

- Can you give an example?
- What types of requests do you typically accept, and which do you tend to deny? What are some typical changes that need to be made, if there is anything typical about this?
    - Can you give an example?
- How common have changes happened in past missions you have worked on?
    - Can you give an example?

What's the process for requesting a change to the [master?] science plan?

What kinds of software tools did you and your colleagues use to plan spacecraft activity?

- Specifically, are there any valuable tools you use to visualize data?

What are data sharing practices like?

- Do instrument teams share data among themselves? If so, to what extent?
- How much scientific data is shared with engineers? How much of this data is important to engineers?
- How is data shared with personnel outside JPL? (is this important?)

Do you know what role mission personnel outside JPL have in the planning and decision-making process?

Automation (Assistive Software)

Goal: To get an idea of perceptions surrounding automation (assistive software) at JPL and how it might be used to improve current planning/scheduling tools.

To our knowledge, for the Cassini mission the ratio of operations to spacecraft execution was around 4:1. Do you think assistive software has potential to improve uplink operations?

- If so, how? We can picture two different scenarios for use of assistive software with our limited knowledge. One would be presenting the team with options. For example, if the magnetometer (MAG) team wanted to collect more data, the system could present them with potential changes to the schedule, with visualizations of how this affects other activities, resources, and data collected. Another use is conflict resolution. For example, an unexpected obstacle causes a change in trajectory or unexpected use of some resource, and the system quickly presents the team with options for rescheduling activities.

- Is there anything in particular you'd want to make sure such a system would take into consideration, or anything that's especially important to visualize?

What was your involvement like with ASPEN, the Automated Scheduling and Planning Environment? We know that it was used experimentally during Cassini to resolve conflicts.

- Can you elaborate on the challenges of incorporating the software into Cassini activity scheduling? Considering what you learned from its results, what are the biggest barriers for incorporating it into future missions?

In your opinion and experience with planning software, what are some of the most difficult considerations when designing systems like this?

NOTES

Introduction

Consent given

Notes begin:

We know that you've had a variety of roles...(reading off interview guide)

- So i've been on the mission for over 20 years, and I have had a variety of roles. ONe of the first roles was an instrument operations engineer. The cassini spacecraft, has 12 instruments onboard. The instruments have 10-20 scientists. The instruments are competing to be on board and directed instruments that are important. Ex: cameras on cassini that was built in house, scientists compete to be on the camera but they don't have to compete for funding. For ____ camera, they had to propose to build the camera. Radiosciensciesub...directed instrument, I was a young engineer/science type that was hired to facilitate that instrument getting incorporated onto the mission. IT was part of the telecom subsystem. The work i did early on was validate commands, figure out how we're going to calibrations, great things we're going to do with DSN. It gave me a broad exposure to people and project. So i was hired on as a distributed ops coordinator, that's someone who works with all 12 instruments. It's part scientist half engineer. The scientists know me and the engineers know me. One of the skills a liason has is being able to talk to both groups. Then the opp came along to join the science planning team, i was in a supporting role for the Titan team. There are 20-30 scientists who care about Titan. In the 4 years of the prime mission, 45 days were within 1 day of Titan so those days became extremely precious in the community and got together early on to share those opps. I was someone who run and wrote software the negotiation of shared resources. Then I became the chair of the mission. That experience gave her the experience gave her a manager for science, planners, etc. When the opp came back to cassini in 2013 or 2014, they asked me to come back to be the key strategic planner for the key finale. It was a contentious time since opp was rare and precious. They knew that someone who is very skilled in working with scientists and engineers, pushing the spacecraft, so they hired me as marching orders for the grand finale of the mission. This is how i learned what skills were helpful along the way

Are you familiar with the europa clipper mission? Are some of these roles and processes are different?

- A little bit of the opposite. If you were on the cassini mission, and you only did titan no saturn, no rings. If you only did titan then it's just like europa. You just do flybys, you fill up the recorder and 2 weeks later you do the thing again. You ignore the rings and everything else. The first time i heard about the concept of the flyby mission of Europa, i knew it was a concept that would work. I've also been hired by europa clipper, i'm 20% on there. I'm the [investigation scientist?] for ice penetrating systems...
-

How does the organizational structure differ between Cassini and Europa team?

- The Europa clipper team of course cassini is quite bit more complicated because we have so many more disciplines. If you just take cassini and you strip away you just think about titan, i see sort of the same structure is forming in both groups. The Type scientists collected them in groups: interior, surfaces, ...that's very similar to the thing groups that formed on Europa: Interior, geology...It's a good thing in my opinion to have scientist who are orthogonal: member of instrument team + thematic working group. The thematic working group that has a broader base of scientists can act as a check on the system. That's not the right concept... if you have one team that you're on, you're quite partisan. But if i'm also part of a team called "interiors". For the interior science to work, i also need the camera to do their part so i get the shape model. It helps balance the group...to have both theme groups and teams. I think it's a good structure, it's a structure that has worked on both cassini, mars mission has it, europa clipper is also employing that. It's a good structure to have overall science balance and trust and verification. Nobody can get out of hand because other scientists act as a check on the system.

In general, do you mind speaking more on Europa Clipper. In general, we're understanding how Europa Clipper might be different from other missions from Cassini or other missions. If we just take a smaller section of Cassini, ex: Titan, there are a lot of similarities there are a lot of similarities for both

Scientist on cassini then went on mars research: Sarah Milkovich - how other missions do things

- We all have the same problems, we're just solving them differently. On a rover mission, rovers take photos, that gets downlinked and then scientists make decisions that is then uplinked
- For cassini, we knew 7 years into the mission what we wanted to do so we had 7 years to argue about it. When we know what the opps are, we can negotiate those resources, then we can start to have those conversations

Can you elaborate more on negotiating resources?

- It's very really for europa, they're still finding their way. They're focusing on getting ready to build things. That's where their efforts are focused. Negotiating resources is something that comes later. So i'll talk about cassini. So you build a spacecraft and you send it somewhere interest and you have these goals, and you have tools in your toolkit, you have cameras, and mass spectrometers, etc. One of the first things you need to negotiate is where are you going to take the spacecraft. I'm going to take one step back for you to have a framework of the type of missions:
  - You can have a flyby mission: ex: voyager. Everything is short period of time, days and months. The pluto mission is a flyby
  - There are orbiter missions: fly by and you repeat what you're doing, couple hours, couple days. Mars orbiter. They're going over the same area again. The venus orbiter Magellan, it took a year to go over once.
  - Then there are landers: they land in one location and last anywhere from days, weeks, months. They are constrained to the area that they are landed. It's like a flyby on the ground
  - Then there rovers: they can go all over, go to what's interesting.
  - Touring missions: cassini is a touring mission. We went in, and out, and high, and low. It's like the suite of instruments. You don't send a rover first thing. That's not what you do. The first thing you do is send an orbiter to see where you want to land. You don't send a touring, you send a fly by to

see if it's interesting enough to do a touring mission.

- Years in advance we needed to maximize the opportunity for scientists. You realize in advance you need to do this to work with engineers and planners to make the most interesting mission. Once you have the opp, then you can have the opp to look into negotiating shared resources. Every mission share resource. Some of them have a generous allocation of power and they never have to turn things off. Some missions have limited power. Every mission has constraints. Once you have the opportunity, once you want to do is negotiate your shared resources
- Negotiating shared resources is all about realizing opportunity. There are 20 flybys because the radar and the instrument can't be on at the same time. So now we have to negotiate "best use" we have to look out for "scientific return". "This is L1 science objective, i should have the resources".
- On Cassini, the key resource was "pointing", the spacecraft was designed to be "unfriendly", she's tricky...all the instruments are body locked. If you want to turn you have to turn the whole spacecraft, and if you want to downlink you can only downlink. Off the top, your day is split: 15 hrs looking at something interesting, 9 hrs of downlinking. There is already a conflict between loading data on SSrecorder, and getting data off SSrecorder. First you figure out what pointing you're going to do (successful technique: i would like to point the radar at Titan and right as we approach, the mass spectrometer it'll be in the "X" direction if you give me X. So Mass Spec is like yay i'll partner with you. Sharing becomes a technique that is effective when sharing resources). Sometimes it's A or B and you have to pick. What you do is you get the group together, people argue for the "science merit". If you can't come to consensus, then we have each side write up an argument/whitepaper, we take it up a chain to the theme groups (acting as checks and balances). The theme groups would pick. There was twice in the mission they wouldn't pick and it would go up to project scientists then they would have to pick
- I don't want to talk to much about europa because they're still in process. They're between a touring. If you know what the is idea for a fly by. Europa has enough power that everyone can be on at the same time, so they'll be less conflict but there will be conflict. The UV instrument wants to point up at a star that means you can't point down. There is always shared resource, there is negotiation to be done. How soon do you know it and how do you deal with it.

Will refers to "managing complexity to maximize science return: science planning lessons learned from cassini" reading, asks about conflicts and scheduling/decision making for Europa?

- That table with the cassini uplink, i just talked about that
- So I would say, yes, op modes? Is something they are dealing with strongly. There are no power issues

P 2

- Missed point at 31:02
- Early 31, missed one. Fly by Europa, but you have two weeks to download the data. The fact you don't have a scan platform, it's a mitigation and it's pretty good
- Navigation: all good on navigation
- Ground system: has the same issue cassini has, we were building in 90s but we were operating in the 2000s. Europa will have this same issue. We built things on technology that is older. Once they're validated you're reluctant to move on them. We try to keep developers around but they don't want to work on tech 2-5 years old so it's hard. They're talking about what their process is but they don't start operating for 7,8,9 years
- Instruments: every mission has its on inter instrument conflict. "Are you in my field of view" "are you sending shockwaves through my system" "are you an instrument that has a scanning mirror so you're jiggling things all the time". This is the time for them to do that, everything is in the prelim design phase. They're going to deal with this reasonably. We'll do this list again to see if it'll
- In flight testing: they'll have to do it. A cost constrained mission wants to constrain costs by not doing operations to the body. I personally think it's foolish. You should try calibrations and operating the bird immediately. So you learn how to operate it when you get to target of interest. The worst thing you can do is wait until europa 1 and learn there is a problem. I'm not a fan of the "let's go on hiatus"
- Cost constraints: ex: calibrations every 6 months and only being able to do it once a year instead.
- Pay attn to op modes: you have to understand to see if there is a power mode and if there is need to share power.
- High priority science payback:
- BDSS: one of things they're doing well. Once you downlink data, you get it, it's deleted. So you dont need to worry about DSN losing your data. What if it doesn't come off in two weeks (not enough downlink). What if you don't have enough space available. It's a SHARED RESOURCE- data storage. *It's possible, that i can see your project managers tell you to ignore this problem or you have to deal with this.*
- No scan platform: they are building the spacecraft very smartly. The camera is pointed down, the mass spac is always in the ram direction. Any planning tool is going to have to accept inputs on how to do it from the scientists and make a decision. They want to make everything look similar but it's impossible to make it identical. Sometimes the camera will collect a lot at the beg and some are the other way around. There are going to be natural variations in the timeline that they produce. The idea is that they would make it as repeatable as possible as that helps with commanding. That drives down operating costs in the future. If you have a set number of flavors (5 diff flavors, lay them down 1 by 1). Another thing is to have little lego blocks, you can break things off. On cassini we used

something called “templates”. At any particular moment when you are so far away from europa, all you have to do is pick between the three, drop it in. And all of a sudden you draw the timeline.

- Templates: for titan, a group of scientists sitting in a room in a year 2000 (4 years before you get to saturn system, we’ve built the spacecraft and decided on the tour, we know we have 45 flybys. Who gets the first one?). The first flybys become extremely important for people to check out that their instrument is working the way they intended. For everyone to see that the radar instrument can see (can/can’t see b/c of clouds). “In absence of actual data, people are arguing a lot”. You have to: “for the good of titan science, what are you going to do?” we tried to let each instrument have their “best shot” we did not degrade anyone for the first 10ish flybys. Fast forward 4 years, everyone’s doing their best shot. Everyone instrument is able to do and more. So now, how do you go forward? We decided the first 12 by saying 1 each. But that’s not going to work for 45, people are not going to achieve their science goals. Now you chop up the opps and you start making decisions and decide A or B. Can you share here and there? On Titan, certain instruments worked really well together, sometimes it’s about a trade. On the inbound side (a lot of people are interested), on approach (lots of people are interested). We had to nego a approach one by one, minute by minute. When we were 1 to 2 hrs out, we didn’t look at each option as carefully right?. *Templates were built in Excel.* Earliest one was hand drawn on paper/pencil. Cassini was built before the internet. In the first 12, everyone got their chance, as we got into the 20s, we started using the templates. We still move through the process step by step so we tackled T20, T21, T22…when went to do the first extended mission, the group in charge told us to take a step back “we have 26 flybys coming to us in an extended missions. Let’s see if we can mix and match and maximize overall science returns by looking at the whole set of opportunities at once”- this maximized time with high powered scientists, got the best scientific return, then we templated around them and planned and around. When we got to the solstice mission, we have 7 year mission, 55 fly bys. We looked at all the close approaches together and chunked it away, this really jumpstarted us.

- Navigation: don’t worry
- Ground system: can’t worry about tech changes
- Instruments bugging other instruments: you don’t know if it bothers another instrument. If so, it might change the plan. You have to be ready for that. Will- how do they find out ahead of time? Ex: a camera looks down but it has a gimbal that looks around so they’re building things to accommodate that
- *****someone should tell you what the constraints are on the instruments*****

- Cassini had nightmares: infrared instrument has to maintain a specific temperature. The radiator can't point at the sun, and can't put at saturn. It became a big problem so we have to figure out to not heat the instrument. "How much can heat you without doing damage to your instrument but still get science?"
- For europa, we're building everyone to work together, so hopefully this is less of the issue/

On meetings

- Cassini started with meetings that were in person because we didn't have video conferencing capabilities then we moved into in person meetings with team
- Titan met on monday
- Saturn met on tues
- Etc.
- When we got to the extended mission, we went to once a month meetings. We're actually still on once a month meetings for closeouts. Science meetings are where scientists co-locate naturally. If they are there, we'll usually attach a workshop to it.
- When the internet came along, we all had websites and we started hosting excel spreadsheets and notes on there. We have this going back to the late 90s.

Gabe Q: as the mission progressed, a lot of the teams developed their own software to plan and visualize themselves to how to plan the mission. What do you use besides excel?

- There's a paper on this: Built and not used, needed and not built (Barbara Larsen)
- Yes, it's all need based. Pointing is a big deal on cassini because we needed to have a tool to see how the spacecraft was going to turn. The tool is complicated and a big responsibility. You can turn the cassini spacecraft and harm the instrument and you will do permanent damage to the camera. So this tool had to be built someone using it isn't it alarmed to harm the instrument. This was an expensive and rigorous tool. It was very slow, and hard to use, and very unwieldy when playing "what if games". One of our scientists on the team developed a tool that created a quick and dirty tool that sees a vague turning damage. "WHAT IF GAMES WITH SHARED RESOURCES". High enough fidelity that it doesn't give you crap but it needs to be fast. The scientists had tools that showed how to do mosaics (high fidelity pointing tools) could do mosaics but that's not what a scientist needed when looking at rings of saturn. They wanted to see a radial distance so the imaging team developed their own tool. They were going to do smaller, shorter pictures, and then stack them.
- There were tools for heating and non heating. There was the official tool and not
- Anything that visualization is more useful than something without 59:16. Templates, timelines, timelines are critical in timing tool. Just suck it up, you have to

have a timeline tool.
- We still have timelines that are spreadsheets (chuckles), they are useful. I don't want to say they're not useful. EVERY MOMENT OF THE DAY IS TIMELINED! Who's doing things at each time. GRAPHICAL TIMELINE IS CRITICAL.

Why was there data loss?
- One of the words was longer than it was supposed to be, it overwrite the other software. It was confusing the solid state recorder. It was recording that it was sick, so we don't write data to it. We did a flyby and the flight software thought it was sick.
- Flight software people have checklists that are 30 pages long because they don't want to make a mistake

You built software for negotiating resources? What was it trying to accomplish that was different?
- The first one was a relational database that captured what everyone wanted to do and what everyone was going to do. You can think of it as an activity planner. You had to pick "you or me, someone needs to pick". If i get picked, all your requests go away. If helps manage requests for resources and who won the debate. Attached to that is the equivalent of modules that ran higher fidelity modules. Tell me what the data volume analysis "how high have we oversubscribed data volume?". We never under, it was always over.
- It was best if you could incorporate it into one larger software with modules. But we had a data volume software, pointing piece of software, other ones that were more subtle but not used as much (are we going to deep so we don't harm the thrusters), we are in titan atmosphere are we using too much hydrosene?- negotiation between other groups.
- We pretty much had software that allowed to model every shared resource on this spacecraft. The inputs for that was desires, algorithms are "what is the spacecraft going to do", how long is that going to take? - all of this decides what your timeline looks like

Because you had all these different softwares and each had their own to visualize data specific to their team. Was there any issues communicating the output of all this software since you have so much of this going on?
- If what is being modeled is so important that we didn't trust the instrument team alone to do it. We usually pulled that in house and did it at JPL. if something was their area of expertise and we trusted them, then all they had to do was report the resorts. Ex: MAPS instrument (wanted to know when the sun is hitting the plasma)- the only consequence was them so they would just report to us
- In a more tech advanced world, we'd want to have a software resident in the

software repository, we would want higher fidelity tests early on. Early on, you need quick, later on you need higher fidelity because you're going to command. If an instrument is going to provide the module, cus they're experts, that's fine. The infrared instrument spent a lot of time writing software to see what's going to heat them, and what's not going to. Since it was harm to the instrument, we incorporated it into the software run at JPL.

Users of the tools? What frequency of use?

- The big relational db, the tool was used by both scientists and science planners. It was used by scientists to input their initial desires and it was used by science planners as negotiation happened, to pick and choose.
- We had version control (we'd get red flags, an instrument would change this). Scientists would use it here and there but planners used it a lot.
- In the perfect world/europa world, we will build the tool, we'll decide on a plan and all the commands would be generated.
- We tried doing that but everyone did their own thing on cassini and then everyone didn't trust each other.

Trusting of a mega system?

- I hope not, we built it in 2002. We're building the next one in 2020. I hope everyone is more tech savvy.
- They are going to validate it, they're not going to let you send commands to their instruments without validating it.

Concerns of automated system?

- You've got 10 instruments, two weeks of commanding, you've got an entire fly by, it's very complicated.
- There's ultimately going to be thousands of commands.
- How do you validate something that has thousands of commands, it's easy to get lost
- What about false positives? That's also problematic.

Are trajectories are changed sometimes? If someone detected a plume on Europa and they wanted to change the trajectory of the spacecraft to try to collect particle data it could take up to an hour to recalculate the trajectory. How often does it happen?

- That's a tricky problem europa has to solve. It's possible an automated planning piece of software could help them solve this problem
- It takes a long time to build a trajectory. It takes a long time to negotiate what you're going to do with the resources. Now you're invested in that, you're balanced, you've run your models, and preliminary runs for data volume, and thermal. And if someone finds a plume and they want to investigate that and they

want to change that. Then they're going to
- Tour person can inject new tour, all the new options. People could see what they're going to see what opps they're going to realize, it is possible that you could be in a world where the team would be ok in making trajectory changes
- If they can't see the opps, they would rather get burned in the hand then give up their opportunity. They would hold their ground.
- Any planning committee is going to be resistant to be that, so that we could hit a button and a plan can get visa
- Project scientist has an authority to say to change all trajectory against all odds. Bob Pappalardo, currently. The cost would be resources. Whatever you come up with is going to be lower fidelity, it might get the plume great. He gets to deal with the outcome of the that. Each of the PIs have been chosen by NASA to choose their L1 objectives. If a project scientist put them a position did not allow me to achieve my L1 objective they could go higher up and fire him.

What are the difference between levels of objectives and who chooses them?
- L1 happens at NASA HQ. Part of it is how NASA interacts with congress and president for funding. NASA gets their direction from there. It's specific and has money attached to it. Congress provides direction ➔ NASA provides plan ➔ congress approves plan
- NASA ops planned has been more rigorously reviewed by congress in the past 10 years
- Large objective: exploring the solar system
- Cassini and clipper are both directed missions, billions
- Next level down is: new frontiers, top at millions. Every 10 years scientists get together and NASA requests this from National Academies that the government to get advice. NASA should be getting a "decadal" Planetary science decadal. Inside they said you should have large, medium, small missions. Large missions should be directed. Medium missions should not be completely open ended, usually one of 5 topics. Small missions are completely open and anyone can suggest what they want and they compete and pick what they want
- Clipper is a directed mission. Juno is a competed mission. Dawn is a small mission (discovery class mission).
- When you have a large flagship mission, the decadal tells you what should be the large science picture. NASA puts out an announcement of opportunity. Instruments are picked. Once these are picked, NASA projects on PS and PIs to identify L1 objectives.
- Once that is done, L2 requirements flow from L1 requirements. They are more detailed. L1 is "we want to understand geographical structure on europa, at least 50 diff type of landforms" L2 "we want to have global image coverage at this resolution to achieve those objectives". L2 requirements are negotiated between

PIs and Ps.
- L3 objectives flow from L2. Ex: build a camera that addresses L2. L3 are negotiated by the project for each of the missions.

If there is something that can be found like a plume, let's leave that to the extended mission? Do they get brought up so early in the process?
- People who are experienced think that there will be an extended mission
- Part of exploring europa is getting the whole coverage. The ice penetrating radar, needs to get us whole cover. We need to get after the whole thing because it's shiny. It would compromise us getting global coverage because we need to understand if it's a global ocean or not.

There are allies or cliques that form. Where other instruments are.
- You form with the instruments
- And disciplines and thematic working group
- When you get in the details, years from now, when you're negotiating resources and someone wins and loses. When you're always arguing on this side, they're my buddy. I'll back them up and hopefully they'll back me up.
- As you will expect, it is a group of humans that are doing it?
    - Who speaks the loudest
    - Who is the backstabber?
    - SCIENTIFIC RETURN = overall best. It shouldn't matter your title if you can make the best argument.
    - It's competition that makes us better
    - Someone who lies successfully, doesn't get caught, and gets teh shared resources and doesn't get caught.

Sharing
- On the planning side, when you're trying to plan something. You want something, and he wants something, she wants something. Sometimes it's better if people rank what happens. If it happens that option #2 is the second best for everyone 1. If everyone degrades a little but everyone gets enough.
- Sharing of data in the downlink:
    - This is contractual. In previous missions like voyager, they had one year to see the data and publish before sharing it with anyone. As we have moved along further, the contracts with scientists have become more demanding. They have to give this data to public faster. We have to give the data within 1 hr of the receipt on ground. We encourage collaboration and their PIs have to agree. Bob has chosen them on the clipper. The contracts are more along the lines that all the data belongs to everyone. We want to encourage collaboration. Since we don't own the data in the end,

he's hoping that people will be less partisan. When we all get the data in the fly by and we get a better product. This is an idea that can work well on a small mission with a strong PI. He/she develop the mission, completed the mission (steve squires on MRRR). He decides who with who. This is one of the first times we've done this where all 10 instruments have been choosing independently. It's a paradigm shift. Everyone likes the idea and we'll see how it changes the group dynamics. He's hoping that people will be less partisan.

Interactions b/wn scientists and and engineers. What sort of processes should we be concerned about?

- There is a huge role during the planning phase. Then there is a bunch of stuff that happens after when they are managing the spacecraft everyday (is it healthy). There is a whole thing that happens after, blah blah blah...
- In the planning process, the engineers' role is local expertise of what the spacecraft can do. The scientist are experts what question they are trying to answer. Some of them are experts on what instrument they build, some are experts are how instruments get together. So when they are arguing they can really get off into the weeds because the spacecraft cannot do that. The engineers are there in the planning process to keep sanity. They are almost like the modules, you plug them in to do higher fidelity studies of some situations but what happens is that "scientists at their heart optimists" and "engineers at their heart is an pessimist". People who are naturally pessimistic make very good system engineers. Left to their own devices, they will do really stupid things to the spacecraft. "We want to send the spacecraft into the plumes". There is a natural tension that settles over time. It settle into chest loops because you don't know what the scientists are thinking and you don't know what the engineers are thinking. "You don't know anything you built the instrument not the spacecraft" "You are telling me i can't do it? I've spent 20 years on this instrument". It is best served when you find a good medium. It's not the engineer's job to decide whether or not to take the risk, PMs decide this. It's not PMs job to decide whether or not to do it, that's the PS's job. Scientist: do this, Engineers: you can't do that. It's turning too fast...
- Opportunity for a planning tool, "quick and dirty" low fi so that scientists can stop "what ifs" to the engineering team that always gets turned down
- How does that change after mission is launched?
  - Engineers are much more involved when spacecraft is in tour
  - How does that interaction between scientists
- Project is dominated by engineers right now. Scientists are secondary right now. Those people like to build things, to operate them. You get a diff type of engineers in building than ops engineers.
- It's hard to predict what's going to be the sticky problems over the year. The idea

the planning software should be flexible, have modules so you can plug in a lower fidelity module and check this ahead of time. That's a good planning model.

Operating engineers looking for different statuses, healthiness of the spacecraft
- NASA lessons learned database
    - Safing events
- "How long is it going to be so that the engineers fix the spacecraft so you can plan again. It's more about timing..."
    - Health and safety checks
    - Anomaly
    - Safing is an algorithm run by fault protection. It's like the brain of the spacecraft asking people all the time how they feel. If it comes back saying someone is sick, it'll run a software to fix something. If the radio is sick, i won't be able to get a command from earth, i better turn on the backup radio

- Planning on a short timeline and a longtime. Can i just pick up in my previous plan? Is that an option? Can i do that? Making sure plans are utterly dependent on everything before. There needs to be some autonomy within it. Start to plan within different times and it'll be perfectly acceptable.
- States inbound/outbound, they have to match. Are they manually inputted in scheduling tool? NO. they are agreed to prior and enforced by the planning process. And then you have initial conditions file that is the final from the previous group. The next person picks it off...hand off...

I need a tool that negotiates the shared resources and it produces a conflict free activity timeline

Phases of missions
- Lifecycle of a mission (send us presentation)
- Cassini is in closeout, for 13 years of operation it was in phase E
- Europa is in phase B. Bob is so invested in Europa because he spent decades getting this approved.
- Phase A: what could we do? We have an idea from the scientists, what could we do? Is the question important, can we do it?
- Phase B: once you get picked. What will we do? Redo all the trade studies to make sure you've done the right ones. Clipper is here right now. They are really figuring out what will we do. We're going to put a camera on here, what is that camera going to do.
- Phase C: exactly how are we going to do that? Up to this phase, it's all paperwork. Maybe they have built some models but nothing that is going to fly is get-

ting built. What is the mass of this? Where the wires gonna go?
- Phase D: Go build it and put it together. Do and test. This is one you learn there is electronic interference. Once you build it(with complete timeline of what we gonna do)
- Phase E: Go do it! First you launch, it make some time to get to target in interest. For Cassini it was 7 years, for Europa it'll take a few years with SLS. While it's in orbit, We need to come up with a conflict free timeline with what we are going to do (where we come in). Get the data, data comes down, analyze, present, publish. Keeps going again.DSN PACKAGE-SCIENTISTS change of trajectory
- *Do we have to deal with change in trajectory.

Participant 3 Interview Guide

Designer

Profile

Participant 3

P3 s an Associate Professor and Chair of the Interaction Design Program in the Division of Design at the University of Washington. He joined the Division of Design in 2005. He is an Adjunct Associate Professor in the Department of Human Centered Design and Engineering (HCDE), faculty in the Master of Human-Computer Interaction+Design Program (MHCI+d), and affiliate faculty in Comparative History of Ideas (CHID) at University of Washington in Seattle.

Research Project:

- high stakes settings in aviation and medicine, interaction design for consumer products, mobile computing, wearable computing, holographic interaction, and the Internet of Things.

Research interests:

- interaction design; industrial design; design and cognition - representation, sensemaking and decision support; systems; distributed cognition, visual storytelling, envisioning, design methods, and process.

Introduction

Hi, [Participant 3]! Thank you so much for taking the time to talk with us.

Just to give you a little more context, our team is working with the UX team at NASA JPL to improve the efficiency with which activities are scheduled for the Europa Clipper spacecraft. The team hopes to combine automation with data visualization to make it easier for the ground systems team to respond to incoming data and any conflicts that may arise during the mission. Through interviews with experts like you, we hope to learn as much as possible about all the variables involved in decision-making in orbiter missions. Also we know you have lots of design experience in high-stake domain and we really want to hear from your perspective to gain more support both theoretically and technically.

Here’s a consent form. We’ll be sharing your responses anonymously between our UW research team and our advisors at JPL.

Do you have any questions so far?

Before we get started today, we also want you to know that we would like to audio record our interview with you as a full transcription of your responses will be greatly valuable for the purposes of analysis. Is it ok with you if we record this interview?

[If **YES**] Thanks so much for your cooperation. We're starting the recording now.
[If **NO**] Not a problem. We'll continue without recording.

High-Stakes Design

Goal: to better understand the process of high-stakes design

What is "high-stakes design"? What kind of concerns should we have when we are doing it?

- What is the constitution of high stakes design?
- Learn factors we need to pay attention to when doing high-stakes design

Can you tell me your work experience on plane cockpit system? What design phases have you experienced?

- To get design insights from his personal experience that may apply to our design process

As designers and researchers who are unfamiliar with the domain language, how do we establish a solid conceptual understanding on the domain?

- Several research methods you recommend?
- How do we communicate with domain experts and translate their words into valuable design insights?

Data Visualization , Automation and Decision Making

Goal: To understand the methodology of data visualization design and how to facilitate automation from data inputs

Taking commercial flight deck as an example, how is data generally synthesized and categorized?

- Learn the process of data synthesis and prioritization

By listening to your lecture and reading your works, we know that data visualization helps pilots get access to different available choices. So what is the relationship between deci-

sion making and data visualization?
- Learning the connection between decision making and data visualization
- Moreover: how do you decide what data to **include** and which to **sacrifice**? Methods for determining this?

In the context of collaborative decision making, how to involve multiple user values and concerns into the design?
- Learn how to fulfill different user needs
- How to facilitate decision support in an automated system?

Do you have any insights from previous work (for example from redesigning the airplane cockpit with Boeing) about constraining problem definitions? We're working in a space where seemingly every subsystem we've identified is heavily dependent on many others. For example, if one science instrument team wants to make some observation, they have to consider not only the research objectives imposed by NASA headquarters, but also the needs of nine other instrument teams, the recommendations of interdisciplinary scientists and the project scientist, as well as all the engineering constraints: maintaining the integrity of a meticulously designed trajectory, power, fuel, storage, etc. An activity scheduling tool could therefore be useful for any personnel involved in the web of social interactions that contribute to decision-making on scheduling.
- How do you begin to constrain the design space so that the solution is aware of all the variables it is connected to but is only meant to be used by a subset of the people involved?

In terms of decision making, can you walk us through several design models?
- Can you give us examples on how design facilitate efficient decision making?

Pertaining to our project

Goal: to get suggestions on narrowing down the problem space and improving the current research plan
(describe our problem space and context)

In your experience, what are some of the challenges that we may face in the design process?

Now we are trying to narrow down our problem space, what kind of suggestions can you give?

Are there any valuable resources or artifacts we can refer to?

Are there any people you think would give us some useful perspective to us?

Do you have any other advice?

NOTES

Introduction

Consent given

Notes begin:

High stakes design question

- Very clear operations flow
- There is a way to make a decision and how to act and make it happen
- Then you have different teams, they're probably all in different places. Different time zones?
- The request probably takes form as a ticket- enter into a workflow where different units have to approve. It's a shopping cart procedure. Find your address, payment information, etc. only when the only thing is done through, the whole thing will be done.
- You know order, team- what information does each person need to make in their realm of expertise?
- What costs are associated? Capacity to do this? Engineering systems?
- When these things move forward to make a decision. What are the data elements needing to be seen?
- A lot of automation and working with data visualization. Supervisory control here.
- Human operators need to be alerted when there are any changes that need to happen
- The data visualization part is to show anomalies, not when they happen but when there is an onset. Pattern based display when things are as not as usual before things get bad.
- Constraints are always happening, the real estate that goes through space and time. How do you get enough function through it. Make sure it's being used, not being overtaxed.
- The payload is that you have something in place. What questions do researchers have, how do they want to use this platform in time. Are things all normal when they do that? Do we expect anomalies? Solarwinds, broadcasts, behind a planet,

etc?

Seeing alerts as a factor for HS design? Other factors?

- People need to be warned
- When do you see something is developing not after it happens
- Ex: radiation and its positioning. Something has been triggered and now you have 4 hours before that disturbance hits the spacecraft. In these 4 hours you will have high alerts.
- Everything that needs to be done, needs to be known
- You need to draw attn to it as it's developing not as it's happening
- People want to know what happens in the next 10 minutes
- Can they roll back to the moment that started it all?
- What actually triggered this mess? Roll back time to the moment it happened would be a cool way to think about it

We have very little idea on what this final thing is going to look at. We don't know yet if it'll be hooked up to the spacecraft so we don't know if it's going to receiving things in real time from the spacecraft. Just a tool for scientists and engineers to see what possibilities are available. And what type of resources are available. It doesn't actually make decisions. What type of considerations should we make on the interface? Should there be some way for the engineers to see them themselves?

- I need to know more about what they do. What are the problems they have currently with current issues. What are the big pain points right now. What is our goal here today. What the decision making process? It's difficult to get a decision in front of several groups. How are we going to review something? Are they scheduled a certain way? If we want to change a name of the course we have to go through a committee, etc. What are the pain points? What do they hope automation can do? What do they hope visualization can do? What happens now if we can do that type of technology. HOw would new technology affect that work process?
- For this one, since it's scheduling activities for the spacecraft?
    - I want to know how busy is this spacecraft?
    - Power? Bandwidth? Who's using it?
    - Time slider (next Thurs how busy will the spacecraft be)?
    - This is a project or a trajectory. It's very unlikely it goes right or left. There are good ways to predict. How do you show things are good? How do you things are going to be edgy soon?

Another thing we might run into, because all these instrument teams are not colocated and have their own specialities. Later in the process we'll have to consider making an interface usable for people from varying degrees of expertise? These people don't have understanding of each other teams

- What is it that they're doing? If there is a decision tab is open, i want to know what they want to know
- In the review process, you see this team is doing this. You see these aspects of your request. You have an idea on how they approve it but what they're looking for? What are the risks associated with these things, if they're not being considered so early? When there is another task being done, what are other things being done? I might potentially lose both? What if one is mission critical and another is something I can do it another time
- Showing this as an opp to see what other teams do
- With every request you create collaborative understanding
- It might also be items people need to wait on. Ex: wait until a certain time until we let him know.
- If something is wrong, the ability to call someone/text someone/to make a decision, that could be a cool way of being in touch
- Let's say there is something going on with the overall mission. What will be scheduled, who are the stakeholders in these activities. A representation of the workflow, context of the people, the fact that they need to workout. Is there a meeting button to call everyone. A request creates a temporary team of reviewers, team, etc.
- Consider also absences and person issues that might arise

Too many types of users involved is why we're struggling

- These people are all scientists with phds, the word user is too practical and insulting sometimes. These people are only knowledgeable and experts. Your system is something for a very small audience and provides cognitive support. It tries to provide representation of what is at stake here. What are the things we need to think about so you can make better decisions. We want to provide cognitive support so that practitioners who operate under high risk can make better decisions. This is not a cellphone app, we're not dealing with users here. We're dealing with people who use this because they need it. They either use it or it's right or they wreck couple hundred of million dollars at NASA and never have

Can you think of an example of your own work, providing cog support?

- Medication template. Layout standardization so they can look at this thing and see all the little trays of syringes and the syringes align with the colors. It tells me i'm ready. Instead of looking at a random arrangement and where things are. You immediately see a thing for that and there is a place for that or it's not there. It cuts out the task of searching for it
- Cog support makes what you'd otherwise have to do in overhead, right in front of it. So you don't have to search it. Ex: your computer freezes, it always knows it

P 3

freezes it just doesn't have an UI to tell you. What if they ask you go to a website and you can't go to it cus your computer froze. What if computer just had progressive disclosure and told you that i'm frozen, restart me.

- Cog support: show me the one thing I think needs to be done and show me how to do it
    - Cut out overhead and keep things people have memory
- Whenever people have to pull out a notepad to write out, if you have to externalize it on a notepad then you can do it.
- It's a good idea to do notes but in this case you should not have to use paper and pencil to deal with software application

While the end outcome is easy to see what's missing and useful, what are some of the deliverables for process on the way?

- You need to know how anesth think?
- What are the common mess ups?
- How do they usually do it?
- You can't ask them because they don't know. Then they come up with all these things by themselves and you as a designer. This is how you can implement it and you cannot ask the question.
- You have to say: we are working on this thing, in your case "do the people who do their designs even want what you want?" or did someone else prescribe it. If they don't care they're not going to provide time.
- Let's say someone else did prescribe it, you can still get the attn of the people by your good idea and be triggered. If we get it really wrong, they might be triggered because we've done it so wrong
- Maybe it might be worth asking the people you work with, where this idea came from. Is there a stakeholder who is really invested with it. Have them connect you with them via skype.
- Is there an advocate for the organization and the change?

Would you do an activity where they also generate?

- That would be great if there is a generalize or something.

Participant 4 Interview Guide

Scientist Engineer

Profile

P4 is a planetary geologist and system engineer at NASA's Jet Propulsion Laboratory. P4works on spacecraft science operations, at the point where science and engineering meet. P4is currently the lead Science System Engineer for the Mars 2020 Rover, which will seek signs of ancient life on Mars. She has previously worked on Mars Science Laboratory (the Curiosity rover), the Mars Phoenix lander, the Cassini-Huygens spacecraft at Saturn, and Mars Reconnaissance Orbiter, where she was the investigation scientist for the HiRISE camera. She has won JPL and NASA team awards for her efforts to return the best possible science within spacecraft engineering constraints.

She earned a Bachelors degree in planetary science at California Institute of Technology in 2000. She moved to Brown University, where she earned a Masters and PhD in planetary geology in 2005

Roles:

- 2013 - Currently
  - **Science System Engineer**

- Mars 2020 Science Systems Engineer, Oct 2013 - present
- Mars 2020 Organic Contamination Panel documentarian, April 2014 - Aug 2014

- 2008-2013
  - **Science Planning Systems Engineer**

- Investigation Scientist, HiRISE, Mars Reconnaissance Orbiter, August 2009-November 2013
- Mars 2020 Science Definition Team documentarian, Jan 2013-Aug 2013
- Science operations systems engineer, Mars Science Laboratory, Mar 2012 – Jan 2013
- Ex-officio member of the Joint Science Working Group for the 2018 NASA-ESA Joint
- Mars Rover Mission, November 2011-January 2012
- Investigation Scientist, UVIS, Cassini, August 2010-March 2012
- Science planning engineer, Cassini, September 2008-March 2012
- Assistant Investigation Scientist, UVIS, Cassini, November

2008-August 2010

- Instrumentation sequencing engineer, Mars Phoenix, March 2008-September 2008
  - 2005-2008
    - **Postdoctoral Researcher**
- Conduct fundamental research on the stratigraphy and history of the martian polar deposits using images, topography, ground penetrating radar data.

Introduction

Hi, Sarah! Thank you so much for taking the time to talk with us.

Just to give you a little more context, our team is working with JPL's Ops Lab to improve the efficiency of uplink operations for the Europa Clipper mission, potentially using assistive software. Through interviews with experts like you, we hope to learn as much as possible about all the variables involved in decision-making in orbiter missions, including the people involved and how scientific and spacecraft data informs uplink commands. Although our research and future design implementation is focused on the Clipper mission, we greatly value any input specific to other, similar missions, as our solution could potentially be applied to future operations.

We'll be sharing your responses anonymously between our UW research team and our advisors at JPL.

Do you have any questions so far?

Before we get started today, we also want you to know that we would like to record our interview with you as a full transcription of your responses will be greatly valuable for the purposes of analysis. Is it ok with you if we record this interview?

[If YES] Thanks so much for your cooperation. We're starting the recording now.

[If NO] Not a problem. We'll continue without recording.

Role / Background

Goal: To learn more about the participant's background, their current role, and motivations they have that inform their work. We also want to learn specifics of how decisions get made.

We know you've had a variety of roles with missions to Mars and also worked on the Cassini mission. Even though our focus is on the Europa Clipper mission, understanding other missions and how they were planned helps us better understand the problems Europa Clipper might face. With the following discussion it is helpful for us to know how anything relates or differs from the Europa Clipper mission, if you are unsure that is okay too.

- **Current Role:** To my understanding a "Science Systems Engineer" is a scientist that is embedded with engineers to make sure that science goals get accomplished. Can you elaborate a little more on your current role?
    - How do you make sure that science goals are not being overlooked?
    - Where does the engineering come in? What did you have to learn in order to better communicate with engineers?
    - If you are unsure about what an engineering decision might entail how do you find out?
    - What are some clues that engineering decisions are missing possible science opportunities?
    - How do you inform your engineering colleagues of a possibility?
    - Do the engineers push back? If so how do you convince them?
- **Background:** Can you tell us a little bit about how your roles have changed over time?
    - For example, you had a few different roles on Cassini. Why did you go from science planning engineer to investigation scientist?
- How are those roles similar or different?
    - Can you tell us a little about how engineering roles differ?
- What are the differences between a systems engineering role and a planning or sequencing role?
- **Roles in relationship to Planning:** Our main focus is to understanding planning and decision making as it effects both the spacecraft and the teams involved. In your many roles at JPL what has been your relationship to how decisions get made that affect either the spacecraft or landers?
    - Has this been different during different phases of the mission?
    - How have you or your team members made sure decisions are based on the most accurate information?

- How do you convince other teams or groups and how have they convinced you of a different course of action?
- **Framing the Downlink-Uplink Process** Our main goal for this interview is to better understand the entire process that happens from downlink to uplink and how your roles and experiences relate to that. Can you walk us through a typical downlink-uplink process? We're particularly interested in Cassini, but we know a lot of your experience comes from Mars rover and lander missions, so feel free to share that too.

Organizational

Goal: To further our understanding of organizational structure and the flow of interactions that define decision-making during the downlink-uplink process in order to identify possible points of intervention

- **Organization Structure and Flow** Help us understand the roles around you and how they function together.
    - Who do you report to? What is the leadership structure like and how do their decisions affect you or the mission you are working on?
    - How do you communicate and share progress/current status?
    - Who works alongside you?
    - How do you communicate with them? Is there a difference in relationship between collocated and remote teams
    - Who do you manage? Who are you responsible for?
    - How do you communicate and make sure goals are getting accomplished?
- What are some similarities and differences working with either Scientists and Engineers?
- What are the similarities and differences between different missions?

Data Collection, Analysis, and Decision Making

Goal: To understand how data is collected, interpreted, and communicated among teams and what kinds of information influence or constrain decision making.

- **Planning & Sequencing** What is the process of a science goal becoming a planned spacecraft/rover sequence?
    - What is sequenced once the spacecraft is launched, and what is

left until orbit?
- We heard from the previous MHCID team that worked on this mission that uplinked sequences execute for 1-4 months, while each flyby happens every fortnight. Why is this?
- Does something similar happen on other missions or is this something specific to Europa that we'd have to ask someone else about?

- **Tools Used** What tools/software have you used to help understand aspects of the spacecraft, "what if" possibilities, and anything related to decision making for planning or corrections to the spacecraft/lander?
    - Can you show us any of them?
    - How were they helpful?
    - What can be improved?
    - What do you or your team wish you had?

- **Instruments** For the Europa Clipper mission there are 9 instruments selected for the mission, of course each of these has their own constraints and requirements. How have you made sure that the instruments have both the engineering requirements and the ability to maximize science opportunities?
    - How do you learn about the constraints?
- How do you solve for them?
    - What can happen during a mission that might change these requirements?
- How do you solve for them?
    - How do you find compromise amongst the teams if a decision needs to be made?

- **Data Visualization** What are some examples of how you view data and/or schedules in regards to planning, status of spacecraft, instrument modelling and anything that might effect you or your team's decisions?
    - Can you show us any examples?
    - How does (example) inform your decisions?
- What are some important aspects that make them helpful?
- What are some instances when they are not helpful, or have unrelated information?
    - How do you you see anomalies, errors, things that make you act? And how do you see that you should stay the course?

- **Sharing and Milestones** From our understanding much needs to be shared remotely at JPL. What are some common ways you share findings and decisions to other team members? How do you keep track of the multiple decisions that have already been made.

- What tools are used for collaboration and what is it like to show and get feedback.
- How do you keep track of what has been shared and who has access?
- How is this different if the information is confidential?
- How do new people get up to speed about prior decisions?

- **Communications:** From our understanding, making a decision is from collaboration from different roles such as investigation scientists and software engineers. We know you worked as both investigation scientists and system engineers. What is the communication process between different roles?
    - How different roles reach consensus?
    - What are the major conflicts between different roles? Can you give us some examples?

Assistive Planning

Goal: To get an idea of perceptions surrounding automation / assistive software at JPL and, in general, in similar high-stakes scenarios

- **Brainstorming** From your experience what are some possible other areas assistive software or processes may lend a hand?
    - What are some ways you think assistive software can help with science goals?
    - What are some ways it can help with engineering requirements or communicating the healthiness of the spacecraft?Who do you report to? What is the leadership structure like and how do their decisions affect you or the mission you are working on?

-

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- How do you solve for them?
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- How do you you see anomalies, errors, things that make you act? And how do you see that you should stay the course?

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NOTES

Introduction

Consent given

Notes begin:

P4: It's a huge topic and every mission does it differently. Europa clipper or Europa lander?

- Clipper

(P4) One of the fundamental differences between Cassini and Mars Recon Orbiter, and two different Mars surface MIssions (Mars Phoenix- sat in one place and didn't go anywhere and Curiosity that drives all over the place). There is a basic different in the scale of which you're planning. Cassini was planning the set of activities for months scale at a time. Mars Recon was doing 2 weeks at a time. Rover and lander does 1 day at a time up to maybe 3 at most. That is fundamentally that drives a lot of how you plan. If it's about how you respond to discoveries, a rover and lander can respond to discoveries very quickly but something like Cassini is very slow to respond to discoveries. On Cassini it took us way longer to plan for the next time because the tour was planned way out in advance. Negotiated years in advance. That's when the planning starts, years in advance. So what you're going to do on any moment on the spacecraft. Whereas ar over, you have some sense of strategic planning on where you're going. The amount of the strategic planning depends on the science you're doing. So if you're a rover like Opportunity or Spirit you have the opportunity to wake up and ask "what are we doing today". As with Curiosity and 2020, we only have only have this time because we have to get going to our next stop. So it depends on what science we're doing and the fundamental construction of the mission. The basic signposts along the way are universal. The scientists have decided on a plan that fit within a resource constraint. The instrument operations people build the command for their instrument set of activities and someone integrates (stitches it all together), we run flight check, health and safety checks, send it out to the vehicle. THen we check for health and safety of the hardware and doing the science of analysis of the data. The way in which all of that is done is the part that varies. We've had a really big push on 2020 about. If this is going to be in operations. When Curiosity landed, it took 16 hrs to build one day worth of the plan (of the people). THey are now down to 8ish hours on a regular process but what we're working with on 2020 is landing in the 10 hour mark and shrinking it down to 5 hour has a our day to day timeline. A lot of things we are going after, the frequency is there what can we automate and what needs to be hands done which reduces the amount of the time people are wrestling with the tools instead of making people do the actual work they need to do. There is also an effect of the science decision making, how much do you need for the decisions you have to do for tactical, responding to what you saw on the downlink vs the decisions that can be made ahead o time (day before), i know roughly what we're going to do based on what we've been doing, seeing, overall plan. THen leave the final details and final decision to hopefully not take as much time because you've taken some of that thinking space and moved it early so it lets you be very efficient on the day of the plan. That's the big picture of the stuff i've been working on and worked with. I don't know if there are little nuggets that you've been working on?

(Gabe) We talked to Trina Ray two weeks ago and she recommended we talk to you since you have experience in so many types of missions. You talked about improving the efficiency for Rover operations. What are some ways they moved from 16 hrs to 8 hr planning time?

- Some of that is that we understand the vehicle better. You think something is going to work but it doesn't quite work that way. You want to take your time making the decisions and understanding the locations and building the sequence as you get to understand how it actually is working together and interacting with Mars. Some of it was from that, and some of it was that as different pieces of software became available. You have long list (here are all the things you want your software to be capable of doing) but when you you only have so much time. You have high priority stuff that you absolutely need and then you have the stuff you really want but it's not fundamental to operating the vehicle. Once you landed, and enough time has gone by, instead of doing thing by hand, someone can write a script and automate it. Certain things like checking flight rules, paperwork that needs to be done everyday could be automated. Curiosity is a very complicated rover, as the team came to understand that, they realized that there were things that needed to be dealt with ahead of time. For example: drilling. You had to know a couple days ahead that it was coming so you can start to build the commands and make sure they were the right ones. SOme of them are through efficiencies, it takes less time. Something that needs to be done in the tactical timeline. It takes less time because of efficiency in tools and our understanding and hence our decision making. There are also places were specific decisions got pulled out in a tactical timeline then those decision get handed down. Those are the two major ways we've compressed. Some of it just that after awhile, you build up a "i know exactly how to write that sequence" this is a routine observation for us and this is a route sequence, pick it up, fix it up, and send it up to the vehicle" From starting with a long time of putting together your daily time and how you can shrink that time. IN 2020, we're doing fundamental changes on how the process works and how the tools work and it's going to "fingers crossed" a much shorter timeline than what Curiosity landed with

So with 2020 you're not putting as much detail in the plan because you can respond faster when the Rover is already on Mars?

- Yes, each day once we're on Mars, there is one group who is looking out 2 days from now to end of the week. What is that we want to do on those days? They're going to talking about a more on the scientific basis rather than instrument basis .Scientitaly we say contact b/wn two units, that looks very interesting, we want to understand their chemistry, and veins in rock. Then they write a plan that has those basic ideas in it and pass it forward. They keep looking out in the distance. Then there is a group that comes in and says they have arrived and contacted the veins. Where exactly do we want to take our chemistry instruments, do we want to do super close up with arm instruments, which particular spot (right there or 2cm to the left), what are the parameters for the instrument sequence. SO the big conversation, what is the science we want to do today. That big conversation has actually happened earlier. I'm going to make my big picture resource ahead of time then i'm going to have block without going in too too much detail and then tactical you fill in the details. That's a fundamental shift you see from previous rovers (8:10 missed some stuff)...(8:15-8:40) They had all that planned out so that this idea that you can do a chunk of big picture science before you work the big details of specific

Internet disconnected...

How does responding to new discoveries differ? If they plan ahead of time a sequence for 2 months prior? For an orbiter mission you might not get data for a week or two?

- That's the timescale. The timescale that people were able to respond to on Cassini was because Cassini was touring so you might have months to years between fly bys. Titan fly bys were pretty regular. When we discovered that Enceladus was as complicated and fascinating as it was .They had done a fly by and scene some unusual signs in the magnetometer data and the spectrometer sets. THey had to go to the project and ask for an additional fly by or a change in the particular geometry of the next fly by. That meant changing the actual trajectory of the spacecraft. That's a big big deal once we've negotiated out. So anytime you asked for trajectory change, you have to ask, here's my stack of scientific evidence on something we have to follow up one. Then it was a negotiation with project science, and folks who plan the trajectory, and the other scientists who don't care about Enceladus and cares about rings on Saturn. It meant we were upsetting their plans. It's a flow process and it's a complicated negotiation between all those people. You have careers. You have a change of command. The project scientist has to make all those decisions. Which is the better thing to do be doing with the spacecraft. The workload of the engineers, whose job it is to calculate trajectory and balance all the requirements such as fuel, and other requirements. And their manager who manage how much time they spend on their work. The first thing we look at is, how many fly bys and what type do we have coming up? Can we use what we already have allocated to follow up? Then we can't we go through the whole process of asking for more but asking for more has all these ripple effects. With a rover, it becomes much more of a question, "how much time can we stay, can we stay for a couple more days before it moves faster", it's a much faster decision and the ripple effect is smaller. We still agonize over it but it's not as a giant a thing to request. An orbiter is this fundamental difference, the orbit repeats so on Mars Recon Orbiter, you took the data but you know you'll see that spot again with the same lighting with the same reason you'll just have to wait. Each instrument worked independently from each other. On Cassini you're arguing passionately for your science and your instrument. So where the spacecraft is pointing, where it physically is in the Saturn system is fairly unique at any given moment. For an orbiter, it's fairly repeatedly. For MRO, it was on a week cycle but the repeat was on days so it came back to the same spot in a couple days. If you don't get what you want this time you can get in a couple days. For a rover, everyone is arguing because sometime we're going to leave. But the science is more integrated, everyone is looking at each other's data but not the case as MRO and Cassini.

Do you think scientists might know each other's stuff more because they're not body fixed?

- I don't know much about Europa. Are they orbiter Jupiter or are they orbiting Europa?
- Ok, this means every minute is going to be crucially thought for in the 8hr stretch. Then there is also science taken for the rest of the orbit. Even if they don't say so now, once they get there there will always be science taken
- Where is the transition between Jupiter science and Europa science
- Otherwise sometimes they'll pick a rock and look at it. All these requests show once you get close to the spacecraft getting there. Because the fly by happens at these intervals, pointing is going to be the biggest commodity. Where is the camera, spectrometer, what is radar doing. Who has priority in it? Does each fly by get tagged with a particular priority (this is what we did on Cassini, this fly by is for a separate instrument) then that guides who is in charge at closest approach, that's the prime time. THen they work compromises on the edges of that. I would think that if you discover something on one fly by, it's going to take many flybys to repeat the orientation of that particular fly by. So what is the planning horizon out that you want to be thinking about this fly by. Here are all of our flybys, Titan planning, or the ICE planning team. This one is X instrument this is Y instrument just based on the geometry and arguments amongst them. Then you start to go back through the details of who points where and who gets which chunk of time. Then it goes on the shelf and later gets taken back and you plan the instrument

details. How far along do you want to plan and then leave to shelf then it becomes a factor

P4: “People get emotionally attached to the work, the more time you work on something the more upset you get one someone comes in and says we’re going to do something different” There is the managing the emotional attachment and the work ebb and flow because sometimes on Cassini based on geometry we had a bunch of Enceladus flybys in a row. The team had gotten used to turn one in every 6 months in a row. You have to argue. I would tell them you have to look ahead at the boat load of these fly bys. There’s the pros and cons and maybe they didn’t’ optimize as much as we could as were cranking through the fly bys but on the other hand we got a bunch of fly bys planned and we got it turned in time. There wasn’t space for someone mulling over things to come in and say we’re all wrong. Cus we’re like it’s done turned in keep going?

When people are negotiating of the plan, what usually happens?

- On Cassini in particular, all of these missions have a role that has different names on different missions. Cassini was science planner. This is a person who works with scientists and embedded with the scientist but also fits in the engineers. It’s a bridge between the two. That’s the job I had, Trina was also a type of science planner on Cassini. So we had a group of scientists who each represented a different instrument and passionately excited about Enceladus. They were the one where we were like here is the trajectory and here are we are looking in any given days. THey would say I want my instrument to do this. I would write that down. We would also have an overall scientists for Enceladus. If two groups are arguing over resource, the overall scientists would say “this is the priority”, “you get half time you get half time”, can we find a orientation for both things. The planners job would be to keep track, and resources. Pointing, time, volume, power, etc. When we’re pointing something we’re not going to point at the sun and burn it out or the radiator at Saturn and burn it in. Here are the ideas of the scientists and herding them into the plan to actually implement. Then that person. When the engineers have a question of something related to the fly by then that person can translate the science in a way that the engineers understand so it’s not too technical of a decision of something they’re trying to achieve. Then there are these big negotiations you kind of bring the science planner and then you agitate for the big change they made.

Earlier you mentioned some of the tools people used. How the different softwares play into this? Homegrown tools about visualizing this? How much do they know about engineering? Do they only care about their science? Do they use tools that enable them to see what other instrument teams are able to use? How do people know the affect what their

P 4

- The specific tools and the group has depends on the specific spacecraft. I want to make a change, what are the ripple effects of this plan. The planner job continues and is in there all the way until we upload the command. It's the science planner who is responsible is everything staying within resources. Is the change here throwing us off from the rest of the plan. That's their job to monitor that. Cassini's tools were super super primitive, we did most of our planning in excel spreadsheets until we uploaded information into a glorified web excel sheet thing then ran scripts off of that to do an analysis. There was also a tool that had the trajectory and where everything is any given second. And a spacecraft model to model turns. Those were what was available to the instrument teams and they each had their own set to do some of the details such as their camera setting. MRO, we had planning tool or have that everyone has where you can see mars, the footprint of your footprint. Different instrument teams then had a layer on top of that had details of planning for their particular instrument. They would turn in their files, the science planner would merge everything and do all the planning steps and everyone can open it up and everyone can see the consolidated steps of observations of what is being done. So they can look that the spacecraft is looking in that, i want to ride along. It's an iterative process to get your data in. you didn't have to all your decisions made. The two phases bled together a lot more because of the nature of the planning for that one. For 2020, we have a huge suite of software planning tools that we build that the scientist can come and use. We have the science planner to work with the plan, everyone looks at the plan, we have visualizers that picks the plan and talks to JPL, the two places that instrument teams have their own software once everything is in the plan and they have to build out the commands. Our plans describe the plan a lot more detail in the timeline view than Cassini do. It spits out the sequence in the end. We are helping them write those tools. Then they have those own tools, when the data comes down we do some data processing for it then they take the rest of it and continue it wherever they want it end up. Then there is downlink health and safety analysis there are some tools that have certain capabilities then they can hitch their tools (lost connection)

Can we look at those tools, or papers we can read?

- Anything Cassini related you should talk to Trina about, i'm 8 years away from that. All the 2020 tools are in development. All of the tools I've been discussing, a lot of them are proprietary. Anything that has detailed information of certain aspects of the spacecraft or instrument are export controlled. There might be, the only thing I can think of, on the Curiosity website they have outreach websites. I don't know if any of those have a quick look of the tools and software.

Participant 5 - Interview Guide

Scientist

Participant 5

P5 is a retired researcher from NASA Ames Research. He has published papers with UW Professor Daniel Weld on planning algorithms (Graphplan). HIs experiences at NASA Ames include rover planning and simulation as well as aeronautical decision making.

- Research Interests:
- Planning with time and resources
- Planning under uncertainty
- Plan and goal recognition
- Intelligent decision aids for aircraft
- Roles: Researcher, NASA Ames Research
- Publications
- http://psresearch.xyz/publications.html

Introduction

Hi, P5! Thank you so much for taking the time to talk with us.

Just to give you a little more context, we are a team of researchers and designers who are looking this with as with as many technical constraints and considerations as possible but we won't be implementing this. We're working with with JPL's Ops Lab to improve the efficiency of uplink operations for the Europa Clipper mission, potentially using assistive software. Through interviews with experts like you, we hope to learn as much as possible about all the variables involved in decision-making in orbiter missions, including the people involved and how scientific and spacecraft data informs uplink commands. Although our research and future design implementation is focused on the Clipper mission, we greatly value any input specific to other, similar missions, as our solution could potentially be applied to future operations. We know you are a expert scientists in planning science mission, we are looking forward to learn valuable knowledge on scheduling and planning tool on scientific missions.

We'll be sharing your responses anonymously between our UW research team and our advisors at JPL.

Do you have any questions so far?

Before we get started today, we also want you to know that we would like to record our interview with you as a full transcription of your responses will be greatly valuable for the purposes of analysis. Is it ok with you if we record this interview?

[If **YES**] Thanks so much for your cooperation. We're starting the recording now.
[If **NO**] Not a problem. We'll continue without recording.

Role / Background

Goal: To learn more about the participant's background, their current role, and the organizational structure of current planning process

- Can you tell me a little bit about your roles as an Senior Researcher?
- How does your work relate to planning process?
- Based on your work experience, what's the org structure?
- How do different roles communicate with each other(data scientists, system engineers, principal investigators, project scientists, etc)
- What are common conflicts during negotiation and how to resolve them normally?

Data Collection, Analysis, and Decision Making

Goal: To understand how similar tool is developed and how can the design methodology apply to our design.

Projects Worked On: Cockpit Hierarchical Activity Planning and Execution (CHAP-E), Single Pilot Operations SPO, Mars Exploration Rover (MER), Mixed Initiative Activity Planning Generator (MAPGEN), Solar Array Constraint Engine (SACE), Tactical Activity Planner (TAC)

- **Stakeholders** Who are mainly involved in planning process?
- What roles are using planning software frequently?
- Any role has the concern that they are not actively involved in planning process?

- **Process** We know that you developed the advance scheduling software that automate the decision process for personnel. What concerns do you have when you are developing it?
- Walk us through your process for understanding a problem. How do you capture all the requirements, constraints, and considerations in order to make decisions for the tools you have made?
- How do you transform stakeholders' needs into functionalities?
- How do you define the success of a scheduling tool?
- How do you accommodate individuals' preferences into design?
- In terms of time and resource allocation, how do you visualize the allocation and available options for stakeholders?

- For scheduling tools you have researched and worked on, what are the their common shortcomings?
- What are people's expectations on these tools?

- Negotiation process and planning: we know there are some forms of communications happen around people such as teleconferencing, how does these two process combine?
- Are conflicts mostly resolved in virtual/physical meeting?
- How do planning software deal with conflicts currently?

- From our understanding, MAPGEN is designed for rover mission. For flyby mission, how do you think it differ or similar with MAPGEN? Designed by John Bresina and Paul Morris.
- Do you know anything about it being applied to orbiter missions?
- How does it relate to your work?
- What are the shared values?
- If you were to to plan a simulation for Europa, what are some of the considerations that need to be considered first and foremost?
- Do you know why it wouldn't be used for europa… is there something about orbiter missions that makes that software not usable

- What are user interface challenges and things to consider into translating planning functionality into interface?

- What are challenges of designing for mixed initiative?
- What are some challenges with mixing human and computer decisions?
- Does it face resistance?
- Visualization tool?

- You mention scoring goals in one of your papers. We're running into the issue of not knowing how to quantify people's science goals when careers are at stake?
- Quantifying qualitative information?

Pertaining to our Project

Goal: to get suggestions on narrowing down the problem space and improving the current research plan

- Based on your experience, any good planning tools worth researching on regarding our problem space?

- In your experience, what are some of the challenges that we may face in the design process?

- Now we are trying to narrow down our problem space, what kind of suggestions can you give?

- Are there any valuable resources or artefacts we can refer to?

- Are there any people you think would give us some useful perspective to us?

- Do you have any other advice?

NOTES

Introduction

Consent given.

Notes begin:

Daphne: Please tell us a bit about your Role and background?
P5: Let's see. So I was at NASA Ames for 20 years. I just retired about 3 months ago. During the earlier part at Ames, I did a lot of work with rovers and we were connected with some of the Mars work that Nasa was doing, so worrying about rover operations & planning. Personally the work i've done is on the theoretical, academic side. A number of people in my group were involved more in missions/operations. Those two were directly involved in MER software, MaPGEN that was used to do daily activity scheduling. P6a has actually done one of the lunar missions and has been involved in science activity scheduling for that mission. One of the things that came out of MAPGEN was SPIFe Software. That has been used for several missions now.

The part of MAPGEN that was most utilized was the timeline representation and the ability for a person to take a task and move it around on one of the timelines and have one of the flight rule constraints be respected. So if you move one thing other things move with it, but you might cause conflicts with flight rules

All of that was involved in SPIFe It was largely graphical display constraint management for scheduling these kinds of activities. There are for some missions an automated scheduling component has been incorporated with SPIFe But that's mission specific. So a lot of what's there has to do with controlling flight constraint between activities, set up timelines, and allow the user to navigate and move around.

Daphne: Mixed-initiative- challenges with mixing human-computer decisions?
P5: So the original MAPGEN system had in it the ability for the person sitting at the terminal to say "schedule the rest of this for me." the trouble is that there's a lot of additional information that it didn't have. If you think about it there's a big science team and they get together & have their arguments. One group wants to do this, the other that. I'd like to do this, but if i can't do this then this has no value to me. They end up reaching some kind of decision, so we'd like to do the following things, and now the planner has to sit down with science goals & engineering requirements... so you may need certain pictures taken for navigation & positioning needs. There's power requirements. You may have to wait until you've got enough sunlight. So there's all these engineering requirements that the scientists only have a rough idea about. So when you go to schedule all these things, you may find out that there are trade-offs, e.g., energy requirements. What tends to happen is there's an iterative component here where in the process of building the plan where they discover what they can't do, make compromises, go back to scientists. Scientists disagree, negotiate again. There's this cyclical process. In that process there's a bunch of things that happen. Scientists may have preferences they don't realize they have

Daphne: Is that their best/worst-case situation?
It could be that but i think what's common is they say they have two things they want to do. If the person planning doesn't realize they want both things equally, they might schedule one but not the other, that's where disagreement comes in. there may be preferences between things they may not have thought about. If i can give you a or b, but not both, which one would you choose?

Daphne: So sometimes they know sometimes they don't...
Yep. in engineering it's often a cyclical process. You come up with initial specification, then you do some trade studies, figure out what's possible in the space, then you go around again. Scientists are doing trade studies to find out what's possible. One of the reasons why the automated planning & scheduling wasn't entirely successful was because it did not have the ability to accept the kind of preference information scientists wanted. Did not explain enough. Scientists want to know why... so how do you answer that question?

Explanation of plans & schedules is something that's an active research area right now

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that could involve hypothetical reasoning. If scientist says “why didn’t you put that in the plan”> what you have to do is go back and tell the planner to make a plan with that thing in it. Show why that plan doesn’t satisfy constraints of chosen plan. The ability to capture preferences, the ability to do explanation. This is the reason why things have to be interactive.

What have you discovered about explanation?
… in SPIFe displays. In the process of moving things around scientists can see constraint violations. That visual display on timeline, seeing constraints that pop up, you can think of that as a form of explanation. Not directly explaining but having that visual does a lot to help explain what plan is doing.

So this is all pre-launch planning… what about planning during new discoveries?
So this is being used on a daily basis (not pre-launch). Based on new discoveries. These kinds of systems are intended to be used on a daily basis. One of the challenges for the MER was they would get downlink, 4 hour science meeting, then do planning & scheduling, then go through simulation & checking, then uplink commands. This happened every day within a 12 hour window.

Best Practices Designing User interfaces?
Being able to visually see the relationship between different activities, constraints… is incredibly important. So in the aviation stuff that i’ve been working on more recently. One of the things that’s effective there is if you can actually use the presentation of the route that pilots are familiar with. So in the case of instrument approach plates there are two views. There’s a lateral view, so looking down on what the route looks like. Then there’s a profile view that shows legs & descent into airport. If you can lay out the various tasks for the pilot, either on the lateral view or the profile view, then they can look… if they can see various waypoints, then they can see i should do this here, do this here. If you can lay that out on the display that’s extremely helpful. I suppose this could be applied to rover, lay out different activities along that map, then that would potentially be a useful way of displaying things. As opposed to just timeline view in which you have abstract view. If you have too much detail, then there’s no way you can put it all on a map. But having the ability to zoom in and out. Whether you got timelines or map, you need some sort of hierarchical representation in which you’re seeing some sort of abstract rep of tasks, then if you zoom in you can see breakdown of more detailed activities.

Daphne: How about filters?
I think SPIFe allows you to do that sort of thing. You can hide certain timelines. Youre a guide and you don’t care about thermal characteristics, you can hide those & see subset you’re more interested in.

Daphne: What about layering?
I don’t know, not something i’ve thought about.

Daphne: Manned vs unmanned?
If you’re dealing with a system that’s totally automated, it’s much easier. Communicating with people is a complicated business. And so if you’re doing something that’s fully automated & it’s trusted, then you don’t have issues with explanation. Then you don’t have issues with explanation & user interfaces. As soon as you’re dealing with people, it depends on whether you’re ... if you’re designing a system which is simply coming out & giving advice. Building a plan which people approve & modify. If you’re dealing with a system where you’re actively monitoring what’s going on and you need to remind the people if they’ve forgotten something, then you need to worry about issues about how you remind & when you remind, and issues of without annoying them. So figuring out how to give hints and when to step in, when to keep silent. Then you’re looking at evaluating whether or not the situation is dangerous, using that as a metric to decide when to step in. it depends on the role of the system. Is it actively monitoring? The third kind which is even harder, where you have mix of automation & advisory capacity. When that mix actually happens... imagine pilot in cockpit. If he’s got human copilot, he can tell them i’m gonna handle this, you handle this. And then there’s some sort of reporting going on, copilot says i’ve done this. If you’ve got a system that’s trying to replace the copilot, you’ve got to have some mechanism by which the human can delegate or assign authority for certain tasks to the system, and then system has to be able to function on just that set of tasks, and understand when it needs help & when it needs to report things,. Whole host of issues that come up with communication and collaboration.

Gabe: How much automation should we know to include?
Levels of explanation. Simplest level- saying ok, here’s the set of things you gave me and were your set of goals or objectives, here’s what i can actually do. Here’s the things that this plan actually satisfies. You can also say something about, here are the resources that are used in this particular plan. You might be able to say for things not included, that they weren’t included because of particular resources. Other things associated with plan that have to do with constraints between activities & sort of a causal explanation. In most cases, you can’t give a full causal explanation without overwhelming the user. I think you have to do that more in a user-driven fashion. Let the user ask why is this here, why is this before that. The effort in the interface in SPIFe is to show some of that causal structure, so moving things around, showing constraint violations. Doing the interface in a nice visual way like that can help illuminate the causal structure.

Daphne: How can we consider trust when designing our system?

P 5

There were some psychology students that did studies on trust with aircraft software. They found that exposing ... so the decisions that the system was coming up with were based on in a number of cases how well you satisfied certain constraints - safety, medical facilities, amount of time - in cases where plane had to make emergency landing. Question is where to go, depends on nature of emergency. If there's smoke, you've got to get down really fast. Whereas if it's a minor medical emergency, you're looking to land somewhere not too inconvenient. So actually being able to say... there's multiple objectives here, having to do with safety, passengers, facilities & maintenance for aircraft, medical facilities. Actually being able to say ok here are the 3 best options, and here's how they rate & how they rank against objectives. Exposing those objectives & how well those solutions did on those objectives. Goes a long way to getting a good explanation.

If you just rank, not break down by objectives, they'd say WHY. if you say this is good because it's pretty close, it's safe, doesn't inconvenience passengers. This one's a little further, medical facilities are better... if i give you that information you can say oh yeah that's why you ranked them this way. Or you can say i want to place more emphasis on medical, & i care less about the distance. Independent of that - that's saying i'm gonna change weighting of objectives - they still trust the system because they got back answers about how they satisfied objectives.

Daphne: Are there edge-cases to consider?
In which people had information system didn't have. They may know something about a particular airfield... if you're landing in denver, you know the airfield is far from center of city, so you might know that's not good for medical emergencies. This happens even if it's two people. One knows information that the other doesn't.

Draw some boundaries around the theory that the scheduler/planner has. You won't get it right at first.

Psychology paper - 2016 - engineering trust in complex automated systems (in ergonomics & design) http://journals.sagepub.com/doi/pdf/10.1177/1064804615611272
Effects of transparency...
Shaping trust through...

*Scheduling problem - activities are given to you, your job is to figure out when to do them.
*Planning problem - you're given more high level goals, and you have to figure out what's necessary to achieve those goals, and then do the scheduling as well.
*Middle - mostly scheduling problems but you can have choices abou resources for given activity. Probably most of the kinds of NASA spacecraft problems, the planning part

of it is really deep - mostly a scheduling problem, but there may be resource selection going on.

There are temporal planning softwares out there that you can download and use.

- FPOP - Kings college london - full planning
- iLOG scheduling software
- EUROPA - in his opinion, not as good as iLOG

Participant 6a and 6b - Interview Guide

Profile

P6a is a Computer Scientist at NASA Ames Research Center, with over twenty-five years of NASA R&D experience in AI planning, scheduling, and execution. In addition to his research endeavors, P6b has participated in several NASA missions. For MER, he was part of the GDS Activity Planning & Sequencing Subsystem (APSS) team and was one of the six original MOS Tactical Activity Planners. For LCROSS, he was the GDS APSS team and the MOS Activity Planning & Sequencing team. For MSL, he was part of the GDS APSS team. For LADEE, he led the GDS APSS team and the MOS Mission Planning & Sequencing team. P6b earned his Ph.D. in Computer Science from Rutgers University, under Dr. Saul Amarel.

- Mars Exploration Rover (MER)
    - GDS: MAPGEN development team
    - MOS: Tactical Activity Planner (TAP)
- Mars Science Laboratory (MSL)
    - GDS: Cognizant Engineer for Dynamic Europa
- Lunar Crater Observation and Sensing Satellite (LCROSS)
    - GDS: Lead of Activity Planning and Sequencing System
    - MOS: Lead of Planning and Sequencing
- Lunar Atmosphere and Dust Environment Explorer (LADEE)
    - GDS: Lead of Activity Planning System and Command Sequencing System
    - MOS: Lead of Activity Planning and Sequencing team

Description from 2007 paper: P6b is a senior scientist at NASA Ames Research Center. After undergraduate work at University College, Cork, Ireland, he received Ph.Ds in mathematics and computer science from the University of California, Irvine. At NASA, he joined a team working on the Remote Agent Experiment, where an onboard AI system controlled the Deep Space I spacecraft for several days. He has also worked on ground planning systems for the Mars Exploration Rovers and other missions. His research interests include planning, temporal reasoning, and constraint satisfaction.

Introduction

Hi, P6a and P6b! Thank you so much for taking the time to talk with us.

Just to give you a little more context, we are a team of researchers and designers who are looking this with as with as many technical constraints and considerations as possible but we won't be implementing this. We're working with with JPL's Ops Lab to improve the efficiency of uplink operations for the Europa Clipper mission, potentially using assistive software. Through interviews with experts like you, we hope to learn as much as possible about all the variables involved in decision-making in orbiter missions, including the people involved and how scientific and spacecraft data informs uplink commands. Although our research and future design implementation is focused on the Clipper mission, we greatly value any input specific to other, similar missions, as our solution could potentially be applied to future operations. We know you are a expert scientists in planning science mission, we are looking forward to learn valuable knowledge on scheduling and planning tool on scientific missions.

We'll be sharing your responses anonymously between our UW research team and our advisors at JPL.

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Role / Background

Goal: To learn more about the participant's background, their current role, and the organizational structure of current planning process

- Can you tell us a little bit about your work? We've been reading up on some of it, particularly MAPGEN (Mixed-Initiative Activity Plan Generator) because we think there's a lot to learn from that software, especially seeing as it was used successfully on JPL-led missions.
    - What have you been working on most recently in this domain and does

        - any of it expand on the insights you gained from MAPGEN?
            - Some of your papers talk about the need for more research on providing useful explanations in automated systems, and David Smith brought it up too.
        - How does LASS (LADEE Activity Scheduling System) differ from MAPGEN, and what lessons learned from MAPGEN were used as opportunities for change in LASS?
        - How does the context of an orbiter mission change the requirements for an automated activity planner and scheduler?

Software & Automation

Goal: To understand how similar tools have been developed and how can their methodologies can apply to our design

- Who uses MAPGEN and/or LASS and how much training is required for them to be able to use it efficiently?

- Can you describe how EUROPA, APGEN, and the Constraint Editor worked together to create MAPGEN's functionality?
    - I'm having trouble understanding how it translated qualitative science objectives into data that its algorithms could use.
    - Describe the process from TAP inputting activities into the database and constraints into the constraint editor to MAPGEN's automatic generation of a plan

- How important is the graphical element of planning and scheduling user interfaces?
    - We had limited access to the actual interface of MAPGEN, but it looks to be largely reliant on text, making it hard for us to visualize what the plan is. To what extent does domain expertise facilitate understanding of the timeline?
    - What are some of the biggest challenges you faced in developing a GUI for the software? Is it simply the vast amount of activities and constraints that need to be represented on the timeline that make this difficult?
        - What recommendations do you have for dealing with these difficulties?

- What does a *nogood* look like?

- Can you talk about the challenges of providing explanations?
    - Is it not enough for the TAP to know simply what activity or constraint caused the *nogood* and where the violation is on the timeline?
    - What is activity expansion?

- Could there be a suitable visual method for identifying and explaining *nogoods*?

- Is there any way for us to test MAPGEN or LASS?

- **Process** We know that you developed the advance scheduling software that automate the decision process for personnel. What concerns do you have when you are developing it?
    - Walk us through your process for understanding a problem. How do you capture all the requirements, constraints, and considerations in order to make decisions for the tools you have made?
    - How do you transform stakeholders' needs into functionalities?
    - How do you define the success of a scheduling tool?
    - How do you accommodate individuals' preferences into design?
    - In terms of time and resource allocation, how do you visualize the allocation and available options for stakeholders?

- From our understanding, MAPGEN is designed for rover mission. For flyby mission, how do you think it differ or similar with MAPGEN?
    - Do you know anything about it being applied to flyby missions?
    - How does it relate to your work?
    - What are the shared values?
    - If you were to to plan a simulation for Europa, what are some of the considerations that need to be considered first and foremost?
        - Do you know why it wouldn't be used for europa... is there something about flyby missions that makes that software not usable

- You mention scoring goals in one of your papers. We're running into the issue of not knowing how to quantify people's science goals when careers are at stake?
    - Quantifying qualitative information?

Wrap-up

- Based on your experience, any good planning tools worth researching on regarding our problem space?

- In your experience, what are some of the challenges that we may face in the design process?

- Are there any people you think would give us some useful perspective to us?

- Do you have any other advice?

NOTES

Introduction

Consent given.

Notes begin:

Can you tell us what you guys are working on now, how does it relate to work on MAP-GEN and more recent work?
- Right now we're back to doing applied research. We have two different projects both involving DSN scheduling for small? For the EM1 mission. We're competing for the same antennas and deconflict their scheduling request and submit a joint to the DSN folks. Help with that problem. Directed scheduling problem. The other one is more basic research, the resource prospector mission (just got cancelled) to use as our point of reference. It deals with more temporal restraints. This problem has spatial, temporal, they have to stay in the line of sight of sun and light. There are a few drop offs here and there. There has been constraint of doing traverses of the rover on the moon. It does various science things and just analyzing where water sort of is and where ice is at different depths. Then we're combining system that has been used as part of LASS and MSPLICE as SPIFe has the front end and the EUROPA as the backend. Then we're using the traverse planner that

comes from XPDES traverse planner. We're using this to deal with the constraints and make plans for the rover. This year we've been looking at strategic planning space of that work. When you're actually executing the plan, undoubtedly differently than you predicted. Like driving or drilling or so on. And how you can revalidate the plan and replan as you go. That's sort of our focus on this year's project. So both of those projects are, DSN not as much, but the RP one is definitely using some of the same software used in LASS and MSPICE.

How do these softwares work together? What are the challenges of making them work together since we'll be designing something like SPIFe. What are some considerations when designing a front end for frameworks for EUROPA?

- SPICE decided not to use EUROPA as a backend, it was initially using that but now it's been afforded to do that. A simple temporal and sub temporal network. It is possible to use a system without EUROPA. EUROPA gives more powerful constraint fixing.The mission MSL is getting by with more enhanced backend.
- You can think of SPIFe more like APGEN, it detects constraints, violations. What EUROPA does is allows you to automatically fix a bunch of violations. You can selectively, there is some flexibility there. SPIFe can make suggestions to fix something, but the suggestions are local. SPIFe might create new violations if you do it whereas EUROPA will try to fix the violations or whatever possible violations in a way of that doesn't cause other violations.

If it were to be something like SPIFe that is detecting constraint violations and doesn't automatically fix them?

- SPIFe provides editing capabilities and move things along and fix things. It depends on the type of violations. If it's a temporal violation then violation of simple temporal constraints networks that P5 might have talked to you about. It can automatically find the solution to the temporal constraints. There could be other violations because of mutual exclusion or because of resource violation then it's up to human operator to fix those manually by using the editing capabilities.

Can you tell us more about the problem you're trying to solve?

- On the europa clipper mission, it only gets 8 hrs to collect information. They're doing 45 flybys and only 8 hours of obs for each flyby. They want to make sure that during the time Clipper is orbiting around Jupiter, they're efficient enough. They want to include some type of automated scheduling software b/c the mission is still in pretty early planning phases. Things are changing a lot that's why we're looking at different missions.

Is it used during it during the mission design phase?

- It's meant to be used during operations

How many instruments are they considering?

- 9

So the plan might change every fly by?

- Potentially, based on new science discoveries

How much time between each fly by?

- It's two weeks or 13 days

So there are a lot of manual input. Do the scientist have an operational working group of things they want to do based on what they want to do so far?

- They're arranged in I don't know how many thematic working groups. That's where they make those types of decisions. We're not totally sure on the structure

At the IWPSS conference, there were some papers by JPL people about the Europa Clipper mission. They're doing some type of study or prototyping. Have you read those papers?

- No, our sponsors haven't referred us to do that
- International workshops on science discovery for space. Pittsburg last year. We can probably send you a link (participants)

That brings up a general question. You guys have developed software for different types of missions like rovers and orbiters. How does that change the requirements for software like this. On rover missions, they have to make decisions a lot faster whereas on orbiter missions they kind of have a more detailed idea of what they'll be doing. I don't know if it's too broad of a question but...

- Most of the mission that the ensemble that the suite of tools have been rovers, surface operations. Except for LASS which was used on spacecraft and orbiter around the moon. There are different challenges there. The main challenge there were teh science constraints are temporal in nature. The observations have happened in certain time of the day or certain times of...it can be expressed in time of day. In landing mission it has to do with more of where the spacecraft was in orbit so it's more spatial. SO we have to assess those into temporal constraints. So that's the biggest difference between LASS and MSPLICE. It uses the same underlying thing as SPIFe as being part of these tools. For this clipper, do you know if the constraints are going to be more to do with what it does for the fly by or time of day/temporal type of constraint...(internet dropped off)
- What about energy, what is going to constrain the schedule the most? Is it going to be energy, data, or temporal coordinates? I think it's mostly temporal or data. We don't know exactly what the resource constraints are. It seems like power

aren't going to be that big of an issue. We've talked to people on other missions like Cassini and she told us that type of resource constraint isn't as big of a deal on Europa as it was like on Cassini. Do you know how long it takes to get data back to the scientists and once you've collected it from those 8 hrs? I can't recall right now.

Are you required to integrate with existing JPL software? Or are you free to design whatever we want? (Participant)

- I don't know if we can access that at all, it doesn't seem to be public at all.

JPL owns the MSLICE tool. SPIFe is, it's an open SPIFe. If you google open SPIFe it will point you to a wiki and the wiki has some instruction on how to install it on a github server.

Have you talked to the human interfaces folks here that help us build SPIFe? Here at Ames? It might be worthwhile to talk to them? We'll send you names and emails if you're interested?

Are you designing something to be used on the mission or just to be used?

- It's just a prototype. They're going to be the ones who develop this. We're just proposing ideas for them and we have to finish this project by August...

So are you more interested in usability than in the optimization for stuff like that?

- We are trying to figure out how much automation we want to include with this?
- What we found interesting with MAPGEN was you could control the automation but you could automate the whole plan or part of the plan. You can do something like SPIFe where we're just doing the constraint violations. We're just designing for the constraints. Since we're not building this. What are some considerations do we need to do know about. Does our concept require a system be highly automated if that is going to be a problem if we don't know how it works. We are interested in usability. I was wondering who was using these systems and how much training is needed for them to use it? SPIFe definitely seems like it could be easy to use. Do you guys know anything about usability problems about these systems. And usability problems with MAPGEN when developing things like LASS?
    - I was involved in that. SPIFe has a lot of things there, lots of tools, shortcuts to help humans plan editors. We have a lot of different type of people use LASS for the planning mission and it was my planning team who used planning. The principal scientists did long term planning with it. We've created these things called templates. They were mini reusable times in all the times we submitted them. A lot of people using it, a lot of training

- sessions with all them. Some of the human interface folks help me do the training. This guy called Steve Alenias (spelling) he helped with the changes that involved in LASSs in dealing with constraints. But everyone got up to snuff and make use of it. That part all worked out i was surprised
- For MAPGEN we had to get beyond the cultural differences. Scientists weren't used to think about the temporal constraints. What is the right level of constraints so you get what you want in the end? Overall, we were lucky where the more senior principal scientists who understood it well and he was able to teach the other scientists about it than if i was the one teaching them. It was not trivial but with training it was very effective. With MAPGEN there wasn't much direct use by the scientists but they had to provide the constraints through the constraints. We had to specify them through. For landres, there was a direct use of these tools through the teams/

Because there were a bunch of roles using it...let's say for example the instrument teams, they were only ok with submitting activity requests.

- Their requests were building activity plans and they didn't have to worry about what everyone else was doing. They were really building activity plans. The activity into the plan and execute it

That is heavily dependent on allocation of time?

- Yes, there was an allocation time that principal scientists help build and each instrument team would be given each chunk of time and they wouldn't in general conflict with everyone else/ that was done before they started their plan. We deconflicted. Sometimes there was an influence on the border of those time slots but those were usually independent so they didn't have to worry about those plans.

Were developed by LASS?

- We had our initial plan for the initial period but during operations these plans and pretty complicated workflow/ They were being built as you worked along. You can take advantage of what you learned before. It was a continuous process for the next lunar days which was a month. Then there were different phases of the mission and different focus. At first we were doing checkout then lasik communication. For each lunar cycle they did an observation and analyzed their data and changed what they wanted to do the next time.

I'm also wondering about. Your papers and P5 as well, mentioned the challenges of explaining constraint violations. Can you touch on that a bit more? I'm guessing it's important for instrument teams identifying that engineering type constraints they might know about. Would the systems identify those for them? What are the challenges of identifying constraints?

- For all of the violations, the main thing was to give a set of code brick? The set of activities that are directly involved in the violation. Then for temporal violations it's just a matter of saying that it's supposed to be in these bound and out of bounds. For resource violations, it has to be an issue because it could be all the activities that have occured to this point to contribute to this violation. For usability you might want to order those from most recent first or even restrict to this...some of the violations come from constraints that...these two activities are supposed to be 3 hour apart, no more than 4. It does give a short english description, it could be improved. It does try to express what was violated. Some are temporal constraints that requesters enter themselves then there are flight rules that are encoded in the dictionary where this has to happen before this and that. Both of those are detected and explaining in english sentences, sometimes better than others. I mean we'll send an link to open SPIFe and play around and look at it. Are there some example plans or dictionaries? There are some simple rover dictionary which is a simplified one of mars rover. But it does have activities conflict to each other. Just download it. You get an activity dictionary for free you just have to create a plan. There are instructions on the Wiki to download the system from github. Give it a try! If you have some trouble building it, you can send me an email. I can give you suggestions

You are saying all the constraints are resource restraints are part of an activity dictionary or database. I'm wondering how science objectives get encoded into these systems? Do they have to get translated into temporal constraints? These type of observations or activities in general in this time frame?

- That's a good Q. typically that's at a higher level than is represented explicitly in the dictionary or plan. This is something that is, not in my mind, automated. It's part of what the scientists do and their individual teams when they come together their operational working groups. They're the ones that get the science requirements in their head and plan what needs to be done day to day in their head/ those goals and activities and mission success plan are. It would take some... to reason about science. And also i'm not sure those scientists would like to give that up. They'd probably want to do it themselves. What's in the dictionary are for the health and safety for the mission. The activity level is higher than the command level which is sent to the rover and executed there could be additional flight rules to be encoded. We try to capture as much activity but there is additional checking done at the command level. The science level is above the activity level.

I have a question- it goes back to the different constraints and asking us what constraints we have to be concerned about the Europa clipper mission so far? There seems to be a lot of unknowns. One question i have of that is. Who should we concerned to be and what sort of questions we should be asking so we do map out all the constraints?

- So who do you see using their design. Is it the ops team, engineers, or the scientists themselves would be using themselves?

I think the science teams and the instrument teams. We've been talking about instrument teams to build activity plans?

- So, there are two separate processes each instrument team will have a plan then all those plan will be merged to create a final plan. In the merging is where there are violations in the constraints
- So another tool that was used on MRRR was SAP science activity planner that was a higher level than MAPGEN. It wasn't directly used by the science folks but used by engineers and tactical planning and strategic planning. SAP i don't have much direct experience since i worked with MAPGEn both as developer and operator is if you want to deal directly with scientists. It's part of Ensemble but a SPIFe like that tool. That's the issue, if you're going to observing EUROPA. You may want to draw a target, specific geographic things...i'm not a planetary scientists. What's the new SAP called? There is a new one called in? There are different sort of planning problems in this, target selection where you want to aim your instrument, collect data on, SAP whatever it's called now, helps do that. And helps do higher level science planning and reuse old science plans as well and helps maintain targets. Here you'll be seeing the same targets presumably. Different fly bys will see different parts of Europa right?

They're trying to cover the whole moon so each fly by has a different inclination and fly by?

- One thing that might be important for Europa mission is opportunistic changes. The problem is the time lag that the thing to communicate for Jupiter. One of the things for plumes on Enceladus that these plumes and they wanted to capture them. Some interests will see a plume but there isn't time to go through the information. There are some instruments to observe it. There might be some automation on the spacecraft completely that works autonomously. That's a different problem...i don't know if you guys will be involved in that...that's a whole diff focus (one person interjecting the other)...very different problem...Interesting but different. Do you want to make any preparation for anything like that. So on the MARS rover they this AEGIS system where they see an interesting rock on the camera, they can turn a high res camera towards it autonomously and observe it in greater detail.

Plume challenge. Changing trajectory might take up to a year...

- So I would try to figure exact what level of plan you are interested in. What are the users, needs, and use cases/ And what level of activity they're most interested in. You can get down to the actual engineers that get down to the tactical plan but maybe you don't want to support them if you want to support scientific. I don't know what they use on MRRR for SAP and it's new name. And MAPGEN. And that's quite a big different than MAPGEN (SAP) cus I was a developer on that part. There was guy at JPL GUy Perzak who is one of the designers of MSPLICE. He was involved in the planning and designer for SAP. If you can contact him, he might be a possible source to talk to?

During the development process, i'm curious what source of documents or ways of keeping these requirements and constraints on everyone's mind. Are they publicly available? A spec that some of these tools might have.

- I don't know about publicly available. Typically there is a book of requirements, like a spreadsheet that system engineers are responsible for collecting and documenting various aspects of mission tools and mission itself. Large spreadsheet, L1 requirement may be down to L6. That's the most detailed documentation of how the tools are to perform and what the science needs to perform. There are interface documentation for example PHOENIX operation. It shows what the data format of. These are publicly available images. So if you wanted to figure out how to encode a FORMA and encode into JPEG you would know how to do it, that's what you could look at? A lot of these things are probably not publicly available.

Question for us?

- What are planning to use to evaluate their final product? Is it going to be user studies? How are you going to evaluate what you've going to accomplish?
    - User studies either at JPL or remote.

Participant 7 - Interview Guide

Engineer + Scientist

Profile Participant 7

P7 graduated with a B.S. in Astronomy in 1991 and a B.S. in Aerospace Engineering in 1993 from the University of Maryland. He performed classified work for the Navy in the area of theatre missile defense, while earning his Master's degree from Old Dominion University in 2000. P7 went on to fulfill his long-time dream of working for the Jet Propulsion Lab in Pasadena and has been a part of the Cassini-Huygens mission to Saturn and Titan for the past seven years. P7 has led the integration and sequencing of the Cassini mission science operations plan and is currently working as a System Engineer with the Flight Engineering Group.

Research Interests:

- Scheduling and planning

Roles: Technical Group Supervisor, Planning & Sequencing Systems, JPL
Currently working on: Europa's Planning, Coordination, and Execution System's uplink concept and has past experience working on Cassini———

Publications: Automated Scheduling of Science Activities for Titan Encounters by Cassini

Introduction

Hi, Dave! Thank you so much for taking the time to talk with us.

Just to give you a little more context, we are a team of researchers and designers who are looking this with as with as many technical constraints and considerations as possible but we won't be implementing this. We're working with with JPL's Ops Lab to improve the efficiency of uplink operations for the Europa Clipper mission, potentially using assistive software. Through interviews with experts like you, we hope to learn as much as possible about all the variables involved in decision-making in orbiter missions, including the people involved and how scientific and spacecraft data informs uplink commands. Although our research and future design implementation is focused on the Clipper mission, we greatly value any input specific to other, similar missions, as our solution could potentially be applied to future operations. We know you are a expert scientists in planning science mission, we are looking forward to learn valuable knowledge on scheduling and planning tool on scientific missions.

We'll be sharing your responses anonymously between our UW research team and our advisors at JPL.

Do you have any questions so far?

Before we get started today, we also want you to know that we would like to record our interview with you as a full transcription of your responses will be greatly valuable for the purposes of analysis. Is it ok with you if we record this interview?

[If YES] Thanks so much for your cooperation. We're starting the recording now.

[If NO] Not a problem. We'll continue without recording.

Role / Background

Goal: To learn more about the participant's background, their current role, and the organizational structure of current planning process

- Can you tell me a little bit about your roles as a Technical Group Supervisor for Planning and Sequencing Systems?
  - How does your work relate to planning process?
- Based on your experience with Cassini and now Europa, what are the differences between org structure? Are there differences or similarities in the following?
  - How do different roles communicate with each other (data scientists, system engineers, principal investigators, project scientists, etc)
  - What are common conflicts during negotiation and how to resolve them normally?

Data Collection, Analysis, and Decision Making

Goal: To understand how planning tools are developed and how we can adapt the process to our design.

Projects Worked On: Cassini and Planning and Sequencing for upcoming Europa Clipper mission

- **Stakeholders** Who is mainly involved in planning process?
  - What roles are using planning software frequently?
  - Any role has the concern that they are not actively involved in planning process?

- **Process** We know that you developed the advance scheduling software that automate the decision process for personnel. What concerns do you have when you are developing it?
  - Walk us through your process for understanding a problem. How do you capture all the requirements, constraints, and considerations in order to make decisions for the tools you have made?
  - How do you transform stakeholders' needs into functionalities?
  - How do you define the success of a scheduling tool?
  - How do you accommodate individuals' preferences into design?
  - In terms of time and resource allocation, how do you visualize the allocation and available options for stakeholders?

- **Roles in relationship to Planning:** Our main focus is to understanding planning and decision making as it effects both the spacecraft and the teams involved. In your many roles at JPL what has been your relationship to how decisions get made that affect either the spacecraft or landers?
  - Has this been different during different phases of the mission?
  - How have you or your team members made sure decisions are based on the most accurate information?
  - How do you convince other teams or groups and how have they convinced you of a different course of action?

- Can you walk us through a typical **downlink-uplink** process?

- **Instruments** For the Europa Clipper mission there are 9 instruments selected for the mission, of course each of these has their own constraints and requirements. How have you made sure that the instruments have both the engineering requirements and the ability to maximize science opportunities?

How do you learn about the constraints?
- How do you solve for them?

What can happen during a mission that might change these requirements?
- How do you solve for them?

How do you find compromise amongst the teams if a decision needs to be made?

- **Negotiation process and planning:**
  Most important resources for Europa?
  How do you anticipate conflicts will be handled?
  Can you walk us through a time when negotiations were necessary and how this was resolved?
  - A time when automation was able to help with this…
  - A time when automation was NOT able to resolve a conflict…

- **In a paper you wrote** "Automated Scheduling of Science Activities for Titan Encounters by Cassini" you discussed utilizing automation to aid with the Cassini mission scheduling and sequencing.
  What was it like to integrate the mission specific requirements of Cassini into ASPEN?
  - What were some science objectives you were working with and how did you integrate them?
  - How did you present constraints to the user?

  How would you describe the purpose of automation in this project?
  How was automation perceived by those who used the tool?
  We know that there was manual scheduling happening at the same time and this was compared to the automated schedules. What were some of the findings, comparing the automated tool from the automated tool?

NOTES

Introduction

Consent given.

Notes begin:

From the research, you are the technical group supervisor of planning and sequencing

system?
I recently left the role. I'm the manager at the function in Planning and execution cross many missions, rovers, orbiters...I left the role I'm now planning, coordination and system engineers in Europa Clipper mission.

What is your responsibility in your new role?
There are few different subfunctions. Generally layout the long range plan and how would we accomplish the science goals. Then all detail things need to occur to instrument activities . There are spacecraft related things, we call spacecraft bus, things like altitude control, power, all the things like that to be on board to make spacecraft itself function. Then there is we called the payload, the instrument All cameras things like that collect science, which it is the purpose.. All things work together. We have to go to detailed commanding to tell spacecraft what to do. All things are need to be validated . All that are under PCE. We develop software to tell spacecrafts do this and this. We model and stimulate to make sure all things are safe on board and carry one in the way of what we want them to do. We always one month ahead of time to set command. These are under PCE. Other part: Being able to Response to what happen on board. There are things that different instrument teams want to change in 14 days. We want to validate these changes so it won't harm the spacecraft.

Europa is doing planning different than other missions, how do we do long term activities?
We are using software scheduling to do it. Having different Instrument team specify what they want to do with the instrument, at different altitudes they want to do different things, solar lighting, different regions of Europa they are interested in, want to look at stars. These are constraints. We use automated schedulers can figure out, we have informer to tell positions of the sun, Juno, earth, altitudes position of the spacecraft, function of time. When you take all info in, you can determine when these certain constraints are met by instruments to accomplish science goals. The software shows when the science objectives can be met. It has to be updated many times what kind of science activities can occur simultaneously and what cannot. What kind of things need to couple together. Some instrument needs warm up activity so that scheduler can figure that out.

Are these constraints visually represented or textually represented?
Textually first. Run the simulation and go back to instrument teams and say here is the time we schedule the activity. The instrument can give thumb up or down.

Negotiation is a long process. Software in europa helps to alleviate that a lot, right?
Yes, we did build the integration menu, which is expensive menu to operate and human labor intensive. On board We have other resources, such as total energy, certain

amount of data available. Each instrument get the allocation to use certain amount that they cannot take data all the time and and go to the higher rate. Electrical power is shared resource. we go to Jupiter and take solar panel, in the belt of total energy line.

Is there situation where instrument borrow resources from other instrument.?
It happens intermediate. Scheduling is long range. Another part is sequencing detail, as we just uplink commands. Now it's the midterm thing, which is the science plan. Especially for big missions like this, there are lots of scientists involved and there are lots of negotiation. Even no matter how proper the schedule is, there is going to be negotiation, I want to add it here. How about give you 2 flybys from now, it's hard to put it into software. All about human decision.

You guys want to get closed to what you want based on constraints using software. It's cheaper this time around because of time comparing to how long it took before?
It is big cost for human operations. To make things happen, it all comes down to human involvement. You can have less people involved, maybe prompt to capture all constraints. It will save money. Everytime there is change to trajectory or there's other model happening too, which is the benefit of automation. Internal to the schedule, model deals with how fast can the spacecraft turn, other things like how much power is available. Models are used by the scheduler. If there's any changes to spacecraft's capability, that it goes to the scheduler and scheduler needs to know that it would impact the plan, We need to rerun the whole long term plan. We do it manually, then it is very expensive. Another thing is that decide to change trajectory, that's pretty common. That would rerun the scheduler as well. And just scientists change their mind, I no longer need this altitude, I want this, that would change geographic constraint, which would change the scheduler as well. Have all this automated save lots of effort.

Can you use it after launch?
Yes. We don't have the final trajectory until 6 months before we arrive. Even we are in orbit, there are updates. One of the cool thing for the scheduling tool we want science to make certain decisions and I don't want it to schedule these activities. We know the exact time when we want . Kind of nail down certain things and have scheduler do their best to schedule things and move things around.

Can you talk about downlink and uplink process for Europa?
We receive data back and someone on the ground. Some missions are very dependent on what just happen on board. Rovers have lots of interactions with the environment. I consider it to be reactive mission. Things can go wrong with rover, wheels maybe new science opportunities pump out overnight. You need to heat up the rover etc. They plan every single day. And they start the day by seeing what happen in the previous day knowing the latest status of rover. For orbiter mission, it is predictable, we know exactly

what it is going to be, what altitude we commanded. It is stable, environment does not change much from day to day.. You can predict things well ahead of time. There are uncertainties on the surface of europa, higher rate reflectivities. Early on in the orbital phase, we learn each instruments and how well they are getting certain data. There will be adjustment. There will be certain adjustments needed for instrument parameter. After getting data there is downlink immediately, they get the data and have the analysis on what kind of updates I have to do. If it is something internal, resolution things like that, that won't affect other instrument, we don't need to validate the command. There are things we called noninteractive commanding. There are other things team want to do that may impact other instruments, we can say no and validate what they are trying to do.. There are lots of things we evaluate on the ground that impacts uplink. Navigation team: They fly closed to the surface of europa, they get lots of data from downlink side where they constantly evaluate things like speed and position, we do the thing called maneuver that we fire the engine and stay extremely closed to the surface of europa. They get data from every 8 hours to see if they use it to do correction to the trajectory and how do they fire the engine.

The downlink process its different for each instrument?
Instruments teams receive information from telemetry same for engineering. The navigation team get from dockler and ranging. It's about monitoring signal.

Receive faster?
No. The same speed they comes down. They get the data the same time we get.

Who make the call on interactive or non-interactive?
When we are dealing with non interactive commands, we can specific commands that we put into category. There are specific sets of commands, they are very benign, affect the data rate, change the operational mode, which like a power mode. They gonna change the altitudes of spacecraft. In the E, we are trying to say you cannot change you power mode..but you have some. But you have Overall allocation for each flyby, if you are able to demonstrate you are within the envelope, then you are fine, we figure it out in the process and it is heavy with the software. We can verify it. We don't want to employ human do it all the time, we have specific time to validate.

Do teams know when requests are benign?
We would have a list, command dictionary, all different commands to be sent. You set it differently for different instruments. Even it is non interactive things, you won't want it to control others.

Can you talk about the validation process?

We always have software to have some of the stuff. So choose Cassini as an example, each individual team and spacecraft subsystem would deliver subsequences to it. And we would all merge them together and run simulation, the simulator would model state changes and things happened on board. Typically there are bunch of errors, we have to figure out which team make those errors. It’s a little bit effort to figure out who to change what. You send these to the team and it take couple of weeks to fix them. And we re merge them again. And then you get less error and you have to deal with that. We have 5 cycles and took 5 months and validate one month sequence . We have 1 month on Cassini and take 5 month to develop and validate it. We have 5 different sequence development process in parallel cause it take 5 times long to develop it.. In each of development process, it goes intensive and expensive. We took lots of lessons form Cassini how are we going to operate. A lots of issues Cassini have to deal is Cassini itself. instruments were co-aligned, they need to do lots of pointing and add things to accomplished side. Errors come in. The biggest complexity is pointing. They have to avoid the sun, lots of constraints. You can’t point to the sun. There are large passive radiator couldn’t point some angles to the sun. Having software that can model these that would violate certain constraints Isi expected to do. We are taking a lots step in europa. Instruments are co-aligned. We have focused on Europa itself rather than many science starts. So all instruments are interested in pointing down to europa and some other instruments collect particles and plasmas and atmosphere. But they can do the same thing together. All all the cameras pointed down to europa and have another one pointed 90 degree up. I guess, we are taking steps that within the automated scheduler, make sure only activities can be scheduled together and include them to the command level end up with knowing that this activity will resulting these types of commands. Activity scheduler know all the details of commanding and whether they can perform together.

So these details of commanding you mentioned is not available in Cassni?
We have lots of instrument teams they control the altitudes of the spacecraft that where the issues are. It is very complex to plan pointing. We do patterns of rings, lots of errors to fix.

Pointed is the biggest resource to allocated in Cassini. What is the biggest resource in Europa Clipper Mission?
We can record lots of data then we can play back. We have the master recorder on board hold lots of data. We only playback fraction of it. We have to constrain the amount of data we record far below we could record to make sure to get data back . In reasonable amount of time, it is a big constraint.
Pointing is still one. We pointed straight down to Europa we call native space. Within couple of days of a closest approach, there are different desires to scan and look at the

stars. Some instruments are interested in pointing the spacecraft things that while other scientists don't want to. There is the intention.

They are not part of the plan. What do you mean that.? Everything its planned out regardless of closest approach?
Yeah. Every flyby is gonna be different. So thought the phase, we cannot track the surface because it is too fast. We have to track the center of europa and drag the view of surface. We don't have the flexibility of point around. On the approach part, we have the template, now everyone in the agreement as we are still four years from launch. As the taste for science grow.,We have a plan to work, but it is template. There are something we have not figured out yet. Once we collect plasma particles, that expose another instrument radiator to the sun so that it has to heat up for a while. Part of solar rays, our main camera cannot observe well solar ray movement, we constantly observe the sun but at some point we park. we have to do pauses for five min gaps so cameras can observe then move solar ray coalign to the sun. There are issues I can tell, cameras say ok here is important regions, there are iterations needed for the movement of the rays. As you are planning the details, there are so many unknowns it is very complex. Everyone agree to the template. As they are getting closer, they want more.They will grow in their appetite.

Who make the call when their desires grow?
At high level we have project scientists. We call PSG called project science group to make high level decisions. Things for multi instruments are made by this group. When going down to detailed decision, there is call science planners, they are engineers that understand how spacecraft operate and measure requirement. We need you need to scan, such such..science planners can make final decisions. They align plans within overall science objectives and thematic working groups adjustive. European agency, they come in Jupiter orbited in the same time with us. NASA says they need imaging help, this is nasa level decision can be made. Co collaboration is not common.

We read the paper that automated scheduling. How to integrate science requirement into Aspen?
We are trying to figure out. We worked as science planners for titan flyby. We took the representative subset we thought how scheduling constraints work for Cassini , of how this instrument is interested in this.. we want to see how software did, we did on 10 Titan flybys. The software couldn't read the trajectory and figure out when the certain time frame the certain lighting angle. I have done a lot of work. I have to look at the table called Cassini tour atlas, and load for different ranges of when certain constraints can meet what and put them into excel The software read the excel and say when the opportunity will be available and go ahead to schedule. We also put the priority to different science activities.

How do we categorize priority?
We couldn't . Because we could not say that one activity is less important than prior activity. The best you can do is to use numbering thing what if this activity is L2, and that one is L3 . Let's suggest another way, too many activities on one single flyby, use it as knob to decide..you will never possible to have another science team to say we are less important than other team.

The tool was not implemented?
No.

How Automation is received in Cassini?
We talked to lots of people. I don't know how people looking that. There are lots of AI aspects we are interested in. There are science people too. We are pleased by Europa that we are doing this.

How to get attitudes from scientists?
To this degree, we interview instrument team lately to see how do they think the current paradigm . They still need adjustments because schedulers take away control and flexibility, We have two different tools. We have scheduling tool and VARYTASK that command evaluate the current schedule against measurement requirement. This instrument has this requirement being met.It is neat. it can evaluate the whole thing.

How do you gain trust for scientists to make sure they don't feel paranoid?
They have gain trust by showing the requirements are met by showing the prototype. They are happy with it.

What are features you want to have for the planning software?
How much resource usage to take into account. We want take data volume into account. One of instrument 14 activities scheduled, we want the scheduler to say you don't have so much data volume, you cannot have this activity. Go ahead to have the timeline to write down the data rate i need to and adjust it whatever.
If we have collaborative sandbox, i like that idea, radar instrument as an example, closed approach, they need supporting imaging cameras to understand the data better. Image gives context. What does it look like in the collaborative sandbox is we have the modeling and simulation of command and what gonna happen, then largely model what the spacecraft command will to do, which is different than instrument internal commanding might do. The main processor, the many computer of the spacecraft, each individual instrument has their own processor where they have internal commanding sequencing.

P 7

Since lots of things happening internally also affect power, data volume. We need to model what they are doing. If not, it hinders collaboration.

How collaboration perform when export happen?
JDS ground data system: we are doing group system share. It is like home directory. It is real time, different time zone. I picture that we have science planning meeting everyone call in, they have visualization like altitudes, different instruments different views, figure out the altitudes. Right now it is sharing powerpoint and WEBEX.

Additional notes:

Role
The way that JPL works, I recently left that role i had a planning and sequencing position across many missions.

Generally laying ot the the long term goal with planning and activities

Space craft things are basically the BUS…
Payload is basically the instrument.
Instrument activities and space craft activities
How those things work together to accomplish scientific goals

Commands sent to the spacecraft, not software commands. Sent one month in advanced, this is all represented by PCE. After a flyby of europa we have 14 days until we fly by again. We need to flyby again and see what to change, what might break.

Europa a more Iterative Model?
I wouldn't categorize it as more iterative. We are using more software… There are different constraints and we will use a e

ephemeris information - position of spacecraft
Other ephemeris info - position of solar systems

When these geometric constraints happen, schedule my activities. We think it will be uploaded many times so in that case it is iterative.

Being automated we think it will be less complicated.

What instrument needs are necessary for them to work

Textual? Text Based?
It is deep in the code now… But yes it says it

Cassini remark 12:33

Each instrument gets its own allocation. We are going all the way to Jupiter and taking Solar panels. It's a long way to go to keep everything powered.

Scheduling is long range is one part of my job. Other parts are closer to the actual

Negotiation of flybys "if you give me a fly by later i will give you one now." This absolutely does happen.

Cost?
Human effort is the most expensive. Planning efforts now will cut down on costs later. There are models on how fast the spacecraft can turn… If there are changes to the model the planner must know what to change. If scientists decide to change their trajectory, this changes their plan. Scientists changing their mind 17:05

After Launch
Three year cruise to Jupiter. We won't have the final trajectory till we arrive…
Once scientists have made certain decisions, we can narrow down the scheduler to be more accurate, we have requirements now for this 18:20

Downlink to Uplink?
I didn't know MRO was doing this… Anytime you have a spacecraft with a lot of interaction like a rover, there is a lot that can go wrong. Gets stuck, scientist opportunity, heating the rover up… Lots to plan, they plan every day. With Europa we know things will be pretty stable. We have month long sequences, that won't change. Lots of uncertainty on the surface of Europa. Instruments will find out how to take data. There will be adjustments.

Is there issues with blurr, calibrating instruments comments 12:20

If there are things that wont affect instruments you can go ahead and do. "Noninteractive commanding" If an instrument might affect another we have to validate it. Have you spoke to our navigation team? MAneuvers three times during orbit, because how close they are to the surface. They need to adjust. Orbit trim maneuvers 24:08

Instrument teams receive telemetry but information on the signal. Engineers get telemetry.
NAvigation receives DOPPLER, they get the same time as telemetry.

Who makes the call, about what to do?
They have very specific set of commands. If it changes the power modes are attitude they cant do it. Acronym NIPSE 26:32

We don't want to have to employee humans all the time… If we had to manually do this for every change it would be a lot of work for a large team.

There is a list a "command dictionary" only certain ones are labeled NIPSE. You wouldn't want an instrument team to have access to a different instrument…

Question of what happened before?
We always had software do this stuff. We would run simulations to model what happens onboard a spacecraft. Cassini: there are a bunch of errors, send out to the instrument teams. They fix them and send them back, send out again. Hopefully they fixed them. With Cassini we had 5month long sequencing periods. We needed staffing this whole time and became expensive. T

Cassini's engineering with instruments not being coaligned...32:30

Passive radiator couldn't be pointed at the sun. Software that can model all of this, how you know when your modelling all these constraints. All the instruments pointing in one direction

Fields and particles instruments pointing at the forward direction. Steps to plan which instruments needed to be performed together. We had individual different instrument teams controlling attitude as well.

Biggest constraints: record a lot more data then we can play back. Rates we can return data lags. We can only play back fractions of the data recorded. In a reasonable amount of time… 37:11

Pointing is still one. Before and after closest approach, there are some instruments that are wanting to point at somethings. 38:30

Everything is Planned out before closest approach?

We can't even track the surface of Europa, it is going by too quick we have to track the center. Scientists hunger for science grows as we get closer. I think there will still be conflicts… Solar Arrays our cameras cannot observe when solar arrays are moving. There are these gaps of 5 minutes to observe, then move arrays again… There might be issue when we get even closer.
It gets very complex as we get closer.

As they learn more does it change?
...43:40

PSG project science group. Make a lot of the big decisions. When down to details science planners… not really scientists but are more engineers. We know the generally requirements, Project science group makes more final decisions. An opportunity can be so good it can go all the way to NASA. Says ESA is coming up on Jupiter NASA might make JPL mission to aid ESA.

ASPEN integration
ASPEN was a Prototype, Trina and I were mission planners. We took a shot at scheduling constraints for Cassini. We wanted to see if his scheduling software could help with hte planning. It was a lot of work for me. It couldnt figure out certain things, it was a lot more manual then I thought. I had to do a lot more work myself. 49:01

How to categorize priorities?
If we were doing this for real, we would never be able to do this. Everyone's objective is top priority. Use the leveling to see what comes out if you try different priorities. Adjusting to find the best options, or suggested to adjust the plan… It was not taken seriously, maybe because of Cassini was not about automations.

Europa Automation
Instrument teams seem interested, no griping yet.

Scheduler is one and another is Veritas. Takes the measurement requirements and the weighs them against the plan.

Trust?
They show the prototype/plan here are your requirements

How much of the resource issues to be taken into account when scheduling. 13 different activities. Toggling resources on and off. Too much into scheduling software. 80%

P 7

After the 20% / calibrative sandbox
There are different processors on board, even certain instruments have their own processors. We need to be able to model what other instruments are doing. If there GDS, science planning meetings and

Participant 8 Interview Guide

Designer

Profile

Participant 8

She's Currently working as a Senior User Experience Designer with NASA's Jet Propulsion Laboratory (JPL) focusing on telemetry downlink data visualization, science targeting, and rover driving visualization tools.

She is a passionate and collaborative designer striving to create tangible and experiences for people by way of thoughtful research and drawing.

As a Senior User Experience Designer at NASA's Jet Propulsion Laboratory, she has had the privilege of collaborating with missions such as Mars 2020, MSL (Curiosity Rover), SMAP, OCO-2, and many more. Her work has been instrumental in demonstrating design methodologies to an aerospace-centric user community. In addition to producing intuitive user experiences for the operational software of engineers,she has cultivated an interest in developing programs for spacecraft missions to better test final products with the end-user communities and simulations for large scale assessments of future operations procedures.

Design Focus:

- User experience design for aerospace-centric user community, downlink data visualization

Introduction

Hi, [Participant 8]! Thank you so much for taking the time to talk with us.

Just to give you a little more context, our team is working with the UX team at NASA JPL to improve the efficiency with which activities are scheduled for the Europa Clipper spacecraft. The team hopes to combine automation with data visualization to make it easier for the ground systems team to respond to incoming data and any conflicts that may arise during the mission. Through interviews with experts like you, we hope to learn as much as possible about all the variables involved in decision-making in orbiter missions. Also we know you have lots of design experience in visualization tools for NASA mission. We really hope we can get some suggestions and feedback for our ongoing project.

Do you have any questions so far?

Before we get started today, we also want you to know that we would like to audio record our interview with you as a full transcription of your responses will be greatly valuable for the purposes of analysis. Is it ok with you if we record this interview?

[If **YES**] Thanks so much for your cooperation. We're starting the recording now.
[If **NO**] Not a problem. We'll continue without recording.

User Experience Design

Goal: to better understand the process of user experience design on spacecraft mission domain

What was it like for you to come onboard. How were you able to learn enough
It's our first time working with NASA. The knowledge domain, which is orbiter mission, is new for us. Also, as Europa clipper mission is in the starting phase, there are too many unknowns on their structure. Based on this situation, what do you think will be the good research direction for us ?

- For this unfamiliar knowledge domain, how do we effectively capture useful information from research?
- Seeking suggestion for our current dilemma

Right now we might research on Cassini and Juno to study its work flow and structure for our next step, as it's very similar to Europa.How do you think we should do it?

- If we make this type of analogy for Europa, how valid is it?

When you are doing your first project with NASA, what do you think is the biggest challenge?

- How do you solve it?

- Are you doing primary research on site or remotely? How do you collect user needs?

We know you have great experience in designing visualization for engineers for monitoring flight safety, is it also related to decision making?

- If so, how engineers make decisions through the interface
- How data visualization inform decisions?
- How do you know the prioritization of data?

In terms of tools and platforms, how do you decide what platform you want to apply for the data visualization?

- Based on our scenario, what platforms are you envisioning from your perspective?

User Test and Prototype

Goal: seeking suggestions on remote user test and prototype

We are not able to test on real users, which means that we could only test people on similar orbiter missoins remotely. We have rare experience in it, any suggestions on it?

- How should we frame the test to make it more valid?

In terms of tools and platforms, how do you decide what platform you want to apply for the data visualization?

- Based on our scenario, what platforms are you envisioning from your perspective?

Pertaining to our project

Goal: to get suggestions on narrowing down the problem space and improving the current research plan
(describe our problem space and context)

Are there any valuable resources or artefacts we can refer to?

Are there any people you think would give us some useful perspective to us?

Do you have any other advice?

NOTES

Introduction
Consent given.
Notes begin:

How have you come up to speed to the amount of information you needed for various missions been on or working with? How were you able to make better design

- I've been immersed in the mars 2020 mission. I'm from the mars science lab. I was .I'm a user researcher. INvolved in ops procedure, watch people make science decisions and watch people make. Science intent = decisions. With engrs team so that their science data can be sent back to earth. Shorter project lifespan.
- It's a technical field, it's more of language. IT's not something you can pick up an article or a book for. You can really understand how people work with one another and see where those people are. You have to be around long enough to hear their stories. So how spacecraft and missions can be improved. That's one of the things, I did a mentorship at UW with HCDE and with interaction design. It's a missing component because you can't be at JPL, talking to people. Flying spacecraft and missions are pretty sparse so for me, being part of the culture and open to asking questions and turning questions into sketches or diagrams that I understand so far. Active participation of what people are willing to share with you.
- I think what you're doing right now, talking to whoever you can. Drawing flow diagrams, for adverse experiences, areas of improvement, etc. If you were here, you'd have to put it in anecdotal form and socializing it. Put the flow diagram in front of other people. Sometimes you hear things and put things in front of them. They read all the presentations on science intent and they don't test the powerpoints and they don't see where their rover is and what their experience is. What are some of the things that can be improved.

How do you create storyboards for this? A lot of information is high level and not detailed. So we don't feel like we can create storyboards.

- A lot of my storyboards look like "i opened my laptop, etc.". I'd have to see what high level thing you're talking about it. Sometimes if it's high level then when you show it to people they tell you "oh it's not like that, etc. I was being vague" I really empathize with where you guys are coming from. You're trying to design to a problem space and you don't have an opp to come down here and work. One of those things that is annoying about JPL is that you're working in a domain that is not common in other businesses. You don't have enough examples and documentation available for people for flying spacecrafts and missions. Just having the right type of schope. The scoping was a big deal for my people. Having your storyboards and your artifacts relating to one specific problem is helpful.

Because we don't have access to people on Europa mission...It's a little bit in helping us understand what we have available to fit into that scope. Speaking to Cassini, etc. How do use broad information to fit within a scope that we might have. Advice to students for prior years?

- What i did differently last year that i had them talk to people who were only do Mars related stuff or geology stuff. We wanted to make immersive experience for geologist/field work to annotate an environment so that scientists and achieve their science goals. So i sent them off to talk to Geologists and going out into the field the characterization of different geological environment. That's the type of thing mars mission needs would do without being part of the missions. That helps. One thing you guys run into is that you get info overload so you just have to figure out what you need to do. So i think one of the things helped...Europa missions is Phase B?. What helps is having a problem statement that is clear, we're going to do A so we can fix B. Super concise problem statement is going to help you out a lot. That was something i figured out last year. Start every meeting with a problem statement and build your research around that goal. This is how mars 2020 was doing it, this is how europa is doing it, etc.

More recently, b/c of the confines of not being able to talk to people on europa so we're trying to pivot our question

- What problems have you uncovered so far for Cassini:
    - Issues with how instruments work together, pointing compromises
    - Issues around automation (some but not robust)
    - Could we increase collaboration around instrument teams?
    - Constraints in real time?
- What science questions do scientists have? (P8) What are the science goals, what are the realistic science question a scientist might ask? So you can see what collab looks like, etc.
- How collaboration at a human level might work and then on a design level what you want to tackle. A lot of the stuff you're on Cassini, myself, and anyone who you're going to contact. From phase B, you're not going to be able to talk to who because they just don't know what that looks like. Having a thought out research question and what you're tackling is what you're tackling. They don't care enough about what the final mission operation concepts are going to be. They're going to care about whether or not they're going to achieve their science goals.
- Sometimes there is animosity across missions, "we're not that mission". Be careful referencing other missions.

P 8

Is it common for when missions are in phase B, that they are restricted?

- They're super busy. There are a lot of mission planner, bigger picture but not just small details. What type of meetings are you going to have during different points of the day. It's one of the newer points in the lifecycle of the mission.

In your research, is there an analog you can think of, type of user and aspects that might help us, give us an understanding of the type of user that it's hard to glean from the outside?

- My people are usually rover planners (planning out where to drive out rovers), downlink (health and safety), geology team - designing tools to identify areas an environment that is scientifically viable. If I wasn't able to talk to JPL people then I would go to universities and talk to people who care about parallel things. We had geologists calling in everyday from UW who are interested into Mars. People who are interested in Europa, might be useful to talk to. For the engineers, it would be hard to find an analog to them because they're studying data that comes. Maybe antenna people or people who are specializing in communication engineering.

How much info can you gather for use types that would help for designing. Do personas make sense?

- I think one the things that comes up with exercise, taking up a small problem with JPL is kind of just to demonstrate, the amount of info you're thrown at, you can distill it into something that allows people to understand how you understand people and their tools. There seems to be a variety of people but this is data that makes us feel that there are individual needs. Clearly we need to do additional research, etc. After we do all this research this is what we understand. "We're limited in what we can collect since we're students" but, you can see this is what we found out.
- If I was your mentor, i wouldn't be harping on your amount of research. I would just be looking to see if you can be resourceful, can you demonstrate a variety of ways to solve this problem, given that you don't have access. There is enough for you to explore this problem space. Here is how we scope things down and the skills that I would look for. Scope things when you don't have enough data.

I just wanted to ask, we're all fans of your portfolio, etc. But specifically, how to test your prototypes?

- What you should do when meeting JPLers for the first time- be very clear with your participants that you're not testing them, you're testing your tool. You recognize that maybe your tool won't facilitate all their needs. The reason why I'm harping on this is that "testing is meant to test the person's intelligence and everyone should be on their guard when testing is involved" Perhaps, phrase it as a “usability study” or something else, but phrase it as you’re a student and run it by you. There are going to be things that are wrong and we want your expert advice. “This is alpha”

- Nice clear script you can pass onto them, hey we’re just going to do these high level things and obviously we want to and then have details when you show up
- Help people understand that you can give whatever feedback and process. They’re new to user centered design so just let them know you want their help.
- I would bring in storyboards and example of my research. SToryboards to capture the scenario. Based off context, here’s our board, etc. This way they can correct you to understanding of the problem
- It’s helpful to have someone shape your understanding of the problem. I hate this tool, this is why we changed it.

How about how much data to put into a prototype? A certain amount of actual information for people to make a decision on the interface?

- I just always just run it by someone I trust (designer on the team to showcase some of examples of what i want them to look at). What type of information would people be required to look at? Sometimes to run by P13. Geological pictures, objects, etc. So you can supplement your usability test, these spacecrafts and what your spacecraft covers. Running it by P13 before you deploy it to other people. I’d totally volunteer to look at your stuff before you head over there. It’s a hard call because absence of data also gives you more info.

A lot of these interfaces can be data heavy. Making sure someone doesn’t get hung up on something that doesn’t matter for us. Making sure we get the details right so they can read the interface naturally that we can then record the responses for.

Participant 9 Interview Guide

Participant 9

Scientist Engineer

Profile

Roles:

- Member, LRO and Chandrayaan -1 Mini-RF Science Teams July 2006 - Present
- Member, Mars Reconnaissance Orbiter HiRISE Science Team December 2001 - Present
- Member, Mars Exploration Rovers Science Team August 2000 - Present
- Associate, Deep Space 1 MICAS Science team March 2000 - Present
- Participating Scientist, NEAR MSI/NIS Team August 1999 - July 2001
- Associate Imager for Mars Pathfinder Science Team July 1996 - August 1998
    - Member, Data Products Working Group, Geology Science Operations Group
    - Chair, Photogrammetry/Cartography Working Group
- Member Mars HRSC Science Team March 2002 - Present
    - Associate January 200 - March 2002
    - Associate Mars 96 HRSC/WAOSS Science Team March 1993 - December 1996
    - Member, Photogrammetry/Cartography, Data Processing Working Group
- Member, Cassini RADAR Instrument Team December 1990 - Present

    - Chair, Data System and Cartography subteam
    - Member, Operations Planning subteam, Cassini PSG Solic Surfaces Working Group, Titan Geodesy Working Group

- Magellan Guest Investigator October 1990 - September 1994
    - Member, Magellan PSG Stereo Analysis Working Group, Reprocessing Working Group

- Associate Voyager Imaging Science Team 1989

Introduction

Hi, P9! Thank you so much for taking the time to talk with us.

Just to give you a little more context, our team is working with JPL's Ops Lab to improve the efficiency of uplink operations for the Europa Clipper mission, potentially using assistive software. Through interviews with experts like you, we hope to learn as much as possible about all the variables involved in decision-making in orbiter missions, including the people involved and how scientific and spacecraft data informs uplink commands. Although our research and future design implementation is focused on the Clipper mission, we greatly value any input specific to other, similar missions, as our solution could potentially be applied to future operations.

We'll be sharing your responses anonymously between our UW research team and our advisors at JPL.

Do you have any questions so far?

Before we get started today, we also want you to know that we would like to record our interview with you as a full transcription of your responses will be greatly valuable for the purposes of analysis. Is it ok with you if we record this interview?

[If **YES**] Thanks so much for your cooperation. We're starting the recording now.

[If **NO**] Not a problem. We'll continue without recording.

Questions -

Walk us through a day in the life of...

- Once the spacecraft has started sending back data...
- There is an anomaly in the data, what do you do next...
- You think of an opportunity and want to see about getting the plan changed...

What is the structure of your instrument team on the Cassini mission?

- Is this different than other instrument teams?
- How do you collaborate remotely?

How do you keep track of your science objectives?

- Is this different after the mission has launched?
- Do you have new objectives after launch? If so what are the steps for how these come about?

Tools used to plan an activity?

- How involved or removed were you from decisions made about the spacecraft?
- How not for planning how did you translate research data into action?
- What tools do you use to collaborate/communicate data?

How are observational geometries determined?

- Do they change when new data is collected?
- How do you decide about what should change?
- How do you communicate what changes you would like?

Help us understand your team's priorities during Cassini mission?

- Does this ever affect other teams?

Is there any communication across different instrument teams?

- Do you know their plan before plan integration?

What type of requests are you sending to science planners?

- Is there anyone else you need to communicate with to have the plan changed

NOTES

Introduction

Consent given, private and public ok.

Notes begin:

I've been involved in more than dozen missions and most of them had no operational planning. Cassini had more but it's more of an unusual case but i'll explain more in a minute. The science planning for that was more complicated than it was for other missions.

You said the missions you worked on had much way in activity planning?

- That's not true at all, there was planning, I just wasn't the one doing it

Can you tell us about the work on instrument teams? One thing we've found surprising, that within one instrument team, members can be scattered around the country. What is it like collab-ing with other people. How did you collaborate on your science goals and research goals?

- Maybe i should explain first what I do that is different than what other people do and that informs our role in a lot of teams
- I am a physicist by training and i do some science in form of geophysicist of planetary surfaces and processes. I got interested in remote sensing and mapping and we have a lot of image processing expertise at USGS Flagstaff and we make controlled...and my group makes topographic products by analyzing stereographic readings. I've been a ... in a protector of in geo...If you have want to do stereo

you need two overlapping images of the same thing and they need to be around the same res, and from two different but not too different directions, and not too different illumination because it interferes with the process. Providing criteria for those things on different plans missions is what i provided on different missions

- In the end, a lot of my work is analyzing that data and making those products
- On Cassini radar team, I've involved in discussions in person, we gather 3x a year and did for mission meetings and we also typically got together at JPL when there were fly by within the radar set coming when those were happening at a rapid pace then we might not do it on everyone but maybe weeks apart. Then we interact in person there. People have their scientific interest and then i would have mine then I would make sure various operations were planning and we made topographic decisions for most people on the team
- We did it mostly by email and there wasn't much telephone going on
- Radar team had a weekly phone conference but rarely on webex, we would usually just email things out when we had something to show
- It was viable and slow place, and degrees of freedom in observation planning. In Cassini, teh mission tours, the encounters on different bodies. Titan, my interest were fixed and planned early on. And then there was a process in which which instrument would negotiate on which fly by and adjust based on altitude and which part of titan the spacecraft would pass over. Then when we had flybys assigned for team, the scientists would get together and decide things: 1) should the radar look to the right or left of the groundtrack during fly by 2) should we put them here or there. This was a simple conversation compared to instruments like the camera that would take thousands of images on a certain fly by

I wanted to clarify your role a bit. You were responsible for identifying constraints. Did you have to determine the right type of observational geometries that the team needed to collect the right data. And other people were more interested in analyzing that data for research output? And you were

- In general across multiple missions that's a fair mission
- On Cassini, because of constraints, we only had the opp to pass over certain select areas of Titan there was much less to be done. I couldn't dictate we would look at this place or this area. I looked at opportunities that might be useful scenarios then i worked with other people and which were the ones that were most scientifically research
- I have done scientific processes in collab with other people and usually I was part of a team and leader of individual efforts like that
- The others did not have the capabilities to turn data into topographic products so that wa a service i provided

In terms of collaboration again, how did you work together to prioritize. We know a little about the negotiation process on cassini, a lot of the time, the way allocation was determined. Each instrument team would prioritize their flybys or a certain part of the activity timeline to observe. Does that sound correct, if so, how were those priorities determined and what role did you play in determining which fly bys were most important. I'm speaking about Titan right now since we've heard mostly about Titan and not about ring science

- There are relevant things between Cassini and Titan and Clipper and Europa. One of the constraints that the radar has that other instruments don't (other imaging instruments don't) is being an active instrument, being an active instrument we are range limited. The...with most detailed images, it only works up to couple .... Kilometers. There other modes like radiometry that can work in longer distances. That got a list of flybys with known ground tracks that could be put in front of the team and which ones are super important. Those decisions as to what are the priorities were made pretty early on in the mission so we were kinda winging it. We had a crude tree of Cassini maps of Titan. We knew we wanted to observe the poles, we wanted to observe..., we didn't know a whole lot beyond that. So then, there were two competing criteria 1) to some extent, we wanted the fly bys we choose to well be distributed and away from each other so that we would cover a lot of territory and see as much of titan as possible. To some extent we wanted it to be coordinated so we could have two tracks over the same area so we could have tell symmetry on one fly by crossing over another. The person to talk to about this because the radar team sent a representative to TOST is [name omitted]. He was in it up to his eyebrows and figuring the flybys and which ones to. After we have a list of flybys then we would come by to the science and how we want to use the flybys the capabilities evolved and sometimes we would start out looking left and then looking right. We would missed the middle but got some good ones it's fine to miss the boring ones. It's always a struggle between covering the more area the first time and going back to certain areas to doing complicated things. It includes stereo, altimery, or imaging or altimetry. It included looking for changes in the polar regions. The more we saw that, the more we saw features that would come and go. Anytime we got anytime close to it, we would try it. Even if it would mean diverting the instrument temporarily to pass over there.

In case like that, i was wondering how you responded to new data? If you collected an obs at the poles, were there any cases where you discovered something that told you you would need need another observation in that area. In that case how did you negotiate an obs in that area if you weren't schedule for that. Does that make sense? It's kind of disjointed.

- At the point of the mission when we were discovering interesting new things and trying to optimize our targeting, we were pretty far long time. No one ever wasted time discussing changing the tour, ground tracks. To my recollection, there was no desire to change the allocation of fly bys. One thing that was helpful in that regard, segments of the mission tended to be repetitive. For ex: when the inclination of cassini's orbit around saturn was low and staying low for a while for certain goals like small satellite flybys then all the ground tracks would go around the equator of titan and it was the matter that some of them were on the saturn facing atmosphere and when the inclination was being increased on decreased because there was a period of ring obs, then the titan groundtracks would go over the north or south pole. This resulted in bundles of rather similar flybys so diff instruments were able to trade those off which each other and not usually not too upset on exactly which one of that bundle they got.

Just to clarify, what does ground tracks mean? The area of titan you're observing?
- No, it's the point directly under the spacecraft.

So when you say the radar would look left to right what do you mean?
- It's done at the function of how radar operates and the point is to form an image we can't look straight down which is the ground track, we have to look to the side
- Typically there is only a narrow range of angle to left and right that we can operate in. if we look too far out, the target is too distant. If we look straight now, the the image is distorted. So there is a narrow range on either side of ground tracks
- THe instrument, we can look where we want only within constraints. We have total freedom on L&R
- The camera doesn't have range constraints. Range determines resolution but you don't have constraints on angles although there only a few reasons to look all the way out, usually you want to look vertically. Their big constraint is that night imaging is not great, day imaging is the best
- I'm going to try to answer your question, most of the decision in the radar team had to do with the left and right within the already set flybys and a little bit with tweaking the angle we're looking at. We really have to look at some type of titan data to base that on. We flew over the north pole once and we found there were lakes and we flew a second one (scheduled anyway) and we found larger seas and once we started to level cover the area, since it fell out of the overall plan then we found the magic island. So the we started talking deliberately to target it again and again even if there was a bit of a stretch for the instrument. The other thing was was that the ISS camera was able to see lakes and seas in the polar regions and there were areas that were extensive and we can see, we'd target there. The third thing was that there were capabilities of instruments that we didn't know when we started out. The altimeter was able to measure the elevation of the surface on the point under the spacecraft on the ground track, it could see into the lakes and get a double return from the top of the liquid to bottom of the liquid and shows you depth of depth and tells you something about the com-

position as well. It was incredibly exciting and we opted in some cases later on that when we had a fly by and we took some time or learn more about it.

You had activities scheduled and you didn't have to negotiate much?

- You can call it negotiating between the team, it was decision making within the team not negotiating resources with other teams

How did that change in mission extension? It doesn't sound like those were as planned out for missions extensions. They had to happen more rapidly. Because you had data from the prime mission, it may have been easier to plan that, how did things change for activity scheduling and decision making between instrument teams

- The tours, and definition of orbit, and where cassini would go. That would create for the extended missions before they were approved because you have to plan early on where you're going to fly. And the assigning of flybys to instruments to done quite early as well and the main difference there was that it was possible to do it more intelligently. At the beginning of the mission we knew very little that was on titan. We need to get some fly by opps and the right distances on the day side with the light. Opportunities for each of the instruments to try their stuff and where on titan we were looking because we didn't know where anything was. When we got to the later fly bys, we knew more about titan and we could say we are very interested in the poles because we know they have liquids because we know this area is interesting cus it might be volcanic. So the negotiations to choose flybys were at the higher level of negotiations. And how to use the flybys within teams, it was pretty similar except we had discovered more capabilities. Initially we didn't know we could look right and left but the engineers invented that and we knew that later on.

I'm wondering about collaborating with other instruments on data. How did you find out for example, the imaging subsystem discovered some capabilities during the mission? HOw was the data shared with your instrument team? What tools are used for sharing data across teams?

- That's a good question. I'm not really sure. The basic radar data were made avail to the whole cassini team fairly quickly after each fly by. But cassini is a mission looking of separate instruments of team leader and they set their own policies so some of the teams were open about sharing their data than others were. But all of them would publicize interesting images and obs and the instrument and radar would make mosaic and all kind of products and some of those would get distributed and made available. That's how we knew the ISS camera could see the lakes and sea in north polar and saw new areas for us. There was no software, it was creation of static products that were emailed me around. This is a very old mission, I have been on the mission since 1991 so lots of old people and old people. We got away with pretty old fashioned meetings and collab

How fast were results shared?

- Within a week for one interesting observation. We would sit at JPL and look at the flybys and there are noodles that are 10 of thousands of lines long and we would go through them together from end to end. We would look at the feature, and see if we've seen them before. Is it a type of features of we've seen before? If they were not worthy or photogenic we would clear about those areas and someone would write up a report and do a image release right away. The other teams were around the same way. If one exposure showed something pretty interesting, saturn and the rings, etc. But there are other types of products that got releases made that took much longer. Mosaic took, models based on data from many many flybys (bits and pieces come together and finally get a coherent a picture) and so it varies.

Going back to software and tools, you said that there wasn't a lot of software use in general. What about within your instrument team. How did you determine which way you were going to look and which side of the ground track you were going to observe? How did you visualize that.

- That was done from the POV the science teams. There were people at JPL that could take the geometric description of the fly by and the base map of titan and create a footprint of what right and left imaging would look at on the map of titan. And that the map of titan would have a map of the radar imaging and the options of where we might choose to observe. This was a one page, one slide product of what we are going to do

Who produced those types of output?

- Radar engineering team. A. Anderson who generated a lot of these slides.

The general structure of your radar instrument team. [name omitted], was he chair?

- [name omitted] was a science team member and we had associates who had the full rights of the science team members and that would be people like graduate people and post docs that were doing an immense of work and data
- [name omitted] had an additional title of TOST member since he went to those meetings
- Apart of that, he was one of our team members
- Then there was an engr team. Essentially at JPL who wrote and entered the sequences and managed the process dataset on the website we got the data off of

The engineering team included people like system engineers?

- Yes

And I'm assuming an investigation scientist who was responsible for coordinating between scientists?

- The radar was a facility instrument, the instruments that were proposed by someone writing a proposal in response to a call from nasa. The person heading that proposal would be the principal investigator and they would choose their own team
- The facility instruments, nasa started off by saying we can have a bunch of instruments but we must have a radar so someone should propose adn build a radar and build a team.
- The one thing that was unusual was that the guy that wrote the proposal and ran the radar and he then became the leader of JPL so the deputy team leader became the team leader and that was [name omitted]. He would have a lot of interesting stories to tell you. Among other things, he would be the very best to suggest the who are the best people to talk to about any certain issue. [email address removed for privacy] He's OoO because of medical but he has been responding to email.

I'm wondering about the tools again, were there anything you wished was different about visualizing or analyzing data or any kind of collaboration tools that you wish were in place? Were operations smooth considering the lack of software tools?

- Given the way the radar operates we got away with what we got ok
- I would have a different view if i had been on the camera team. On the camera you have to target every individual frame. You have to point and get the right filter. And that is more scheduling work and you need more tools to see what images are

I'm on Europa imaging camera team

- It's going to be a combination for the two we'll use a close flyby and use a wide angle camera to take a noodle of images under the spacecraft. In this case we look at the ground track rather than the left or right.
- That's kind of a done deal.
- We can take 4 very high res images at a varied angles
- Which one should we double up and take stereo and that's going to need real software complexity to display those opportunities and hypothetical choices on top of everything you know about Europa, which means you know the existing maps going in... more and more clipper data as you go

Is software like that being developed?

- I don't know yet. There is a history of tools like that that have been used
- One of them is a java based tools, JMARS, JASTROID, etc.

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- What have we got so far on the Europa camera team is people writing typically IDL/Matlab programs to evaluate full range of possibilities so we have a definition of where the flybys and where are the sun is going to be
- Ex: If we need the sun to be 10 degrees and the resolution depends on the range then what areas of the fly by can we potentially image at? We have maps of these sorts of things but they're only a guideline as to where future decisions would be made.
- A large part of europa could be imaged at high res but if you make a choice in one area that rules out obs somewhere else because of time and data volume so you won't get all of europa on high res you'll get on a large area, a small tiny area. We'll need tools to figure that out. It'll require people to work on that, it's not entire science teams trying to visualize what's on their head

- Another team i'm on the MRO camera team, it's a high res only camera. It shares the spacecraft with other camera. In certain orbits, there are certain number of images that they can take but it can be done on diff latitudes of the orbit. On any given two week period there are a number of orbit, you have opps on the two week period, which 10 of them do they obtain images at. They use the JMIRE software to see where the software is going to be and where it could be. It lets them see what images are they taking with high res in the past so they can go back and get the second half of what was attempted. It lets them evolve the science and the whole world is able to make requests or suggestions for areas they want to observe. Then there is one person who sits down in that process to go through in that scheduling and someone else does it. They look at what's possible and they try to weigh the science priorities or program priorities then they're huge landing sites. That person gets obsessed with that type of stuff and comes up with the plan and this what we're going to do in that 2 week period. Based on earlier input on what

Is that person a science planner?

- That's done in rotation by scientists on the HIRISE.

Is there a chain of command when on rotation?

- No, unless someone messes it up. People are very diligent on
- Each team member might be their science interest, it might be volcanoes, atmospheric, etc. it's acknowledged that their interest area is going to get more attn then other topics.
- The person who has that info so people have more topics than most people

Balancing people on teams?

- HIRISE yes, on cassini radar team, yes

- In other teams and team psychology of trust varies a bit. Some are less functional than those two which are really good mature well interacting team. Which

Why do you think those two teams are more successful than others?

- The personality is set by the person building the team. [name omitted] @ University of Arizona is on the team he's on everything. He is the PI of HIRISE what is the secret? And some teams have meetings and PI needs to read the rules before the meeting. Don't pick people to be on your team that you don't like working with. We don't have rules of the road, we had a two min discussion but you assume you're all grown ups. Don't screw each other, play nice, have a nice time. If it's not working, I'm going to have to write rules
- Some other teams there are rules of the road. We will do this and that before you have rights to see any of the data. A large part of it is the PI is that the personality of the people they select and the nature of the instrument and the data and how much analysis before they can do something useful and something like that
- These kind of trust issues come out more strongly between teams than within teams some teams have some a fortress mentality and this is ours and even though you're on the same spacecraft and we can collab and we're not going to show you my pretty pictures and others are open.
- Europa, the management from the outset try to cultivate open and collab arrangement. The statement is that we don't have instrument teams, one team with multiple instruments and ofc people have their focus areas. Everyone on clipper is encouraged to see all the data and encouraged to work together.

What are some reasons someone or team might become paranoid?

- It can take anywhere up to couple decades of fairly strenuous effort to have an idea for instrument and flown and used to get the data in their hands and then you write a paper before anyone else you get your moment of glory that's the pay off. If you have bad experiences of being scooped in that process you're likely to feel very betrayed

Can you speak more about the team and team vs team vs outside?

- More paranoid teams people usually trust each other there are isolated incidents that someone decides to publish a paper on someone else and not talk to anyone else. In the really healthy teams the reaction is that person is don't do that again you should've said something! In the more structured teams there was a harsh reaction and publishing and throwing someone off the team and making the set of rules to signing on team and who knows what.

Social aspects of team dynamics recommendations

- Janet Vertesi and anthropologist lived with various tribes of planetary scientists

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- That is published as a book
- Her insights have been really useful to us and the foremost is that every-one mission has its own culture.

Participant 10 Interview Guide

Designer

Profile

Participant 10

Part User Researcher, part Systems Engineer working on Planning and Execution Software for Europa. Has also done UX work (VR/AR systems?) for Mars missions.

She was involved in measuring human performance in complex systems. She participate in data collection, data coding, and data analysis.

Research Interests:

- Human computer interaction
- User Experience
- Situation Awareness

Introduction

Hi, [Participant 10]! Thank you so much for taking the time to talk with us.

Just to give you a little more context, our team is working with JPL Ops Lab to improve the efficiency with which activities are scheduled for orbiter and flyby missions. The team hopes to combine some scheduling software like those used on current missions (SPIFe, M-SLICE) with data visualization to make it easier for the ground systems team to respond to incoming data and any conflicts that may arise during the mission. Through interviews with experts like you, we hope to learn as much as possible about all the variables involved in decision-making in orbiter missions. We really hope we can get some suggestions and feedback for our ongoing project.

Do you have any questions so far?

Before we get started today, we also want you to know that we would like to audio record our interview with you as a full transcription of your responses will be greatly valuable for the purposes of analysis. Is it ok with you if we record this interview?

[If **YES**] Thanks so much for your cooperation. We're starting the recording now.
[If **NO**] Not a problem. We'll continue without recording.

Background & Roles

Goal: to learn about what it's like to be a UX researcher and Systems Engineer

What is the group of Systems Engineers like? Is it a diverse group?

What are your responsibilities as a Systems Engineer?

- Are you responsible for just one instrument?
- What kinds of software do you use as a systems engineer? Are you working on designing any software for that role?

What is it like to be both a UX researcher and a Systems Engineer? How do you balance both and how does each inform the other?

- How was training for the Systems Engineering role? What kinds of things did you have to learn?

Research

Goal: to learn about participant's research experience and methods for working with JPL personnel

It's our first time working with NASA. The knowledge domain, which is orbiter mission, is new for us. Also, as Europa clipper mission is in the starting phase, there are too many unknowns on their structure. Based on this situation, what do you think will be the good research direction for us ?

- For this unfamiliar knowledge domain, how do we effectively capture useful information from research?

- Seeking suggestion for our current dilemma

When you are doing your first project with NASA, what do you think is the biggest challenge?

- How do you solve it?
- Are you doing primary research on site or remotely? How do you collect user needs?

We know you have great experience in designing visualization for engineers for monitoring flight safety, is it also related to decision making?

- If so, how engineers make decisions through the interface
- How data visualization inform decisions?
- How do you know the prioritization of data?

In terms of tools and platforms, how do you decide what platform you want to apply for the data visualization?

- Based on our scenario, what platforms are you envisioning from your perspective?

Based on our knowledge, you researched in human performance in complex systems. Based on our problem space, what are your design recommendations on managing complexities and data visualization?

- Regarding different constraints, science objectives, and resource allocations, how do we facilitate these data to help stakeholder make decisions efficiently?

User Test and Prototype

Goal: seeking suggestions on remote user test and prototype

We are not able to test on real users, which means that we could only test people on similar orbiter missoins remotely. We have rare experience in it, any suggestions on it?

- How should we frame the test to make it more valid?

In terms of tools and platforms, how do you decide what platform you want to apply for the data visualization?

- Based on our scenario, what platforms are you envisioning from your perspective?

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Pertaining to our project

Goal: to get suggestions on narrowing down the problem space and improving the current research plan
(describe our problem space and context)

Are there any valuable resources or artefacts we can refer to?

Are there any people you think would give us some useful perspective to us?

Do you have any other advice?

NOTES

Introduction

Consent given.

Notes begin:

Can you tell us a little about your background?

- My background is a bit different because i'm start off as human factors psychologist that's what I'm in undergrad for. Human factors focuses really on usability studies, the quant side, metrics, and psychological/controlled experiment stuff. That's what I have training in, I came to JPL to do that. I had to do some of the UX tasks, like visual design, that kind of stuff that I didn't learn in school. I have come into role at JPL.
- At a human factors grad, you get some training in systems engineering. Like requirement wrangling, workflow diagrams, etc. In psychology you write a ton. You make organization out of mess. Making actionable items out of qualitative data.
- I started as a UX researcher for quant assessment of some software tools. I worked on software going on ONSITE (hololens mars app). We render the terrain in hololens to see mars, i'm still on that project. From that I got pulled in being a systems engineer on Europa Clipper Mission. Lots of roles overlap.
- As a systems engineer, you go to a lot of meetings. There are a lot of planning processes. It's like inventing a new company, what are things everyone needs. How do we plan and budget for that. There is a lot of brainstorming, organization, talk to different people and make sure everyone is on the same page. Human

factors come in handy there. But basically my manager thought the skills I learn from ux researcher were useful to systems engineering so i got into that position.

Is there a specific instrument you're responsible for?

- No. I'm responsible for the planning and execution software.
- How familiar is it you. Basically you have to get all these instruments, on Mars it's everyday. On Europa it's every two encounters, we plan the activities or the science that is going to be done. All the instruments are going to have their activities. All of this gets integrated into planning and sequencing software. The central point which everyone's plans get into. IF i use any jargon you need me to explain, let me know. It's very much on the software side. We need to decide What kind of software capabilities do we need to have to accomplish the goals mission operations people need. If mission ops person says we need to know what data came down and w/in 6 hrs make a new plan, then we think "what software rolls in that". You need automation for that 6, hrs is a short time, you need to show the user what they got down.The software capabilities you confer is needed for the process people are planning around. That's what i do. Your first guest is right, there are science planners. The science planners take the needs and desires of scientists. Scientists want to say "I want to take a picture up there, I need to do it at this time b/c we're flying by at 3pm" then the science planner goes, OK, I need X by X picture of this feature on Europa and it's going to happen this time so I'm going to translate this into an activity I can feed into a software which is the P&E software. Planning (what i'm going to do), Execution (what you're going to send to the spacecraft and complete the actions). Science planners are our main users and what we deal with.

Some of our earlier experts have been in the expert domain of planning and scheduling. And we learn about the difference in planning and scheduling. The tool you're targeting is planning specifically rather than scheduling?

- Who did you talk to, it might help you
- If this instrument is going to do this for
- Planning is a higher level thing. Scheduling is more detailed schedule. If i say this instrument can work this altitude, looks like we have window here we have to schedule that. For the actual sequence i need to model the behavior of the instrument to make sure it have the power.
- I need to see if the pointing is correct, some high fi modeling that needs to occur to think of sequence
- Scheduling is the higher level thing
- Let's say you're going to bake a pie, certain order of even I need to make the pie and I say there is a window here I can use...I don't know where I'm going with this. Between 3 and 4 i can put the pie in the oven. After you do your more fine

- tune scheduling it's maybe between 3:15-3:48. You find more details afterwards to refine the plan.
- When you schedule things, you schedule things not considering all the constraints cus that's too much for the software. So you make the high level schedule for the entire mission and then as you get closer and closer to the event (two weeks out), you model it at a higher fidelity (a real schedule we can send to spacecraft). The first sched is for humans to plan with each other to make sure we got all the science we need, the next one is making sure we can implement it to send to the spacecraft (do we have all the battery power to do this plan, if so, maybe we have to make this one activity 20 min shorter. We can still do that activity, but we have to make it shorter. It's higher fidelity of detail happening is the software)

Can you watch us into the details of how science planner coming into that software. What info do they have externally outside the software. What is the process flow you are having the modeling software off of?
We are accumulating the requirement of the software. Rover dont consider pointing, because they can point the camera wherever they want. All pieces can move independently. But for orbiter, if you want to change the camera, you cannot do that, because there is gamble, you want to turn higher spacecraft, so one activity one activity affect other instruments so you need to model pointing.

- To answer your question, I can't answer cus we don't have the workflow down or what software we are using.
- My job is to work for the subsystem needs and to gather requirements on what people want to do and how fast they want to do
- I think you need to know anything about planning and sequencing its' cus everyone does this on any mission
- On any robotic mission, orbiter or rover, you have some similarities
    - One, You have multiple instruments
    - Two, Usually not colocated, teams are all over the place, there are scientists all over the place
    - They all need to make their activities
    - There needs to be a central point where everyone puts their plans together and you model at higher fidelity we send to the spacecraft
    - There are some similarities that exist for all missions

We can't understand the interactions between people, can you speak to a legacy process on how the science planner gets the constraints that they know they need to get a plan back?

- I would point you to the book by "seeing like a rover". It give the overview of how spacecraft operations work in the first place. It tell you How do people work in first place, people need software people they need that role because it apply certain accountability for certain product, People are shift which you have schedule work for them they say they are on shift, meaning that I will be science planner for tues meaning that Il show at 8 am and leave..Everything is Europa is too early to tell the workflow. One way we know about constraint is that we define spacecraft behavior activity definition. You have activity definition..

- If i take this picture, I need this closed to the planet, i have this 8x8 frames for this picture, this far from surface, this much lighting that's kind of a description of what the spacecraft, constrains the spacecraft behavior to the definition so we can understand what it's doing and how much resource needs to do that. Maybe that activity cost you 20 percent battery.
- Video game. You have different spells.In different spell there is cost associate with in Mana..
- There are differences between active and passive. For active spell, things you are doing cost some amount of resources. it turns on and off when it is off it's probably costing resources at a fixed lower rate you know what i mean. Activities function on the same way, you are not casting a spell, you're making an obs you get a data product back. Maybe it's picture, maybe it's a geochemistry unit.
- You tell the software i'm going to do this activity and it knows that it's going to cost this much battery for you. Maybe you can't do it at that time because you're not going to be equipped to see that feature.

And so the orientation of the solar panels is that sort of refueling the potion?

- Using that analogy, those are ways
- Anything refill that power, you can use a way of doing it. At a high level, you think of your resources of manna, anything that replenishes your manna then you do more resources.
- Curiosity rover goes to sleep to conserve energy and it uses an RTG (way to give spacecraft energy, similar to solar rays can give spacecraft energy using the Sun) or how much power you have

The role of person taking into accounting these constraints? The process those people communicates back and forth would it be the instrument teams the science planner would be mentioning like hey we can't do that we have these engineering constraints. We don't have enough power, whatever the constraint might be?

- I think that's reasonable. We've yet to see how it works on Clipper. Different missions have different workflow. Yes, The science planner can go and look look at these constraints and tweak things a little bit and go back and check with the scientist you know we have to move these activity over there is it ok? cus it's at 10am instead of 3pm cus the lighting will be diff. Science can say, yeah that's fine. Or sometimes they aren't ok with it. How much it is ok? There is back and

- forth, whether planners are talking to scientists or someone else to get science perspectives, it varies. Sometimes there is science representative, or sometimes maybe people there is engineering constraints scientists talk to engineers about that. On MSL they might talk to rover planner, the scientists really want to get the rock, the planner might want to say “Oh that hill is kind of steep so we can’t do that one, what about that other one. Once they come up to the decision, the science and planner work something out and they come up with a solution”. The planner is responsible to moving the activities in the software. They don’t have to interact with the scientist.

A little more about that interaction not with scientist, would would it be? Investigation scientists? Is it someone who is in charge of thematic work group?who is the representative

- It could be, it’s going to be an unsatisfying answer. It could be a lot of people. Sometimes it can be someone who is on shift for a certain role, maybe that role is responsible for making sure someone gets into plan, could be thematic working group. We wear a lot of hats. Someone from the thematic working group might also help the planning for the mission. They might interface with science planner to make sure scientists get what they want to have. So they work with longer plan. Someone who is part of this might help with something else.
- I don’t know if IS would fill that role? It might be the same person but it might be called something else. IS is not something I’ve heard of ops before but I’m new to JPL so i’m not the most knowledgeable.

At external sites, those responsible for certain instruments, would it generally not go to the PI. It would go to someone who is responsible for going through those sites for that instrument?

- I don’t have firsthand experience so i can’t reallys say but i would say that the PI is not doing the day to day planning. They probably have somebody who is in charge of making sequences for their instrument. Interacting with their software or their science planner at JPL or wherever the homebase of the mission is. I’d find it unlikely that the PI is making the sequences. They will be involved on the high level schedule to make sure they get the data, all these instruments have L2 requirements for data they need to observe. For day to day they are not the PI is super busy.

FOr the tool you are designing, would you ever envision you would have multiple roles day to day? But you’d need to glance at it in an admin capacity?

- It’s so early that i have no idea.
- We’re going to design this tool to fit in.
- Have you heard of the distinction into MOS or GDS?
    - I only bring it up because there is a mission operations and there is a

ground data system (GDS is all the software). We want to make our software around what the mission ops wants to do. Even though I might have ideas on who might be using the software, ultimately i want to make it so i am designing softwares the mission operations imagines. So it splits it up. I wouldn't be the person deciding who is using the software, somebody else decide this cos they make the high level plan. I think it would be our job to make sure that support all those users which means one person is in the details and they're in the plan.. The other person cares about high level stuff they just want to look at it. To me, it makes sense but it's too early to think about who are users are going to.

We know how early it is but we're working kind of blind out of there. Is there is a 1, 2, 3 user. Is there a hierarchy like that? Is it mainly meant for a certain type of user. Based on previous mission s other roles are going to peek at this, what's happening next?

- For my planning and sequencing subsystem our primary user would be science planner that could be the person at JPL and some instrument representative whoever is making the sequences who would want to look at our software at all. They are most concerned with the plan and the stuff we are going to do.
- People love powerpoint, people might want to take photos of the timeline and share
- ANyone who makes the sequences is prime users. Science planner or instrument representative whatever that role would be.

Testing possibilities say something on the instrument team to say something is even possible would that be outside of the realm as possible features for your tool? Is it after the decision is made after, they want to change something based on observation? After downlink there's a change to the instrument, maybe there is an opportunity. Are those what ifs what you're studying as well?

- Yes, we will need software to do what if scenarios, i don't' know if it's two different pieces of software. One is primarily for plan or second for what ifs.
- But people do need the place to see how does this change effect. What is the butterfly effect of me changing this one thing. We absolutely need to do this, a capability that is useful.

Do you have any recommendations, ideas on how certain representations of that can occur? One thing is how hierarchy of priorities might be thought about. What are some possibilities that can be visualized. What ways are you taking into an account, whether they be what if or errors, primary, any possible spacecraft failure?

- I couldn't pull a question from that.

How are you priorities represented in software? Is it about opportunities, constraints, are there anything you're starting to see some sort of architecture you're starting to plan out? How are you starting to think about your info architecture as you're starting to design.

- hmmmmmmm we're not there yet
- People are going to need to see the effect of their changes but for this fly by, for this flyby geology is paramount so maybe the instruments we really need to get data on these instruments. Maybe there is one feature we get really good view on, one flyby. We need to make sure everyone gets their data.
- For the rover, you are on the surface of the planet if you didn't get some observation you can do it tomorrow because the rover is really moving cus it's only moving as much as you want it to move. So you have some flexibility there. With an orbiter you don't, you are in motion and your path is predetermined there based on trajectory. You can change it but you really want to get your science right. If you have on eopp to see something you want to make sure your instrument see that, we plan way ahead of that, we wants a high degree of certainty we can see that. People can work together, instrument A says to B, i need to take more cover at this time, and maybe they say it's ok
- I don't know at this time.
- The idea of doing what if scenarios and reprioritized things and showing the effects of changes is important because, if a proposed change happened the instrument I want to know how it effects me: do i have more or less obs time, now what, what did i change and how can change to get what i want? What can I change to have the things/observations I want.

With your bg in human factors and working in UX? Do you have advice for us on how to test for us and prototypes and certain level of fidelity on what might be required?

- No, i haven't seen a lot of remote testing of prototypes
- I've seen even ones i'm colocated and they use sketch and invision for shareable then there is some way to get feedback

What about in person? We don't know what that environment looks like feels like coming in blind?

- It's hard to do research remotely i'm' sure, so good job you guys
- Uhh, let me see, just from my psycho background i found that i prefer to interview people in person because i feel like they can be more frank with me. There is something bout person to person communication, sometimes if i want them to be frank about something i won't record them. Something turns on in their brain when you ask them to record them. I know as a ux researcher, that they're just using it for note taking but sometimes when they're not on record people can tell you an honest person off record. For those reasons it's really good to talk to people in person
- If you want high level feedback or maybe some type of web thing using invision

or sketch could be helpful but i've never been in your situation before. Where i'm collecting data on people remotely.

- I do have to interview team on mars curiosity scientists not at jPL so i have a lot of phone conversations with them but i am not testing out prototypes i'm talking about their experience with the software
- If they're in town for a conference on team meeting i go to the science team meeting and talk to them.

What comes to mind a little bit, maybe the recording or the remote process. We don't collect a lot of pain points, it's a lot of general process and we're just not sure if that's a cultural thing if everyone stay more positive on how they describe the missions they're on. In your research are you able to find pain points you're able to find actionable?

- I can see the psych effects because i know people are more likely to talk positively
- Most thing are positive but they aren't sharing it cus there needs to be a level of trust and familiarity for people to share pain points with you. From user research, you can tell them you just research on this product and you didn't design it, because they don't want to tell you your thing sucks.
- People just want to be nice
- If you could come here and set up a paper prototyping session you could get more pain points than google hangouts and skype but i think for the type of info you're trying to get, it's probably ok. We're trying to get high level roles, we're not really at a place where we need pain points so i think it's probably ok. You can do good research without that. That being said, i was wondering what you guys are designing?

Our mission brief is using automation to improve uplink operations. We haven't gotten into an ideation phase on producing actual ideas on solving these problems. We're just figuring out the problem sourselves. There are a lot of overlap that it sounds like where your software you're designing would go. In the way of make in scheduling easier or help suggest certain outcomes or what ifs?

- I'm not your mentor anything but i think a good capability that is applicable is the showing people the effect of their changes.
- If you have a plan, and you're scheduling an activity and you change something and you want to know what the butterfly effect down the chain. It give you the activity the last 30 min instead of 1 hr. There are effects of power, time, duration, etc. i can't think of a good analogy right now. What is the effect of changing one activity or if you want to get to a certain place, what do you need to change in your schedule to make your activity 1 hr instead of 30 min. If you have a goal state in mind, the software can kind of help you get there. That's a big thing. You're doing with a large dataset, a large plan, a lot of layers in that plan. Showing effect of

that decision and suggestion on changing effect to get to goal state is helpful.
- I can see how that can be in my area of planning and sequencing but it's so early right now i couldn't even tell you
- My work right now, i've been using at all the software we've used on other missions to do this and that capability. Scheduling, simulation, etc. then i gather data on who wrote it, and what language, who do i contact for more info, etc. things we can build and reuse try to make cost effective decisions some of the software is too old, you can't use it. Maybe some of its components can be used by us? You can do those trades before you can know everything that is out there.

So you were mentioning the possibility for this software to be useful for its users like planners and scientists to viz of changes. Based on research you've done so far and other tools? Are you aware of any issues of visualizing changes to activity plan on mars missions you work on. Have you seen any problems you have, people submitting request it's just a matter of them to see the effects of the changes they make and it causes problems down the chain and someone who builds sequences have to deal with all these problems?
- I'm not sure, that's mostly. I don't know of any software that tells you if you're going to insert an activity that go- you cannot insert because of this. It's not knowledgeable enough on how one part affects this. Humans can diagnose this pretty easily if they have a problem. It's a large dataset, you have to somehow look at the whole thing and how does this one piece here affect other pieces much further down the line. In other software, you might have little reminders or little tips like try doing this or it has smart heuristics but i dont know of any software that does that right now. That would be one way to show how the changes you're making are affecting other people's plans.

Follow up question. You mention the research you're doing analyzing other software? Are your findings publicly avail?
- No i can't share. I don't think it would be that useful for you. I think you're interested in other tools and how they show this, is that right?

Yeah, we've done our own competitive analysis on industry tools and tools on other missions that do the same thing and things we are thinking about. Like SPIFe and MSLICE (very familiar- P10)?
- That is the planning and sequencing software for Rover. I'd be working years into the future is would serve a similar function to MSLICE, showing you the plan and integrating functions

For that are your primary users also science planners?
- For MSLICE, yes, i think science planners are the primary users. MSLICE can also

show you pictures so scientists can look into that to create the targets
- You're familiar with targets? A target is a way to specify a way in a scientific area. This rock is interesting, we refer to that as a target

How are targets shared right now?
- It's all over the place. A target is a software concept, i place this picture on a mesh/rock. I'm indicating that i want to do science to that rock so i'm going to take a picture, drill, or some geochemistry, i mean can share the mars website that is public to you and they have a cute little log they talk about things doing recently that might give you a feel for the workflow
- Sharing the actual info of the software, i can't
- If you've seen the rover book MAESTRO, i can send it to you

Participant 11 Interview Guide

Participant 11

Scientist Engineer

Profile

Roles:

- Advanced projects design team (Team X) leader
    - Mars Mission
- Leads a team of engineers and scientists
- Deputy team leader who became the team leader
- Cassini Radar Investigation team lead
- Involved in planning for Viking, Magellan, Cassini, and three Shuttle missions

Publications:

- https://ieeexplore.ieee.org/document/4161722/
    - This paper discusses two recent formulation phase model-based engineering design pilot projects at the Jet Propulsion Laboratory. It describes how model-based functional and state analyses were synthesized and integrated with system performance simulation and mission planning then piloted in the formulation phase of two deep space missions.
- https://authors.library.caltech.edu/37439/1/04776451.pdf
    - Cassini RADAR Sequence Planning and Instrument Performance

Introduction

Hi, P11! Thank you so much for taking the time to talk with us.

Just to give you a little more context, We are a team of researchers and designers in the Human Computer Interaction Design program here at UW. Our team is working with JPL's Ops Lab to improve the efficiency of uplink operations for the Europa Clipper mission, potentially using assistive software. We're talking to experts like you who have extensive experience on other missions to learn as much as possible about all the variables involved in decision-making in orbiter missions, including the people involved and how scientific and spacecraft data informs uplink commands. Although our sponsors are working on the Clipper mission, we believe that there is a potential for our solution to be applied to future missions. ~~Although our research and future design implementation is focused on the Clipper mission, we greatly value any input specific to other, similar missions, as our solution could potentially be applied to future operations.~~

We'll be sharing your responses anonymously between our UW research team and our advisors at JPL.

Do you have any questions so far?

Before we get started today, we also want you to know that we would like to record our interview with you as a full transcription of your responses will be greatly valuable for the purposes of analysis. Is it ok with you if we record this interview?

[If **YES**] Thanks so much for your cooperation. We're starting the recording now.

[If **NO**] Not a problem. We'll continue without recording.

Questions -

As someone who has extensive experience with planning and coordination between teams, can you speak about the highs and lows?

P11

- How does it vary mission to mission or inform other missions?
- Areas for improvement?
- Pre planning vs in flight?

Walk us through a day in the life as a radar team lead on Cassini...

- Coordinating between scientists...
    - Negotiating resources...
- You think of an opportunity and want to see about getting the plan changed...

What is the structure of your instrument team on the Cassini mission?

- Is this different than other instrument teams? Compared to your experience on Mars?

Help us understand your team's priorities during Cassini mission?

- Does this ever affect other teams?

How do you keep track of your science objectives?

- Is this different after the mission has launched?
- Do you have new objectives after launch? If so what are the steps for how these come about?

Can you speak about the relationship between instrument teams? We know that there are high functioning and collaborative teams but we've also heard about high pressure to deliver research, how does that dynamic play into inter team dynamics?

- Is there any communication across different instrument teams?
    - How often do meetings happen and how what type of meetings?
- Do you know their plan before plan integration?

How often do instrument teams uplink?

- What kinds of things do teams uplink, e.g., what kinds of instrument settings are changed?
    - Things like op modes?

How detailed is the plan before launch, i.e., how set in stone?

- What exactly is planned and what is left for (a) science planning phase (T-8 weeks) and (b) sequencing phase (T-4 weeks)?
- How often did your team discuss changing the plan?

Op modes

- Instrument settings?
- Are op modes one of the things they update in the team? Non interactive command?
- When does that type of planning the place (minor or advanced planning in science planning phase)

How often do TWGs meet and what is the agenda for those meetings? Are they generally the same?

- How often does discussion of changing the plan occur?

What other meetings take place?

- How often did you meet with your instrument team and what was usually discussed during those meetings?

NOTES

Introduction
Consent given.
Notes begin:

Roles

- Runs the cassini Radar science team (for charles elachi)
- Ever since the early design days i've been apart of that tema. Role is to keep

team organized & keep them doing research. Oversees uplink-downlink operations for cassini.

- Prior to that - experience with Magellan ops team. Little bit of work with voyager. First big job was for Viking (viking lander) for about 10 years
- Designed mission operations systems for 3 shuttle payload missions. Part of shuttle engine radar series (81, 84, 96)
- Teaches for Caltech system engineering

Team dynamic

- As time has progressed, mission operations changed a lot. It has gone from very manual operations that consisted of a bunch of team meetings that fed into other meetings & handwork to prepare commands for spacecraft. We have a lot of computer assistant but Cassini is still pretty manul. Some of the later Mars missions have been considerably different because it doesn't involve coordination with orbiter elements that are subject to Kepler's laws.
- Basically things haven't changed much? Section called mission planning (how going to accomplish science objectives). Second is scheduling, take those observation requests & put it onto a timeline (put latitude & longitude on timeline by translating that into time). Third is sequencing -preparing commands for spacecraft that involves some simulator that does a pretty accurate simulation of what spacecraft will do. Simulation sequencing looks for errors & identified conflicts (overrun buffers, data issues, etc.).
- That hasn't changed much but we have better, faster sequencing & automated checking. A lot of errors are still human errors. Changed in implementation but in essence is same as much.

Human errors?

- Those three elements sound like sequential but there's really a lot of iteration. As you get closer to sequence you get lower and lower problems. Negotiations are discussed by science teams (those you don't really call errors you call them conflicts). As you get lower you get conflicts about applications on spacecraft. Most of our stuff uses DSN, which is always way oversubscribed. THose errors are common & involve insufficient look at details. You scheduled a downlink event but someone else has decided they want to do maintenance on an antenna.
- If you have to replan over observation you go back to redo the plan. If you want to reschedule something you don't have to go far back in chain. Mistakes we make are generally one subsystem not being aware of constraints of other subsystem. One of the things that happens in orbiter missions is where sun is shining. You can't have sun shining on radiator that is supposed to keep something cool. Those are really easy to miss because geometry is complicated. That's why we have a lot of simulators that simulate not only where spacecraft is but also

where sun is - we simulate whole solar system. Biggest error is communication between subsystems.

Communication between subsystems?

- We try to get subsystems to write down constraints that we try to code. Try to catch those automatically by coding them. At the end it ends up being a lot of human review. Simulator -> human review after human review so that you understand bad things that might happen.

Non-interactive commands & op modes

- Doesn't do a lot of interactive commanding
- About halfway thru operations design for cassini, either before launch or shortly after launch we discovered that if we were to regard all instruments as independent, there would be so many combinations of instruments that could be on at the same time. Since cassini is power limited, analyzing that number of combinations turned out to be more than op system could handle.
- People came up with operational modes. We knew that instruments 1,5,etc. Could be on at the same time. So we would allow that combination of instruments to plan independently and that's called an operational mode. So we defined a bunch of those that... The spacecraft teams analyzed those modes sufficiently that nothing could go wrong as long as you stayed within those modes. That enabled instruments to do non-interactive commanding. That was really a way of simplifying operations by limiting number of possible combinations.
- The idea was to determine all op modes before science planning. As i recall that didn't work perfectly because instruments discovered some things they wanted to do didn't fit within those op modes. Radar discovered it would take hours to warm up, so had to go back and rebuild & reanalyze op modes. It was a lot less clean than we'd hoped.

How is need conveyed from subsystem to another... how do teams learn what other teams want to do

- That's what mission planning team does. By diff mechanisms, the instrument teams individually decide what they want to do. The mission planning team takes all those inputs and looks for first order conflicts, e.g., two instruments can't work together because of power limits. You then get into discussions with teams that sometimes involve executive decisions, i.e., negotiations. Generally you'll try to do more subtle things than that like how much flexibility do teams have on observation requests.
- Those discussions - people have tried to do those in an automated way. Tried several times to figure out mathematical possibilities, which have not worked very well. Better to ge teams together & do negotiations.

- There's more complex problems - i can move my volcano observation so it doesn't interfere with that occultation but there needs to be a certain amount of time that spacecraft needs to move around to point camera. There's a constraint on moving spacecraft cause camera might overheat. We've developed a lot of software to help that avoid geometric conflict. Sometimes if early enough in the mission you can redesign the hardware.

Meetings
- Guidelines, like keeping number of people in meeting to a minimum. You want to try to foresee the kinds of expertise you need. You need someone who understands how difficult it is to turn spacecraft around. You need someone who understands how to move spacecraft * how you can't. Someone who knows about instrument safety. You need a mediator.
- 25:00-28:00
- Really detailed stuff - involves spacecraft simulator

Who facilitates
- No specific answer

Within instrument teams
- We kind of do that sequentially. Teams have to individually come up with observations that satisfy their objectives. Narrow down to one set of observations.
- Teams may get together weekly.
- Later missions haven't relocated all science teams - money issue. Have been using more teleconferences.

Objectives
- Matrix - objectives - can instrument satisfy this objective. This becomes foundation for plan.

Diagram

- output from "affects other instruments" - negotiation between teams
- Eventually you have to get yes out of that box
- Mission planning
- Adaptive change
    - So i discovered i want to do something new, want to put in a whole set of observations. Go back to mission planning process & look for conflicts. If you don't find conflicts there. Then scheduling. Then you go to next one, sequencing, find some you can't handle so you could go back to scheduling phase.

- Plan before you got to downlink - what already exists. Starting with type of opportunity, which is what you start doing before launch & doesn't finish until you execute.
- Magellan
    - Plan was for mission was not going to be adaptive. What that meant was that plan wasn't going to change based on discoveries. Turns out that's a huge cost driver. It cuts the amount of effort that MOS system has to have a whole lot. Biggest loop in that chart doesn't exist anymore. If you decide to be adaptive you have a huge amount of complexity because of time pressure to make changes.
    - Should cassini be adaptive or not? He argued that it should be because it was going to be adaptive whether they wanted it or not. Pressure external & internal would be so great (to investigate new discoveries).
    - Cassini didn't end up making a ton of changes.
- What you don't say here is minor problems with spacecraft which would not involve emergency shutdown. Lead to a whole set of constraints, like losing memory on spacecraft - will affect science schedule, which may force you to go back to objectives & prioritize in case you can't accomplish some.
- Discrete cosine transfers?
- Health & safety assessment - most of things that come out are either things are fine or small changes
- "Probably don't want to get into sequencing"
- Simulation - happens at different levels of detail. Happens all throughout. Every time we come up with an observation plan.

- Talk to mission planning & design
    - Steve chien & Peter M.
    - Can point you to a lot of literature about how this is done

Participant 12 Interview Guide

Participant 12
Engineer

Profile

Systems Engineer 1

Science Planner and Sequencer (Cassini Mission to Saturn)

- Sequence Implementation Process Lead - Systems engineering role in a team of 3-4 to successfully implement, sequence, uplink, and execute multi-week plans for Cassini. Responsible for managing critical spacecraft resources including data volume allocations, spacecraft pointing, telemetry modes, and overall fidelity of spacecraft sequences. Tasks include working with many teams (local, domestic, and international), running analysis on products, recognizing and analyzing errors, negotiating schedule with DSN, sequencing commands, monitoring sequence execution, and reacting to anomalies.

- Magnetosphere Target Working Team Member - Coordinate the long-term planning and high-level science integration in support of the Magnetosphere Target Working Team. Make sure that science plan is feasible in a data volume, time, and pointing constrained mission. Analyze plan to mitigate flight rule violations, understand spacecraft constraints, and work as liaison between science teams to negotiate pointing, timing, data volume, and flight rule violations and waivers.

- Scripting - Fixing bugs and improving current tools, creating new scripts/tools for team using IDL and PERL. Example: Created tool to shorten anomaly response time for the recovering instrument from a sick event by analyzing current spacecraft memory state and planned commands.

Qualifications

- Professional experience in spacecraft mission operations and control; data analysis; problem solving and anomaly resolution; proposal work

- Skilled in preparing and presenting subsystem reviews; preparing and carrying out testing procedures; teamwork; leadership and task-delegation; grant writing

- Solid knowledge of mission operations; planning; testing and verification

Introduction

Hi, P12! Thank you so much for taking the time to talk with us.

Just to give you a little more context, our team is working with JPL's Ops Lab to help improve the efficiency of uplink operations for the Europa Clipper mission, potentially using assistive software. Because the mission is in its early stages, our approach is to try to learn as much as possible about operations on similar missions to get an idea of how Europa can learn from their successes and challenges. Through interviews with experts like you, we hope to learn as much as possible about all the variables involved in planning and scheduling for orbiter missions post-launch, including the people involved and how scientific and spacecraft data informs uplink commands.

We'll be sharing your responses anonymously between our UW research team and our advisors at JPL.
Do you have any questions so far?

Before we get started today, we also want you to know that we would like to record our interview with you as a full transcription of your responses will be greatly valuable for the purposes of analysis. Is it ok with you if we record this interview?

[If **YES**] Thanks so much for your cooperation. We're starting the recording now.
[If **NO**] Not a problem. We'll continue without recording.

Overall Goals

- **Learn more about Systems Engineering**
- **Uncover some of the inner workings of Working Group meetings**
- **Learn about software involved in planning and scheduling** (and sequencing)
- **Uncover some of the challenges of coordinating across instrument teams and dealing with conflicts and anomalies**

Role / Background

Goal: To learn more about the participant's background, their current role, and the organizational structure of current planning process

Role + Rapport Can you tell us about your roles on the Cassini Mission? How did you become a Systems Engineer, and what have been the most enjoyable and/or challenging aspects of that role?

- It looks like your official title was Systems Engineer but you also had a role in science planning and sequencing and as a part of the Magnetosphere Working Group. Is it common on Cassini for systems engineers to be part of Working Group meetings?
- You say there were only 3 or 4 of you (Systems Engineers). Were you all solely responsible for implementing and sequencing those multi-week plans or are there other roles involved in implementation and sequencing?
    - Were there more Systems Engineers earlier in the mission?
- It sounds like you had a lot of responsibility managing and communicating between science teams. Were there any supporting roles involved, e.g., Investigation Scientists, with whom you worked closely to make sure that teams worked together?
- Because you were part of the Magnetosphere Working Group, were you mainly responsible for the instruments involved in that team?
    - Were you responsible for coordinating with instruments in other Working Groups, or were the other Systems Engineers responsible for that and you coordinated with them?

Operations

Goal: to learn more about operations and what happens between various downlink and uplink processes

Day-to-Day Can you walk us through a typical day during operations?

Phases We've heard a lot about the downlink to uplink process but most of it is high level. We understand that while there's a larger multi-week or month-long plan executing there's a lot going on on the ground that involves long-term planning for the next major sequence but also lots of responding to the frequent downlinks that occur. Our general understanding is that for each long-term plan there is a planning phase followed by a scheduling phase followed by a sequencing phase.

- Were you involved in all three phases?

TWGs Can you walk us through a typical Working Group meeting?

- What about a meeting where there was a new scientific discovery and the team was discussing how to respond to it?
- What about when there was a spacecraft problem the team had to respond to?
- What about when everything was going smoothly?

Responding to Downlink What kinds of anomalies did you have to respond to?

Cohesion & Conflict What are some common reasons for errors or conflicts you've discovered when validating plans?

- Did you experience any problems because of teams being unaware of what other teams were doing?
  - How did you mediate this? Any lessons learned that helped foster cohesion during operations?

Tools

Goal: to learn about how software facilitated planning & scheduling, how it can be used to improve those processes

Variety of tools You had a role in planning, scheduling, and sequencing. Were you using different software tools for your different roles?

Experience Can you tell us a bit about your experience with the kinds of software you used during operations, especially how you helped improve certain software?

- I was especially interested to read that you created a tool to shorten anomaly response time for an instrument recovering from a sick event (by analyzing current spacecraft memory state and planned commands). What were some of the challenges building that tool?
  - How did you analyze planned commands and determine how to reorganize them to respond to instrument anomalies?

NOTES

Introduction

Consent given.

Notes begin:

I used to work on Cassini and I work on proponoun(?) now.

Gabe: I already know about the mission. so before you get started today, we also wanted to ask if it was it's okay with you. If we record the conversation will just be like the recording won't leave our team will just be sharing amongst ourselves.

So to get started, can you tell us a little bit about your roles on the Cassini mission? And how did, did you end up becoming a systems engineer? and what was it like to join suddenly in the mission?but what was it like to kind of join the mission when it was already like?

Before I worked at JPL, I worked in lab in Colorado, with the University of Colorado where I did spacecraft operations, I helped not so much with the planning, but with the downlink side of things and analyzing data. So I think that's how I got chosen to be part of Cassini is because I already had experience with flight projects and working on a missions and then being on call. So I think that's how I became a systems engineer on Cassini.

I want to have a little bit of about that role. It sounds like you have a lot of responsibility, like, we've had a few interviews with other NASA JPL people. And it sounds like the systems engineering role is pretty diverse in its responsibility. So we're hoping to hear a little bit about your experience in that role?

So the Cassini or all that I was on was a science planning and sequencing team. And it was a pretty broad role. Originally, it was two different teams in the original part of the mission. And you either did the science planning part of it, working with the science or the instrument teams to play in their science, or you worked on actually creating what they wanted to do into commands. But by the time I got into the mission, I think it was been like, maybe clump here operations. So they had combine those two teams, and an effort to reduce costs. And so the ROI had really covered a wide range of responsibilities. And so, like, the first half of it was the more science planning. And so we worked with the actual people who worked on the instruments to understand what they wanted to do with their time. And because each of the 12 instruments had an assignment per track of time of being crime, right, so, and then all the other to instruments could choose to also do things at the same time, but only one instrument had control the spacecraft at a time. So we helped work with them on where they wanted to point the spacecraft. the timing of it. How much data they were going to take great, until that was the first part. And I guess it was really systems engineering, because you're not just working with them. One team, you still need to listen to the concerns and the requests of everyone else on the team to make sure that the plan that was made can suit all needs, or as many needs as possible, right. And not only do you need to be aware of what the scientists want any, but you have to be aware of what the spacecraft can do safely. So whether it can turn as fast as they want. Or if it can point certain parts of the spacecraft couldn't be pointed at the sun. So you had to make sure that the science orientation didn't like endanger the spacecraft. so that was the first part of the role was the more science II part. And then the second half of the world was integrating all of those requests, or all of those activities from all aware sites, instruments, as well as from the spacecraft engineers. So there was the people who controls the thermal subsystem and the telecommunications subsystem, the power subsystem, and the cal..?, or I said, attitude, where it's pointed. And so you have to make sure that everything can be integrated together. There are lots of iterations, because, of course, the first time and not everything worked, not all the plants were compatible. And so there were really five iterations when you put everything together.

When you say that the science and science planning and sequencing that used to be 2 teams, did they combine it because of cost? I mean, we've heard from other Cassini people they learned a lot throughout the, throughout the mission and were able to streamline a lot of processes. Do you think that that was also resulted that that they were able to figure out how to combine science planning and sequencing? Or was it really just a cost thing? And you, you kind of had to
Just take on extra responsibility?
I didn't join the mission until the last like two years. And so I did, I wasn't there to see the transition from planning teams to one. But I do think what other people have said is correct, that after so years of operating, you really get to know how the instruments and the subsystems work, and you can streamline the process, And I think they did a impressive job of streamlining the process by the time I got there.

So do you think that it was a good thing that that one person or one role is doing science planning and sequencing, as opposed to you doing the sequencing and having to communicate with science planner as well? Do you think it helps to have that as one?
It probably helped in some place that there was maybe less of a hand off more integrated understanding from one step to another. Although did the first half the science planning part, you're not necessarily taking everything you plan, you're not continuing with it all. The way to sequencing are only some of the segments you work on at the beginning you like, sometimes someone else is going to sequences, it's what I'm trying to say. So there's not a complete one to one continuation. But you do work with the people like right down the hall, who did the science planning part. you can just walk down the hall. So that was nice.

Your official title was a systems engineer, but you were also assigned planner in sequence? Where was it? What were the other science vendors and sequencers also sys-

tems engineer? Or did that very like? Were there other roles, who were doing planning and sequencing? Or was it mainly you're a team of systems?
I'm looking at right now. Someone title because I think a lot of us are systems engineers, but other people are called Mission Operations engineers. Which I don't. I mean, we all did the same job. So obviously, we could all depending on what our title was.

But you are kind of, unless I see that you are also involved in,we all have a panel about fixing the tools we are using, and we integrate creating new tools too. Was that something unique to a systems engineering? I'm guessing you had a different understanding that then, like a missions operations engineer?
I did a lot of tool work, like fixing tools and writing new ones. I think because of my background, I had just graduated the year before. And I think I was trained on a lot of different scripting languages, that other people that I work with your I've been at JPL already for kind or, years, it's hadn't learned. So I want to say it was because of the mission ops engineer vs. assistant engineer. Although a lot of the people on Cassini science planning and sequencing, we're more of a science background, and I did have an engineering background. And so that probably led to a difference in what we focused on. I know,a lot of people had PhDs and astronomy, or I don't know, other types of science, and they did focus more on like on top of their planet, science planning and sequencing tasks. They didn't have more science oriented side tasks, whereas I did have the more engineering type tasks.

So earlier, you said that you were kind of more in charge of, like, one team, but you are also. I mean, you were still responsible for coordinating with the other teams. Are you referring to your role in the magnetosphere working group? Yes. Okay. So with that, working Group involve different instruments, and you were mainly focused on on those instruments, but you also have to coordinate with other working groups?
Yeah, correct. So the work that on the segments. I worked on the magnetometer team was had the prime control the spacecraft, and so we, first of all, before we planned anything else, we plan to their activities, and we planned all the other ones around what we had done for the mag tweak.

I'm wondering about the, like, how does those working group meetings go? Is, are there. Is there like a typical structure for them? Would you be able to walk us through like a typical working group meeting, or was that to the kind of different on like, what stage of the mission?
by the time I was there, the very most important activities had already been laid out. So by the time I got there, we basically had the shell of the activities laid out. So there would be what they call pies. And if you talk to anyone about the pre integrated events, but

those were like the very most important activities at the intermission. And so with those in mind,the main science liaison for the mag tweak, would take that those activities that are, must happen, and then he filled in the gaps. And I'm not sure if he talked to other teams, other instrument teams when he did that, or if he was so experienced, that he was able to understand what everyone would probably want. But basically, he would bring us this timeline. He put together and it would have the activities. He thought that would happen. And the pointing and timing, he thought they needed. And then from there, we would take kind of the skeleton. And so I think we would meet and we would talk about what point they needed to happen and the timing, as a group, and then we would go and I think, work with other instrument teams to make sure we got all their inputs.

what was the role that was responsible for handing off that plan to you guys?
We generated the plan together. I'm the person I'm referring to is [name omitted]. And he was like the medic Working Group leave or maybe facilitator. I think I don't know the term.

Were there any instances during those working group meetings when you were responding to new discoveries? or, or, like, anomalies? How did those meetings. Go, when you were responding to incoming data?
I didn't have any experiences like that. they were pretty far along with the plan. By the time I arrived, because I was new to the mission. Now, cuz the process was different, right?

In those working means, when you're discussing like, how to use the resources and how to point the spacecraft? How did that. Where did each instrument involved in the working group have an idea of how they wanted things to work? And it was kind of about negotiating among teams, or was it like, more collaborative than that, like, what is more discussion, more discussion, and less like, people proposing things?
I'm probably not the best person, I could give you the names of other people. But it was interesting between the different thematic working groups, there were different dynamics, I saw the one that I was on magnet working group. it was a really collaborative kind of easygoing group. They really understood each other's needs, and I think, worked together very well. We're understanding of what other people need to things. But also, I think it's part of because of the instruments that do the magnetosphere measurements are, they have a lower level of need, as in terms of data volume. And so it was contentious people saying, I need this much data volume. And other people saying, well, I need this much. So you can't do that because the amount of data they needed was lower.
But if you talk to someone who worked on the Saturn working group or target, they had

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a lot more, I would say, heated discussion from what I've heard, because they're the instruments that take photos of Saturn like they use a lot more data. And so it's a larger resource use to do their activities and so it sounds like from other experiences, not my it was it's a lot more challenging to work with those teammates or team members and to get them to agree together. So my experience was very laid back easygoing thing and the plan was pretty much accepted because other people we worked with.

so our understanding of the, the planning and sequencing process is that there's like, some long range plan like that last a few weeks or months, but then there's also a lot going on during that time. Like, there's downlink happening, and uplinking of, like, my narrative is changes, is that correct? so what kinds of things are happening? In or what kinds of things are being up linked during the time between plans? And what was your role? And in that, like, did you have to. That was a minor changes like apart from that, that long range plan? What was it? How did those things go?

there's kind of like two different types of commands we would set up periodically during the execution of the long range plan. The first category is things we expect to do, right. OTM is the orbital trip maneuver went the thrusters are firing and making sure the space-craft is on its correct half. Those thruster firings can addressed the path of spacecraft. And so we know when those are happening. And so we can plan for them. And so during a long sequence, there could be like, three of them, maybe five. And so we would actually make a schedule before we even applying the plan to the spacecraft before it started executing, we would net out, okay, there's going to be an OTM on the mic. So we would have the schedule like the week before, but planning out, okay, we're going to receive this information at this time. And all the teams involved, so some instruments aren't affected by like, little tweaks in the maneuver or the trajectory. I'm like the ones to sensing the magnetosphere. But the cameras are really sensitive to little changes. And so they would likely need to update where they're pointing, if the if we got off the trajec-tory a little bit. So those were kind of expected. And so what we would do is we would have the schedule that everyone agreed to ahead of time. And so the maneuver would happen, and then we get the data down, and then everyone's we would immediately look at it and like, send, do some analysis of basically the error of the trajectory and send that to the instrument teams. And they already knew, Like, how much time they had to respond to us, usually, like a day or two. And so then if they said, Yes, please, we need to update our pointing, and then they would let us know, and we'd have to make sequence the commands and then uplink the commands. So sometimes the air we're small enough that nobody wanted the update. And so we wouldn't have to generate the plant com-mands and then uplink them. But more often than not, they would want to update the pointing. And so then we would have to generate the command and uplink them. And I asked, When I say a change the pointing it's not actually adjusting what the spacecraft is doing, it was just to update our knowledge of where the spacecraft is pointing.

Because these maneuvers were happening, you had to kind of model like what I was doing to the spacecraft.o yeah, usually it's fraction of a percentage of change. But some instruments were more effective than others. So that's one type of change like one type of coming demanding that you would need to do like periodically during the execution of the long term sequence. But the other type is things that you can't anticipate, like when an instrument We call it go sick, like it's not working correctly.Like if you get a cold, but this instrument goes into sick mode. So those you can't anticipate. And so that's the other time where you need to, the instrument is responsible for understanding if something's wrong. And this applies not just the instruments of systems, but to any of them, like telecom or attitude control. So they would need to identify a need to set more commands, and then we would help create them if necessary. And then uplink them.

So I saw that you wanted the tools that you worked on was responding to those sick events and helping recover from them. Um, can you talk a little bit about what are some of the what were some of the challenges when building up?
Yeah, so the process usually was specifically for the sense to rent was, it would go six sometimes. And we instrument teams with the engineers on the ground would realize it, and then they'd have to generate commands and uplink them. But there was, you have to be aware of what the mode instrument what's going to be in at the at the time of uplink. You figure out that instrument sick on Monday, and you know that you are going to uplink the like things that will fix it. On Wednesday, you have to know exactly what was supposed to be happening on Wednesday, so that you can put the instrument back in the mode. It was supposed to be in, right, because now there's going to be different data rates and different modes. And so you'd have to be able to create the correct set of commands so that it would be in the correct mode at the correct time, basically. And that could take out a couple days of in between the time that you realize it's sick, and the time you can command. It is rightness, basically not taking science data. And at the end of the mission, since the orbits were so much shorter than previously, you we wanted to get the instrument back into its happy science taking mode as quickly as possible. And so what I did was create a script to do the analysis part. And instantly, instead of having to look at the plans, and like, because he had to look at the information of what we're doing supposed to be in anyways. So what I did was I compressed all that, and so did it all with code so that you could just run the script, and then you would now a second later what command you're supposed to send up. So that's what I did.

So how was it done before then? Like, how are they, how are they doing it before that

script was involved?
The instrument teams. So the instrument team also is in England. So that's another factor, right? Is someone in England would look at all this information, like, oh, what mode? What mode is it supposed to be? and at what time is it supposed to be in this mode, and they would tell us what commands to uplink so then we would have to generate the commands and then uplink them. And so what we did as part of this process is we after I created the script that show them that I could, I could analyze the our script could do this analysis for them and do it correctly, that cut out some time because we didn't have to have the people in England do it and then tell us what to do. And then we do it, we could just do it without asking them ACC team in England what to do. And so, especially, useful if it's nighttime in there and they're sleeping It's weekend or whatever, we could cut down the response time by taking them all really out of the loop. Mean they favors approval ahead of time.

Are those modes something that's determined ahead of time like planning the long range plan, or those updated during those like periodic uplinks?
That was her plan during those long range planning for that instrument. It's very predictable. you can plan it way ahead of time.

But are they were there other instruments, where it wasn't so easy to plan, and they have to respond closer to execution?
By the time I got there, everything was pretty oiled machine, I can imagine that the beginning of the mission, there were a lot more of those, you know, commanding during execution events, because they're still learning how their instrument works. But by the time I got there, it was pretty well understood.

I'm wondering about some of the other tools they used, especially like, for pre planning and sequencing, like how, where our plans share, where those plans with software which toes like planning tools, so when those long range plans were were created, where they created with some software, and then shared with working groups and instrument teams, like a timeline tool, for example, that have activities, I lay out in a timeline.
Yeah, so there iis one called Sims will see CIMS. And that was web based. And we have a team, I think they were mg GSS. I don't know what they they are responsible for developing and deploying the tool. But that one was the timeline visualization. Well, I don't know if that's what you could call it, it was time ordered listing of everything that was happening. So basically look like an Excel spreadsheet. And that were what all the instrument teams across the world used, and what we used at JPL to assistance engineers to make sure we had everyone on the same page for the activities. And if they wanted to

update how much data volume, they were taking, they would update it in The Sims database, we would see it at JPL. And we could we have the control to accept their changes. Or if it doesn't look right, we could call or email them to clarify or ask them to change it to something else.

There were other tools involved for modeling, simulating that kind of stuff. And so those were separate and kind of done in conjunction with the timeline schedule?
I think the only modeling that was integrated within the Sims like activity database was the data volume, so that when you would take, it would have all the activities with all the correct data volumes and durations, and it would simulate, and it would take in the DSN like downlink schedule. And with all of that, it would model how much data was on the data recorder. And when it. How much was being down linked, it didn't tell you what data was being done, you have to figure that out yourself. But it would just tell you like the amount of data being sent to Earth, So for modeling. The other tools were, I think, called seek chin. And that is more of a black box to the or was a black box to us, we would just run like, type in the correct command align with the correct arguments. And that would do the simulating of everything, like what all the subsystems are doing, especially power wise. And it would compare everything to make sure we weren't breaking any flight rules or constraint. And so that was not a visual, it did not have a visual tool aspect. You just typed in a command. And then you get this output, which was this, like, crazy text that you would put in an Excel file, and then trying to each line, you just have to figure out what exactly the error was, and then try to deal with it. Yeah, that was my least favorite tool that we had, I had lots of complaints about it, because, I mean, it's a complicated spacecraft. So firstly, it's kind of the complicated to, to compare what's getting in the way of other things. And, but the output wasn't a very user friendly or human readable format. I think that as people used it over the years, they just got used to it. as a newer person. I thought it was really frustrating. At least the first couple times that we used it, like, three of us would sit down in a cube together and just go through it line by line together. And, and that was huge waste of time, because that's three people doing this really tedious job, doing the same thing.

...was it just for generating commands?
It was identifying conflicts, but it wasn't doing anything to resolve conflict. And also, I guess there's just, like, a list of conflicts that you can ignore that, um, that like, over time, that systems engineering team would know, oh, yeah, that conflict, we see all the time. And we can ignore it, because it's actually not wrong, or it doesn't matter. And, but that wasn't called out, usually in the tool. And it's like, oh, you can ignore this or it just spit everything out. And you had to know, we just had a wiki tool, and it would have a list of

things you can't ignore. Someone who worked on the team for, like, seven years, with no automatically looking at it, oh, I can ignore that. But as a new person, I would have to be constantly referring to the wiki or asking my colleagues.

Diagram
instrument data is like this science data coming from the instruments, not the year saying that the health and safety and not the engineering or?
Gabe: Yeah, okay. Yeah, JPL processes. Some data. Is this just a general specifically for Cassini? It is kind of trying to translate across missions, but most of the interviews. We've done our with Cassini's people, p12: The record, Dana, I think, probably depends on each mission, there could be some big database where all information goes, or they could be storing and if their own locations. Okay, um, I think that, like, broad data that JPL pre processes is going to be in some database, and the instruments can grab it.And then if they make higher level products, like, if they're taking all the, like, once and zeros and turning it into an image, then that would have to be saved. And it could be saved back to the JPL database.
uz there's different types of data. So the working group would only necessarily need to know the science part like what they discovered science wise, but the instrument operators, will it also need to know if the filter wheel was turning correctly, or if the voltages looked.So there could be planning changes, instrument level planning changes based off like the engineering part of the answer it. But as well as the science collection.
I think non interactive commands depends on the structure of the architecture of the mission. But either the instruments could create the commands like on Cassini or other missions, that might be the, like, people, the systems engineers for them, like at the mission level, creating the commands. Important thing is that non interactive, I'm commanding is that it doesn't need to be verified at the system level, maybe at the instrument level, have to verify that it's good for their hands, but they don't have to make sure that it someone else like a system engineer doesn't have to make sure that it's ok with the telecom system and a propulsion system. It just within the instrument. So, okay,
I just don't know that everything would go through with a thematic Working Group. There could be something that maybe if you're specifically talking about other teams, you should say. Maybe instrument teams.

Where there are there any Were there any important meetings that you were involved in regularly that I thought would happen around here that are represented?
There might be conflicts, I guess you have the arrow to show that there could be problems that need to go back and be fixed.I just don't know if it would feed back further into your process. Like maybe negotiate and update clan or. cos if this modeling shows, there's like a big conflict tonight? Well, I'd have to go back further than that.

But when you get down to validating the commands, there's could be more nuances. Like, for example, some computers can execute a command like two commands within a certain amount of time, like you could say, one second them. So there could be two different instrument teams trying to command the something at the same time. And you wouldn't know that if you're just looking at the individual instruments commands, but when put it all together, you can see that, there's like an overlapping. And so one team is going to have to change the timing, But I guess a good point is the problem, I think the diagram does a good job of showing that there's a lot of stuff happening on this, like science activity planning, before it even gets to sequencing. So a lot of conflicts will be resolved. I think you've shown this on the left hand side of the diagram, a lot of things would be resolved before it even got to sequencing. And I think, yeah, that is the goal is that everything science, why should be locked down as much as possible. Now, the complex should have been negotiated before it gets to sequencing.

If you could add that during this health and safety that you're showing right here. For spacecraft, there could be some feedback into planning, right? It's not necessarily just like one line that doesn't touch anything else. There could be another feedback loop is there like a major problem with the spacecraft isn't the only thing that could happen, you could be having a minor problem with the instrument, or you could be having not even like a problem. But you just realize, Oh, I could be getting better data if this and this, or something like that. And so you could have a feedback coming from health and safety assessment backup to planning somewhere like maybe that evaluation of data that you're showing, what kind of data you're referring to? Yeah, this is science data, and health and safety data, or just science data.

Things that have been on the spacecraft can affect what happens with the science, like if something is going wrong. For instance, the cameras can't handle a lot of Jenner like vibration. And so if something on the spacecraft, That's nothing like has nothing to do with the instrument is causing more shaking, I mean, the instrument team, it's going to need to know that, right? So they're going to have to work with subsystems like attitude control, or the propulsion people, So it's not as like separated like science and engineering, like the science instruments in engineering spacecraft, people aren't as separated, as you might think pieces.

Participant 13 Interview Guide

Participant 13

Designer

Profile

UX Designer

Mission: Europa

Introduction

Hi, P13! Thank you so much for taking the time to talk with us.

Just to give you a little more context, our team is working with JPL's Ops Lab to help improve the efficiency of uplink operations for the Europa Clipper mission, potentially using assistive software. Because the mission is in its early stages, our approach is to try to learn as much as possible about operations on similar missions to get an idea of how Europa can learn from their successes and challenges. Through interviews with experts like you, we hope to learn as much as possible about all the variables involved in planning and scheduling for orbiter missions post-launch, including the people involved and how scientific and spacecraft data informs uplink commands.

We'll be sharing your responses anonymously between our UW research team and our advisors at JPL.

Do you have any questions so far?

Before we get started today, we also want you to know that we would like to record our interview with you as a full transcription of your responses will be greatly valuable for the purposes of analysis. Is it ok with you if we record this interview?

[If **YES**] Thanks so much for your cooperation. We're starting the recording now.

[If NO] Not a problem. We'll continue without recording.

Goals

- **Learn more about Systems Engineering**
- **Uncover some of the inner workings of Working Group meetings**
- **Learn about software involved in planning and scheduling** (and sequencing)
- **Uncover some of the challenges of coordinating across instrument teams and dealing with conflicts and anomalies**

Questions

- How do roles differ across missions?
    - Are science planners called something different because we have talked to so many people who said they are planners
- How many distinctions are there within system engineering?
- What is the general responsibility of system engineers and how much variety is there within that?
- What are some main known process changes between Cassini and Europa?
- How many different roles are there within an instrument team?
- How do people move from mission to mission?

NOTES

Introduction

Consent given.

Notes begin:

How do roles differ across missions
- From what I have learned, the names, depending on kind of mission they have. THey staff this, if they have tactical and strategic planning almost daily, you are going to need different kinds of roles to manage that type of process.

- If you have something that is something more of an orbiter or fly by, maybe only you come up with a set up of a commands once every two weeks, then you're going to have a different roles. Within that, there are some probably commonly used terms, however, those change in nuance between each mission. So the amount the person is funded or amount of time they spend in operations or the exact roles they do, even within a mission, some of the roles will change. Investigation scientists on Europa, each of them, may kind of come with a different background and expertise. Some of them might be more pure science, hybrid of science and engineering bg. As the mission progresses, they will work with their team to do things that need to be done so it might not be the same across teams. So you might have one person who looks at the health, telemetry back from spacecraft and using that to inform what the commanding might be. Where you might have another investigation scientists that is only look at their science data dn looking to see if they got the science goals. Each of the teams themselves is going to be kind of different. Does that give an easy answer, they're very kind of idiosyncratic

My takeaway is that it's dependent on instrument team and the needs of the instrument team and those differ?

- I would say it's a mix, it depends on how specific you go you can go say for instance that each IS considers themselves to be a conduit between instrument and science. If I interview grocer checkers- i can see at a certain level they do the same thing but if i really wanted to go into the weed i could find some nuances and differences.
- There are differences but there are some commonalities
- The thing that change the most is that it will be a project level and a little bit of a difference
- The difference between europa and cassini
- For science planner, this is something, this is a term that is quiet conflated. And there could be, a lot of different definitions. I actually don't know what they are.

We heard from sarah milkovich, that title differs from title to title. She said she was technically a science planner and so was trina but they weren't called that officially so it's kind of confusing. From your experience, do you think it still makes sense does it still make sense for targeting our users. Does it make sense, within cashiers, it's only if you break down the nuance to find these differences. In your difference is this enough to turn into different personas and users or consider them separate?

- So, yeah, basically what you want to find, people who are using planning and sequencing software. The people that are doing that doing and then maybe secondary, the people who communicate with those people.
- So it's really about, i want to make. And the word plan, is super conflated. It's

a word that is overused in too many different areas. You guys for the project, originally as it set out or maybe you discovered a new area. We're looking for the people who are laying down the tracks for what the schedule for spacecraft command are going to be. Each missions has done it a little differently. Sometimes there is one person who is verbally talking to people. I think on cassini they had a db to submit proposals they wanted.

- The question is, who would've been interested in...this is one of those situations where just talking to that person would be useful but just talking to the people who might be able to use it so that the system can be designed so that they can collab sequence
- There are two directions you can go with: 1) you can choose to look at who do we create a system who are working on the same codebase (activity sequence and merge it) 2) How can you help make it easier for people to understand the implications if they were going to move something over and take someone else's resources. What would some software design be for that?
- You can talk to someone who has done that before, they might have worked with something similar to that. People might have, the person who has done that role in each instrument team, they might have a different name
- It's like you guys, you have a small group trying to achieve this thing. The mission got extended, they stay there forever. Next thing you know, they stayed there for another task
- Finding people by their title is not useful, it would be helpful to categorize them by what they're trying to achieve

What's related to that is the systems engineer role, there are a lot of names. We know that Dave Mohr was responsible for merging of sequences, but we know that other system engineers have very different roles?

- Did you guys do a bit of research of system engineer is?

Yes, that role comes up a lot. From out interview, it seemed that the responsible is diverse. Alice is as well.

- System engineering is kind of like design whereas designers you can be everywhere from designing the software architecture to actually building the code and everything in between
- Often times you're one of the couple things in between
- The majority of people who work at JPL, are considered systems engineers. But, they all do different things
- As far as I know, this is something we talk a lot about the design group. Because we are constantly try to figure out what our contribution and collab with system engineers are. The distinction element hasn't really come up, there isn't much we can tell of a distinction

It’s helpful to be flexible in that role? Depending on where their skill set are, they can be adaptable?

- yes , similar to designers. Sometimes i’m doing AR, sometimes user research, design, etc. but my title is ux designer

Since we had an assumption that it stemmed from military structures that the roles would be more rigid..

- Yeah it might be true, JPL is a bit of different, we existed before NASA actually. We are half run by caltech and half run by NASA. in other NASA centers, they are civil servants and there si a different process. JPL has a different culture. We have a hierarchies but e function in a matrix management style. We have a specialty, area of focus. Ex: i’m in HC group, I have a boss for Europa, then I have a boss for the other project i’m working in. It depends on what your speciality is, some people are system engineers in operations in planning sequencing and command or something like that

And that is something that has been through in JPL as in it’s legacy? Is it something that NASA changing at all, is there a move to be more flexible

- I don’t know

What are the main known processes that change between Cassini and Europa? Are you seeing carry over from Mars, etc.

- Yeah for sure, so first of all, the mission are very different and stages are very different. With Cassini and Europa, i’m still kind of learning about the processes about Cassini. There are some of the similar things, let’s see, recently I just learned about the dynamics of how the theme groups worked and informed cassini
- But in terms of process change, i’d have to dig through my notes for this one
- The main kind of thing that is difference is, i know more sort of about the engineering and science differences of cassini or of the orbital mechanics of cassini vs europa, cassini was had different phases of the mission and there are some challenges for the mission
- Without looking at my notes i don’t remember specific process changes between cassini and europa, i’m still trying to map that out

It’s more about how things are for europa, maybe if you just talk about Europa. If you think of something after the call, if you want to send us those notes it would be helpful

- One of the biggest difference between cassini and europa, europa has very early on in the process has started created a model of the mission. Which dave may have spoke about. Which what we’ve doing is generating so we’ve generating this model so we can figure out what opps, risks, conflicts, might exist in the mission. We're using that model to design the mission itself, as we continue to get data back, we'll continue updating the model. Then we'll use it with our scheduling software to test if the things we're trying to schedule are a good idea or if they're going to cause conflicts.

- We're building this modeling engine and model itself that is going to allow them to test more rapids and ideally let other people test their sequences as well to see if they're going to violate anything, to test their models
- This is a conceptual difference, we're doing this much earlier than other missions
- Cassini had a lot of people on it, with europa we're trying to have a leaner operational team. Look for opportunities to reduce process where human process isn't needed where computer can help human process. But making sure to preserve the important part of human process and science process. That is one thing we are figuring out right now. I don't know if dave talked about the timeline we're looking at
- Another difference between cassini and europa is the way they plan what is going to plan. They took their planning process was a 4:1 process. 4 weeks planning for 1 week, meaning that's why they had to have so many people. So we're looking to have a 1:1 process so we can have the same time planning as executing which would create a quick planning and executing

The 4:1 ratio, we learned from our last talk with Dave. We went through our diagram from uplink to downlink and we were asking more targeted questions from that. We were talking about the diff cycles and process that take place. He was talking about the long range planning, the plan for the next uplink cycle with start 8 weeks in advance of execution then science planning happens for 4 weeks and at t minus 4 weeks is when sequencing starts. So is the 4:1 ratio the sequencing thing or does it refer to the science planning process cus both hpapen for 4 week?

- So you can have 4 weeks if you plan for 4 weeks execution. Then you would have 4/4=1 if you plan 4 weeks have one week of execution than it's 4 to 1.

I don't know how long the sequence are for?

- I don't know if the sequences are executions of 4 weeks cus it's 2 diff fly bys at a time

We still have to work on updating the diagram based on what Dave told us but we can send it to you. It's the first time we went through it during an interview, there are lot of changes we need to make.

- Instead of me talking about what i think you don't know. It's more constructive for me to know what you don't know

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Beyond process, beyond the 1:1, i wonder culturally what's been changing. How is it being perceived by team members? Everyone sees the change as positive? The human elements?

- There are mix of responses. Some people who don't' have very complex instruments and are not very reactive, they're like fine. Some instruments that need to be more reactive, it's a mix. Some of them who are more complex, more sequencing, or takes their data longer to process so that they can understand they are not sure two weeks is going to be a long enough
- It's an ongoing conversation about figuring it out
- We just finished going through and introduced each instrument team to the process you were talking to dave about and we're just in the process and see what's coming up so it's a very new thing to us

So we've been trying to understand the roles internal to these instrument teams. Some are internal and some are external JPL. Can you talk to us about diff roles instrument teams?

- On Europa there is an investigation scientist who is the person who works between the project and the instrument team. It's like an ambassador between both. Usually they're located at JPL, sometimes at APL. The mission for europa is a split operations which we're still deciding so part of the project is going to be happening at APL but the main commanding will be happening at JPL. The investigation scientists make sure that when the project is making decisions that the instruments and specifics and needs are represented and when things come up they make sure to pass on the info to them
- You also have PIs, the PI is the person who applied for funding from NASA and was given and won the bid/proposal for their instrument. They have soft of a powerful position on the mission. They cannot be removed because they are the head of this instrument. They designed it, the got the funding for it. They kind of in the same position as the project scientists as bob pappalardo.
- They oversee their team, and working under them would be the Co-Is, i'm not sure exactly what they do. I assume support the PI in some way.
- In addition to the investigation scientists you have the investigation engineers, they do a similar job b/wn engineers and scientist back and forth
- Then you have team members, they can be a mix of scientist and engineers working on it. At this time in the mission, they really aren't funded yet. So they haven't come into the project. As we get closer to operations, they might be doing different things as ended they might be designing software tools, the analysis, data processing that type of thing

So would you say, PI would removed from teh in the weeds design decisions. Or are do

they get into details
- What do you mean?

Say they find something, an anomaly, if they find something on one fly by of europa, if they decide they want to change the camera or something, changed direction. Would the PI would be involved in that level
- The PI is the CEO of the company, the company here is their instrument. The value of the instrument is being able to accomplish it's science. So some of their instruments can only do their science if all of europa gets mapped. Plama instrument or magnetometer, in order for them to understand where the magnetosphere is they need to get a whole view of europa and other side of jupiter is in order to get what the baseline is.
- If you were the PI or CEO o the magnetometer and you knew your science would only be delivered if you got something and all of the sudden a plume shows up, then it would require and people say we're going to change the trajectory then all of a sudden you realize you instrument is not going to be able to get that data, that's going to affect you. You're going to start participating in the conversation about that.
- The way that those conversations happened, right now are being designed. For instance, they have not yet finished designing the process. Again we're not going to get there unil2 2025, we're still 8 years out. The process by which you will, theme groups, decisions, and instruments, are still being decided
- You can imagine that if you are the CEO of the company, you found out a decision is being made and your cohort of your companies would devalue what you spent your whole life doing, are they going to be sitting down at the computer using the software. If you make it usable enough, anyone will use it to see what options. Are they going to be in charge of it it probably not

Would they look at something like this…
- If you make any tool that makes someone understand the complex situation understandable enough. Then they can make quick tweaks and how they would impact your resources, then ofc
- But they would not be the person in charge of planning

Some people who are cassini and some of them on europa clipper. What is the process of moving someone people missions? Is there a gap?
- Hmmm that's a good question, staffing for missions…i don't know, if i can really say…i'm pretty new here, i've only been here for two years.
- Well first of all, so JPL is a small place and bit of context about staffing…JPL is a small place, the experience people get from working on operations is so niche, there are a lot of other places you can come from and have that experience so

you can actually...if you work at JPL, you can...the human centered designers are supposed to work in operations to get contacts on software they want to work on. Sometime people decide they like operations and they want to get into it

- People stay there for a long time, and people make career moves through the lab
- Because it's so niche and unique, the titles of what people do are much less telling than other places where that person is an engineer that person is a designer. It's kind of a small place. It's knowledge base and once people are in, wherever they want. There are certain math i can't do. In terms of learning to operate to learn a sequence timeline, a lot of people can learn what to do. So people might come in specifically do to do operations, some people come in as grad students and undergraduate students and stay and do their postdocs there. If you are an university and you're doing your phd and working off science team, that's how you might get there. Some people just really like operations, there is a range of diff types of thinkers. Bt there are thinkers who get focused on specific type of details. This is true for anyone you interview but if you ask them abstract out high level thinking, they just don't do it. I just do my job, it's very specific i just do it. Some people you'll find, like sarah milkovich, i'd assume when she was in ops of what she's good and she had a lot of ideas on how the processes can be improved. She made that known as other opps because avail, which made her a good candidate for a new mission
- Oftentimes what will happen, we have more jobs than we have people to feel because it's so niche, so what will happen is we will say we need a ground data system architect, the only we can find that understands the domain is working 100% on mars 2020, can we get them to 25% or 50%. People get borrowed and if you're on a mission that is retiring, then it's kind of known that you are going to become available and you would talk to your group supervisor, they're like your agent. So they might found out about other opportunities, and you are doing a peer review about someone and really excited about a project. You would like your supervisor know you would come up with an opp and other project

Coming on a mission, what about leaving a mission. What about others, do you wait for a milestone or stopping point?

- No, i think people...i don't think it's frowned upon. There are def projects that are more high profile here that you get more attn for. There are flagship projects, software on the flagship projects. I don't think people look down upon but you leave whenever you want. People like are very committed to the projects. Oftentimes they are very passionate about it, there has been some challenges on diff missions on scheduling or mars stuff or being on mars time and people are coming in at the middle of the time. On some missions too, they're understaffed. There's one woman that can't take a vacation because ops would stop if they can. People speak openly about those things about being challenges, they'll leave the project if the opp for them comes up.

- I have no idea, from the lab perspective. It's expected you'd find work life balance, good for your career, etc.
- It'd be bad if you left in the middle of a critical project but i don't think there is an expectation that you stay on a project in entirety

I just gave a talk about this in new york. I gave a talk about what it's like to be a UX designer in a engineering centric environment where they literally have no idea what you have to offer. Just cus you're a designer, they don't' think you're great. Cus systems engineers have a very specific way they're problem solving and they've been doing it for years. How can you convince people or show people what they're value is. The point i was making is that really rigorous user research allows you to learn and wrap up knowledge very quickly if you're doing it right. People will be impressed you are speaking their language so quickly. But no one will stop to hold your hand to teach you stuff.

There isn't a moment to stop and hold your hand

- Yes there is a mentorship program from diff parts of the labs. You absolutely you can get lunch and coffee. This goes to the user research side of things, you become an embedded agent. You can take the initiative to set up observation of operations. You can take the initiative to talk about what things mean, we have a youtube channel. But it's on you to do it.

When you mentioned notes earlier? Would you mind sharing them with us?

- I'm the process of doing data analysis and i have my report due next week. I don't know if it's done, it might be too, i can see if it's shareable
- It's due in two weeks actually...

ITERATIVE DIAGRAM