TEAM **KAIROS +**
NASA Ames HCI Group

# *Mobile Procedure Viewing: Research Report*

SPRING REPORT 2012
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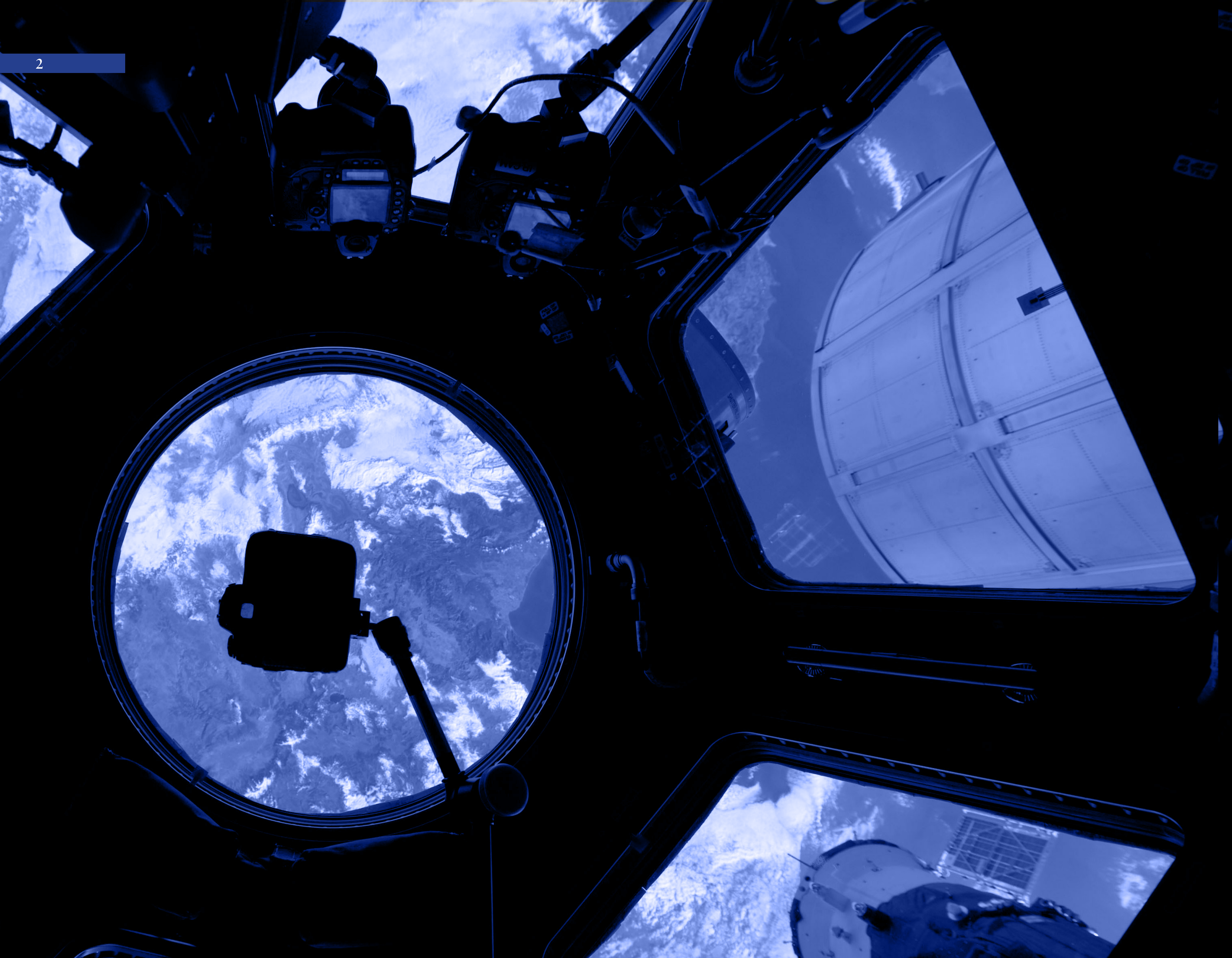
Carnegie Mellon University



# *Mobile Procedure Viewing: Research Report*

*kairos* |ˈkaɪrɒs| NOUN

*the propitious moment for decision or action.*

ETYMOLOGY: *Greek* καιϱός *opportunity; weather.*

# TABLE OF CONTENTS


**INTRODUCTION p.6**

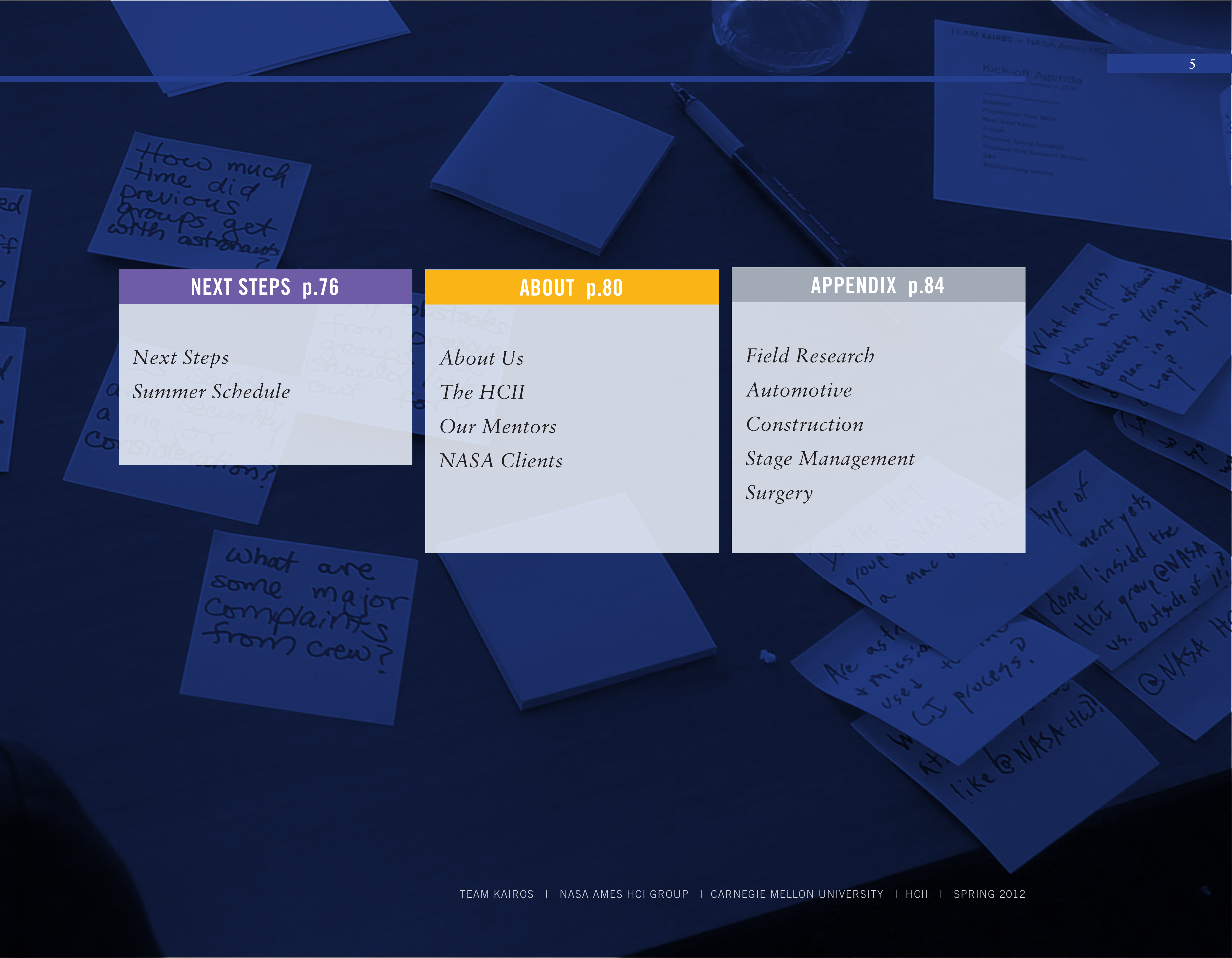
*Executive Summary*
*Background*

**RESEARCH p.12**

*Methods and Processes*
*Literature Review*
*Competitive Analysis*
*Field Research*
*Analogous Domains*

**DISCOVERIES p.42**

*Considerations*
*Insights and Visioning*



**NEXT STEPS p.76**

*Next Steps*
*Summer Schedule*

**ABOUT p.80**

*About Us*
*The HCII*
*Our Mentors*
*NASA Clients*

**APPENDIX p.84**

*Field Research*
*Automotive*
*Construction*
*Stage Management*
*Surgery*

# INTRODUCTION


EXIT 25
F.M.
528
NASA Pkwy
1/2 MILE
EXIT 26
H
Bay Area Blvd
Baybrook Mall
Dillard's
macy's
JCPenney
Sears

# EXECUTIVE SUMMARY

*As the Space Shuttle era ends and NASA shifts its focus to the exploration of near-earth objects and beyond, new operational conditions will require crewmembers to perform their duties with increased autonomy. A software system that facilitates the complex act of executing scheduled tasks with minimal support from ground crew will be critical to the long-term success of such missions.*

*The goal of Team Kairos is to understand how crewmembers and ground crew communicate in different mission contexts to accomplish scheduled tasks, and to develop a mobile solution that facilitates and coordinates the completion of those tasks. Our work will culminate in the generation of a working prototype that supports operations both on the International Space Station and future exploration missions.*

**RESEARCH**

To ensure that our ultimate design addresses the complex problem of procedure execution and users' true needs and desires, we gathered data to discover these criteria and guide the design process. Owing to the difficulty in obtaining time with astronauts, much of our research focused on studying analogous domains in which complex procedures are regularly executed. Our field research included observation at Johnson Space Center, three contextual inquiries in analogous domains, five semi-structured interviews with key stakeholders, and a few brief conversations with former crewmembers.

To familiarize ourselves with academic research on pertinent high-level concepts, we conducted a literature review. Additionally, a series of competitive analyses—specifically focused on enterprise-level coordination tools and checklist iPad applications—investigated existing software products and trends that can aid in procedure execution.

**DISCOVERIES**

After collecting, analyzing, and synthesizing all of our research, the data revealed several salient themes across all domains. Some of these themes provided actionable opportunities, while others acknowledged unique contextual elements or constraints of the space domain.

*Considerations*

- In high pressure operations, staff must provide assertive direction and moral support
- Future missions must account for intermittent ground–crewmember communication
- Inventory management issues can delay procedure execution
- Individual crewmembers read and understand procedures at varying degrees of granularity

*Insights*

- Critical contextual information should not be obscured by items of less immediate concern
- Methods that encourage memory recall can support consistent procedure execution
- Existing procedure support systems do not prioritize users' most pressing needs
- Instructive systems should not make superfluous demands on users' cognitive load

Actionable opportunities are accompanied by a targeted set of design recommendations that we feel will inform our upcoming ideation and concept validation stage.

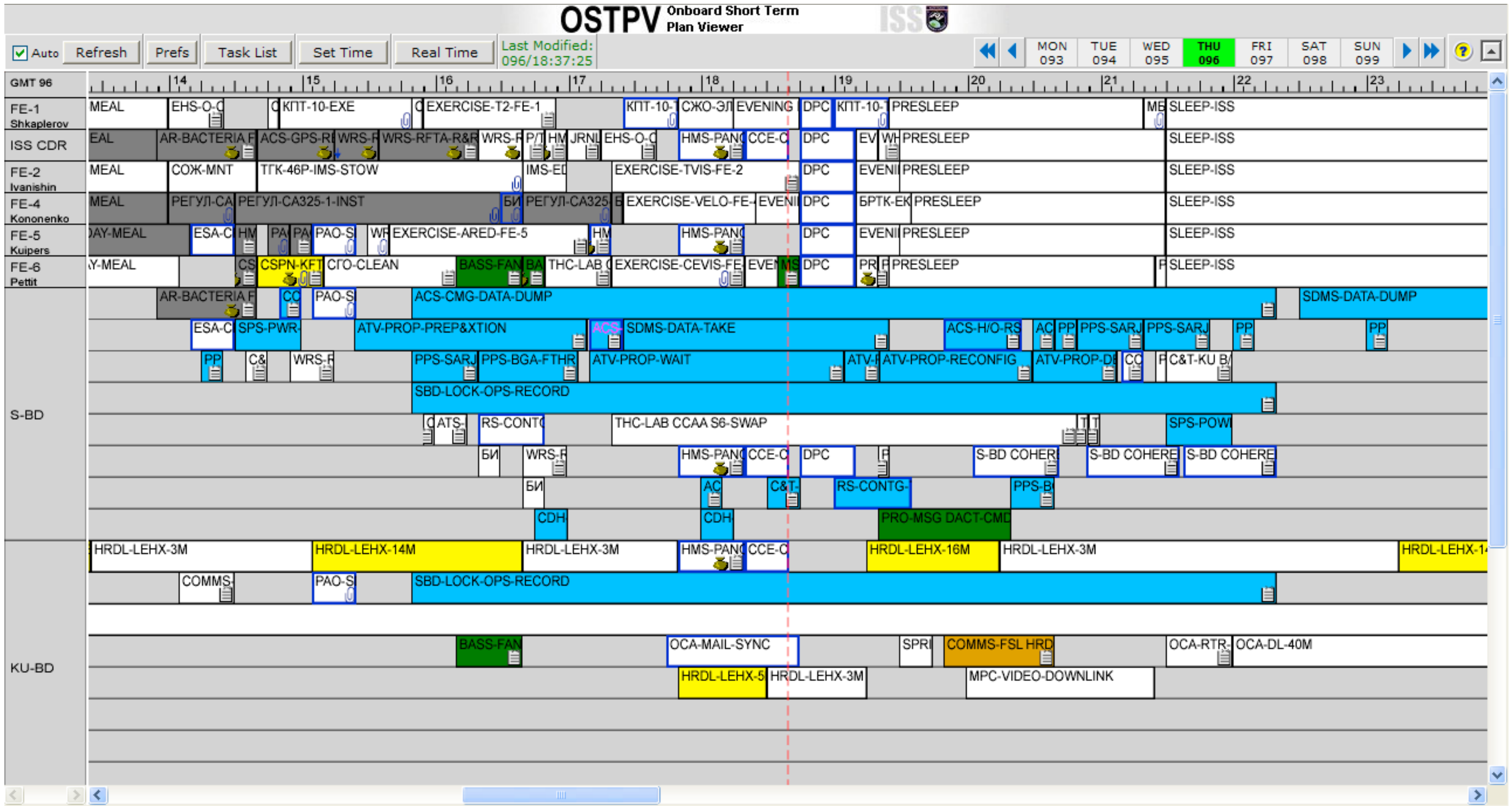
# BACKGROUND

### PROBLEM DESCRIPTION

As NASA shifts its focus to the exploration of near-earth objects and crewmembers operate with increased autonomy, software that facilitates the procedure execution with limited support from ground crew will become increasingly important. Team Kairos seeks to identify and design the most important features of such a system, culminating in the generation of a working prototype. We hope our design will help prevent errors and encourage crewmember autonomy.

The primary schedule software aboard the International Space Station (ISS) currently is called the Onboard Short-Term Plan Viewer (OSTPV). It allows crewmembers to view their daily schedules as well as the activity of other crewmembers and ground crew. This software operates alongside a procedure and inventory viewer called Integrated Viewer (IView), such that crewmembers can jump directly from a scheduled task to specific instructions and inventory requirements for that task. Technically, procedures are currently stored as either Microsoft Word or XML files, and inventory stowage locations are stored in the Inventory Management System, with procedure-specific tool locations authored in the Automated Stowage Note tool.

NASA has prototyped mobile crew assistants in the past. A mobile version of Score—a planning tool developed at Ames Research Center—was used in NASA's underwater analog mission in 2011. Mobile Score lives as a JavaScript-based web application that works with the existing Score planning system and acts as a mobile-centric view for its content. Mobile Score does not examine or reimagine the presentation of procedures, which is the primary goal of our project.




*"If I wanted to know what task I was supposed to be doing right now, that actually took a bit of work [...] it's super compressed on the timeline and it just—there were a lot more buttons on this thing than you needed" [1].*

1. *Aquanaut 1 interview, p. 94, ln. 28*

# RESEARCH


KINCAID STREET - 50' R/W
KINCAID STREET - 50' R/W
PROPOSED ITEMS
JORDAN WAY - 20' R/W
JORDAN WAY - 20' R/W

*Site superintendents keep detailed plans in their offices for reference and tracking status.*

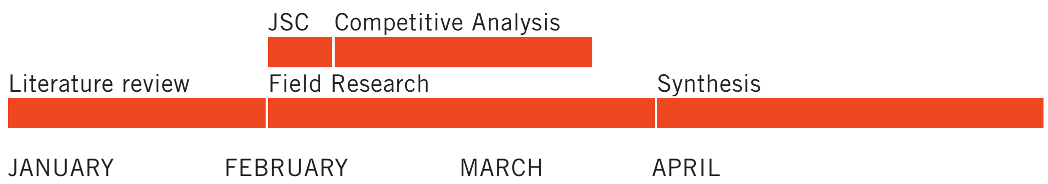
# METHODS + PROCESSES

*To ensure that our ultimate design supports procedure execution and users' true needs and desires, we gathered data to discover these criteria and guide the design process.*

As our final prototype is intended to be used by very specific users, we dedicated the bulk of our efforts to understanding the environment of procedure execution in space from the perspective of crewmembers and their ground crew. However, because we could not conduct contextual inquiries in person on ISS, much of our research involved examining terrestrial systems that could be considered analogous. Our field research took the form of **observation** at Johnson Space Center, **four contextual inquiries** in three analogous domains, **five semi-structured interviews** with key stakeholders, and a few **brief conversations** with former crewmembers.

These user findings are further supplemented by additional research aimed at gaining a greater understanding of existing resources that may be leveraged to influence our final design. We conducted a **literature review** to familiarize ourselves with several crucial, high-level concepts in procedure execution. A series of **competitive analyses** investigated existing software products and trends that can aid in procedure execution, specifically focusing on enterprise-level coordination tools and checklist iPad applications.

**SCHEDULE**



# LITERATURE REVIEW

*To better inform our understanding of the problem space, we performed an academic literature review. We initially chose about a dozen relevant topics to survey before settling on a few especially salient themes. We decided to explore the following hypotheses in depth:*

- Successful combination of disparate systems can provide benefits to information retrieval and data presentation
- Social codependency negatively affects team communication
- Contextual checklist systems can support efficiency of task execution
- Cognitive load limits may be flexible depending on context

**SUCCESSFUL COMBINATION OF DISPARATE SYSTEMS CAN PROVIDE BENEFITS TO INFORMATION RETRIEVAL AND DATA PRESENTATION**

Procedure viewing on ISS involves the integration of several sources of information from disparate systems. Like most current systems with which users retrieve information [1], it does not consider anything about the systems from which data are sourced. In a proposed interaction model to rectify this problem [1], a user manipulates classes of objects in an "information workspace," thereby understanding the sources of various data without leaving the semantic workspace context. This model may help to inform our methods of presenting data in a way that helps users effectively manage multiple, disparate systems. While a conceptual model is a solid foundation, actually implementing such a model may prove difficult. In [2], Lee and Bressan take a more technical approach to the problem of coordinating data sources. They note the benefits of considering potential naming conflicts, format conflicts, scaling conflicts, unit conflicts, and interpretation conflicts between different systems. They also especially focus on attributing data to their proper source. Finally, they suggest a hierarchy of flexible views and different levels for different data abstractions in the final workspace.

**SOCIAL CODEPENDENCY NEGATIVELY AFFECTS TEAM COMMUNICATION**

When does communication break down and why? How does the culture and psychology of the team affect the functioning of an organization as a whole? McMillan [3] examined the idea of organizational codependency, a logical extension to the greater corpus of work on social codependency. The author suggests that if social codependents function dysfunctionally, then such a pattern might emerge in organizations as well.

Barshi [4], examining airline pilots, has found that technical expertise and individual experience are distributed among team members. These experiences must be coordinated in novel and complex ways, which poses a challenge in the usability of a traditional hierarchy. Caldwell [5], who specifically examined ISS missions, notes that coordination, knowledge sharing, and information flow among physically distributed and highly-trained team members requires "a new paradigm of distributed supervisory coordination," and he ultimately concludes that future missions may need to move more ground knowledge onto in-vehicle systems.

**CONTEXTUAL CHECKLIST SYSTEMS SUPPORT EFFICIENCY OF TASK EXECUTION**

In stressful situations—particularly when that stress onset is acute—performance and attention can both suffer [6]. In many domains, such as nuclear power plant engineering and terrestrial flight, formal verbal or written checklist systems have mitigated some of these mistakes. Much work continues investigating the use of checklist systems in more novel domains.

A recurring discovery in our literature review is the use of pilot-inspired checklists in other domains. In a study of anesthesiologists, 95% of participants found the checklist useful and 80% wanted to use checklists in future surgical simulation [6]. Using a checklist for laparoscopic procedures also lowered mistakes; a 2007 study [7] found 53% fewer incidents among surgeons using checklists for those procedures.

Lingard [8] examined communication breakdowns among team procedures in an operating room (OR). They found that a common

1. *Rao et al., 1993*
2. *Lee and Bressan, 1997*
3. *McMillan and Northern, 1995*
4. *Barshi and Healy, 1993*
5. *Caldwell, 2005*
6. *Hart and Owen, 2005*
7. *Verdaasonk et al., 2008*
8. *Lingard, 2004*

set of problems—increased cognitive load, routine interruptions, and "increasing tension in the OR" resulted from about 10% of all team exchanges. Additionally, tension among roles in the OR led to communicative breakdowns in which hospital regulations were skirted to stay on schedule; this culture was eventually accepted by the OR staff as a whole. The authors suggest the use of checklists as a possible solution to communication failure, but they do not examine procedural failures; they also note that more research into communication failures is necessary.

#### COGNITIVE LOAD LIMITS MAY BE FLEXIBLE DEPENDING ON CONTEXT

Finally, workload and performance relationships are an important consideration when designing for the complex requirements of procedure execution in space. We examined psychological issues surrounding memory and cognitive load and methods attempting to mitigate such issues in various domains. Discussions of cognitive load often begin with Miller's regularly-cited theory [9], which suggests that short-term human memory holds 7±2 items. Recent research has suggested that this number is needlessly absolute—although a number of models have been proposed since (see, e.g. [10, 11, 12]), human working memory can be extended or shortened based on several contextual factors.

As designers, we should assume that working memory is simply very limited, and our software should therefore require as little of that space as possible. Chandler and Sweller [13] make this recommendation, and they employ learning to use the computer as an example to show the sources of cognitive load (intrinsic and extrinsic). They argue that you must physically integrate instruction and environment to minimize the need for the user to mentally integrate the two sources. Interestingly, Basahel et al. [14] found that optimal performance appears to occur at moderate levels of workload; extremely low or extremely high workloads are correlated with poor performance. The authors even suggest that a compensatory solution for mental underload is adding a light physical workload.

We found support in the literature for all of our initial hypotheses, and we also discovered questions that informed our field research plans across our analogous domains. In turn, these findings have guided our design recommendations for improved performance in procedure execution.

*9. Miller, 1956*

*10. Card et al., 1983*

*11. Detweiler and Schneider, 1987*

*12. Farrington, 2011*

*13. Chandler and Sweller, 1996*

*14. Basahel et al., 2010*

# COMPETITIVE ANALYSIS

*We began our competitive analysis by reviewing several enterprise project management solutions. While these applications were important sources of information on large scale planning, they did not have specific capabilities to address the needs of in-context task execution and step-by-step procedures. We then shifted our focus to examining iPad applications.*

*We chose personal to-do applications to understand the constraints of information presentation and navigation on mobile devices. The creation of a feature matrix helped aid the selection of applications to examine in-depth. We evaluated their ease of use, feature-set, and overall design. In our evaluation we identified several important features: hierarchy, information granularity, quick-note taking, and prioritization.*

**APPLICATION**

| **FEATURE** | TOODLE DO | THINGS | AWESOME NOTE | OMNI FOCUS | TASKA | REMEMBER THE MILK | TASKER | NUBI DO | 2DO |
|---|---|---|---|---|---|---|---|---|---|
| FILTERING/SORTING | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| SUBTASK MANAGEMENT | No | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| PRIORITIZATION | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| NOTE TAKING (VOICE, DRAWING) | Yes | No | Yes | Yes | Yes | Yes | No | Yes | Yes |
| CONTEXT-BASED ALERTS | Yes | No | No | Yes | Yes | Yes | Yes | No | Yes |
| COMPLETION TRACKING | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| TOUCH CONTROLS | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| UI AESTHETICS | Yes | No | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| SYNCHRONIZING | Yes | Yes | No | Yes | Yes | Yes | Yes | No | Yes |
| EMBEDDED TASK METADATA | Yes | No | Yes | Yes | Yes | Yes | Yes | No | Yes |
| IPAD VERSION | Yes | Yes | Yes | Yes | Yes | Yes | No | No | Yes |

**FEATURE AVAILABILITY**

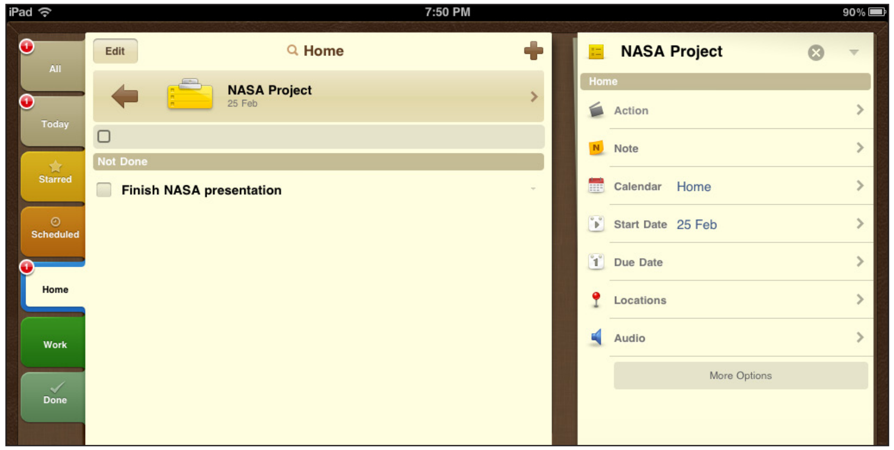
Yes

No

Based on this feature matrix, we selected *Toodle Do*, *Awesome Note*, *OmniFocus*, *Taska*, and *2Do* to review in depth.

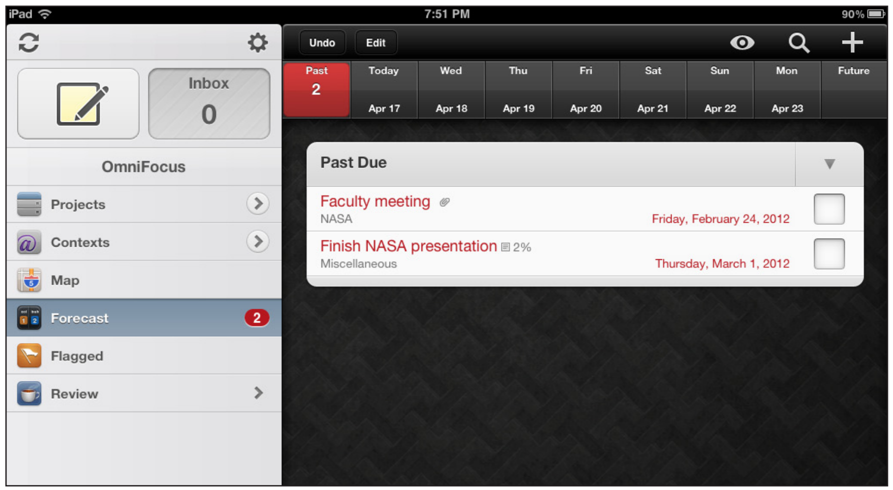
### CLEAR HIERARCHY IS ESSENTIAL FOR NAVIGATION

In dealing with many levels of information and task execution within the context of several tasks a day, it is important that navigating through the levels of information is clear. Additionally, this navigation should help keep the user on task by providing cues for upcoming details of a task as well as surfacing important reminders from earlier in the task. *2Do* and *OmniFocus* show a similar navigation paradigm that demonstrates this hierarchy concept in varying styles.



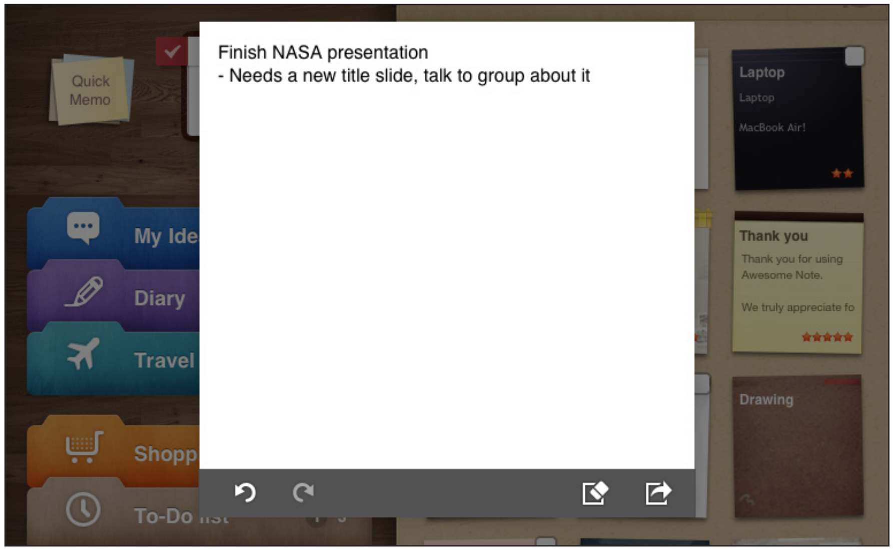

### MANY LEVELS OF GRANULARITY LETS USERS FOCUS ON THE TASK AT HAND

*OmniFocus* provides detailed views of both a single day's tasks and of individual task details. This allows users to focus on the important tasks in a given timeframe, while not being overwhelmed by peripheral information. The application has a timeline overview so that the user does not get lost inside of the procedure. Providing additional levels of granularity by diving into the procedure-specific task steps would be useful for our future software.



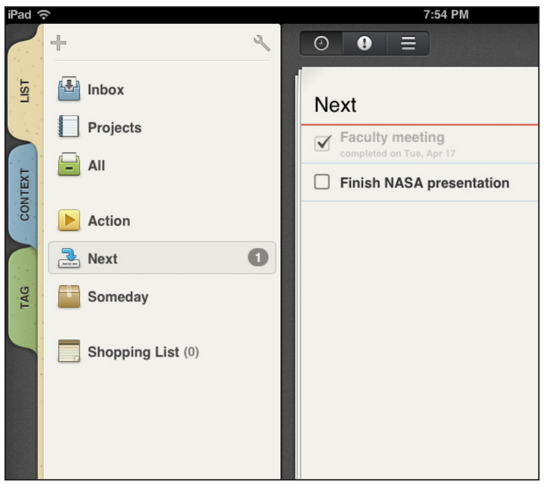
### QUICK-NOTES TAKE ADVANTAGE OF THE AFFORDANCES OF A MOBILE DEVICE

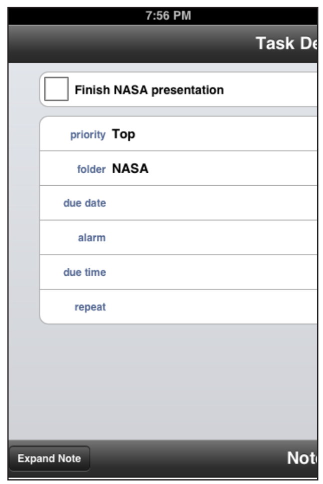
Our solution will be used in the context of task execution. As such, a user may need to quickly make annotations when working through a complicated task. This ability should be quick and easy to do, either through typing or drawing. *Awesome Note* allows the user to quickly jot down notes, which the user can then categorize at a later time.




### PRIORITIZATION AND CONTEXT FILTERING GIVE USERS HIGH-LEVEL OVERVIEWS OF THEIR DAY

Prioritization could be useful for crewmembers to understand which tasks carry the most importance during the day's activities. Additionally, harnessing contextual information such as telemetry data would help the user make decisions without having to constantly reference those data at a different terminal or in a different application. Both *Toodle Do* and *Taska* show examples of adding task priority.



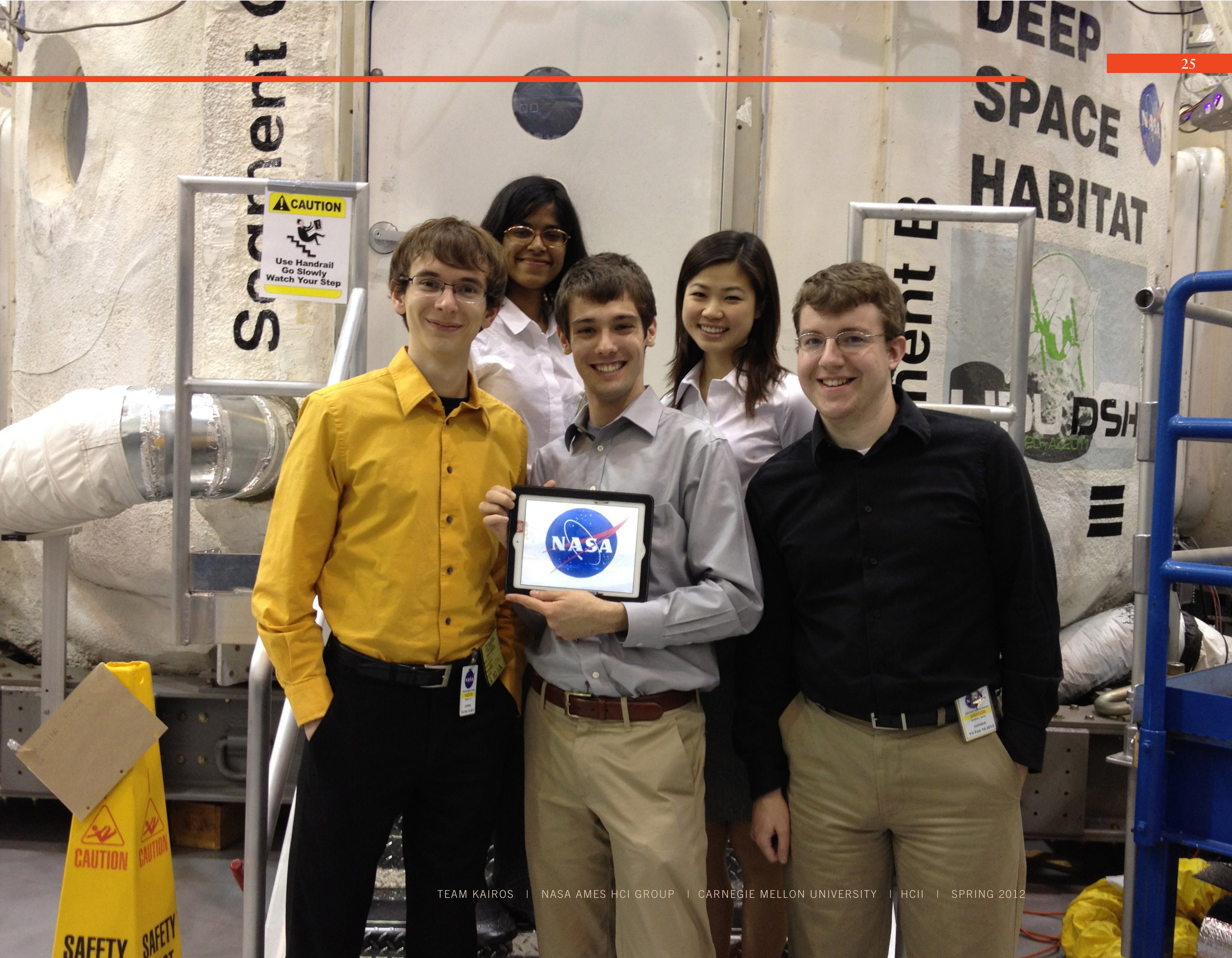




*More information about these applications is in the appendix, p. 88*

# FIELD RESEARCH

*Our field research began with a three-day visit to NASA's Johnson Space Center in Houston, Texas. We conducted a series of interviews and observations there, which provided a key opportunity to gain insights into procedure execution on ISS.*

*Although we were not able to speak with current or former crewmembers while at JSC, it was clear that we needed the thoughts of actual procedure executors to better inform our research insights. From both chance encounters and local availability, we secured time with a variety of space-related interviewees. They included a former astronaut who flight-tested ISS hardware and visited Mir in the 1990s, two current astronauts at outreach events, and two NASA scientists who served as aquanaut crewmembers on an underwater analog mission.*


CAUTION
Use Handrail
Go Slowly
Watch Your Step
DEEP
SPACE
HABITAT
NASA
CAUTION
SAFETY

**JOHNSON SPACE CENTER**

The first day began by observing flight controllers finishing their day at the Mission Control Center, where ISS support staff monitor the current expedition and can send certain commands to the station. We also toured the public viewing area of the Space Vehicle Mockup Facility, where much crewmember training occurs.

The next morning, we spoke with a team of flight controllers and procedure writers, who briefed us on their current workflow and shared anecdotes about crewmember frustration and troubles with procedure execution.

Next we examined a rapid prototyping lab in which new displays for the Orion Multi-Purpose Crew Vehicle (MPCV) cockpit are being created. Engineers there spoke about some of the difficulties crewmembers can have in physically manipulating displays during launch and reentry sequences—in which there are heavy physical forces acting upon the users.

We later spoke with the Branch Chief of Space Human Factors and Habitability at JSC, whose department supports all of the human needs of crewmembers on ISS—from preparing space food to reducing noise in sleeping quarters. He relayed the importance of capturing data in situ as much as is feasible, and he explained to us why NASA conducts analog missions on Earth to simulate the harsh environment of space.

Finally, he led us on a tour of NASA's Deep Space Habitat, used for the past several years to conduct the Desert RATS analog mission.

On our final day at JSC, we met with the Advance Mission Planning Group Lead to discuss the importance of a better procedure viewer in NASA's future exploration missions. We also received an overview and tutorial of NASA's current software support systems from two Daily Operations Group (DOG) trainers, whose job involves providing the same training to actual crewmembers. They explained all of the components of OSTPV and IView, and they provided helpful context for crewmembers' current frustrations with the system.

*More information about JSC in the appendix, p. 90*

## ASTRONAUT INTERVIEWS

As previously mentioned, astronauts are notoriously difficult to track down. During our research period, we were fortunate to have opportunities to speak with two astronauts about their experiences in space, albeit briefly in one instance. One had recently returned from ISS and was giving an outreach talk, while the other was retired and serves on the faculty of a university. Together, they wove an intimate and often conflicting portrait of what it means to be an astronaut and the variety of opinions that are to be found among the astronaut corps.

### *Summary of Interviews*

The first "interview" could only be labeled as such in the broadest sense. Upon discovering that an astronaut would be visiting campus, several members of the team leapt into action in an attempt to ask some of the pressing questions raised by our research. Ultimately, a compromise had to be made, and we were admitted to a private presentation and question-and-answer session. Though we were unable to ask questions ourselves, many subtle insights came to light, such as astronauts' emotional reactions to being in space [1] and a telling anecdote in which a simple mistake had global repercussions, in which an astronaut accidentally pulled a fire alarm, "I pulled that plastic cover off those little buttons and I pushed that button... I mean it had huge consequences—every fan on the space station shuts down. A lot of equipment on the space station shuts down" [2].

The second interview was conducted in a traditional semi-structured format. Though retired for over a decade, the astronaut we interviewed was able to provide important insights into the rate at which procedures change in NASA [3] and the culture of the astronaut corps. A veteran of several Shuttle missions, his perspective on procedure execution was quite different from the feedback we had received about operations on the ISS. We were able to see the actual procedure packets used in-flight, which led to the revelation that the visual form of procedures has changed very little since the years of Apollo [4]. This is an observation that the astronaut shared, and a problem with which he had long been frustrated. His personal recommendation was to establish an expert knowledge system that would enable crewmembers to achieve more autonomy by delegating mundane tasks to a database of known errors and by referencing this database to resolve issues and perform certain procedures [5].

1. *Astronaut 1 lecture, p. 74, ln. 20*
2. *Astronaut 1 lecture, p. 74, ln. 37*
3. *Astronaut 2 interview, p. 76, ln. 16*
4. *Astronaut 2 interview, p. 76, ln. 10*
5. *Astronaut 2 interview, p. 83, ln. 26*

### AQUANAUTS

Perhaps the closest analog to NASA crewmembers in space are NASA analog crewmembers on Earth—that is, scientists and engineers selected by NASA to serve as crewmembers on missions that simulate many aspects of a harsh space environment. We conducted semi-structured interviews with two aquanauts who have previously served on NASA's Extreme Environment Mission Operations (NEEMO) missions; they also have knowledge of and have otherwise supported NASA's Desert Research and Technology Studies (DRATS), the Flashline Mars Research Station at Devon Island, and the Pavilion Lake Research Project missions.

*Summary of Interviews*

The aquanauts candidly related their experiences as both crewmembers and later advisors to NASA's analog missions. While they had differing levels of procedure use—one of the aquanauts had written most of the procedures—both spoke to the surprising levels of stress they experienced during procedure execution, with one noting that "everything is a little bit harder" than anticipated [1].

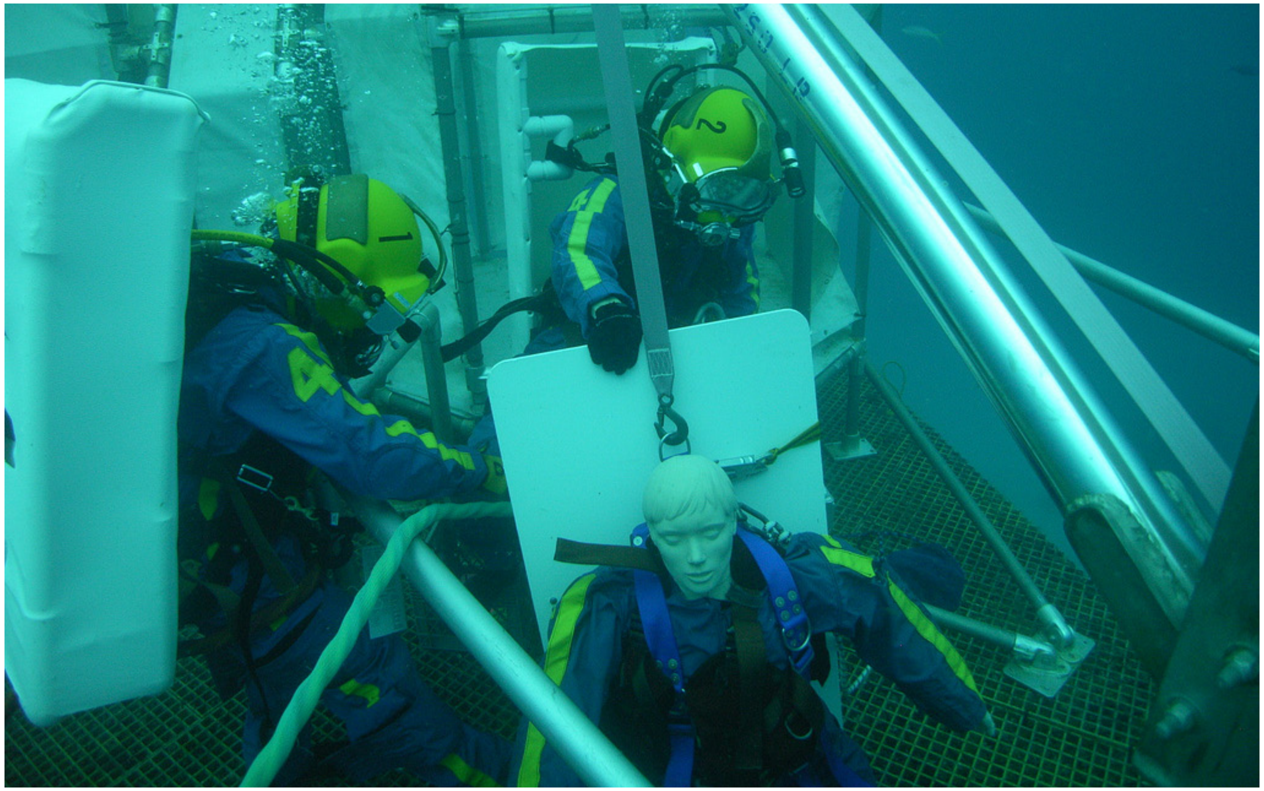
Both spoke to the importance of these analogs in providing user feedback for future design work. Although they specifically focused on how their experiences had informed their own work at NASA, they insightfully noted that their usability frustrations with the custom software generally made completing their assigned tasks harder. One said the crew wanted to use tools they were more familiar with, such as Excel or Outlook, rather than the tools they were provided [2].

In general, both noted a tension at NASA between an engineering-centered culture, where everything that is flown on a mission is optimally designed for performance and efficiency, and a user-centered culture, where technical efficiency might take a backseat to usability or friendliness. Ground-based tests simply cannot simulate the stress and complications of a mission environment, they said. They even expressed a desire for procedures to provide scheduled time for likely complications.

Finally, both aquanauts mentioned that in highly stressful environments, self-reporting task completion status is a secondary concern. They would rather the system be able to infer data like the start and end times of each procedure (and any sub-tasks for which such inference is possible). Although both felt it was burdensome to self-report these data, they cited different reasons: one user faulted the software as overly cumbersome [3], while the other said that it's simply hard to remember to make such status updates manually [4].

1. *Aquanaut 2 interview, p. 110, ln. 31*
2. *Aquanaut 2 interview, p. 111, ln. 4*
3. *Aquanaut 2 interview, p. 110, ln. 14*
4. *Aquanaut 1 interview, p. 95, ln. 35*

*More information about these applications in the appendix, pg. 96*



*Aquanauts test emergency procedures before they are used in space.*

We gained a better understanding of our problem space following our initial field research at Johnson Space Center. Because observing crewmembers in context is difficult, we focused the next phase of our user research on analogous domains where we could observe users working in context.

# ANALOGOUS DOMAINS

*Our investigations into the people and systems that make space exploration possible made it abundantly clear that no terrestrial endeavor has quite the same variety of processes and constraints. Even so, critical issues emerged that are common with many other domains—inventory management, complex communication, and authority tension, to name a few.*

*Identifying domains facing as many of these issues as possible, we set out to discover their individual solutions, seeking insights transferable to problems faced in space. We ideated several research foci to investigate, and began to brainstorm analogous domains in which we could observe work in context.*

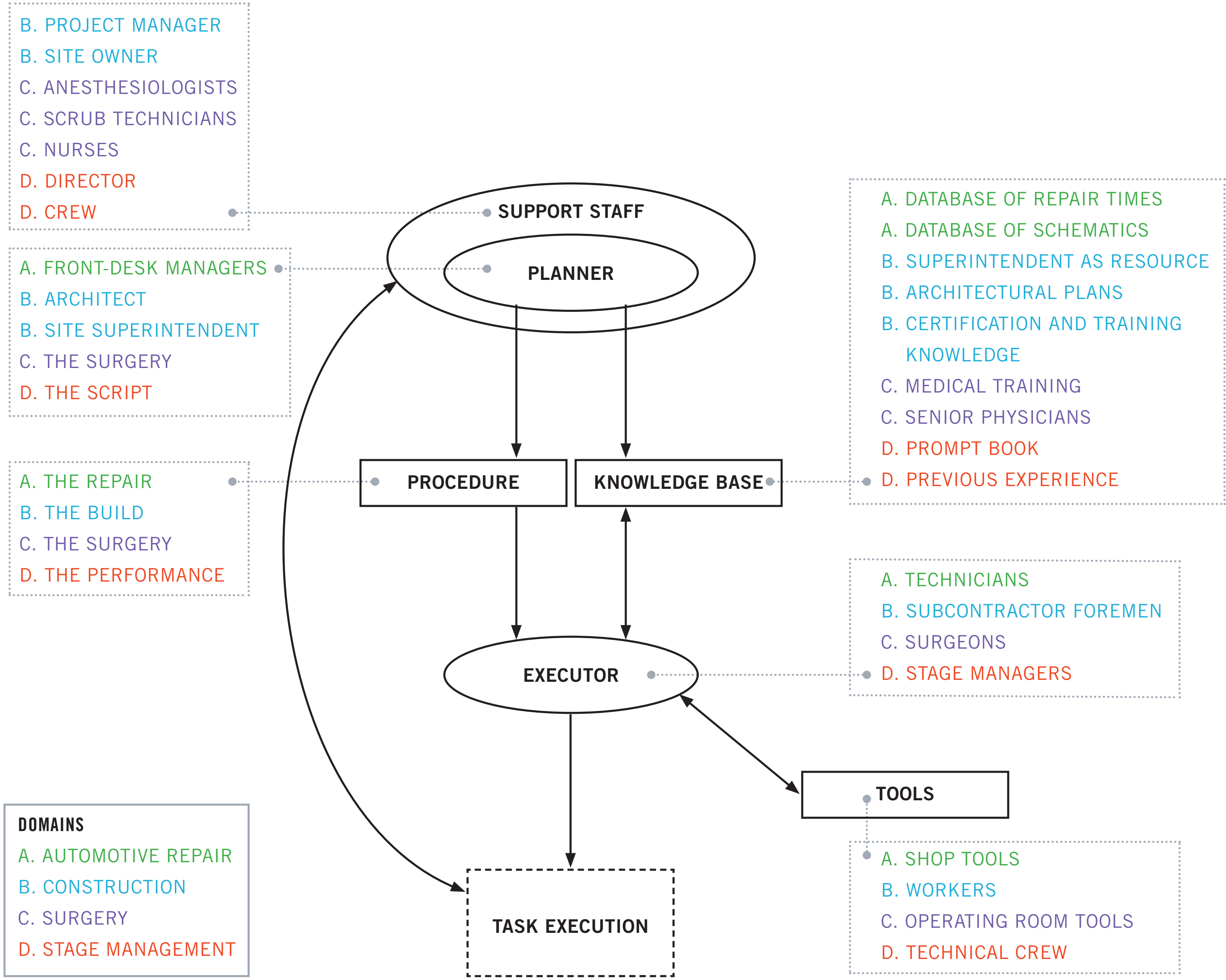
| CHARACTERISTICS \ DOMAINS | SPACE | AUTOMOTIVE REPAIR | COMMERCIAL AVIATION | CONSTRUCTION | EMERGENCY DISPATCH | FIELD SCIENCE | MILITARY | MINING | PACKAGE DELIVERY | STAGE MANAGEMENT | SURGERY | TAXI DISPATCH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **VARIETY OF PROCEDURE EXECUTION** | 3 | 2 | 2 | 2 | 1 | 3 | 3 | 2 | 1 | 2 | 3 | 1 |
| **EQUIPMENT MANAGEMENT** | 3 | 2 | 3 | 3 | ● | 3 | 2 | 2 | 3 | 3 | 3 | 2 |
| **PRESENTATION OF TELEMETRY DATA** | 3 | 2 | 2 | 2 | 2 | 3 | 3 | 1 | 2 | 2 | 3 | 1 |
| **REMOTE/INTER-ROLE CODEPENDENCY** | 3 | 1 | 3 | 3 | 3 | 1 | 3 | 2 | 1 | 3 | 2 | 2 |
| COMPLETION STATUS/TIME TRACKING | 3 | 1 | 3 | 3 | ● | 2 | 2 | 2 | 1 | 3 | 3 | 2 |
| COLLABORATIVE PLAN EXECUTION | 3 | ● | 3 | 3 | 2 | 1 | 3 | 2 | 1 | 3 | 3 | 2 |
| DISPARATE SYSTEM INTEGRATION | 3 | 2 | ● | 1 | 2 | 1 | 3 | 1 | 1 | 1 | 2 | ● |
| PHYSICAL CONSTRAINTS | 3 | 2 | 2 | 3 | ● | ● | 2 | 3 | 2 | 2 | 2 | ● |
| COGNITIVE DEMAND | 3 | 2 | 3 | 2 | 1 | 1 | 3 | 1 | 1 | 2 | 3 | 1 |
| AUTHORITY TENSION | 3 | ● | 2 | 2 | 1 | ● | 3 | 2 | 1 | 1 | 2 | 1 |

**RELEVANCE**

| | | | |
|---|---|---|---|
| High | 3 | Low | 1 |
| Moderate | 2 | None | ● |

After identifying the relevance of other domains to space, we selected *Automotive Repair*, *Construction*, *Stage Management*, and *Surgery* to research further.

*Here we present an abstracted model of procedure execution in space. In researching analogous domains, we carefully considered how the roles and systems within those domains mapped to those of the model. This mapping guided our research approach for contextual inquiries and interviews.*


B. PROJECT MANAGER
B. SITE OWNER
C. ANESTHESIOLOGISTS
C. SCRUB TECHNICIANS
C. NURSES
D. DIRECTOR
D. CREW
SUPPORT STAFF
PLANNER
A. FRONT-DESK MANAGERS
B. ARCHITECT
B. SITE SUPERINTENDENT
C. THE SURGERY
D. THE SCRIPT
A. DATABASE OF REPAIR TIMES
A. DATABASE OF SCHEMATICS
B. SUPERINTENDENT AS RESOURCE
B. ARCHITECTURAL PLANS
B. CERTIFICATION AND TRAINING KNOWLEDGE
C. MEDICAL TRAINING
C. SENIOR PHYSICIANS
D. PROMPT BOOK
D. PREVIOUS EXPERIENCE
A. THE REPAIR
B. THE BUILD
C. THE SURGERY
D. THE PERFORMANCE
PROCEDURE
KNOWLEDGE BASE
A. TECHNICIANS
B. SUBCONTRACTOR FOREMEN
C. SURGEONS
D. STAGE MANAGERS
EXECUTOR
TOOLS
DOMAINS
A. AUTOMOTIVE REPAIR
B. CONSTRUCTION
C. SURGERY
D. STAGE MANAGEMENT
TASK EXECUTION
A. SHOP TOOLS
B. WORKERS
C. OPERATING ROOM TOOLS
D. TECHNICAL CREW

## AUTOMOTIVE REPAIR

*Method: contextual inquiry*

*Automotive technicians use visual cueing to convey procedure status; additionally, a national database of historical procedure execution times helps them plan very accurate schedules.*

### *Key Observations*

*Prioritizing tasks*
Technicians use asynchronous communication tools to provide task execution feedback to their managers and follow a priority queue—literally a stacked set of clipboards for each technician—to find their next task [1].

*Omitting Needless Data from the View*
Technicians don't need the granularity of schedule information that OSTPV provides; it's less important to them that they have a three-hour task ahead than simply knowing that they have a task ahead.

*Money is a Motivator*
Technicians are incentivized to finish tasks quickly and efficiently because they are paid based on the industry-set standard for that task's time completion [2].

1. *Automotive CI, p. 120, ln. 27*
2. *Automotive CI, p. 122, ln. 26*

### *What We Learned*

We spoke with technicians and managers at a small automotive shop as well as service managers at a large auto dealership. The work done by technicians was a close analog to crewmember procedure execution. At the automotive repair shop, managers were physically separated from the procedure executors, but these managers had to ensure that the cars were being serviced in a timely and efficient manner without directly stepping in. The individuals we spoke with detailed how they created the schedule for the day, how they were able to keep track of their status while in a procedure, how they estimated procedure times, and how they understood and executed complex procedures. At the auto dealership, we found similarities in physical layout and workflow for the managers and technicians, but found slight differences in the style of status tracking and communication style. Overall, the similarities between the two were significant, and each CI served to reinforce the findings of the other.

### *What We Saw*

At the automotive repair shop, the technicians were scheduled by the management and asked to complete procedures in the order the management defined. This order was conveyed through a stack of clipboards in the garage; the ones closer to the top of the stack had higher priority, while the ones at the bottom were less important. The planners obtained their information for the time it would take to execute a procedure through an industry database of time estimates. Historically, technicians have completed the procedure in less time than the estimate suggested. Instead of blocking out specific intervals for an activity, the technicians simply knew the estimated time it would take to complete it. In this way they knew how many hours a given procedure took to finish, but they would not have (or need) information for exact start and stop times.

They used checklists, which they initialed when they finished a certain item on the list. Like crewmembers, however, their compliance varied: sometimes they would just remember what they had and had not finished at the time they chose to fill out the checklist.

The shop subscribed to an additional automotive database that contained detailed procedure execution information for different makes and models of cars. When the electronics were broken in a car, they used this system to look up information—often wiring diagrams. The system consisted of a searchable database within Internet Explorer. If a procedure was complicated, the technicians printed out the schematics or instructions and brought the pages with them to the site of procedure execution.

If the technician ran into a problem while fixing the car that could result in an unexpected delay, he filled out a form to indicate this to the managers. This way, the managers could reschedule and replan, and the technician could get paid for his extra work. If this were to happen, and work is put at a standstill because of the problem, the technician could place the clipboard in a bin labeled "problems," so the managers would be able to understand the status of the procedure.

*"Everybody's got their own slots. They take them starting at the top in the order that they're in. The top one is the one I want them to work on" [1].*


*1. Automotive CI, p. 117, ln. 17*

*More information about automotive repair is in the appendix, p. 98*

### CONSTRUCTION

*Methods: contextual inquiry and semi-structured interview*

*The strict hierarchical organization of a construction site means that individual procedure executors rarely need to understand the big picture to complete a task successfully; however, changes in that big picture can cause significant bottlenecks in task progress.*

### KEY OBSERVATIONS

*Birds-eye View of Task Execution*
Procedures aren't specified to subcontractor workers at any deeper level of granularity than measurement and placement specifications—there aren't instructions on how to build a stud wall, for instance, contained within the plan [1].

*Task Importance is Secondary to Execution*
Individual construction workers don't have—nor do they need to have—an understanding of how their daily activities fit into the larger plan for the construction project. Because of the hierarchical nature of construction, the foremen simply assign them tasks [2].

1. *Construction CI, p. 166, ln. 31*
2. *Construction CI communication flow model, p. 107*
3. *Construction CI, p. 158, ln. 24*

### WHAT WE LEARNED

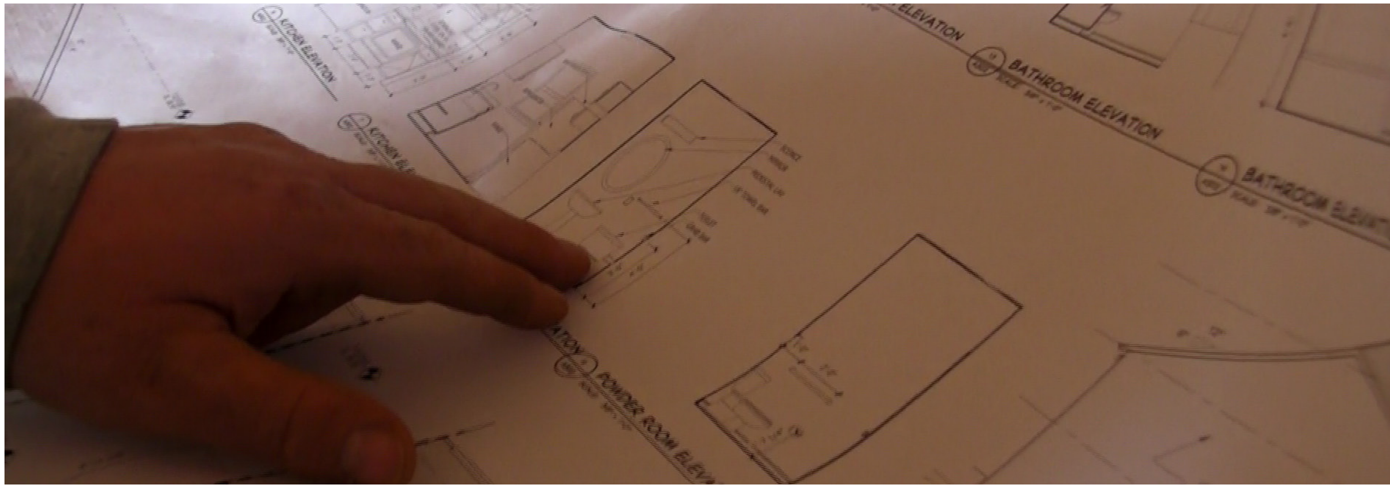
Construction management involves planning, coordination, and control of a long-term project, usually with the cooperation of many interests spread across many physical locations. Site superintendents and subcontractors work very closely with highly detailed, procedural plans, and they also track task completion and task correctness in order to both meet project and owner goals and to avoid future legal problems. Additionally, there is a large amount of inventory management.

### WHAT WE SAW

We conducted a contextual inquiry of a 40-unit housing project in Pittsburgh—an ongoing project that involves the staggered coordination of several subcontractor disciplines. Among the disciplines on site during our observation were excavators, framers, plumbers, electricians, and HVAC specialists. We were led around the site by the site superintendent, the on-site coordinator of the project. He plans the schedule with an in-office project manager; they do so using the plans and specification book provided by the architect.

Although construction management is complex and can involve breakdowns at any stage of the process, the site superintendent indicated that he uses his personal experience to solve problems and dynamically replan work. For the most part, he makes it a point not to talk much with individual workers, noting that "If I see them doing something wrong, I'll go to their foreman, or their lead" [3]. He gathers all the subcontractors on a weekly basis—he noted that doing so helps resolve any collective tension an individual foreman may have with him personally. The main bottlenecks he described involved waiting on other roles (for example, getting a report from a structural engineer on how to deal with an unexpected soil problem or waiting for a change order to the owner to be processed), but he tries to plan his schedules with some buffer time in case of delays—though not every project affords that luxury. In many instances, plans are also at the mercy of the weather, which can cause additional problems.

We also spoke with the plumbing foreman, who described how he assigns work to his crew and how they execute those plans. For the most part, the workers know how to do each procedure—plumbing procedures are general enough that the scale of the project has little impact on their work, and each plumber is highly trained on the necessary procedures. They work very closely with the plans from the architect; if they discover a problem, they make sure to report it to the superintendent: "I have a set [of plans] in the trailer which doesn't leave—this set—which I will mark this up with notes, and all the as-builts will be on here" [4]. He noted that this was primarily for his legal benefit; in case any changes result in problems, his company will not be at fault if the plans indicate approval to build something in a certain way. Tool management is handled on a per-worker basis, as plumbing tools are very basic. Furthermore, there is enough work to be done and enough time to do it that rarely is one subcontractor occupying the space needed by another.




*The workers know how to do each procedure—plumbing procedures are general enough that the scale of the project has little impact on their work, and each plumber is highly trained on the necessary procedures.*

*4. Construction CI, p. 160, ln. 19*

*More information about construction is in the appendix, p. 104*

## STAGE MANAGEMENT

*Method: contextual inquiry*

*Thoughtful long-term notetaking facilitates consistent execution and creates an effective artifact to aid in the distribution of procedure knowledge.*

### KEY OBSERVATIONS

*Feedback Through Stage Notes*

A detailed document outlining the behaviors of actors in a given situation (the stage manager's notes) may provide inspiration for systems through which NASA can gather more informative feedback from crewmembers by active or passive means [1].

*Checklists and Responsibility*

Backstage crew successfully follows a detailed checklist, ensuring that the actors have the tools they will need to carry out their mission. The assistant stage manager is also held personally accountable if an actor goes on stage unprepared and must improvise to compensate for this error [2].

*Love For Work*

The stage culture we observed is a close analog to NASA's. Though they were working long hours and operating under stressful conditions, these were people who showed an obvious love for their craft and a dedication to collectively accomplishing their goals.

### WHAT WE LEARNED

The stage manager is the glue binding the various disciplines involved in a theatrical production. His position involves the coordination of long-term planning and scheduling among actors, crew, and technicians; procedural execution under rapidly changing contexts; and close communication amongst multiple designers. The stage manager is involved in every stage of production, from rehearsal to the final performance via the creation of a living document tracking cues and interactions throughout the play [3]. This living document is constantly updated as new elements are added and removed, a process that often continues until opening night, when the stage manager will be in charge of coordinating cues and ensuring that each discipline is doing its job [4]. For these reasons, the challenges of stage management can provide opportunities and insights that can be applied to coordination and relationships among people, procedures, and tools relevant to space flight.

### WHAT WE SAW

For our investigation, we conducted a contextual inquiry with both the assistant and principal stage managers during a technical rehearsal for a major theatrical production. The assistant CI was an active question and answer session, while the principal CI consisted of significant periods of close observation, as rehearsals are largely uninterruptible.

The CI began by following the assistant stage manager as she performed her pre-show duties for a two-man production at a major local theater. During this time she was in constant motion: gathering props, checking on the actors' status, coordinating the various disciplines, and ensuring the

1. *Stage CI communication model, p. 99*
2. *Stage CI, p. 199, ln. 7*
3. *Stage CI, p. 203, ln. 30*
4. *Stage CI, p. 203, ln. 41*

stage was properly equipped.
When asked about her relationship with the actors, she replied "I kind of liken myself to a wrangler of cats and a mother wrapped into one" [5]. She ensures that before, during, and after performances, the actors' needs are met, be they physical or psychological.

Transitioning to the principal stage manager was a sharp contrast. His role was stationary and methodical, though still largely concerned with coordination and communication [6]. Throughout the CI, he was constantly listening to and speaking over a headset, relaying orders, calling cues, or writing in his notebook [7]. This notebook is critical to the production as it must be constantly updated with every sound, lighting and blocking cue for the show. As a living document, it can (and frequently does) change up to and including the night of the show. It must be maintained not only so that accurate cues may be called, but so that another stage manager could, hypothetically, call the show from them if the original stage manager should be unavailable.

*"All the documentation is in order and put it in this book here. So that when we go back to it, we all pull those cues and they all get executed the same way. So that each show comes out the same way" [8].*

*5. Stage CI, p. 201, ln. 16*

*6. Stage CI, p. 204, ln. 14*

*7. Stage CI, p. 204, ln. 30*

*8. Stage CI, p. 204, ln. 14*

*More information about stage management is in the appendix, p. 110*

### SURGERY

*Method: Retrospective interview*

*In carrying surgical procedures with efficiency and accuracy, it is essential and beneficial to have experience, a focus on immediate needs, and strong team communication process.*

#### KEY OBSERVATIONS

*Physical Cues Reinforce Memory*

Physical cues are extremely important to help reinforce memory of complicated procedures. In one anecdote, a surgeon described a model of the spine he kept in an OR during his early residency days [1].

*Tension in Communication*

Each member of the surgery team must strike a balance between focusing on their personal roles and communicating amongst themselves. Cultural tension occasionally causes this to break down, as surgeons may not heed their support staff and others may be hesitant to interrupt the surgeon in his work [2].

#### WHAT WE LEARNED

Surgery involves highly detailed, knowledge-based procedures and close coordination with support staff, all done in an environment of changing priorities and time pressure. Surgeons in the operating room require close coordination with support staff in performing each task and set of subtasks. To facilitate this coordination, surgeons developed formal checklists to use before, during, and after surgery. Additionally, nurses and surgeons verbally confirm crucial data about each surgery—such as which arm to open—before beginning. Finally, surgeons have devised systems of visual cueing through diagrams and notes to facilitate the recall of a certain set of skills or procedures when required.

#### WHAT WE SAW

In brain surgery, as in space, procedures follow a strict set of subtasks, and there is a necessity to adhere to guidelines from training. Surgeons work most frequently with nurses, scrub technicians, and anesthesiologists; they also have an attending surgeon that serves as a supervisor and general reference. Among the most salient themes from our interview were an observed need for experience, memorization, and knowledge of the principles behind the procedures and strong real-time communication with support staff.

Surgeons focus primarily on the immediate needs of their procedures and on handling unexpected occurrences in those procedures—finishing the procedure quickly is a secondary concern. However, residents and support are still motivated to complete procedures efficiently to avoid extensive schedule breakdowns. One surgeon commented, "You can't really take shortcuts in the actual surgery. The surgery is the same no matter where you put it or where you do it" [3].

1. *Surgery interview, p. 189, ln. 38*
2. *Surgery cultural model, p. 114*
3. *Surgery interview, p. 177, ln. 29*

There is a balancing act between completing surgeries with accuracy and being efficient in getting the day's work done. Given the large support staff involved in a single surgery, surgeons want to finish efficiently so that everyone can go home when their shift is scheduled to end [4].

Surgeons focus their attention on the task at hand, mentioning that in their early days as residents they would often try to speed things up by ignoring problems and returning to them later, only to be faced with greater problems. They claimed the best way to reduce errors is to get better by doing more surgeries, and to prepare extensively beforehand by staying up to date on current techniques—even occasionally referencing Google [5].

The surgeons also noted a changing surgery culture, especially in urban hospitals. Patients want "the guy that's done 10,000 aneurysms," not a general surgeon [6]. With such hyper-specialization, procedure errors are fairly minimal.

Although the procedures do not vary during subsequent executions, each surgery still involves a distinct set of people working together—for instance, each surgeon has their own personal preferences in equipment placement. According to the surgeons, the support staff has tried to reduce grave error by making procedures and information more explicit. For example, anesthesiologists place tape on the wall noting needed supplies and details of each particular surgery, and there is a checklist that is read by the nurses before and after each surgery in which the tools for the procedure are counted.

Before these processes were developed, few support staff were willing to question the surgeons' decisions, respecting their authority. However, in light of mistakes that occurred, an informal system of aforementioned checklists and tape was created to alert everyone to pre- and during-task statuses developed [ [7].

After collecting and analyzing these data through work models and affinity diagramming, we began to explore cross-domain synthesis to find emergent themes. The next section describes our discoveries.

*4. Surgery interview, p. 176, ln. 6*

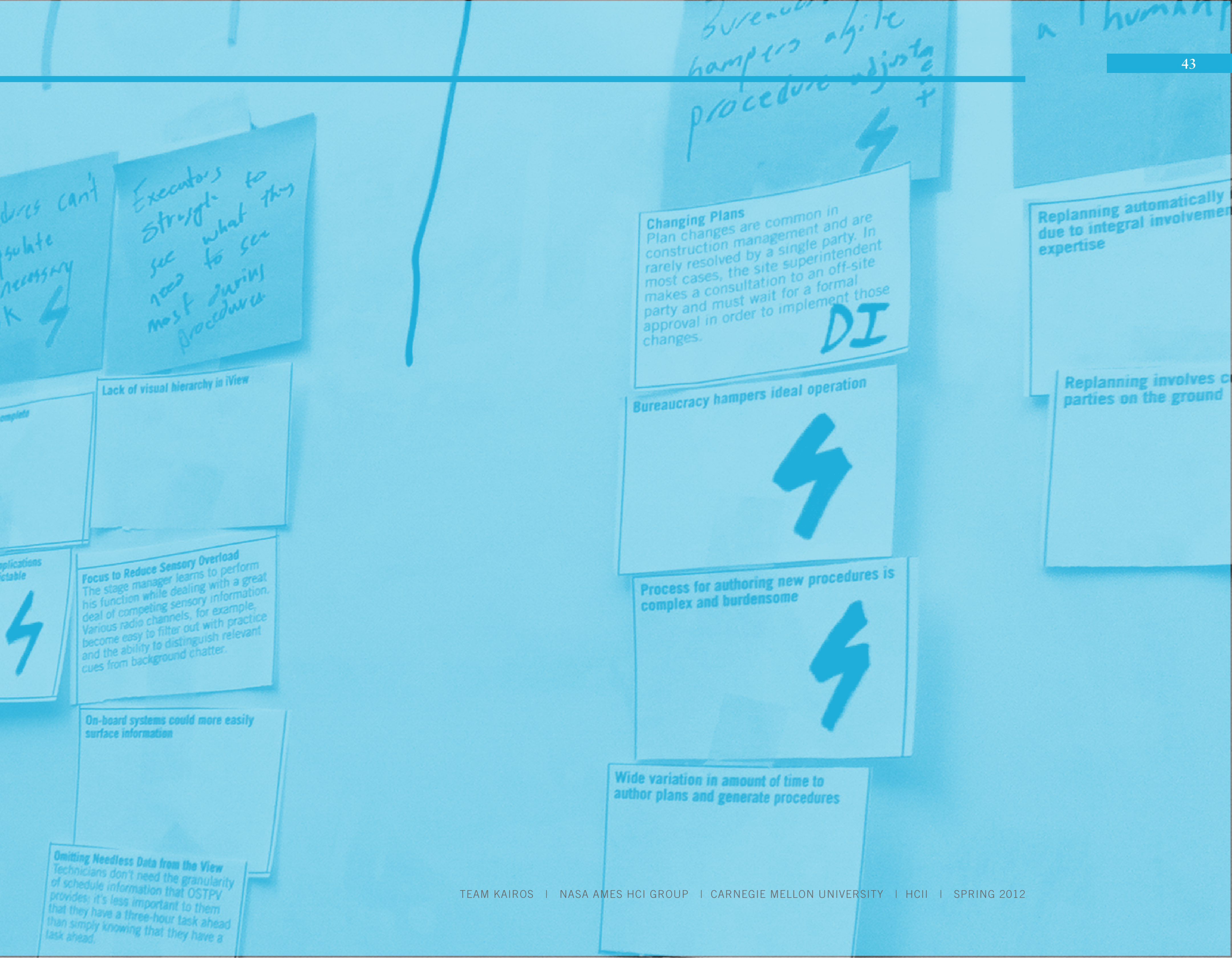
*5. Surgery interview, p. 189, ln. 22*

*6. Surgery interview, p. 186, ln. 20*

*7. Surgery interview, p. 180, ln. 33*

*More information about surgery is in the appendix, p. 114*

# DISCOVERIES


Executors struggle to see what they need to see most during procedures
Lack of visual hierarchy in iView
Focus to Reduce Sensory Overload
The stage manager learns to perform his function while dealing with a great deal of competing sensory information. Various radio channels, for example, become easy to filter out with practice and the ability to distinguish relevant cues from background chatter.
On-board systems could more easily surface information
Omitting Needless Data from the View
Technicians don't need the granularity of schedule information that OSTPV provides; it's less important to them that they have a three-hour task ahead than simply knowing that they have a task ahead.
Changing Plans
Plan changes are common in construction management and are rarely resolved by a single party. In most cases, the site superintendent makes a consultation to an off-site party and must wait for a formal approval in order to implement those changes.
DI
Bureaucracy hampers ideal operation
Process for authoring new procedures is complex and burdensome
Wide variation in amount of time to author plans and generate procedures

*The field of space exploration is full of technical marvels, from the massive rockets that allow humans to transcend their earthly bonds to the life support systems that make extended stay on ISS possible. Though these mechanical systems receive an appropriately rigorous amount of attention and testing, it is important not to lose sight of the other critical component of manned space flight—the crewmembers themselves.*

*Guided by the principles of human-centered design, our goal is to design systems which appropriately address the complexities of human behavior and psychology. Drawing inspiration from the Cupola on ISS, the huge window that serves little utilitarian function but has an incalculable impact on crewmember morale, the analysis of our findings strives to always keep the user's needs at the forefront of our considerations.*

***The old design adage that "the user is not like me" has perhaps never rung more true than in designing for crewmembers.*** *These are individuals who have extreme personalities, exhaustive training and personal needs dramatically different from those found in most terrestrial domains. The constraints and insights that follow are our attempts to summarize and analyze these factors as we strive to design a truly holistic solution to the problem of procedure execution.*

# CONSIDERATIONS

*After distilling our research, it became clear that the space domain presents unique constraints and considerations for our future design process. In this subsection, we present these considerations and their supporting evidence.*

## CONSIDERATION 1

*In high-pressure operations, staff must provide assertive direction and moral support*

**FINDINGS**

- There is a great deal of stress placed on those executing tasks
- Professional respect can make appropriate criticism difficult
- Moral support eases tension in high-stress roles

*See page 48*

## CONSIDERATION 2

*Future missions must account for intermittent ground–crewmember communication*

**FINDINGS**

- The current system requires scheduling around communication lapses
- During long communication delays, conversations likely shift from voice to text
- Users more frequently switch tasks during a communication delay while they wait on responses to inquiries

*See page 50*

## CONSIDERATION 3

*Inventory management issues can delay procedure execution*

**FINDINGS**

- Problems with physical tool-finding can delay procedure execution
- Crewmembers deal with a cumbersome process to look up needed tools
- There is variable compliance by crewmembers in updating stowage data

*See page 52*

## CONSIDERATION 4

*Individual crewmembers read and understand procedures at varying degrees of granularity*

**FINDINGS**

- Crewmembers cannot be expected to know how to do everything; they need procedures
- Procedure execution gets easier with practice

*See page 54*

## CONSIDERATION 1

*In high-pressure operations, staff must provide assertive direction and moral support*

### FINDINGS

- There is a great deal of stress placed on those executing tasks
- Professional respect can make appropriate criticism difficult
- Moral support eases tension in high-stress roles

In any field that differentiates between "on-stage" and "off-stage" operations, tensions can arise between those who do and those who plan. Be it a stage manager and an actor, a site superintendent and a subcontractor, or ground crew and crewmembers, the success of human-to-human communication and support systems rely heavily on a delicate balance of cultural factors and considerations. Though ground is there to provide crewmembers with necessary information, psychological support becomes crucial during stressful operations. Conversely, ground must also know when crewmembers are able to be interrupted or even criticized. Both our analog studies and our time at JSC revealed interesting facets of this cultural exchange.

**THERE IS A GREAT DEAL OF STRESS PLACED ON THOSE EXECUTING TASKS**

Even during the relatively simple procedures conducted during NEEMO missions, analog crewmembers experience significant stress, to the point where future ISS commanders are often chosen in part due to how they conduct themselves in such scenarios [1]. Despite years of training, ISS crewmembers still experience a level of uncertainty when conducting crucial procedures [2], as even slight mistakes can have disastrous consequences [3]. With both the crewmember's extremely busy schedule and the pressure to not get behind on their activities [4], a clear picture of the general stress level involved in these missions emerges.

**PROFESSIONAL RESPECT CAN MAKE APPROPRIATE CRITICISM DIFFICULT**

From interviews at JSC and in the surgery domain, we observed that communication breakdowns often occur when support staff does not wish to interrupt a procedure with important feedback or criticism, as it would both interrupt the flow of action and potentially cause authority tension among the parties involved. Ground crew seems generally hesitant to reprimand or criticise crewmembers, even when such comments may ultimately be to their mutual benefit [5]. In other domains, certain players take on the role of an authority figure, delivering these messages directly, but with tact. Though the CAPCOM occupies this role to an extent, there appears to be no clear parallel in space to a stage manager or site superintendent, who take on responsibilities in both planning and leadership roles.

**MORAL SUPPORT EASES TENSION IN HIGH-STRESS ROLES**

As highly trained experts in very demanding conditions, crewmembers have a need for support and understanding. Stage managers ensure that actors have everything necessary to do their work, from throat lozenges to someone who can listen to their problems [6]. The role of the ground crew, in addition to their crucial technical roles, seems to mirror this desire to put crewmembers at ease so that both parties can operate nominally. The true challenge lies in finding the balance between this support and necessary criticism.

1. *Aquanaut 1 interview, p. 91, ln. 30*
2. *Astronaut 1 interview, p. 74, ln. 22*
3. *Astronaut 1 interview, p. 74, ln. 28*
4. *Astronaut 1 interview, p. 72, ln. 14*
5. *Astronaut 1 interview, p. 74, ln. 37*
6. *Stage CI, p. 200, ln. 35*

## CONSIDERATION 2

*Future missions must account for intermittent ground–crewmember communication*

**FINDINGS**

- The current system requires scheduling around communication lapses
- During long communication delays, conversations likely shift from voice to text
- Users more frequently switch tasks during a communication delay while they wait on responses to inquiries

As crewmembers travel further away from Earth, they can no longer expect the near-instant communications the currently enjoy. Instead, delays of up to twenty minutes may become commonplace for missions to a near-earth asteroid or beyond. NASA's current systems are tailored for near-instant communications, though their analog missions have experimented with procedure execution under both communication delay (in which a data connection is constant, but significantly delayed by distance) and intermittent communication (in which no connection can be made from the station's current position). Both cases present a problem when dealing with tasks that require constant ground support to be executed properly. Our software should therefore be designated to support any changes NASA makes to procedures as execution paradigms shift.

**THE CURRENT SYSTEM REQUIRES SCHEDULING AROUND COMMUNICATION LAPSES**

NASA's procedures are structured such that many require crewmembers to rely on communication with ground crew to accomplish tasks. While this is a perfectly viable solution for managing crewmembers in near-earth orbit and during circumlunar missions, it becomes intractable when there is a long communication delay or only intermittent communication availability. Even for ISS, planners must schedule activities requiring input from ground around times when the station loses communication. When speaking with members of the Daily Operations Group at JSC, we found that large tasks are often either rescheduled to avoid these breaks in communication or broken into smaller pieces that can be stopped and resumed when communication are available again [1].

Any software we design must take into account that procedures may have to be executed without the direct support of ground crew.

**DURING LONG COMMUNICATION DELAYS, CONVERSATIONS LIKELY SHIFT FROM VOICE TO TEXT**

Conversations between ground crew and crewmembers typically involve brief questions and clarifications. As communication delays become more extended, it is more practical to use text messages instead of voice messages. Text saves bandwidth, and text messages are more easily self-edited for clarity before sending. During the communication delay lengths tested during NASA analog missions, only text was practical. One analog crewmember said that during those extensive delays, "you stop trying to have a conversation in a normal sense of the word, and you're just passing messages" [2]. Any support provided to crewmembers through our system will not be real-time and will presumably consist of text. Data can also be passed in the form of images or short videos, but in our conversation with analog crewmembers, who had experienced these communication delays, the users indicated a preference for text-based communication.

**USERS MORE FREQUENTLY SWITCH TASKS DURING A COMMUNICATION DELAY WHILE THEY WAIT ON RESPONSES TO INQUIRIES**

When crewmembers are working on tasks during a communication delay, there are occasions where ground crew support is still needed. In those situations, crewmembers often switch to another task to maintain productivity. Delay may be an inevitability, but crewmembers want to maintain productivity while that delay occurs [3]. New systems must support this task switching by making it fairly easy to both change tasks and resume a task at the exact position where the crewmember left it. Task switching will only become more common because of these communication issues, and our system must support that eventuality.

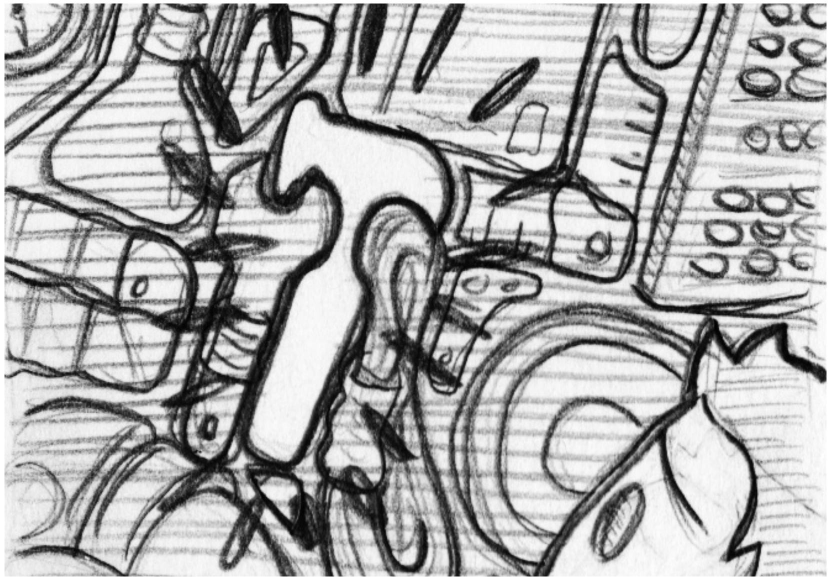
1. *DOG trainer meeting, p. 59, ln. 5*
2. *Aquanaut 1 interview, p. 97, ln. 36*
3. *Aquanaut 1 interview, p. 99, ln. 30*

## CONSIDERATION 3

*Inventory management issues can delay procedure execution*

### FINDINGS

- Problems with physical tool-finding can delay procedure execution
- Crewmembers deal with a cumbersome process to look up needed tools
- There is variable compliance by crewmembers in updating stowage data



Crewmembers benefit from an inventory management system that provides support for navigating through the large volume and types of tools available on ISS. However, problems may arise when needed parts are not readily accessible during procedure execution. Problems in finding, replacing, and accounting for the right tools for each specific procedure can increase frustration.

**PROBLEMS WITH PHYSICAL TOOL-FINDING CAN DELAY PROCEDURE EXECUTION**

There are more than 30,000 items tracked aboard ISS, whose physical size was described to us by one crewmember as feeling “like 8 buses all connected together” [1]. Even with an exact location, it takes time for a crewmember to gather tools for a particular procedure. Tool locations for a given procedure are only synced when that procedure is authored, which can cause further problems.

During our interviews at JSC, we heard a particularly salient anecdote in which one crewmember had to call a past crewmember to ask him where he had placed a tool the last time this procedure had been executed, more than a year before [2].

**CREWMEMBERS DEAL WITH A CUMBERSOME PROCESS TO LOOK UP NEEDED TOOLS**

Crewmembers have several separate windows open on their computer to view the procedure notes, stowage notes, and their schedule and timelines. If a crewmember opens a window in order to see a stowage note, there is no physical description provided for any of the tools [3]. In the stowage notes, the tool is described with a part number. For consumable parts, which will not be restowed upon procedure completion, the crewmember must additionally report an accurate part or serial number to ensure that the inventory system is later updated.

**THERE IS VARIABLE COMPLIANCE BY CREWMEMBERS IN UPDATING THE STOWAGE DATA**

Crewmembers are often forgetful in updating the stowage note in situations when the tools have been replaced in a different location. In other situations, they may indicate verbally to the crew that they left a tool in a new location, at which point someone on the ground must manually update that item’s location [4].

1. *Astronaut 1 interview, p. 73, ln. 23*
2. *Flight controller meeting, p. 32, ln. 33*
3. *Flight controller meeting, p. 31, ln. 39*
4. *Flight controller meeting, p. 32, ln. 27*

## CONSIDERATION 4

*Individual crewmembers read and understand procedures at varying degrees of granularity*

### FINDINGS

- Crewmembers cannot be expected to know how to do everything; they need procedures
- Procedure execution gets easier with practice

NASA hires crewmembers with a variety of prior experience—from pilots to chemists to doctors to teachers. Because the main focus of ISS is science research, NASA chooses crewmembers who understand the considerations and challenges associated with scientific research in space. These crewmembers are trained on skills, not the ability to execute a specific procedure. NASA relies on detailed procedures on missions to provide the reference tools and instructions necessary for any crewmember to complete any task; however, given the wide variety of background knowledge crewmembers can have, these procedures are read and understood at different levels of granularity. Sometimes they will only glance at it briefly; sometimes they will not use it all.

Practice makes perfect in space as well as on Earth, and our evidence suggests that crewmembers rely on specific procedures less and less as they repeat them during their mission. As crewmembers grow more familiar with a given procedure, they are less likely to use the software tools provided to reference it—and thus they may miss a valuable opportunity to provide feedback to ground crew on their progress in situ. Finally, despite their extensive training and prior practice with a particular procedure, crewmembers must still occasionally reference the procedure document, which in all cases must be complete and accurate.

**CREWMEMBERS CANNOT BE EXPECTED TO KNOW HOW TO DO EVERYTHING; THEY NEED PROCEDURES**

At first glance, it is tempting to suggest that procedure errors might be to solved by choosing crewmembers with a wider set of prior skills and/or to provide more training on historically error-prone procedures. However, a place as large as ISS brings with it a huge variety of maintenance, operations, and science tasks. One crewmember described her role on ISS as "being a jack of all trades" [1]. Crewmembers occasionally lack confidence in themselves to perform the incredible variety of work that is required on ISS [2]. Because there is too much work on which to train, it is unreasonable to assume that any crewmember could have complete knowledge of the systems on which they are working. Crewmembers instead rely on procedure documents to execute work.

NASA maintains a detailed procedure library to provide crewmembers with detailed instructions for theoretically any task they have scheduled. The ground crew expects flight crewmembers to consult these procedure documents when executing every procedure—to follow its steps exactly, and to report back any anomalies. In reality, procedure compliance is variable. Despite this, our evidence suggests that every crewmember will need to reference even a familiar procedure that they have already executed in the past, and especially during unforeseen or uncertain situations.

We found deep evidence that these kinds of impromptu procedure references exist in other domains with highly-trained executors as well. The surgeons we interviewed relayed stories of consulting books, asking senior surgeons, and even searching Google to provide guidance before surgery [3]. In automotive repair, where stress levels are presumably lower, technicians still rely on digital wiring diagrams and vehicle-specific advice stored on a computer to ensure they correctly service a vehicle [4].

1. *Astronaut 1 interview, p. 74, ln. 22*
2. *Astronaut 1 interview, p. 72, ln. 9*
3. *Surgery interview, p. 189, ln. 22*
4. *Automotive CI, p. 136, ln. 13*

**PROCEDURE EXECUTION GETS EASIER WITH PRACTICE**

Academic research has long suggested that deliberate practice can improve skills performance, and this property applies to space execution skills as well. Indeed, the aquanauts with which we spoke confirmed that they use procedure documents less and less as their experience increases. One aquanaut said that after executing a given task "half a dozen times," he no longer needed to reference the document at all [5]. The other confessed that because he had written the procedures he rarely referenced them at all.

We heard again and again the value of procedure practice in other domains. Automotive technicians keep mental notes that help them diagnose common problems: "A lot of times if you find something that stumps you even a little bit, you're going to remember it. You're not going to let that go" [6]. Through practice, initial difficulties surgeons had in adjusting to new technologies eventually grew to increased comfort and speed with them [7]. Construction foremen know exactly how to manage certain difficulties that arise in their projects [8]. Stage managers take very detailed notes to support a more consistent execution with each subsequent performance.

5. *Aquanaut 1 interview, p. 92, ln. 14*

6. *Automotive CI, p. 137, ln. 20*

7. *Surgery interview, p. 189, ln. 7*

8. *Construction CI, p. 154, ln. 1*


FOOD

# INSIGHTS

*The previous considerations helped us understand our problem constraints. In this subsection, we present the insights from our research synthesis that will guide our design moving forward. For each insight, we present recommendations and a brief vision.*

## INSIGHT 1

*Critical contextual information is obscured by items of less immediate concern*

**FINDINGS**

- Users are given a long-scale schedule to execute tasks, which hides more immediate information
- Executors struggle to see what they need to see most during procedures

**RECOMMENDATIONS**

- Reimagine how schedule viewing integrates with procedures, prioritizing immediately relevant information
- Create a visual hierarchy of importance while viewing procedure data

*See page 60*

## INSIGHT 2

*Methods that encourage memory recall can support consistent procedure execution*

**FINDINGS**

- Notetaking aids in consistency of execution when tasks are executed again
- Pre-task inventory management helps minimize surprises during execution
- Multimodal contextual feedback can minimize procedure execution errors

**RECOMMENDATIONS**

- Integrate notetaking into procedure and schedule viewing
- Provide passive feedback to ground crew as the task is executed
- Provide a simple means for crewmembers to provide active feedback on task status
- Allow crewmembers to simultaneously see procedure notes and physical/visual cues

*See page 64*

## INSIGHT 3

*Existing procedure support systems do not prioritize users' most pressing needs*

**FINDINGS**

- Current systems make procedure progress reporting unnecessarily difficult
- Crewmember needs and technology change faster than system changes have been implemented

**RECOMMENDATIONS**

- Passively collect data during software use and task execution to help improve both the system and procedures
- Provide a simpler means for crewmembers to report procedure feedback

*See page 68*

## INSIGHT 4

*Instructive systems should not make superfluous demands on users' cognitive load*

**FINDINGS**

- Overly-specific procedure descriptions contribute to cognitive overload
- Shared resources and customization increase uncertainty during operations

**RECOMMENDATIONS**

- Use visual hierarchy within procedures to communicate information needs
- Make switching between users as simple as switching between tasks

*See page 72*

## INSIGHT 1

*Critical contextual information is obscured by items of less immediate concern*

**FINDINGS**

- Users are given a long-scale schedule to execute tasks, which hides more immediate information
- Executors struggle to see what they need to see most during procedures

**RECOMMENDATIONS**

- Reimagine how schedule viewing integrates with procedures, prioritizing immediately relevant information
- Create a visual hierarchy of importance while viewing procedure data

In both OSTPV and in Mobile Score, crewmembers are presented with a large-scale view of task execution. These views include information about tasks that are not scheduled to occur for several hours, and they often obscure the tiny sliver that may represent their current task. Similarly, in IView, crewmembers are presented with a large level of detail for the entire length of a procedure. These details often obscure important notes involving how procedures should be executed.

Because crewmembers are generalists in their training and procedure knowledge, systems should be adapted to make scheduled tasks and procedures as easy to follow as possible, even taking into consideration the varying level of complexity. The current systems prioritize the availability of data over user focus, which can have a detrimental effect on procedure management by users.

In our analogous domains, we found that users often only have direct access to the plans and procedures that are momentarily relevant. This helps them efficiently keep track of what they need to be doing and what they have done, while minimizing irrelevant information. We found that simple task prioritization and focus are essential in managing groups completing work; incorporating these work-styles may be greatly beneficial in helping crewmembers manage their time and procedure execution.

**USERS ARE GIVEN A LONG-SCALE SCHEDULE TO EXECUTE TASKS, WHICH HIDES MORE IMMEDIATE INFORMATION**

Current NASA scheduling software uses "swim lane" layouts to show crewmembers what tasks they are required to complete. This style of layout has been common since at least the Apollo era, with the Apollo 11 flight plan looking similar in design to OSTPV today. This display can be zoomed horizontally to see tasks for several days at once, or just a period of an hour or so.

From speaking with users in analogous domains, we found that most use tools that let them focus on a single task, while giving less importance to future or past tasks. For example, technicians at an automotive repair shop are given a priority-sorted list of tasks to complete via a wall of clipboards. A manager at the shop noted that clipboard slots determined exactly how scheduling would work that day, saying that the technicians "take [clipboards] starting at the top in the order that they're in" [1]. That wall is simply a visual cue for future work; while executing a task they collect a single clipboard and focus on only one task, with possibly one or two other tasks being completed concurrently on other clipboards. When the technician wants to switch tasks, he initials next to what has been completed on the current clipboard, and moves to the other task and its related clipboard. The entire time he is working on a project, he has a single clipboard in front of him. This system deliberately limits the scheduling information to two situations: when those creating the schedules are looking for input on completion, and when a user needs to switch to the next task. The managers can look out a glass barrier and see current task execution status at all times, whereas the technicians usually wait until they need to move on before viewing the list of tasks.

Construction workers have a similar system for accomplishing necessary tasks. Because construction is managed hierarchically, each layer of the hierarchy receives tasks based on the direction of the layer above it, with increasing specificity all the way down the line. The workers actually executing the construction plans only need to be aware of the tasks they are assigned to complete for a given day, not how they fit into the larger schedule for the construction process. That type of scheduling is managed by subcontractors, who exist in the hierarchy above those executing the tasks. That group has semi-regular meetings to discuss scheduling, but those executing the plans do not participate in them. They are solely focused on execution.

1. *Automotive CI, p. 117, ln. 18*

**EXECUTORS STRUGGLE TO SEE WHAT THEY NEED TO SEE MOST DURING PROCEDURES**

Procedures are often an extremely complicated series of steps that must be done exactly as-specified in the procedure document. Each procedure or task contains notes—some can be ignored, others must absolutely be read. When executing the procedure, users must make sure to manually advance each step and, when finished, manually open up the next procedure. Frequently, procedures reference other procedures, which must be opened manually as well. This tedium makes it more difficult for crewmembers to find relevant information quickly.

IView, the system with which the crewmembers view procedures, contains different sets of notes of varying importance. The operations note, or "ops note" is often disregarded by the crewmembers [1]. However, the execution notes have "important information that is critical to executing that activity" [2]. Clearly there are important differences between these two fields, yet there is no visual hierarchy distinguishing them. Failure to read these notes can cause crewmembers to execute steps out of order or execute steps that could have been skipped altogether.

This is not just a problem for crewmembers. Our research into analogous domains showed us that deciding what information is the most valuable is often a learning process across different disciplines. The stage manager spoke specifically of a need to focus to reduce this sensory overload: "with a lot of people talking, it can be a little rattling, and you sort of have to be able to listen and filter what's important for you to respond to and what is sort of secondary information that you just need to be aware of" [3].

1. *DOG trainer meeting, p. 50, ln. 38*
2. *DOG trainer meeting, p. 49, ln. 24*
3. *Stage CI, p. 214, ln. 27*

**RECOMMENDATIONS**

*Reimagine how schedule viewing integrates with procedures, prioritizing immediately relevant information*

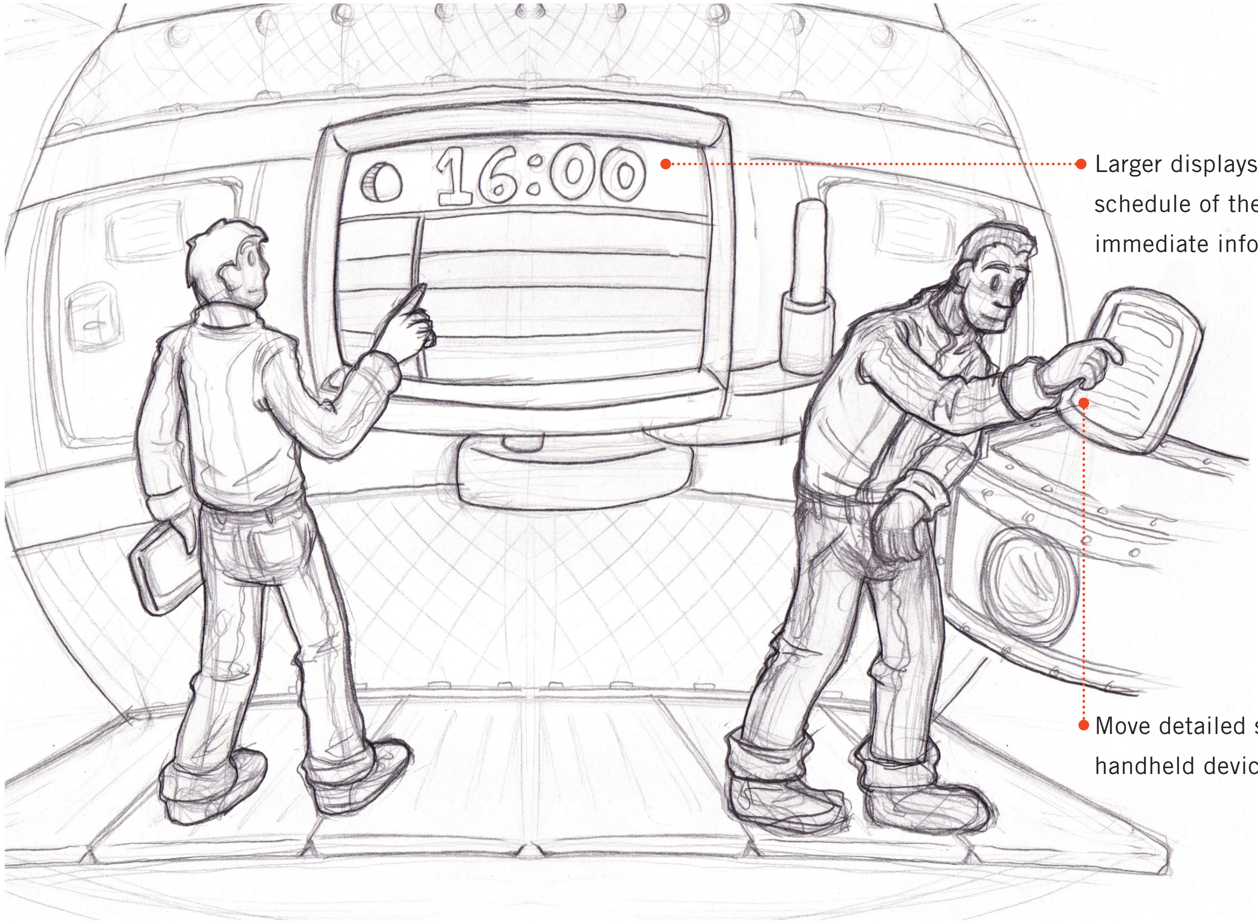
Prioritized displays of information, like we saw in the automotive repair domain, are able to minimize the amount of information any user must process at a time. We hope to modify the current swimlane-focused layout to prioritize immediate needs while still providing the user with important task context.

*Create a visual hierarchy of importance while viewing procedure data*

Users should be able to understand at a glance which notes fields are vital to task execution and which fields can be safely ignored. We hope to create a visual hierarchy that will prioritize important notes, both for reading and input.

## VISION

Though the nominal view for crewmembers is often to focus on their most immediate task, it is still important for them to be aware of the daily schedule and schedule interactions with their crewmates. What if this high-level view could be moved to a centrally-located display screen? It would serve as a constant visual reminder of the team's daily progress. This view would still, of course, be accessible through crewmembers' individual mobile assistants.



## INSIGHT 2

*Methods that encourage memory recall can support consistent procedure execution*

**FINDINGS**

- Notetaking aids in consistency of execution when tasks are executed again
- Pre-task inventory management helps minimize surprises during execution
- Multimodal contextual feedback can minimize procedure execution errors

**RECOMMENDATIONS**

- Integrate notetaking into procedure and schedule viewing
- Provide passive feedback to ground crew as the task is executed
- Provide a simple means for crewmembers to provide active feedback on task status
- Allow crewmembers to simultaneously see procedure notes and physical/visual cues

Industries such as aviation, surgery, theater, and nuclear power have been known to use a formalized checklist system in order to prevent errors and bring a routine to checking pre and post task. In our research with surgeons, we discovered that nurses read off the inventory of the supplies before and after each operation as a matter of routine to ensure that no tools or supplies had been lost in the process. Likewise, stage managers also use checklists. Stage managers and backstage crew have checklists that are created, modified, then followed, ensuring that all the crewmembers have their necessary props and tools. Additionally, the stage manager uses a “prompt book” to annotate specific occurrences as they happen on stage, and these notes are solidified by creating a revised prompt book. This new book is essentially a set of procedures used as a guide by the actors and crew to guide the remainder of the performances.

### NOTETAKING AIDS IN CONSISTENCY OF EXECUTION WHEN TASKS ARE EXECUTED AGAIN

Notetaking and general data gathering is omnipresent in our analogous domains. In stage management the prompt book is a living document—it is not simply written during the first rehearsal and set in stone; it is constantly updated with new notes and cues depending on what the actors executing the procedure need. Also, in the case of the prompt book, the stage manager’s notes provide a detailed document outlining the behaviors of actors in a given situation. The handwritten notes are essential for the performance, serving as cues for the actors to follow over and over again [1].

This in-context notetaking is present in ISS procedure execution as well; a mobile solution should assist in helping NASA gain more informative and spontaneous feedback from crewmembers. For instance, the as-executed procedure may differ subtly from the as-planned procedure, a particular design opportunity is to provide an effective method of gathering feedback on those differences. ISS crewmembers occasionally provide this feedback, but it

1. *Stage CI, p. 204, ln. 14*

is rarely provided consistently. Affording better avenues for crewmembers to take notes and store them in the system can only serve to increase the effectiveness of future execution of the same tasks.

**PRE-TASK INVENTORY MANAGEMENT HELPS MINIMIZE SURPRISES DURING EXECUTION**

Because consistency is a primary goal of live theater, formal checklists of responsibilities are used by the assistant stage manager to minimize errors. Backstage crew follows a detailed checklist, ensuring that the actors have the tools they will need to carry out their mission. The assistant stage manager is also held personally accountable if an actor goes on stage unprepared; she must improvise to compensate for the error. Stage props to be used during performances may be small in volume, but still the props must be consistently accounted for during each performance.

The operating room has, over time, developed inventory management through formal checklists. The staff has a systematic way of managing inventory that requires less deliberation and more automacy. Checklists were incorporated into surgical protocols because errors were previously widespread. Surgeons now expect nurses to read aloud and account for all the inventory before and after the procedure, and that other specifications for each individual surgery are announced and confirmed by all other staff roles in the operating room. In this way, there is less ambiguity about what is being done, and less room for miscommunication as well.

**MULTIMODAL CONTEXTUAL FEEDBACK CAN MINIMIZE PROCEDURE EXECUTION ERRORS**

Physical cues reinforce procedures and provide support. In one anecdote, a surgeon described a model of the spine he kept in an OR during his early residency days [2, 3]. In this case, physical cues were extremely important to help reinforce his memory of complex procedures. Current procedures on ISS lack contextual feedback or physical cues beyond words or photos associated with a step in the procedure. Considering interesting ways to provide such feedback and cueing may create a more intuitive method of performing duties and reduce the chance of error.

Tactile, tangible feedback—a clipboard a technician previously used or the car keys of a car he previously worked on, for instance—provide important cues about the status of task execution that cannot be easily replicated digitally [4]. Viewing the procedure in physical context can further increase efficiency. Automotive technicians use a backroom computer to print out supplemental telemetry and other data—usually writing diagrams—in order to bring it to the car and quickly reference it when they are working. At JSC, flight controllers we spoke with expressed a general feeling that the crew needs to be reminded. A system that supports such reminders should be integrated into a system that afford more crew autonomy.

2. *Surgery interview, p. 189, ln. 38*

3. *Surgery interview, p. 189, ln. 26*

4. *Automotive CI, p. 115, ln. 8*

## RECOMMENDATIONS

*Integrate notetaking into procedure and schedule viewing*

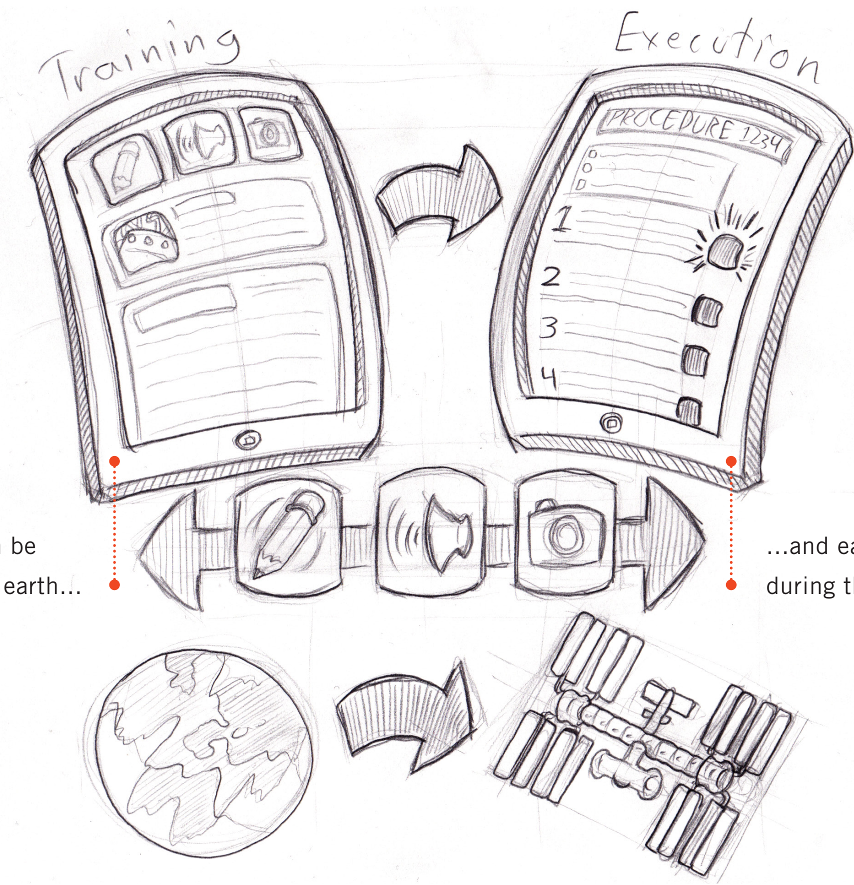
Providing a single interface that allows notetaking in context with procedure and schedule viewing would help capture spontaneous thoughts from crewmembers that may prove helpful for future executions.

*Allow crewmembers to simultaneously see procedure notes and physical/visual cues*

This creates more effective procedures from better associations, thereby reducing their cognitive load and allows a natural mapping of tool to system. Alternatively, one could simply provide a diagram that triggers crewmembers' memories of complicated procedures.

## VISION

What if thoughts were captured easily throughout both training and execution? This would be a crucial step towards the asynchronous support of crewmember autonomy. Photos, audio, or text notes could be easily captured during training and made easily accessible during actual procedure execution, where they can be supplemented with in-situ insights. This media could then be shared with planners on the ground and future crewmembers attempting the same tasks.




Text, audio, or visual notes can be easily taken during training on earth...

...and easily accessed or ammended during the execution of the procedure.

## INSIGHT 3

*Existing procedure support systems do not prioritize users' most pressing needs*

**FINDINGS**

- Current systems make procedure progress reporting unnecessarily difficult
- Crewmember needs and technology change faster than system changes have been implemented

**RECOMMENDATIONS**

- Passively collect data during software use and task execution to help improve both the system and procedures
- Provide a simpler means for crewmembers to report procedure feedback

High levels of political and financial pressure necessitate a deliberate pace of operations, carefully considering every aspect of a mission before execution. As the experiences of crewmembers increase our knowledge of how humans adapt to space and advances in technology open doors to novel ways of supporting them, NASA must make important decisions on how to incorporate these elements into their operations.

Although there is wisdom in the adage "don't fix what isn't broken," NASA is quickly entering a dramatically different era of space exploration. The accelerating pace of technology, crucial partnerships with commercial space flight companies and a focus on targets increasingly distant from earth promise to fundamentally alter the way operations and procedures are executed. Existing models may need to be drastically altered, and emerging insights from crewmembers will need to be captured, evaluated, and implemented quickly and efficiently in order to maintain nominal operations in light of these constantly changing criteria. Going forward, the need for crewmembers to effectively communicate and independently operate will only increase.

**CURRENT SYSTEMS MAKE PROCEDURE PROGRESS REPORTING UNNECESSARILY DIFFICULT**

Progress monitoring is an essential way of gathering information. By informing the ground crew of what task they are currently working on, updating task completion status, and leaving notes afterwards, crewmembers provide invaluable data that can be used to improve future scheduling and procedure generation. As noted by NEEMO aquanauts [1], however, this careful monitoring of progress is the first thing to drop off while crewmembers are under stress. Current processes for this tracking are not intuitive and all too easy to skip over while focusing on more important tasks.

Compliance in progress monitoring is strained by the constraints of current technology. Though many channels exist through which crewmember information and feedback can be gathered [2], their less than optimal implementation often causes them to be of limited use [3]. In addition to being a low priority during procedure execution, technical constraints limit compliance by burying feedback tools in the interface or by making the process of updating tasks burdensome.

In our analogous domains, these issues were largely solved through the application of practical experience and visual cueing. Automotive technicians, for example, have established industry standard times for the execution of certain procedures, a resource which planners can draw upon when creating schedules [4]. Similarly, the construction superintendent was able to visually verify progress by comparing visible progress with his prior knowledge of execution progress [5].

**CREWMEMBER NEEDS AND TECHNOLOGY CHANGE FASTER THAN SYSTEM CHANGES CAN BE IMPLEMENTED**

Comments from aquanauts [6] and anecdotes from existing ground crew [7] indicate that they are very enthusiastic about the adoption of new technology in support of procedure execution. Combined with the initial success of the Mobile Score system, there is clear potential in integrating cutting-edge technology in space missions [8].

In order to adapt to the changing needs of space exploration, NASA must not be overly cautious of dramatic changes in both the form and content of its procedure execution support. Conversely, the implementation of every requested feature is a failing strategy, as proven by certain existing software systems [9]. The existing notes left by astronauts on specific procedures must also be considered, though the interface for recording them should be made faster and more accessible to allow for greater compliance [10].

1. *Aquanaut 1 interview, p. 95, ln. 41*
2. *Flight controller meeting, p. 20, ln. 35*
3. *Flight controller meeting, p. 57, ln. 14*
4. *Automotive CI, p. 140, ln. 24*
5. *Construction CI, p. 153, ln. 42*
6. *Aquanaut 1 interview, p. 93, ln. 2*
7. *DOG trainer meeting, p. 70, ln. 24*
8. *Aquanaut 1 interview, p. 95, ln. 23*
9. *DOG trainer meeting, p. 54, ln. 1*
10. *Automotive CI, p. 117, ln. 31*

## RECOMMENDATIONS

*Passively collect data during software use and task execution to help improve both the system and procedures*

By gathering data passively, lack of compliance with procedure tracking protocols becomes a non-issue. Passive progress monitoring would allow ground crew to keep track of the procedure, and also would provide support for the crewmember seeing progress in their procedures. This information can also applied in a number of ways, from more accurately predicting procedure execution times to conducting software analytics.

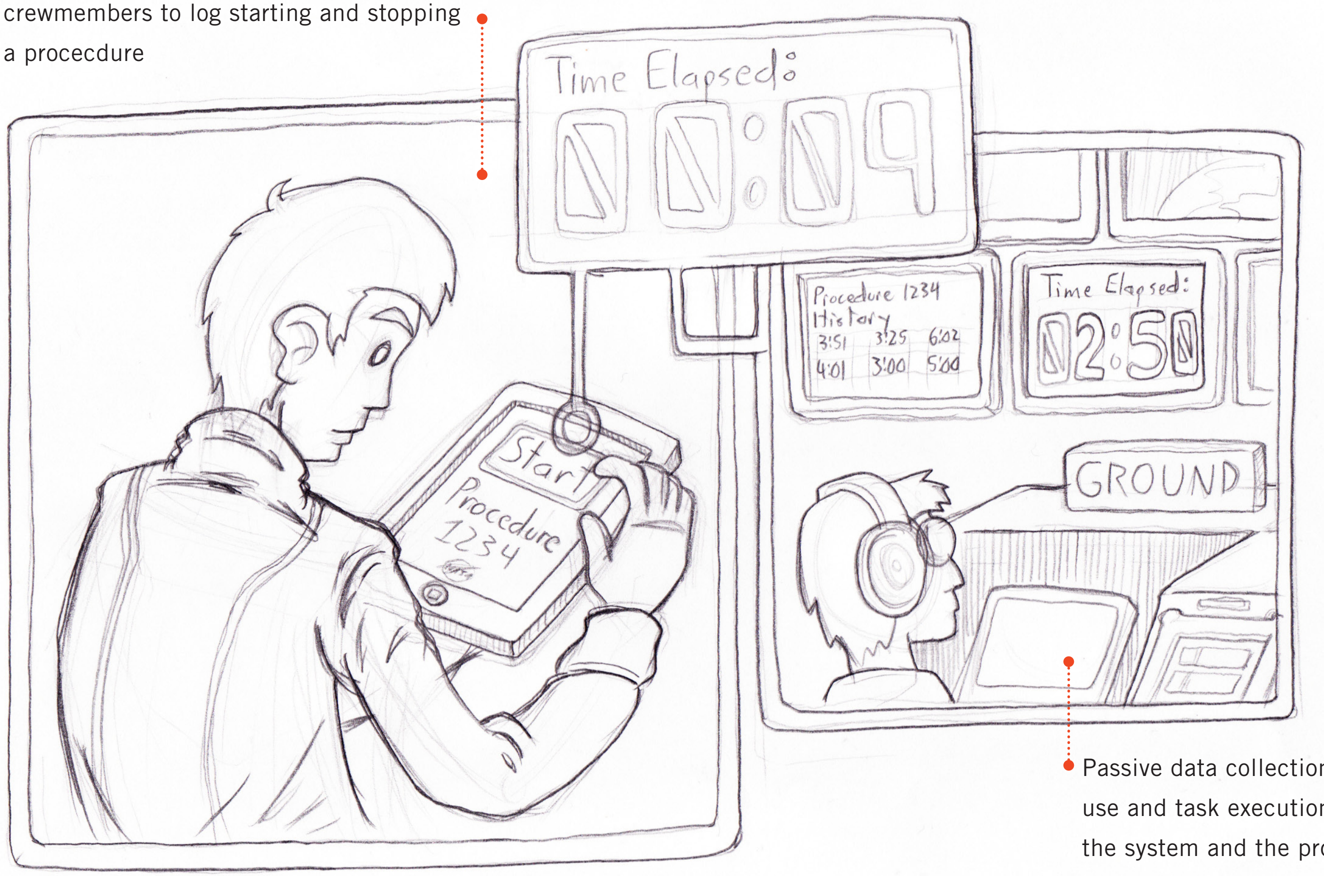
*Provide a simpler means for crewmembers to report procedure feedback*

If crewmembers are able to easily communicate the differences between as-planned and actual procedure executions, then planners can more adequately adjust this procedure for future executions. Collecting this feedback can also help NASA infer future necessary changes in their software for crewmembers.

## VISION

What if gathering thorough procedure data could be as unobtrusive as possible for crewmembers? Simple (but mandatory!) interface elements could promote wider compliance with status updates, while wearable devices or advanced detection systems could gather additional procedure execution data.

Simple launch screen makes it easy for crewmembers to log starting and stopping a procecdure




Passive data collection during software use and task execution help improve both the system and the procedures

## INSIGHT 4

*Instructive systems should not make superfluous demands on users' cognitive load*

**FINDINGS**

- Overly-specific procedure descriptions contribute to cognitive overload
- Shared resources and customization increase uncertainty during operations

**RECOMMENDATIONS**

- Use visual hierarchy within procedures to communicate information needs
- Make switching between users as simple as switching between tasks

Crewmembers have a lot on their minds during operations. From their scheduled tasks to unexpected circumstances to the necessities of everyday life, there are a multitude of concerns competing for their attention. Ironically, the system designed to alleviate this load occasionally aggravates the problem by introducing complications of its own. Ideally, support systems like OSTPV and IView would produce next to no additional demand on crewmembers' attention, conveying their schedule and procedure information instantly and with complete clarity.

Such software is, regrettably, the realm of pure science fiction. That said, there are specific areas in which existing software can be changed or improved to lessen this imposition on cognitive load. At both the smallest and largest scales of the software—the procedure instructions and the overall window and UI structure—fundamental improvements can be made so that crewmembers can dedicate their entire minds to the tasks at hand, rather than to their instructions.

**OVERLY-SPECIFIC PROCEDURE DESCRIPTIONS CONTRIBUTE TO COGNITIVE OVERLOAD**

Crewmembers are trained as generalists, not as domain experts, which leads to both opportunities and disadvantages. When supported by detailed procedures and direct communication, a generalist is capable of executing a huge variety of tasks with relative ease. Take away these support elements, however, and only the knowledge of an expert can ensure success. This necessitates the existence of the current procedure authoring paradigm, in which the crewmember receives a highly detailed, highly specific, highly inclusive list of steps to follow. This can lead to unintended psychological and cognitive repercussions, as the crewmember is inundated with superfluous information.

Intelligent expert systems could serve as a more autonomous alternative to this process [1]. Procedures could be supplemented or potentially replaced by an integrated knowledge database that crewmembers can refer to prior to a procedure or in the event of an unexpected incident. The concept of plans with varying degrees of specificity exists in other domains, such as architectural blueprints. References exist for common operations like constructing a stud wall, but serve as secondary resources rather than mandatory steps.

**SHARED RESOURCES AND CUSTOMIZATION INCREASE UNCERTAINTY DURING OPERATIONS**

The shared use of computers aboard ISS leads to difficulties [2]. In addition to physical constraints imposed by a general lack of portability in the laptop computers used, confusion arose due to multiple users engaging on the same machine. One crewmember's custom setting may feel strange or even unrecognizable to another, and it is often unclear if multiple opened windows can be closed without disrupting the previous user's workflow.

1. *Astronaut 2 interview, p. 78, ln. 4*

2. *DOG trainer meeting, p. 57, ln. 20*

## RECOMMENDATIONS

*Use visual hierarchy within procedures to communicate information needs*

Procedure descriptions should adhere to principles of communication design, bringing the most important information to the forefront by visually distinguishing them. This process could be conducted by means of pre-formatted templates so as to not add to the workload of planners.

*Make switching between users as simple as switching between tasks*

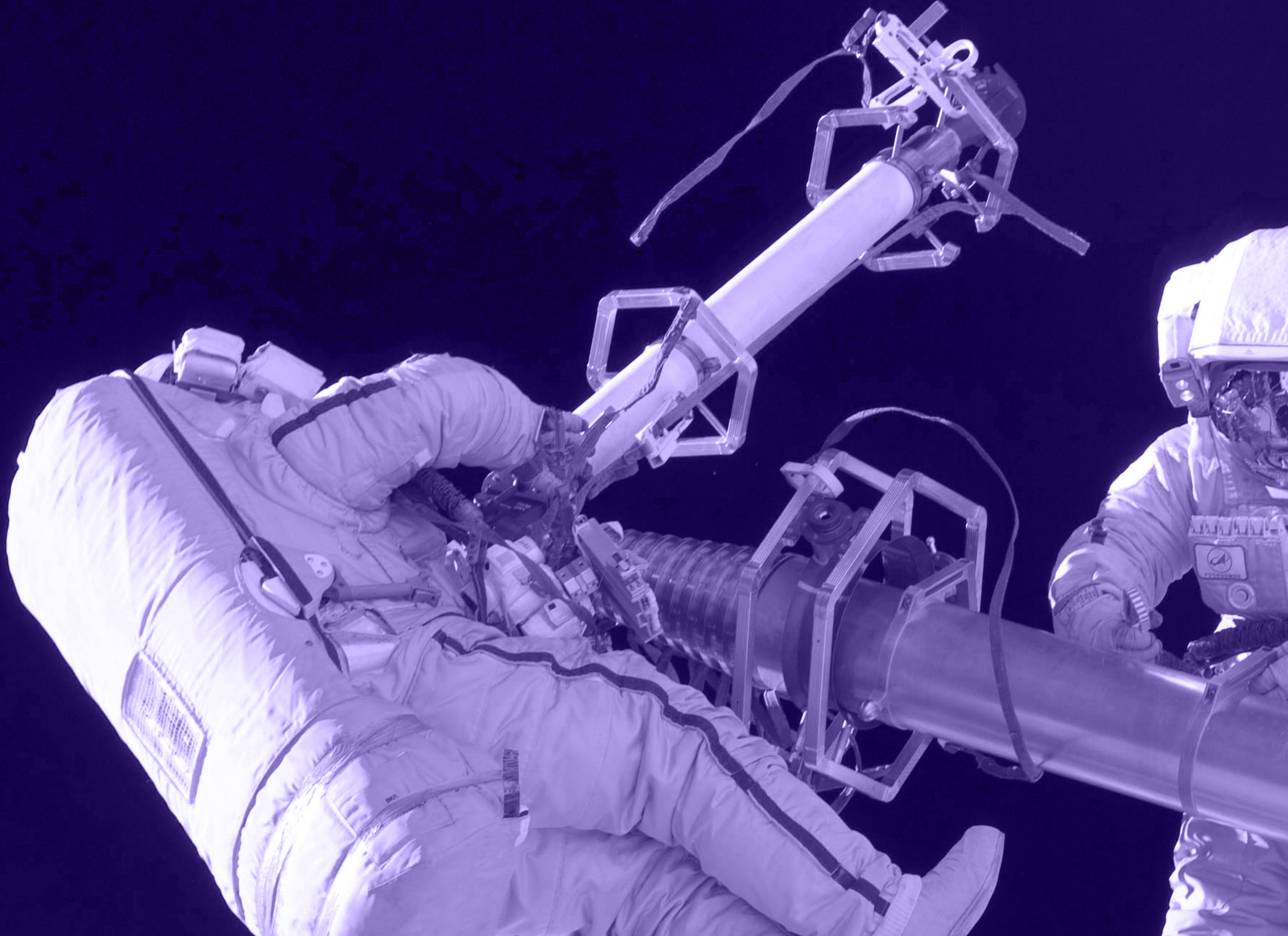
A quick, unobtrusive user identification system can prevent confusion over ownership of workstations. The system should leverage the resources of its hardware platform.

## VISION

Handing off devices between crewmembers should be a seamless transition. The mobile crew assistant should be able to quickly recognize its associated user through face recognition or other biometric sensors for an intuitive and swift user recognition system.

Make switching between users as simple as switching between tasks

# NEXT STEPS



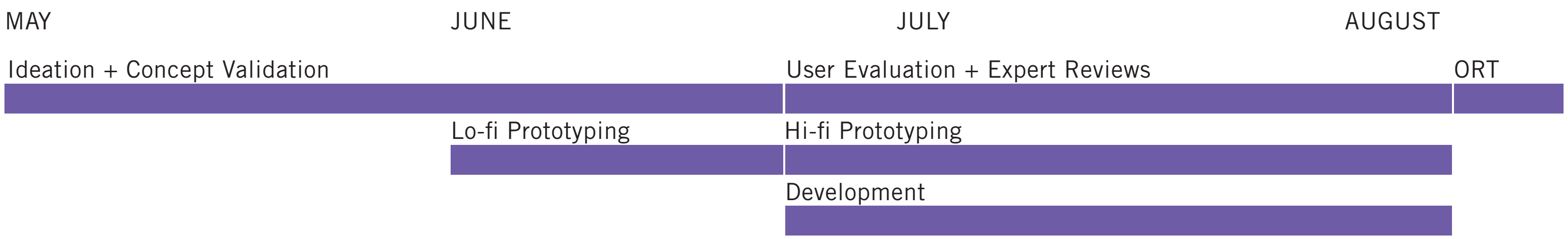

РОССИЯ

# NEXT STEPS

*Based on the data we collected, analyzed, and synthesized, we provided a targeted set of design recommendations that we feel would provide the most value for the team at NASA. It is our goal to take our design recommendations and use them to inform our work of envisioning, designing, prototyping and testing a mobile crew assistant for crewmembers on ISS and beyond.*

*After our spring semester at Carnegie Mellon University in Pittsburgh, we will be relocating to NASA Ames Research Center in Mountain View, California, for the summer and and dedicating our efforts to the design and development phase of our project.*

**SUMMER SCHEDULE**



# ABOUT US

**DIANA CHEN, PROJECT LEAD**

Diana Chen has a BA from University of California Berkeley. She combines psychology, mobile UI design, and theater in order to create delightful user experiences. Her favorite space movie is *Spaceballs.*

**JOE MEDWID, USER EXPERIENCE LEAD**

Joe Medwid has an undergraduate degree in architecture from the University of Virginia. As User Experience Lead, he uses his varied skills in interface design, storyboarding, illustration, and improvization in order to create truly engaging design. His favorite space movie is *Wall-E.*

**ESTEN HURTLE, TECHNICAL LEAD**

Esten Hurtle has a degree in journalism from the University of Missouri and has worked on digital news projects for a variety of clients. He focuses mainly on software development and enjoys new opportunities in mobile and data analysis. His favorite space movie is *Sunshine.*

**KEVIN MCMILLIN, RESEARCH LEAD**

Kevin McMillin has a BS in computer science from Barrett, the Honors College at Arizona State University, where he explored design toolkits for physical learning games. He dives deeply into new domains with past projects in unified communication, simulated social networks, and Esperanto. His favorite space movie is *The Cat From Outer Space.*

**SAMIA AHMED, DESIGN LEAD**

Samia Ahmed has an undergraduate background in communication design from the School of Design at Carnegie Mellon University. Samia believes in an iterative design process, clear communication, and strong typography to synthesize user research into meaningful systems. Her favorite space movie is *Galaxy Quest.*

# THE HCII

The Carnegie Mellon Human-Computer Interaction Institute is an interdisciplinary community of students and faculty dedicated to research and education in topics related to computer technology in support of human activity and society. The master's program is a rigorous 12-month curriculum in which students complete coursework in programming, design, psychology, HCI methods, and electives that allow them to personalize their educational experience. During their second and third semesters, the students participate in a substantial Capstone Project with an industry sponsor.

The Capstone Project course curriculum is structured to cover the end-to-end process of a research and development product cycle, while working closely with an industry sponsor on new ideas or applications that may work with their existing human-to-machine technology. The goal of this 32-week course is to give each student the opportunity for a "real-life" industry project, similar to an actual experience in a research/design/development setting.

Company sponsors benefit from the innovative ideas produced by the students, to fix existing systems or reach into new markets. Some companies also use this project as a recruiting tool, offering industry positions to the top producers in their project team.

For questions about the content, or to learn how to sponsor a project please contact:

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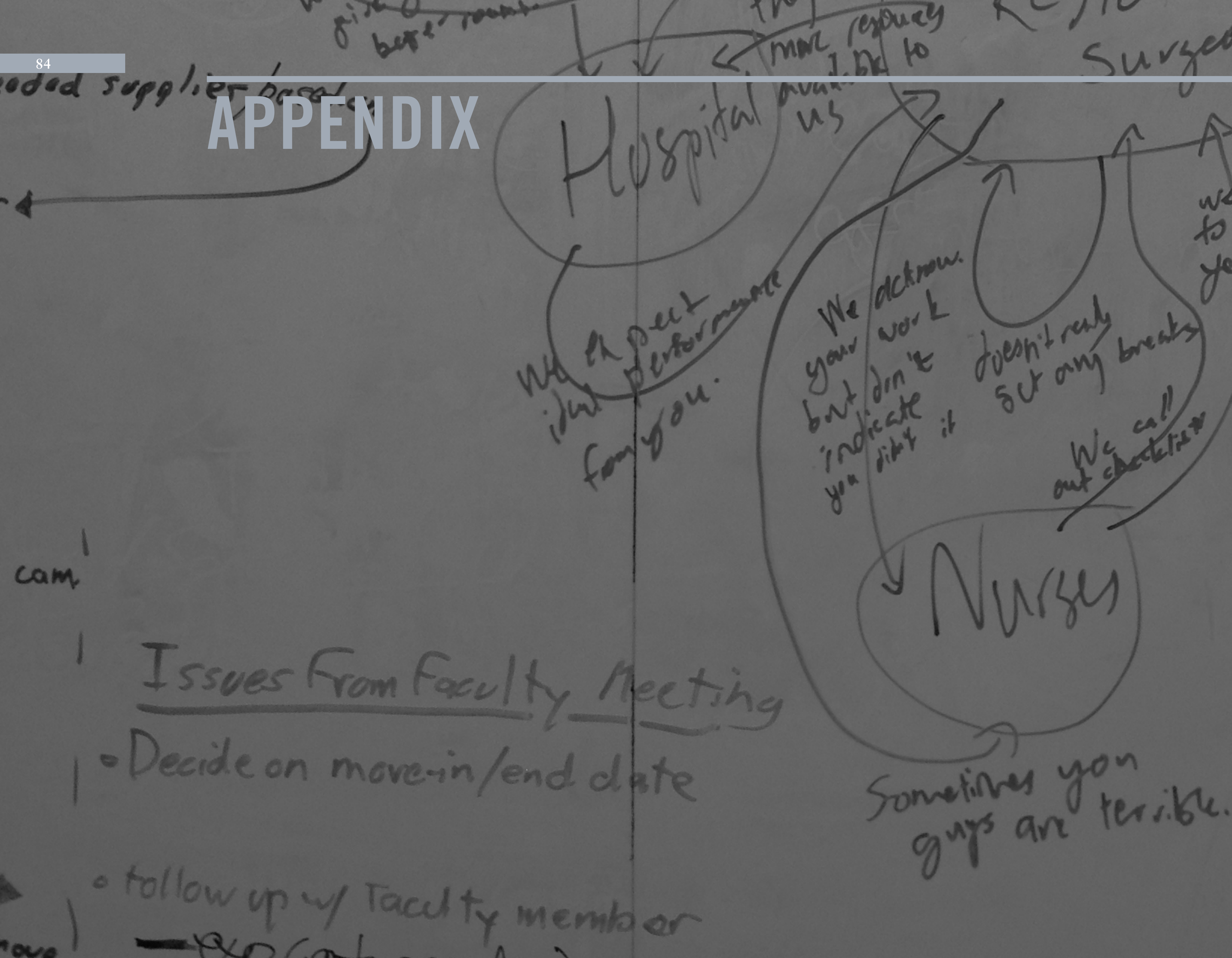
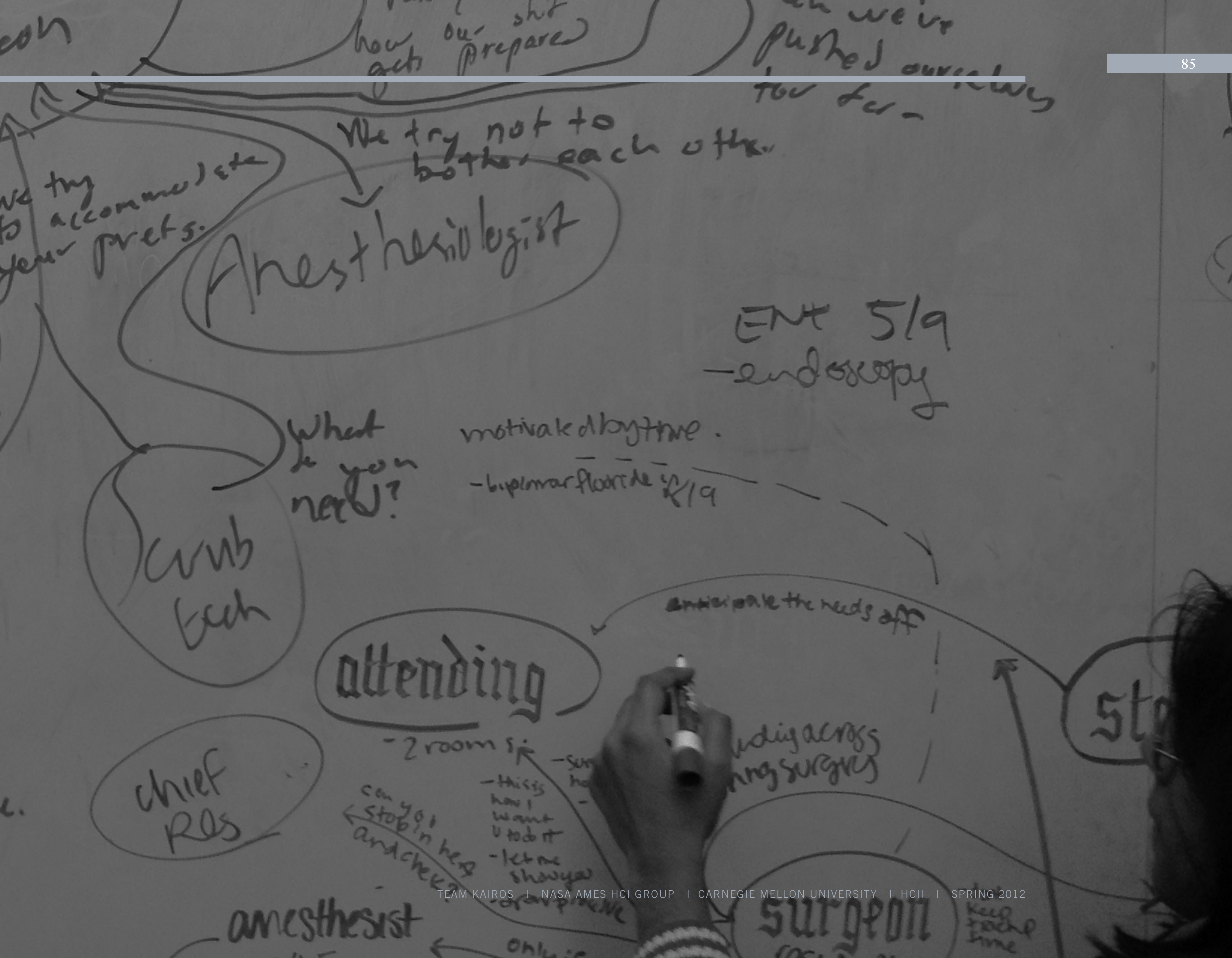
# APPENDIX


Hospital
We expect ideal performance from you.
We acknow. your work but don't indicate you did it
doesn't really get any breaks
We call out checklists
Nurses
Sometimes you guys are terrible.
Issues From Faculty Meeting
• Decide on move-in/end date
• follow up w/ Faculty member


We try not to bother each other
we try to accommodate your prefs.
Anesthesiologist
ENT 5/9
-endoscopy
What do you need?
motivated by time.
Scrub tech
anticipate the needs of
attending
-2 rooms
chief Res
surgeon
amesthesist

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# COMPETITIVE ANALYSIS APPLICATION OBSERVATIONS

**OMNIFOCUS** has a large number of features that support collaborative task execution in many different circumstances and environments. It's "forecast" view that shows all upcoming events in a calendar-like format would be extremely useful for our project, especially if it allowed the user to adjust the granularity of the displayed events (ex: 30 minutes out, 6 hours out, one day out, etc). While the "projects" and "contexts" concepts would make task-switching significantly easier, astronauts do not usually have such a clean separation between tasks and task categories. Additionally, the location feature, while extremely helpful for tasks on Earth, is useless on a spacecraft. The UX is fairly complex and requires a steep learning curve. It does not make use of any touch gestures or touch-specific UX on the iPad.

**TASKA**'s primary navigation visualizes categories such as "inbox," "projects," "next," "shopping lists," etc. While these categories are not specifically relevant to NASA, they are contextually specific to the needs of to-do list making. This specificity is a reminder that the structure of our proposed design for NASA should build around the specificities of the needs of that information. Like other applications, it allows the user to group sub-tasks within each to-do item. Taska lacks different ways to visualize all of the upcoming items, instead only offering basic filters, such as "all," "starred," "overdue."

**2DO** functions based on a model of "calendars" that tasks are grouped under. This allows for a tabbed navigational structure which allows users to pull out information related to specific categories, in addition to viewing a calendar of tasks. Additionally, 2Do offers the ability to add sub-tasks to an entry, allowing for more detailed itemized actions to take. Like OmniFocus, some of 2Do's most useful features include location- based information, and tagging, which may be irrelevant to NASA's needs.

**AWESOME NOTE** takes a very literal approach with "folders" to represent projects, limiting the user to only view a few projects at a time, a technique that could help direct users' attention to only the most pressing tasks. Its main purpose is to capture notes and ideas, rather than direct the user to work on specific things. However, to aid that goal, it has excellent rich media capabilities and even contains a drawing tool that lets the user create quick sketches of ideas. The user can drag a note between projects on the screen to move it, as well as write a quick note that you can move to a folder later. The idea of quick note-taking in-situ is extremely appealing for the project, though we may have to translate "quick notes" into "quick indications of current status."

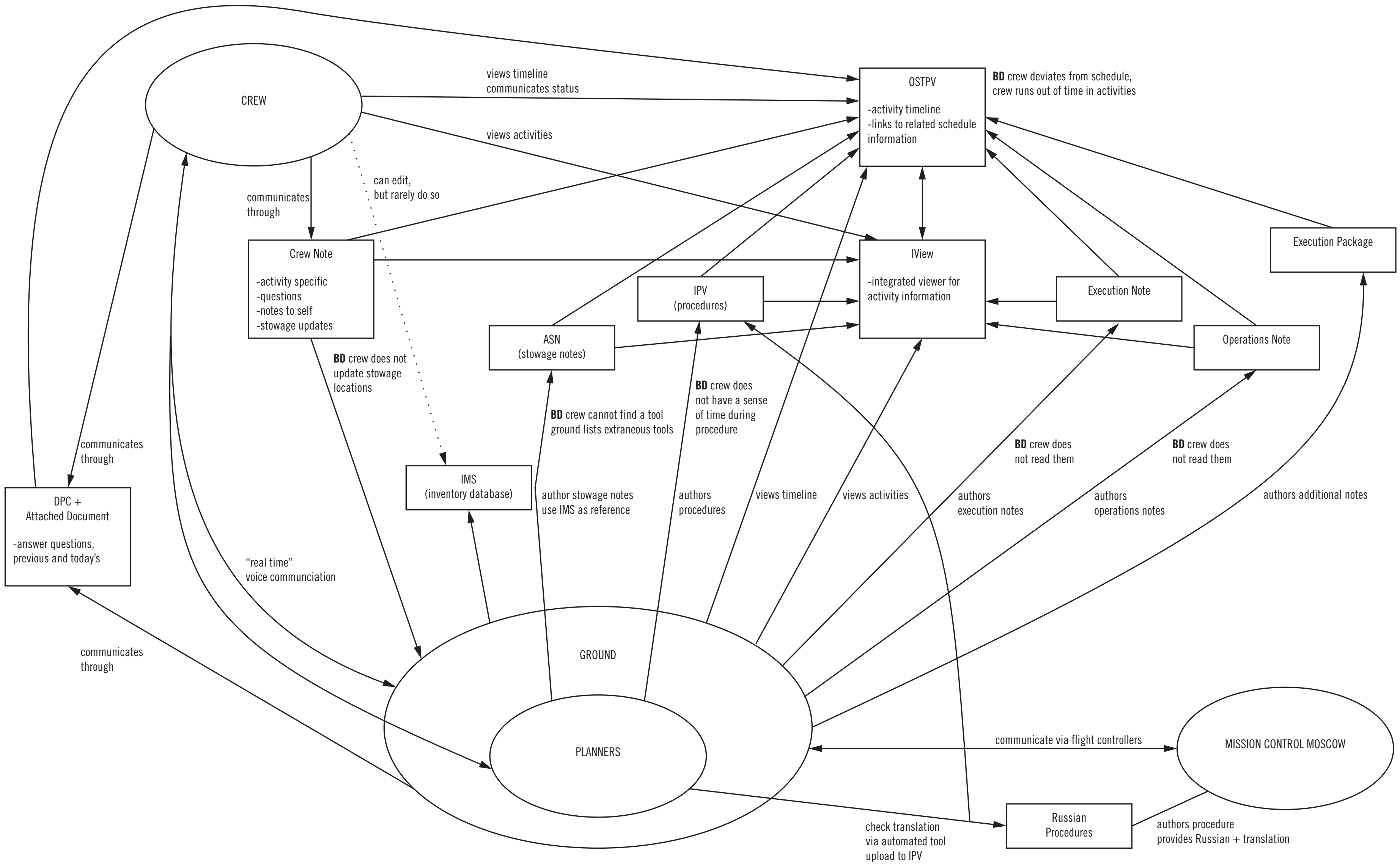
**TOODLE DO** primarily shows interaction and navigation paradigms that do not map well to either to-do list needs, or NASA's schedule viewing needs. The two column to navigation, with content surfacing on the right, and navigational items on the left fell short in that it is impossible to close out of items on the right, meaning that the user can navigate to an entirely different part of the application or tasks, and still be viewing irrelevant, detailed information on the right. The navigational menu drilled deep in sub-menus of information that had no breadcrumbs to offer the user contextual information of where they were in their task management, leading to confusion. This application lacked any calendar or time based view of upcoming tasks, instead relying on specific filters such as as "today, tomorrow," not allowing for a way to find a sorted overview of all of the tasks. Additionally, in terms of mobile interactions, it was sometimes unclear how to edit data, commit information changes, or clear a menu that may have surfaced.

# JSC SEQUENCE MODELS

| USER | STEP | TRIGGER | TOOLS | ALTERNATIVE STEPS |
|---|---|---|---|---|
| Planner | Write procedure | New program, procedure doesn't exist, emergency procedure | Word, LSAR | |
| People unfamilliar with procedure | Verify procedure (PV) | Procedure finished and requries verification | C9 | Straight to "Convert to XML" |
| ODF | Convert to XML | Procedure tested | XML | |
| Planner | Check XML procedure against original | XML procedure finished | | |
| Planner | Input into IPV | XML procedure verified | IPV | |

| USER | STEP | TRIGGER | TOOLS |
|---|---|---|---|
| | Procedure writing | New large-scale mission (ISS, Orion, etc) | CPS/SCORE, ASN, Word, IPV |
| Long-term planners | Long term planning | Mission 1-2 years out | CPS/SCORE, ASN, Word, IPV, IMS |
| Crew, disciplines | Procedure training | Upcoming mission | IPV, Iview, OSTPV |
| Short-term planners | Day-level planning | 2 weeks out | CPS/SCORE, ASN, Word, IPV, IMS |
| Disciplines | Procedure writing | No existing procedure | ASN, Word, IPV, IMS |
| Crew | Procedure execution | OSTPV tells crew to do it | Iview, OSTPV |
| Crew | Crew doesn't do something | No time, item hard to find | |
| Flight planners | Consider replanning | Item crew skipped is important | Expertise |
| Planners | Identify when item can happen | Replan is necessary | Knowledge base, expertise |
| Planners | Submit change request for approvals | Replan is complete | PPCR |
| MCCH, flight directors (sometimes planners) at JAXA, Russia, ESA, partners etc. | Approve request | Told to approve replans | |

# JSC COMMUNICATION FLOW MODEL



# FIELD RESEARCH KEY OBSERVATIONS

**PROCEDURE GENERATION WORKFLOWS AND TIMES VARY WIDELY**

Timescales for procedure generation vary between a few years and a few days. Plans are generated as far in advance as six months, but replanning happens much more quickly.

**AUTOMATIC REPLANNING WILL REQUIRE ENCAPSULATED HUMAN EXPERTISE**

Scheduling, dealing with timeline changes, and updating procedures requires knowledge of planning and flight rules—as well as knowledge of individual crewmembers. Any future system to automate replanning will need to encapsulate this expertise.

**REPLANNING INVOLVES COOPERATION OF MANY PARTIES ON THE GROUND**

International partners, real-time planners, and pressure and payload concerns can slow replanning.

**CREWMEMBERS ARE GUNG-HO ABOUT USING TABLET DEVICES**

Crewmembers have “been begging for mobile devices for years.” ISS planned to originally use PDAs for procedure execution, but the technology wasn’t yet available a decade ago.

**POOR INTERNATIONAL SYSTEMS COORDINATION LEADS TO MORE DELAYS**

All Russian scheduling and planning is translated by hand by each agency, and those translations are doubly-listed in the OSTPV view for internationalization issues.

**SHARING COMPUTERS AMONG ASTRONAUTS CAN LEAD TO CONFUSION**

There are 21 computers onboard for 6 crewmembers, but a previous crewmember using IView might have left the window open, leading to confusion when another crewmember opens that computer.

**CREWMEMBERS FREQUENTLY NEED REMINDING**

Crewmembers aren’t given a visual indicator that a task has been updated; much of that is done in a daily planning committee meeting. They frequently don’t communicate progress updates to ground crew.

**THERE IS A LACK OF VISUAL HIERARCHY IN IVIEW**

The “ops note” in IView is ignorable, while the “execute note” is crucial. This hierarchy isn’t clear.

**COMMUNICATION LAPSES CRIPPLE THE CURRENT SYSTEM**

Planned communication blackouts can change during the day, and the crewmembers don’t know when communication blackouts will occur unless they check the timeline.

**ADDING INFO TO OSTPV IS HARD; IT’S PRIMARILY PASSIVE**

OSTPV will let you change anything without conferring flight rules; the current note system should be expanded.

**OSTPV IMPERFECTLY REPRESENTS TENSION BETWEEN FLEXIBLE AND TIME-CONSTRAINED PROCEDURES**

Colors are used inconsistently; singular crewmember activities are often represented as multiple activities to remind the ground crew when to do things.

**DUE TO LIMITED MOBILE SCREEN SPACE, THE CURRENT MULTIPLE-WINDOW SYSTEM NEEDS RETHINKING**

The crewmembers are limited to a single window at a time, and while IView attempts to consolidate several previous multiple-window systems, it’s still distinct from OSTPV.

**STOWAGE DATA MAY CHANGE AFTER PROCEDURES ARE GENERATED**
Sometimes procedures list items that are unnecessary or necessary only for steps which won't be executed. Procedure writers generally catch most of the changes, but there are instances where crewmembers spend a significant chunk of time looking for a tool they won't need.

**FINDING AND REPLACING TOOLS REQUIRES HUMAN DATABASE UPDATES**
There is variable compliance by crewmembers in updating stowage data. In general most of the time the crewmembers verbally note stowage changes, which are then updated by ground crew.

**THERE ARE LIMITED SUPPORT TOOLS FOR FINDING ITEMS**
There is no physical description of stowage items.

**TOOLS ARE HARD TO FIND**
There are more than 30,000 tools on ISS, and sometimes they're stored behind racks which require moving.

**THE PROCESS FOR AUTHORING NEW PROCEDURES IS BURDENSOME**
"To be honest I always feel like I'm writing new procedures." Procedures currently cannot be changed once and updated everywhere. There is no full data source on what might break.

**ASTRONAUTS ARE GENERALISTS, MAKING ASSIGNMENT AND EXECUTION OF SPECIFIC TASKS HARD**
Astronauts are taught skills, not procedures. The flight control disciplines train the crewmembers, and an informal listing of training levels per astronaut helps in scheduling.

**SOCIAL AND TECHNICAL COMPLICATIONS MAKE PROCEDURES UNPREDICTABLE**
The crew sometimes doesn't read notes, so surprises in procedures can happen all the time at the expense of the schedule.

**ASTRONAUTS SELF-REPORT NOT HAVING ENOUGH HOURS IN A DAY**
The crew is free to go about their days—everything they can do in the order they want (with the exception of time-critical tasks). However, crewmembers stay up late to finish work and usually spend part of their lunch break finishing a morning task.

**CONTEXTUAL TELEMETRY DATA IS NOT PRESENTED WITH PROCEDURES**
Irrelevant steps in the procedure are sometimes presented, but live telemetry comes from another machine. There is little in-context interaction in procedure viewing.

**PROCEDURE NAVIGATION IS STATIC**
References to other procedures require opening a separate reference document. You have to close one window to move to another.

**FEEDBACK IS ONLY GATHERED ACTIVELY**
As it stands, crewmembers must actively make the effort and take the time to mark status completion or notify ground crew of any feedback as related to procedure execution.

**DESPITE MANY CHANNELS, GROUND CREW FEEL THEY NEED BETTER FEEDBACK FROM CREWMEMBERS**
While crewmembers have multiple modes of communication, such as by comm and by leaving crew notes, there is still a need for a more intuitive way for crew to leave feedback and for ground crew to receive their messages.

# ASTRONAUT KEY OBSERVATIONS

**NO ONE CREWMEMBER CAN HAVE COMPLETE KNOWLEDGE OF ALL SYSTEMS**

Confirming what we had learned at JSC, our first crewmember confirmed during her lecture that not only did she have to learn the crewmember's set of generalizable skills, but many of these basic mechanical skills were entirely new. This is a crucial insight to remember going forward, as even the most general assumptions about past knowledge and expertise level of users may be erroneous. Similarly, it also gives us a greater appreciation of the crewmember training process. Any education curriculum that can take a scientist who has never held a wrench before and teaches her to perform critical station repairs must be efficient, indeed.

**ISS DOESN'T FEEL CROWDED**

Or at least, it seemed so to our guerilla interviewee. It is sometimes easy to lose sight of the fact that ISS is approximately the length of 8 school buses, not a cramped capsule. Many of the problems inherent in operations on such a massive station will not be present in the Orion MPCV [Multi-Purpose Crew Vehicle], or the DSH [Deep Space Habitat], the operation conditions for our ultimate design.

**ASTRONAUTS STILL EXPERIENCE DELIGHT, THRILL AND WONDER AT BEING IN SPACE**

Another element that's easy to forget during formal investigations is the excitement of actually being in space. Even astronauts, for whom operations could be rightly considered another day on the job, have strong emotional reactions to their conditions. To quote our first astronaut, "there I am [on ISS], flying and graceful. And I did actually love it, it's like living in a different world."

**THERE IS A SENSE OF BEING A TEST SUBJECT**

Our first crewmember made a point to note on her application to the corps that she “understood what being a guinea pig is about.” Since biological experiments on human adaptation to zero gravity are a crucial part of space exploration that are unlikely to go away soon, there is a possibility for this issue to cause psychological damage in the future.

**MINOR LAPSES OF ATTENTION CAN LEAD TO MAJOR CONSEQUENCES**

This finding refers to a specific anecdote in which the crewmember carried out a step in an emergency protocol procedure without first checking in with ground, resulting in NASA erroneously concluding that an actual emergency was taking place. Situations such as this may be prevented through improvements in procedure execution systems.

**INTELLIGENT EXPERT SYSTEMS COULD AID AUTONOMOUS CREW OPERATION**

A combination of automatic computer systems (cite) and an electronic knowledge database derived from prior experiences and analytics data (cite) could provide much of the information crewmembers need to operate autonomously. Though these would be an imperfect replacement for ground crew, they could suffice in situations where there is a significant comm delay. These systems have long since been proposed, but have yet to be adopted at NASA.

**ON-BOARD SYSTEMS COULD MORE EASILY SURFACE INFORMATION**

A criticism from the second crewmember was the lack of information given to the crewmembers themselves, as opposed to the large number of resources that can be accessed by ground. This reveals a delicate balance that may have to be re-evaluated in NEO missions between not burdening the crewmembers with extraneous knowledge and providing them with the tools necessary for autonomous operations.

# ANALOGOUS CREWMEMBERS KEY OBSERVATIONS

### ENGINEERING REQUIREMENTS VS. USER DESIRES

There is a difference between what engineers put in systems and what might be psychologically necessary. Engineers won't build something that they don't think is necessary for survival, but users may not feel that way and want something more.

### ASTRONAUTS AS NON-EXPERT OPERATORS

It's not reasonable to assume astronauts onboard ISS and beyond are expert users. NASA wants people who understand science as well as system mechanics on missions.

### PROCEDURE MEMORY

After a procedure has been done several times, it becomes less necessary to look at a list of procedures. However, blood draws on NEEMO are an example of a detailed procedure that did require consultation.

### MOBILE SCORE'S SUCCESSES

Users are usually working on a task away from a laptop. Users of Mobile SCORE, especially on the iPad for NEEMO 15, have expressed positive thoughts about the system.

### OSTPV HAS PROBLEMS

Internally, OSTPV is sometimes avoided. Users expressed a desire to use more familiar products like Excel or Outlook. Compressed timeline events are useless—they can't be easily selected or even seen at a glance.

### PRIORITIZING TASKS

Users don't need to look at far off events. They are concerned about what is happening in the near-term and direct their attention at those problems.

#### SHARED WORKSPACES

Users need to be able to do multiple things at once without closing out of everything. Shared workspaces on statically positioned laptops pose questions relating to cultural etiquette.

#### MONITORING TASK COMPLETION

The first thing that drops off when under stress is marking task progress and completion. It's hard to locate every individual menu item and button to mark tasks as complete. Telemetry may be able to be used to infer task status instead.

#### NON-IDEAL COMMUNICATIONS

At 20 minute comm delay, conversation isn't possible—only text and email. Intermittent comm is also an issue, not just delay. For these intermittent communications, astronauts tag up in morning, go about their day, and tag up again in the evening. When under communications delay or intermittent communications, users can still ask ground for help, but must be concise.

#### ANALOG MISSION STRESS

Tasks that users do in NEEMO and analogs are usually not extremely complicated. However, they are still stressful. NASA uses these experiences to help select future ISS commanders.

#### TASK SWITCHING, COMM DELAY, AND AUTONOMY

Switching between different tasks happens more when under delay, as users need to move on while waiting for responses. Some astronauts prefer this autonomy and don't want their backrooms to be intimately involved even with real-time comm.

#### PROCEDURE-RELATED STRESS

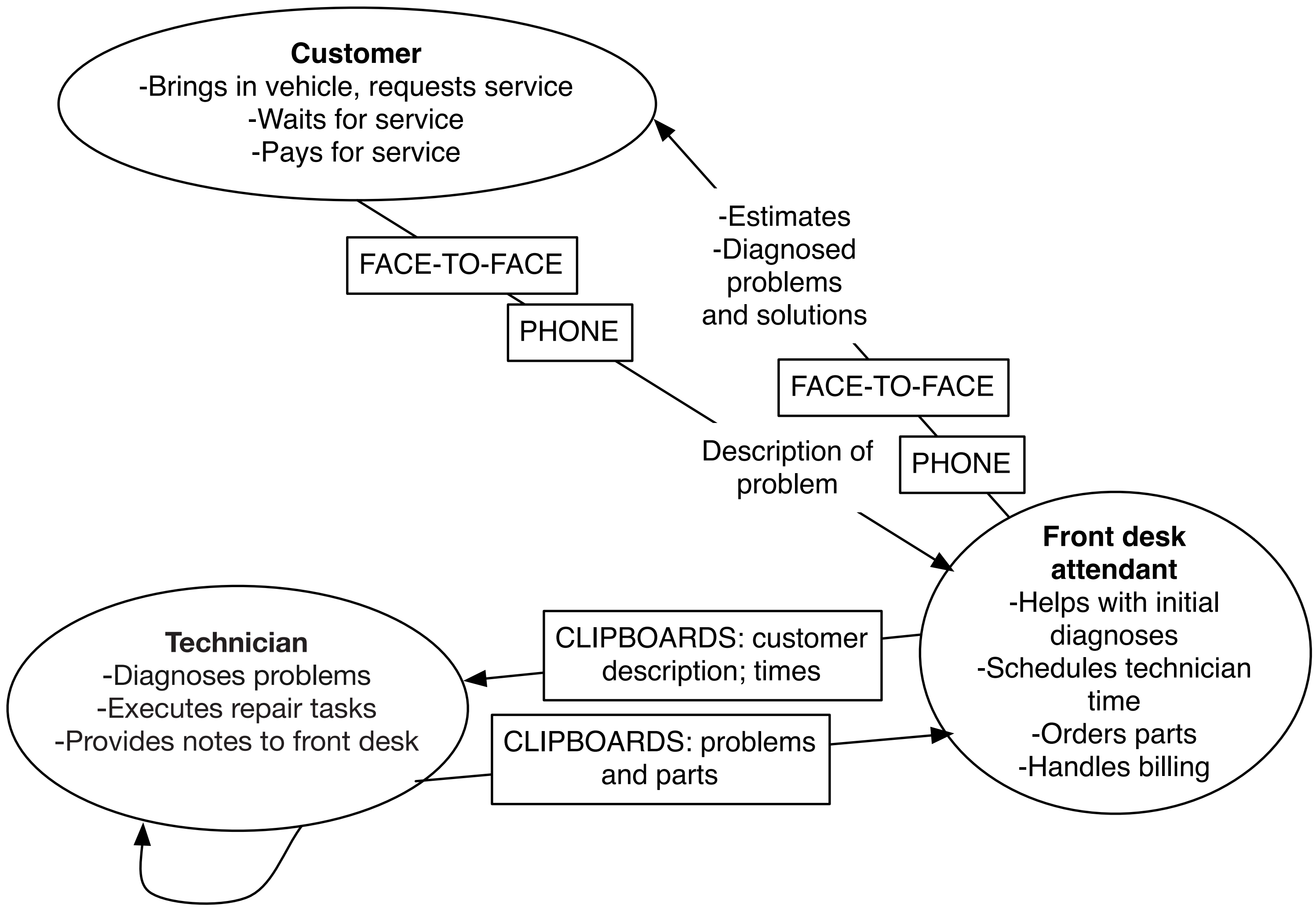
Astronauts have to pick out life-and-death procedures themselves and pay specific attention to them. Saying something once or twice doesn't result in knowing it well enough to act on it. Certain tasks seem small, but can be overwhelming in situ under stress.

# AUTOMOTIVE SEQUENCE MODEL

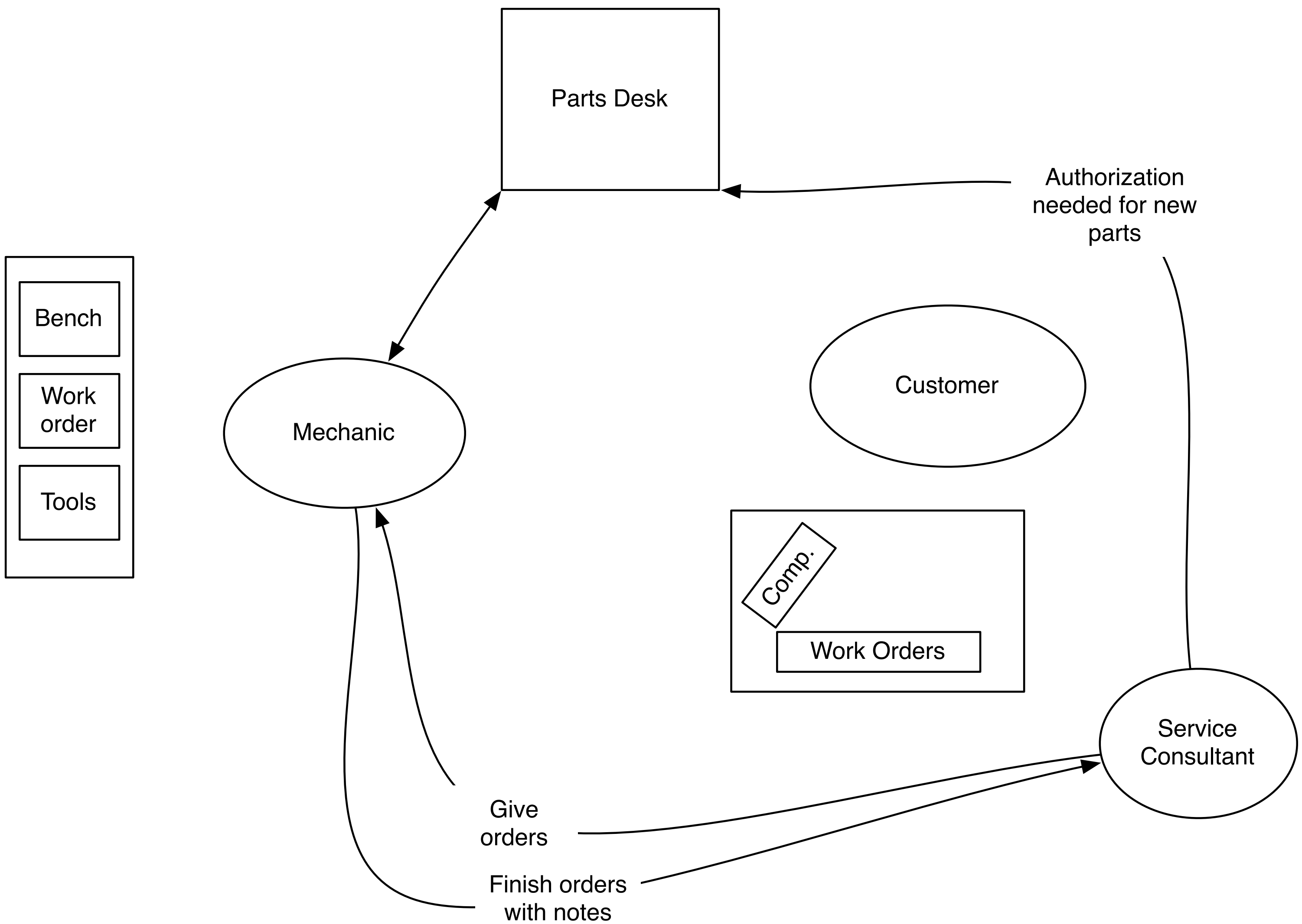
| USER | STEP | TRIGGER | NOTE |
|---|---|---|---|
| Customer | Customers begin arriving | | 88 |
| Front-desk | Notes written up | Customer has a problem with their car | 88 |
| Front-desk | Notes placed on clipboard | Notes written | 88 |
| Front-desk | Set system status to waiting for tech | Tech not there, or see below | 66 |
| Front-desk | Update any tasks that need updating | Owner wants progress update, front-desk notices lack of task completion details | 69 |
| Front-desk | Place clipboard on tech's stack, in priority order | Tech there | 88 |
| Front-desk | Clipboard goes to first priority slot | Customer needs car by specific time | 72 |
| Tech | Tech recieves clipboard | Tech has reached that clipboard in order | 88 |
| Tech | Tech inspects car, test drives | Tech recieves clipboard | |
| Tech | Tech looks up code on computer | Tech wants to be sure of code | 29 |
| Tech | Tech writes down codes and problems | Codes refer to actual problems, or tech finds a problem | 21 |
| Tech | Tech goes through checklist,performs 48 point checkup, writes down everything | Estimate process taking place | |
| Front-desk, tech | Front-desk makes estimate | Tech explains what's wrong | |
| Front-desk | Clipboard goes into "estimate" bin | Front-desk calculates estimate | 88 |
| Customer | Customer approves estimate | Customer arrives | |
| Front-desk | Front-desk prioritizes car | Estimate approved | |
| Front-desk | Front-desk works out a way to prioritize so two mechanics aren't working on the similar car | Repairs needed on cars that require identical, specialized tools | |
| Tech, front-desk | Tech works on car | Tech recieves clipboard from front-desk | in video 16-11 |
| Tech | Writes initials on list of problems (each tech does this differently) | Problem is handled | 35 |

| USER | STEP | TRIGGER | NOTE |
| --- | --- | --- | --- |
| Tech | Tech fills out pink slip | Car has problems that will take more time than originally thought, from estimate | 55 |
| Front-desk, tech | Front-desk pays tech extra | Customer cannot or will not pay for increased cost | 78 |
| Tech, other techs, front-desk | Front-desk selects most qualified tech to work on task | Tech originally working on task is sick | |
| Other tech | Qualified tech finishes work | Qualified tech assigned task | |
| Tech | Tech switches cars | Parts come in OR time-sensitive task needs to be checked | 43 |
| Tech | Tech looks up car history | Tech has a hint of a problem, ex: car running badly | |
| Tech | Tech looks up wiring diagram or other schematic | Something is wrong that the tech doesn't remember how to fix | 16 |
| Tech | Tech prints out diagram or schematic | Tech can't remember diagram/schematic easily | 88 |
| Tech, front-desk | Tech gives clipboard to front-desk | Parts not available in-house | 88 |
| Front-desk | Front-desk orders parts | Front-desk recieves clipboard | 88 |
| Front-desk | Clipboard placed in "problems" area, status set to waiting for parts | Parts are ordered by front-desk | 19 |
| Tech | Tech gives front-desk clipboard for "waiting for customer" bin | Borderline problem, not sure if needs to be fixed | in video 16-11 |
| Tech, front-desk | Front desk puts clipboard in "waiting for customer" | Tech needs customer input, or customer away for more than 10 minutes | |
| Front-desk, customer | Customer provides direction | Front-desk speaks with customer | |
| Front-desk, tech | Front-desk informs tech of customer directions | Front-desk speaks with tech | 88 |
| Tech | Tech places clipboard in "finished" bin | Tech is finished with task | |
| Customer, front-desk | Front-desk gives keys back to customer | Clipboard in "finished" bin, customer arrives | |

# AUTOMOTIVE COMMUNICATION FLOW MODEL



# AUTOMOTIVE PHYSICAL MODEL



# AUTOMOTIVE KEY OBSERVATIONS

### PRIORITIZING TASKS

Technicians use asynchronous communication tools to provide task execution feedback to their managers and follow a priority queue—literally a stacked set of clipboards for each technician—to find their next task.

*"about 8 o'clock, usually be about usually fifteen of them [the clipboards] up here, and about 11 o'clock on a good day this looks like a white wave" [1]*

### OMITTING NEEDLESS DATA FROM THE VIEW

Technicians don't need the granularity of schedule information that OSTPV provides; it's less important to them that they have a three-hour task ahead than simply knowing that they have a task ahead.

### SCHEDULING MORE TIME THAN IS NECESSARY

A trained mechanic usually completes procedures in less time than the industry standard suggests, which means that very little real-time time tracking of task execution is necessary to avoid scheduling delays.

*"Most technicians who have done a job at least once have a really good idea of what tools they need and how to perform the operation. They've done it before, so they're familiar with it and they almost always can beat the time" [2]*

### KNOWING YOUR CREW

As on the ISS, the front desk planners have a mental model of each technician's training and experience, which he can use in order to assign the most appropriate technician to a given task.

### VIEWING THE DATA IN PHYSICAL CONTEXT

Technicians use a backroom computer to print out supplemental telemetry and other data—usually wiring diagrams—in order to bring it to the car and quickly reference it when they're working.

*"If it's something small that we can remember, then we don't have to, but when we gotta really chase into something we'll just print it out" [3]*

### VISUAL CUEING FOR FEEDBACK

Tactile, tangible feedback modes—such as a clipboard a technician previously used or the car keys of a car he previously worked on—provide important cues about the status of task execution that cannot be easily replicated digitally.

### MONEY IS A MOTIVATOR

Technicians are incentivized to finish tasks quickly and efficiently because they are paid based on the industry-set standard for that task's time completion, with only a minor allowance for unforeseen circumstances.

*"We work of off a flat rate system, and the industry standards are set in our computer as far as how long a job will take" [4]*

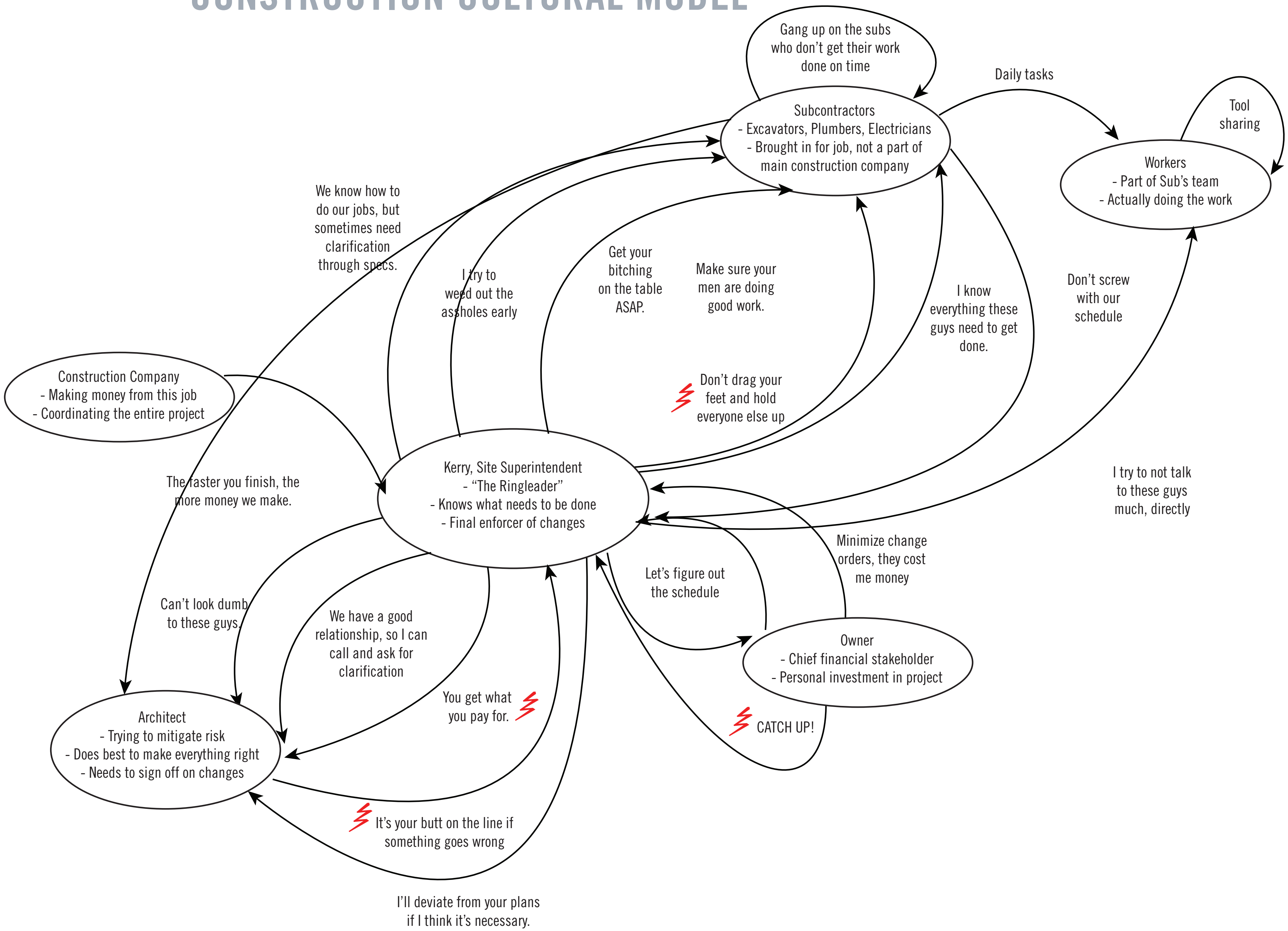
1. *Front-desk manager, p. 120, ln. 27*
2. *Front-desk manager, p. 122, ln. 28*
3. *Technician, p. 136, ln. 14*
4. *Front-desk manager, p. 122, ln. 26*

# CONSTRUCTION SEQUENCE MODEL

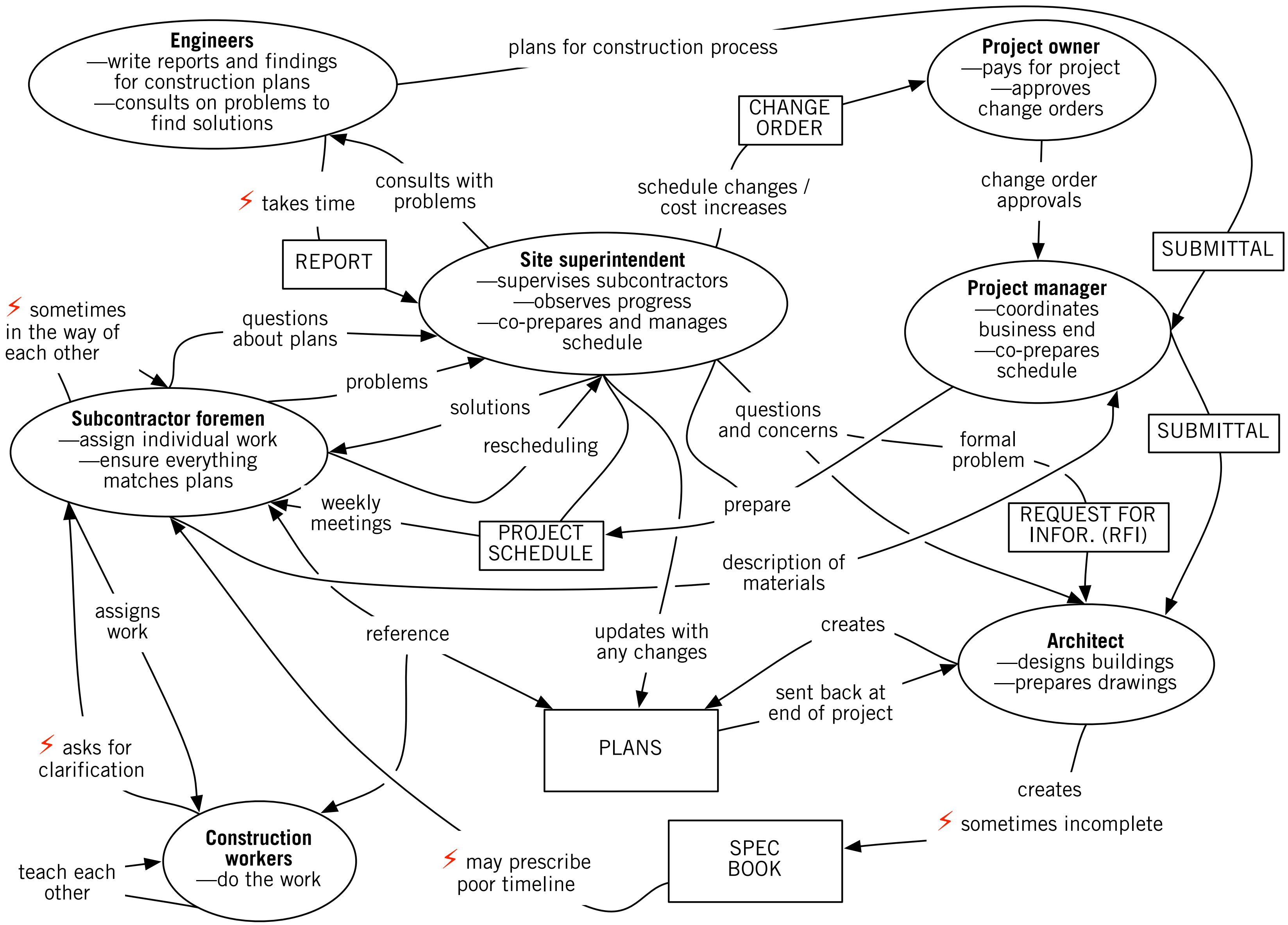
| USER | STEP | TRIGGER |
|---|---|---|
| Excavators | Excavators dig out foundation | |
| | Weekly meeting | |
| Contractor | Looks for bad soil | Experience matches with previous knowledge of bad soil |
| Money drawn | Work stage finished | More work can be done |
| Subcontractor | RePal pours foundation | |
| | Plumber does underground | |
| | plumbing, electrical | |
| | RePal does blockwork | |
| | Steel gets set | |
| Excavators | Get water mains in, excavate street | Foundation and excavation done |
| Subcontractor | Turn off water | Water main work |
| Superintendant | Observe water work, make sure | Subcontractor turns off water |
| | it's not creating problems | |
| Framer | Framer can't enter | Excavator has street torn up |
| | Framer comes in | |
| Subcontractor | Construction delayed | Rain |
| Owner | Owner tries to get on track | Delays |
| Superintendant | Superintendant eats up flex time | Flex time available in schedule |
| | Electrician, plumber, heating come in | |
| Subcontractors | Other subcontractors criticise slow subcontractor | Subcontractor is an "asshole", |
| | Drywall contractor comes in, does drywall | slow at doing work, unconcerned |
| Painter | Painter does painting | |

| USER | STEP | TRIGGER |
|---|---|---|
| Finishing carpenter, plumber, mason | Set finishing (cabinets, casework), trimwork, bricks | |
| Subcontractor, superindendant, architect | Superindendant speaks to architect for clarification | Trivial question from subcontractors |
| Subcontractor, superindendant, architect | Superindendant fills out RFI, gives to architect | Non-trivial question from subcontractors |
| Superintendant | Go over paperwork to ensure ADA compliance | Finishing in progress |
| Architect, superintendant | Make sure ADA compliance is met | Superintendant collects paperwork, does research |
| Architect | Architect reviews paperwork, passes responsibility back to superintendant | Paperwork presented |
| Soil and structural | Took longer than expected to finish report | Engineers busy |
| Owner, contractor | Change order filed | Schedule changes or cost increases |
| Owner | Money comes in late for change | Owner takes a while to sign change |
| Architect, landscaper | Flooring goes down, landscaping gets done | |
| Landscaper | Landscaper consults spec book | Legal reasons, can't remember what they need to do |
| Landscaper | Landscaper plants, regardless of weather | Spec book legally requires it |
| | Door test, checks weather-tightness | Project finished |
| Architect, owner, tenants? | As built plans sent to archetect and owner | Project finished |

# CONSTRUCTION CULTURAL MODEL



# CONSTRUCTION COMMUNICATION FLOW MODEL



# CONSTRUCTION KEY OBSERVATIONS

### LIMITED AUTONOMY

Architects submit plans of varying complexity, depending on the type and scale of a project. For less-complete specifications, subcontractors are often left to their own devices to execute their tasks successfully. Like astronauts, this autonomy only carries so far—to avoid legal troubles, construction crews must implement plans as exactly as is possible.

### TASK FEEDBACK

Feedback and time tracking on execution is largely implicit and visual—the superintendent has enough experience to know how far along a given task is by inspecting the work.

### BIRDS-EYE VIEW OF TASK EXECUTION

Procedures aren't specified to subcontractor workers at any deeper level of granularity than measurement and placement specifications—there aren't instructions on how to build a stud wall, for instance, contained within the plan. Construction workers are trained on individual procedures, and construction work largely involves repeating those procedures.

### CHANGING PLANS

Plan changes are common in construction management and are rarely resolved by a single party. In most cases, the site superintendent makes a consultation to an off-site party and must wait for a formal approval in order to implement those changes.

*"I have a set [of plans] in the trailer which doesn't leave, this set, which I will mark this up with notes, and all the as-builts will be on here."* [1]

### DEGREE OF COORDINATION

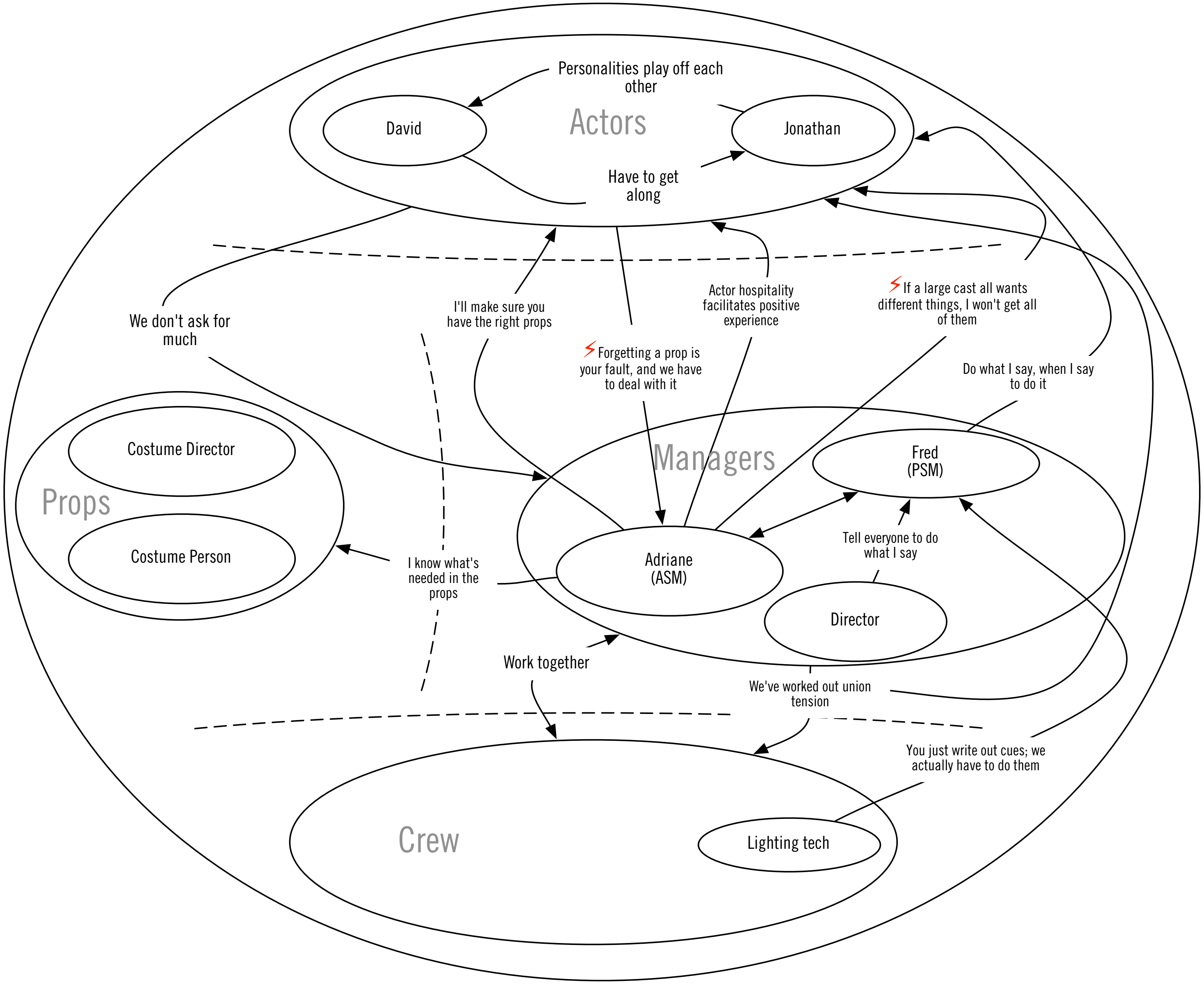
Much coordination and physical separation of stakeholders—architects, the project owner, construction workers, management, and consulting engineers—can cause bottlenecks that delay the plan. Many plans build-in these anticipated delays.

### TASK IMPORTANCE IS SECONDARY TO EXECUTION

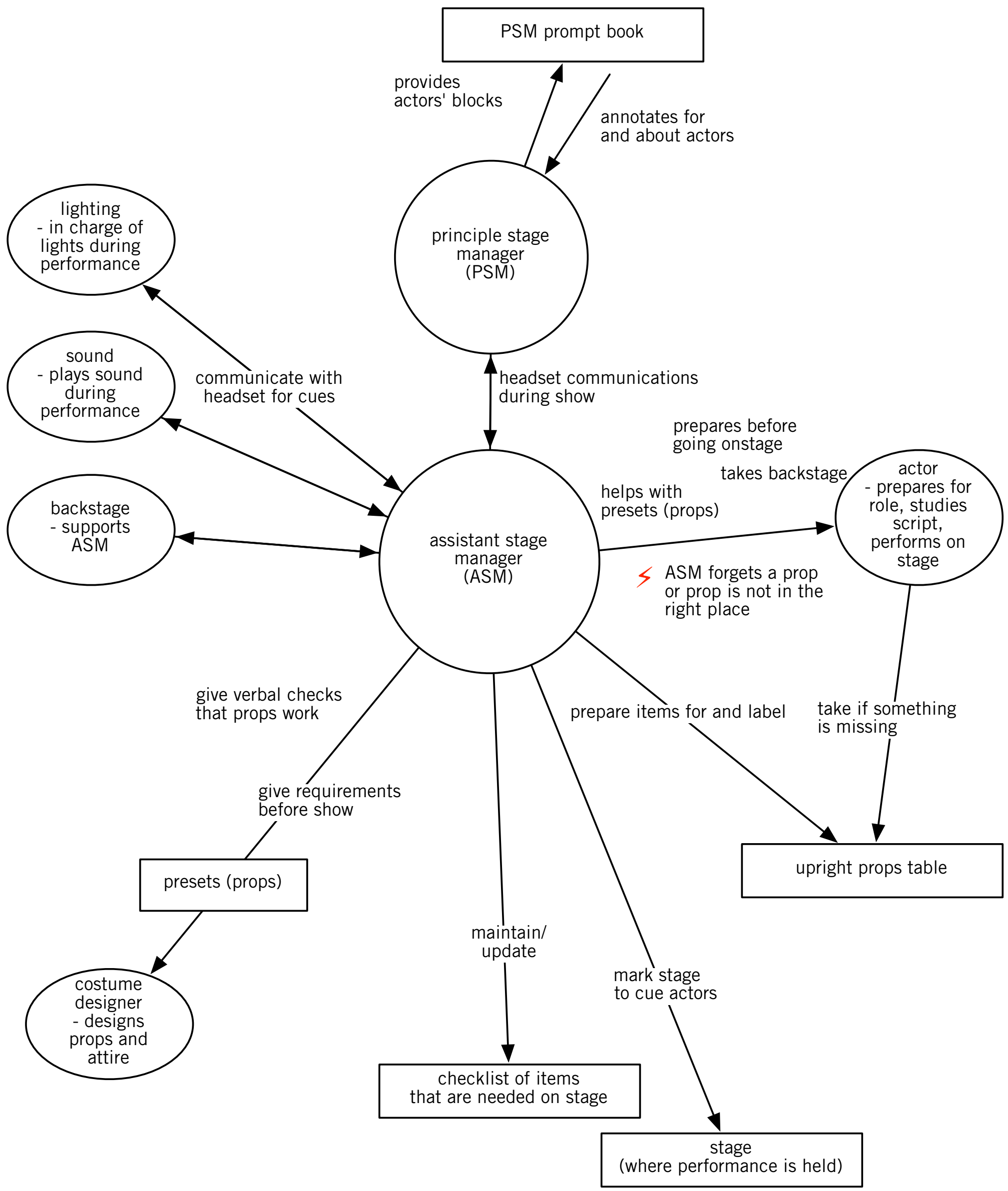
Individual construction workers don't have—nor do they need to have—an understanding of how their daily activities fit into the larger plan for the construction project. Because of the hierarchical nature of construction, the foremen simply assign them tasks.

1. *Site superintendent, p. 160, ln. 19*

# STAGE MANAGEMENT CULTURAL MODEL



# STAGE MANAGEMENT COMMUNICATION FLOW MODEL



# STAGE MANAGEMENT KEY OBSERVATIONS

**FEEDBACK THROUGH STAGE NOTES**

A detailed document outlying the behaviors of actors in a given situation (the stage manager's notes) may provide inspiration for systems through which NASA can gathering more informative feedback from astronauts.

**CHECKLISTS AND RESPONSIBILITY**

Backstage crew successfully follows a detailed checklist, ensuring that the actors have the tools they will need to carry out their mission. She is also held personally accountable if an actor goes on stage unprepared and must improvise to compensate for her error.

**FOCUS TO REDUCE SENSORY OVERLOAD**

The stage manager learns to perform his function while dealing with a great deal of competing sensory information. Various radio channels, for example, become easy to filter out with practice and the ability to distinguish relevant cues from background chatter.

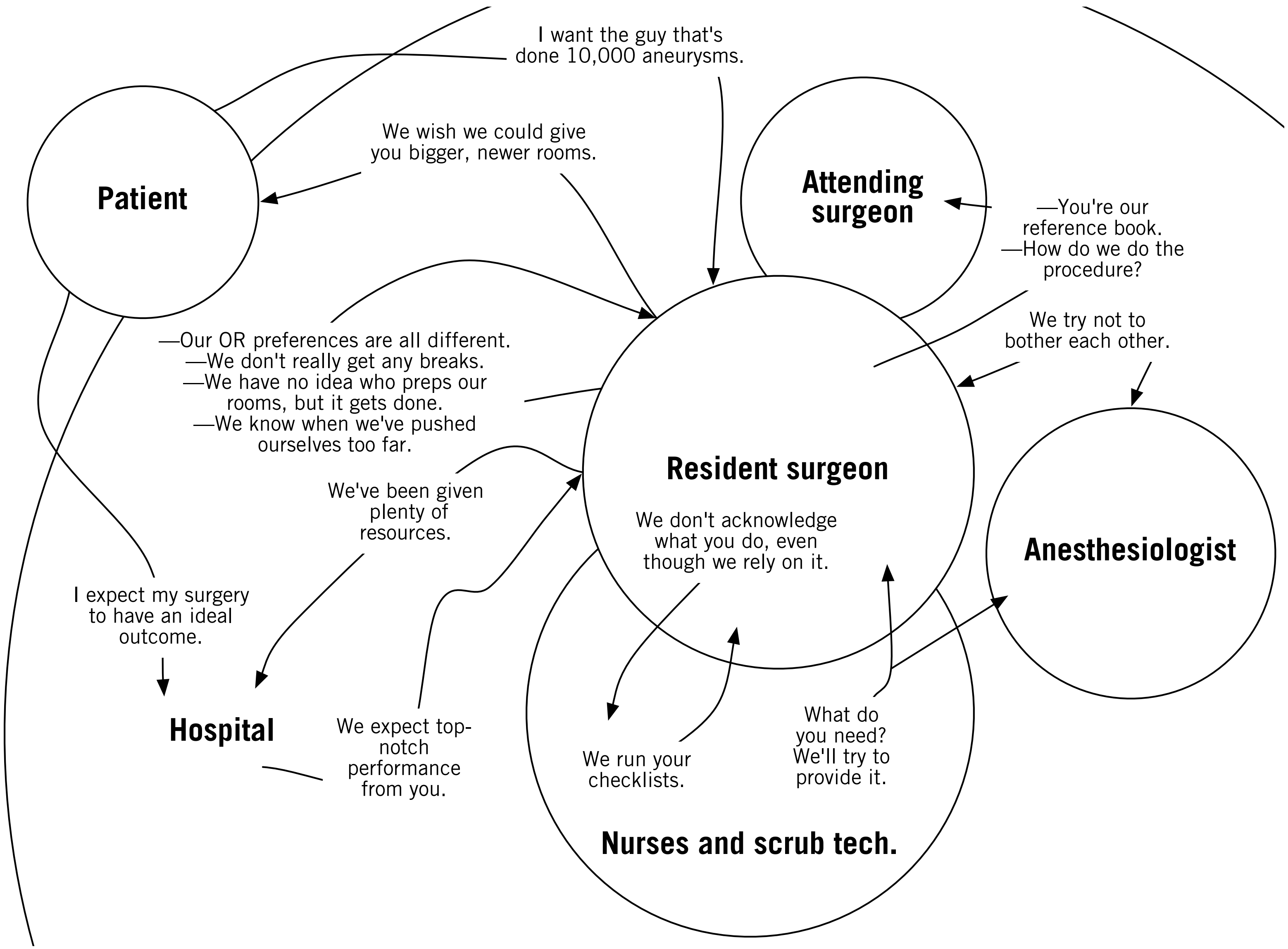
**NO SENSE OF AUTHORITY TENSION**

The stage manager serves as a cooperative point-of-contact between the actors and the other creative staff members. A warm rapport is established, providing potential inspiration for the astronaut / crew relationship.

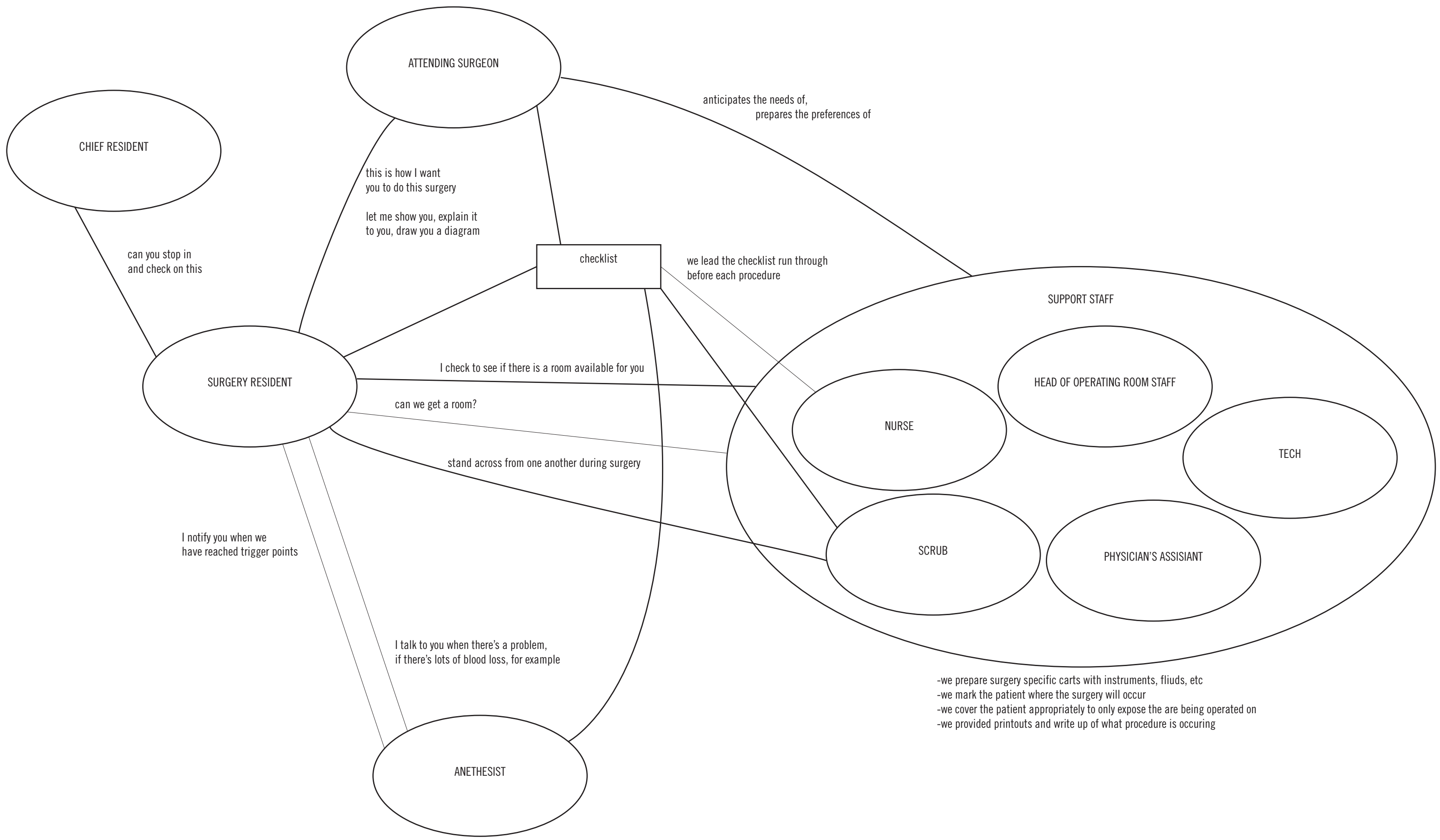
**LOVE FOR WORK**

The stage culture we observed is a close analog to NASA's. Though they were working long hours and operating under stressful conditions, these were people who showed an obvious love for their craft and a dedication to collectively accomplishing their goals.

# SURGERY CULTURAL MODEL



# SURGERY COMMUNICATION FLOW MODEL



# SURGERY KEY OBSERVATIONS

### SURGEONS HAVE PERSONAL PREFERENCES

In order to maximize their performance in the OR, surgeons have many preferences regarding staff, location, and the ergonomic arrangement of their work space. This causes inter-surgeon tension, especially when workspaces are rearranged.

*"So the OR staff at the beginning of every case is given a list of the surgeon's preferences and [...] if one surgeon likes to use a certain instrument when he's doing this, the staff will have that instrument ready and available and they'll know to have it up" [1].*

### INVENTORY MANAGEMENT THROUGH FORMAL CHECKLISTS

The operating room has a systematic way of managing inventory. Checklists are always read by nurses and confirmed by all other staff roles in the OR.

### PHYSICAL CUES REINFORCE PROCEDURES

Physical cues—in one anecdote, a surgeon described a model of the spine he kept in an OR during his early residency days—are extremely important to help reinforce memory of complicated procedures.

### TENSION IN COMMUNICATION

Each member of the surgery team must strike a balance between focusing on their personal roles and communicating amongst themselves. Cultural tension occasionally causes this to break down, as surgeons may not heed their support staff and others may be hesitant to interrupt the surgeon in his work.

### TIGHTLY-KNIT PROCEDURES, BUT RESPECTFUL DISTANCE

There is close communication during surgery between surgeons, nurses, and technicians. However, anesthesiologists and doctors make a point not to bother each other. This is ingrained and part of all procedures, including preparatory work, tools, and support during surgical executions.

### SURGEONS WANT TO REMAIN ON SCHEDULE

Surgical residents work long hours, and inevitably some surgeries have complications that delay later surgeries. Surgeons make a point to work as efficiently as possible, but they don't take shortcuts during procedure execution.

*"The goal is to get everything done efficiently. Everybody wants to be home by 3:00, that's the surgeons, the patients, the staff, everybody wants to get home as soon as they can" [2].*

1. *Surgeon, p. 178, ln. 25*
2. *Surgeon, p. 176, ln. 7*

*Appendix CD includes:*

- Research report
- Appendix
- Transcripts + recordings
- Research data
- Photographs

*Thank you to*

## OUR CAPSTONE FACULTY AND STAFF

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## OUR RESEARCH PARTICIPANTS

*without whom our project would not be possible*


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