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Investigating Real-Time Planning and Execution of Human Space Missions

NASA

HCII

Carnegie Mellon

Team Lumina

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EXECUTIVE SUMMARY

PROJECT

Central to any human effort in space is the smooth and reliable execution of technical and operational tasks by astronauts. From current Shuttle and International Space Station missions to future extended planetary exploration, unique planning challenges call for better tools that enable astronauts to execute complex tasks, often under shifting conditions.

To this end, our interdisciplinary team of five Carnegie Mellon Master of Human-Computer Interaction students, working with the Human-Computer Interaction Group at NASA Ames Research Center, has been tasked to design, develop, and evaluate a prototype assisting real-time execution of human space missions.

PROCESS

To inform our final prototype, we utilized Contextual Design methods to explore planning both at NASA and in analogous domains that exhibit similar planning and execution challenges. Our user research investigated the hallmarks of planning commonly exhibited across many disciplines, including real-time re-planning, unforeseen circumstances, remote communication, and authority tension. With these foci in mind, we conducted six Contextual Inquiries and three interviews in the domains of human space missions, surgical ward, and news broadcasting.

In addition to our user research, we performed a literature review surveying domains with planning workflows that map appropriately to human space missions. Finally, we analyzed several project management software packages, as well as other industry-specific planning tools, to investigate current methods and approaches of addressing challenges in planning and execution.

FINDINGS

Our research findings consolidated into five prevailing problems of human planning and execution:

1. **Inflexible plans** fail to capture the invariable nature of execution.

2. The difficulties of communicating **experiential and *in situ* knowledge** result in uninformed plan making.

3. **Shift handoffs** within roles often involve poor information transfer, resulting in poor situational awareness and increased operating expense.

4. **Dependencies between highly siloed roles** ungracefully accommodate human error, which has cascading effects.

5. Any **single representation of the plan** fails to accommodate the varying needs and responsibilities across roles utilizing the plan.

These five challenges of planning provide a guiding framework from which to approach and produce an innovative interface design that addresses the unique needs of human space missions.

BACKGROUND

In 1998, NASA joined forces with four international space agencies to begin on-orbit construction of the International Space Station (ISS). More than a decade later, the station nears completion, and crew teams perform regular six month rotations onboard. Home to scientific research involving a range of physical sciences, astronomy, meteorology, human studies, and space medicine, the space station offers a significant advantage over previous NASA programs through its ability to support long-term scientific studies. Because the work performed aboard the ISS represents such a large investment of time and money, a significant amount of effort is dedicated to the optimization of crew time in space. An astronaut's workday is planned down to the minute in order to ensure that they can accomplish the maximum amount of work during these hours.

This plan undergoes a lengthy creation and review process, bearing constant scrutiny from many roles, and is iteratively refined until it reaches an execution-ready state. Long-Term Planners (LTPs) begin the process with high-level planning from six months out. As execution time approaches, the plan is refined in the hands of Week-Long Planners (WLPs) and Short-Term Planners (STPs).

Finally, Real-time Planning Engineers (RPEs) manage the plan up to three days prior to and during execution. As the plan passes through each of these roles, it is progressively refined and manually inspected for constraint violations, missing information, and typos.

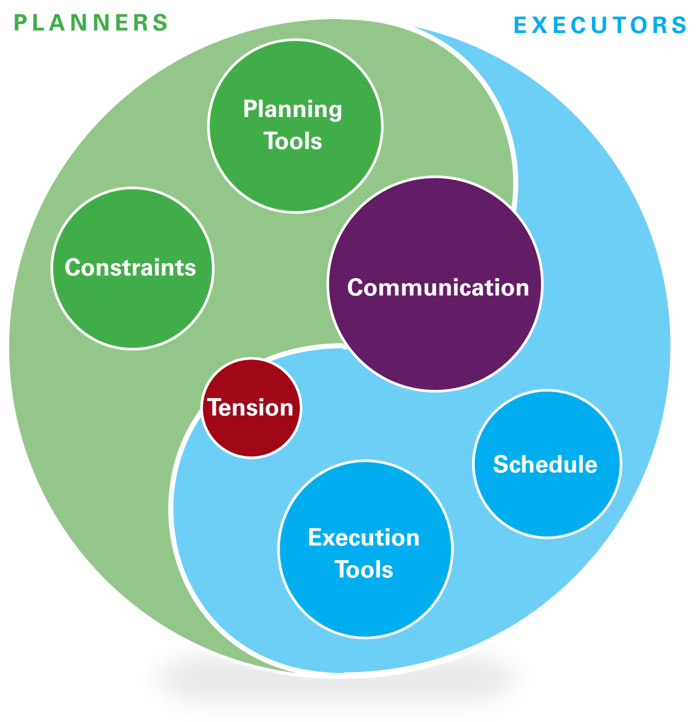
The complex problem space of real-time planning and execution presents many research opportunities. Multiple roles possess different mental models of the plan, planners and executors must account for multiple levels of constraints, international partners negotiate with differing priorities, and unforeseen events necessitate dynamic re-planning after execution has begun.

PROBLEM SPACE

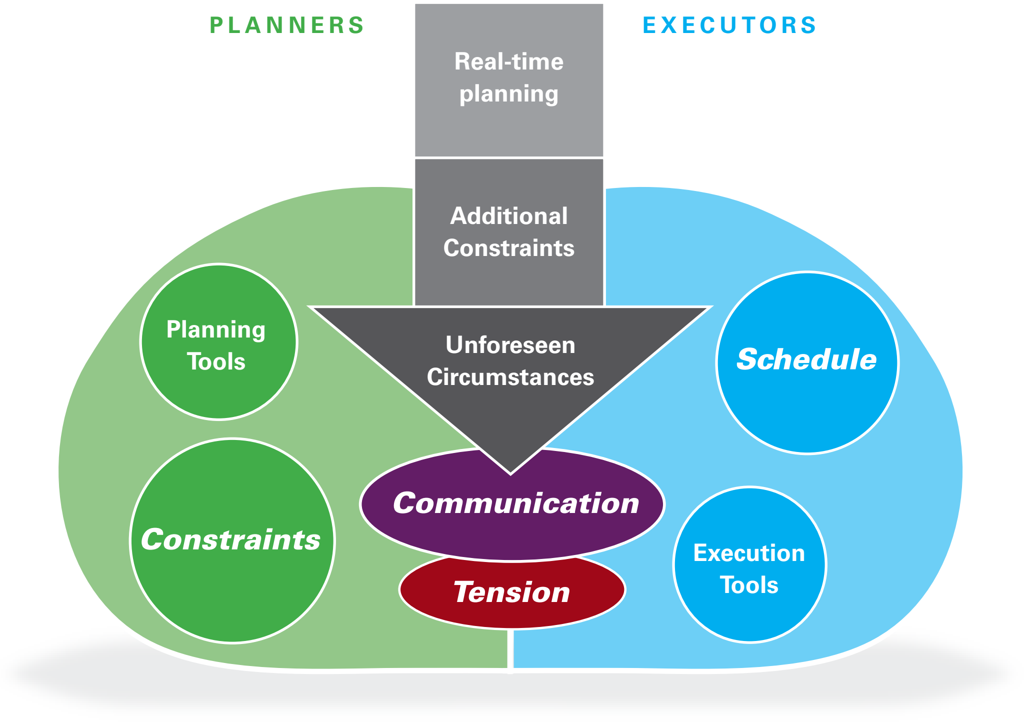
Based on our understanding of the project landscape, we constructed this framework depicting the difference between the "ideal" and "real" states of human space mission planning. In the ideal world, planners and executors work synchronously toward successful completion of planned tasks. Some communication is a must and a bit of tension is unavoidable. More than often, however, unforeseen circumstances introduce additional constraints and necessitate dynamic re-planning. As a result, the volume of communication grows, and tension may heighten between the two groups.

To guide our research, we developed a **hunt statement**, to provide focus along the way.

> *"We want to understand the cultural context, communication strategies, and unexpected circumstances affecting real-time planning in order to facilitate the efficient execution of human space missions."*



"The Ideal World"



What often happens

PROJECT TEAM

Our design team is comprised of five Carnegie Mellon University Masters students in the Human-Computer Interaction Institute with multi-disciplinary backgrounds including computer science, information systems, mathematics, communication design, and cognitive science.

Katy Linn
Project Coordinator
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Katy Linn is working toward a Masters Degree in Human-Computer Interaction at Carnegie Mellon HCII. She holds an Bachelor's Degree in Computer Science and Mathematics from Vanderbilt University. She most recently worked for Microsoft as a Software Development Engineer on the Solution Development Platform Team of Office Live Small Business. Outside of the office, Katy enjoys soccer, singing, and science fiction.

Christine Wu
Technical Lead
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Christine Wu is currently a masters student at Carnegie Mellon's Human-Computer Interaction Institute. She grew up in California and received her undergraduate degree in Computer Science from UC Berkeley. Prior to attending CMU, she worked at VMware for seven years as a developer, shouldering responsibilities from UI design to UI development. In her spare time, she enjoys reading, shopping, traveling and sharing good food with family and friends. On her recent trip to New Zealand, she swam with dolphins in the southwest Pacific Ocean.

Jesse Venticinque
Design Lead
jdventi@gmail.com

Jesse Venticinque, a Bay Area native, earned a B.S. in Cognitive Science and a Specialization in Computing from UCLA in 2007. Shortly after graduation, Jesse joined Google to battle web-spam and improve search quality, but quickly moved on to Predictify, a Bay Area startup providing a prediction platform that adds an interactive, forward-looking dimension to current events. As the sole UI Engineer, he led interaction and graphic design, user experience and front-end development. Outside of HCI, Jesse enjoys Bay Area sports, cycling, and current events.

Jennifer Lu
User Research Lead
jennlu.is@gmail.com

Jennifer Lu is a recent graduate from UCLA with a B.S. in Cognitive Science and a Specialization in Computing. During undergrad, she worked in the UCLA Statistics Department on various web development projects and conducted cognitive psychology research at UCLA's learning and memory lab. In her spare time, Jennifer enjoys gaming, playing her recently purchased ukulele, cooking/baking, and learning new things. When she was still in shape, she danced for 26 hours to fundraise for the battle against pediatric aids.

Noah Levin
Web / Documentation
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Noah Levin is currently an Accelerated Masters student at Carnegie Mellon finishing up a B.S. in Information Systems and Human-Computer Interaction with a minor in Communication Design. For the past two summers he worked as an Interaction Designer for a local strategic design consulting firm, LotterShelly, doing work for such clients as PNC Bank, Carnegie Mellon, and GigaPan Systems. Outside of HCI, Noah plays bass and sings in a folk-rock band, loves to row (kayaking and crew), and once appeared in a Sour Patch Kids commercial.

RESEARCH

To maintain a user-centered design process, our first step was to conduct ethnographic research and collect data from real people. However, because of limited access to people at NASA, we began by exploring other domains with similar challenges and practices in planning and execution. We selected three domains to research in addition to our target, News Broadcasting, Surgical Ward, and Airlines, based on a strong mapping to fundamental factors of planning for the International Space Station:

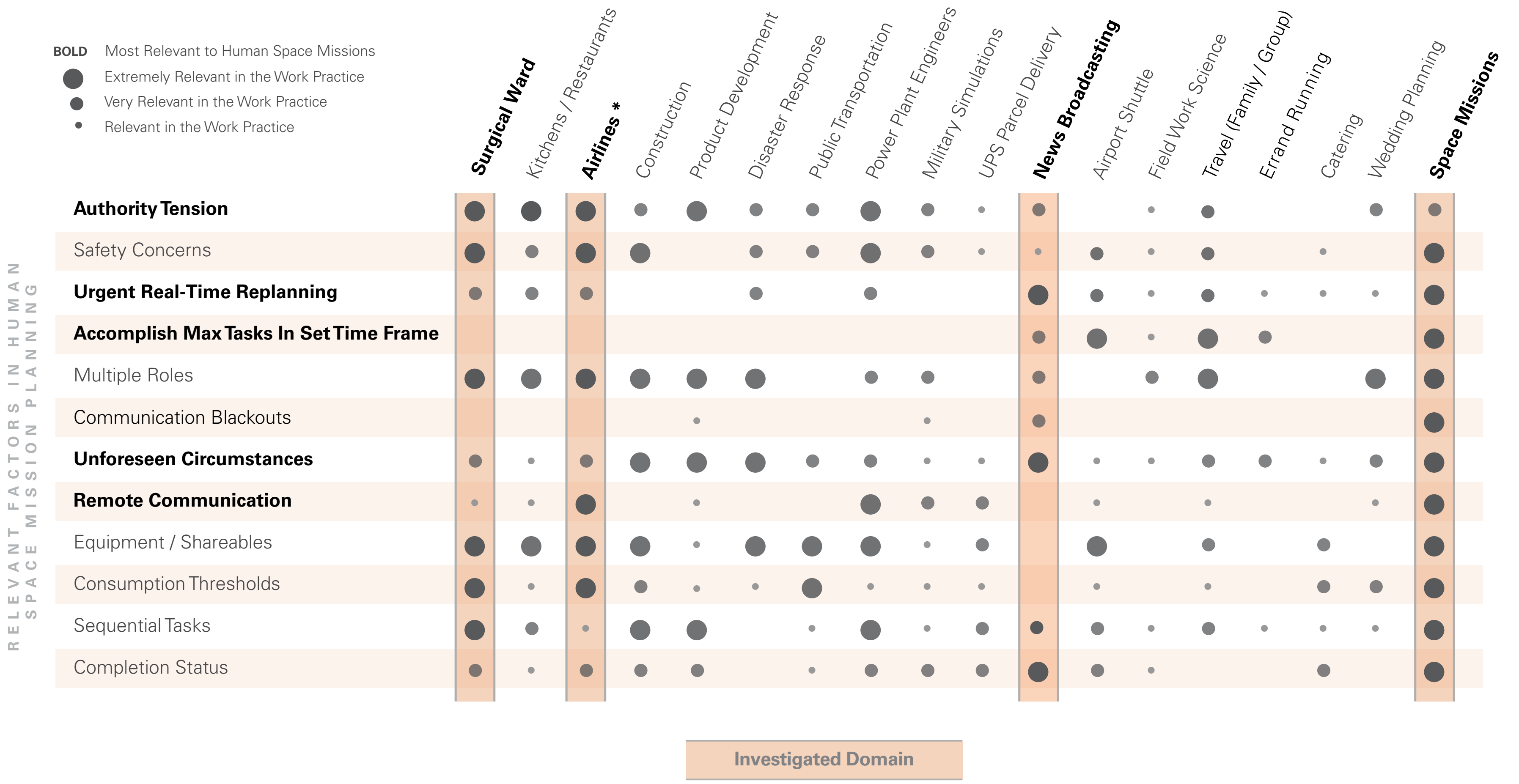
1. The propensity for **Authority Tension**
2. The need for **Urgent Real-time Re-planning**
3. The occurrence of **Unforeseen Circumstances**
4. The need for **Remote Communication**
5. The goal of accomplishing the **Maximum Amount of Tasks in a Set Time Frame**

We were able to conduct field research in News Broadcasting and Surgical Ward, and include Airlines in our literature review and competitive analysis.

RESEARCH

ANALOGOUS WORK DOMAINS

The following framework depicts the mapping between planning factors in human space missions and identified analogous work domains. The relevance of each domain was determined through discussions with our client and faculty, along with our collective prior understanding of each domain.



* No CI performed

RESEARCH

LITERATURE REVIEW

A literature review allowed us to explore planning in analogous domains and gain sufficient background knowledge in preparation for our CIs. We reviewed existing ethnographic accounts in the Airline, Surgical Ward, and Space domains in addition to relevant research in Cognitive Science.

Our research revealed distinct planning challenges and unique approaches to structuring work and managing resources. In addition, we discovered common planning problems and methods for addressing these problems across all domains that contributed to our research findings.

See Appendix A for detailed results from our literature review.

SUMMARY OF FINDINGS

AIRLINES

Airline planning exhibits much overlap with human space mission planning. Both domains have issues with authority tension, urgent real-time replanning, safety multiple roles viewing and modifying the plan, and remote communication. Several potential opportunities for NASA were found in reviewing relevant literature in the airline domain; these include: the use of historical booking to forecast data, managing different types of resource constraints (fuel, maintenance, crew restrictions, etc,.), and handling the issues of decentralized software.

References listed in Appendix A (p. 44)

SURGICAL WARD

The Surgical Ward exhibits complex planning workflows. The staff often executes under evolving situations and strong resource constraints. In conjunction with a variety of coordinative artifacts, one role, the Charge Nurse, is primarily responsible for generating the daily plan, assigning responsibilities, and updating the plan during unforeseen incidents.

This domain offers many design opportunities for human space missions, including the consolidation of planning roles, public and collaborative planning artifacts, and the consideration of the plan as a contract between stakeholders.

References listed in Appendix A (p. 50)

SPACE

Planning for human space missions requires a substantial amount of time for preparation before the actual date of execution. With expensive consequences when a plan is not adhered to by executors, everyone must be ready to respond quickly and critically. Effective communication amongst personnel and efficient use the tools used in this process are critical to a successful mission. A literature of human space missions provided us with a solid grounding for our user research in this domain.

References listed in Appendix A (p. 56)

COGNITIVE SCIENCE

Individual planning is an activity that synthesizes several different cognitive processes and levels of functioning and is heavily related to problem solving, strategizing, and metacognition. Generally, individuals plan in service of achieving satisfactory future states through specifying and executing intermediate goals.

The most appropriate and actionable literature we reviewed that will inform our design decisions for a planning tool is the Model Human Processor, which considers the fundamentals of human cognition including memory, perception, and attention, to derive a set of "Principles of Operation" that guide HCI.

References listed in Appendix A (p. 61)

COMPETITIVE ANALYSIS

To broaden our understanding of current planning and execution practices in industry, we examined several project management software packages, and three industry-specific planning tools. Microsoft Project, Easy Project .NET, and Primavera are critical path project management tools marketed towards IT organizations. In addition we examined three planning tools utilized in the Airline, News Broadcasting, and Space industries.

The consolidated analysis revealed important aspects of project planning support across tools and improved our understanding of current methods and terminologies. In addition, the exploration of industry-specific tools exposed different approaches to tailoring planning and execution to the specific needs and requirements of a domain. Results from the competitive analysis, summarized below, ultimately influenced our research findings.

Our analysis was structured around major planning themes that surfaced during our initial exploration of the problem space. We documented the notable features and functionalities of each tool with screenshots and short descriptions.

See Appendix B for a detailed analysis on each product.

IDENTIFIED PLANNING THEMES

Multi-User Collaboration
Allowing multiple people to create edit and execute portions of a plan

Issue Tracking
Identifying problems in a plan and assigning responsibilities to resolve

Execution Management
The real-time plan execution interface

Progressive Granularity
Viewing and managing the plan at increasing resolutions over time

Version Control
Viewing and duplicating previous stages of a plan; tracing the life-cycle of a plan

Task Dependencies
The ability to create contingent relationships between tasks

Resource Management
The allocation of personnel and equipment

SUMMARY OF FINDINGS

PROJECT MANAGEMENT TOOLS

Commercial project management software typically utilizes the Critical Path Method, which models a project in terms of the activities, durations, and dependencies in order to determine the longest set of sequence-dependent activities required to complete the project. These tools promote features such as task dependency modeling, issue tracking, and visibility into the personnel and equipment allocation. While all analyzed tools support some level of asynchronous communication, the tools differ in support of multi-user collaboration and concurrent communication. Additionally, beyond supporting undo, these project management tools ostensibly do not support version control or tracing multiple versions of the plan.

INDUSTRY-SPECIFIC TOOLS

Generalizing from our analysis, these planning tools are tailored to handle industry-specific constraints, such as flying conditions in Airlines, or anchor reading rates in News Broadcasting. Additionally, features and functionality in these tools mirror the unique needs of the workflow in each industry. Interestingly, tools in each industry vary in their support of the planning and execution divide. While some industries maintain a strict division between planning and execution in tools with separate interfaces, others combine planning making, iteration, and execution into a single display.

Microsoft Office Project   ORACLE | PRIMAVERA   easyprojects.net   APENPS   Lufthansa Systems   SPIFe

FIELD RESEARCH

To gain an informed understanding of human planning, we utilized a variety Contextual Design methodologies to explore and interpret existing behaviors and tools around plan making and execution. At the crux of the user-centered design process is the in-context observation of current workflow procedures, cultural influences, and relevant supporting artifacts. The following describes our user-research methods in detail.

CONTEXTUAL INQUIRY

In order to fully understand and internalize the complex processes and possible problems involved in planning and execution, user research must be conducted in the naturally occurring context of work. As such, we conducted six Contextual Inquiries (CIs) across three domains: with an Assignment Editor at a Pittsburgh News Broadcasting Station, a Charge Nurse at a Pittsburgh Hospital, a Week-Long Planner (WLP) and Short-Term Planner (STP) at NASA Johnson Space Center (JSC), a Real-time Planning Engineer (RPE) at JSC, and a Flight Controller working at the Telemetry, Information Transfer and Attitude Navigation (TITAN) console at JSC. In addition to the six CIs, we were also able to briefly talk to people with roles that directly interacted with our main CI participant. Though we were unable to use audio or video recording during any of our CIs, we documented the investigations with photographs and copious notes in all cases, from which we were able to extract and process data. Through these CIs, we were able to gain insight into the workflow, cultures, and artifacts relevant to the respective planning and execution tasks.

CONTEXTUAL OBSERVATION

Due to the nature of the work that we wanted to understand, Contextual Inquiry, which requires interrupting participants in their work flow to ask questions, was occasionally not appropriate. For example, it was not possible to interrupt the TITAN during his shift handoff, nor the Producer during the news broadcast. Under these constraints, however, we were able to observe work in-context as a 'fly on the wall.' This technique allowed us to observe the execution of plans, and observe how execution teams react to unforeseen circumstances and dynamically re-plan in the high-stress execution environment.

RETROSPECTIVE INTERVIEWS

Because dynamic re-planning necessitated by unforeseen circumstances is somewhat capricious in nature, it was not possible to predict an appropriate time to observe it. In these cases, we relied on Retrospective Interviews to collect valuable data. While the main goal of this method was to reveal anecdotes about unforeseen circumstances and dynamic re-planning, it was often a valuable method to elicit sensitive information, such as authority tension.

RESEARCH

PLAN LIFE CYCLE

The framework to the right depicts the basic flow of a plan from inception through execution, at the most granular level. This model allows us to move through the diagram for any given scenario and helps to highlight the major findings in this report.

LIFE CYCLE

Plans are driven by needs, which we label Plan Content Sources. In most domains, a Content Compiler helps list this information so that planners can begin to assemble a structure and timeline around it. At this point Plan Reviewers, Instruction Writers, and Plan Coordinators work under a Plan Lead to formulate and build a first draft of a plan. Then, using Planning Tools (software or physical artifacts) as a communication device, planners begin to work with executors to revise the plan until it represents the ideal form of execution. This revision process is extremely iterative and can begin months before the execution of a given task. Unforeseen circumstances can act as content sources because they are handled by planners in similar ways; they must move through the different roles to find their way into the timeline.

BACKGROUND

The Plan Life Cycle is a consolidation of smaller and more specific models created from our Contextual Inquiries. The Plan, shown in a callout box between planners and executors, is intentionally vague because this framework focuses on high-level planning workflow. Our upcoming design phase will explore The Plan at a more granular level to determine how to best represent relevant planning factors in software.

See Appendix D for all work models.

ROLES AND ARTIFACTS

Plan Content Sources: Originate plan content

Visionary: Sets organizational goals and priorities

Content Compiler: Gathers plan information from other sources

Plan Reviewer: Suggests changes

Plan Lead: Determines final plan content and assigns responsibilities

Plan Coordinator: Schedules and sequences the plan, and manages resources and constraints

Plan Change Implementer: Updates the public plan and resource consumption

First Responder: Responds to unforeseen incidents and escalates to appropriate personnel

Execution Director: Monitors real-time progress and makes final decision for plan changes

Execution Supporters: Have specialized knowledge and access

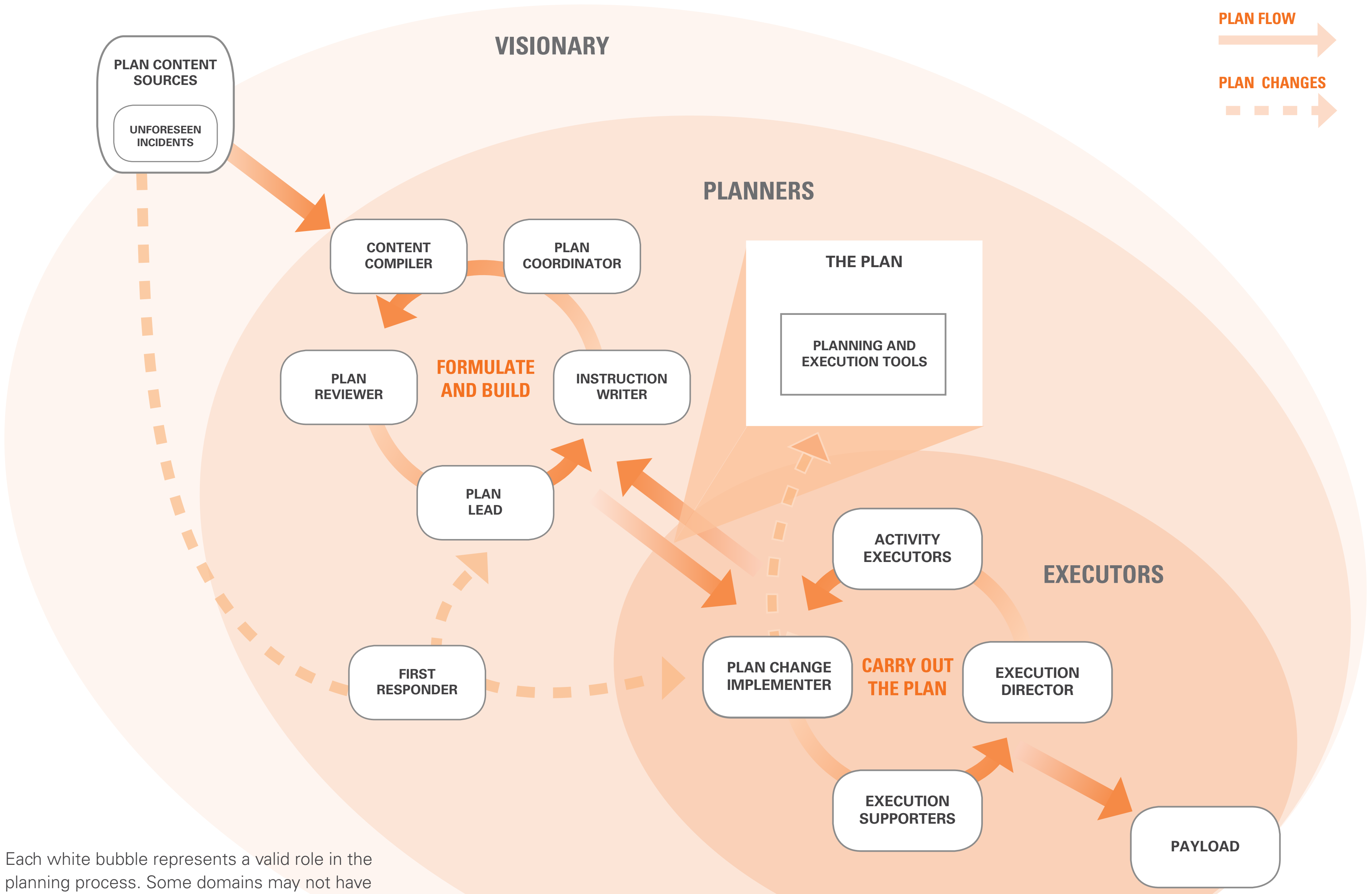
Activity Executors: Executes plan activities and generates payload

The Plan: Structures work, responsibilities, activities, tasks, resources (equipment, thresholds, personnel), notes, and instructions

Planning Tools: Supports building the plan

Execution Tools: Assists executing the plan

Instruction Writer: Creates execution instructions



Each white bubble represents a valid role in the planning process. Some domains may not have personnel for each role, and other domains have people who perform multiple roles.

NEWS BROADCASTING

We selected News Broadcasting as an analogous domain because of the potential to observe authority tension, urgent real-time re-planning (during broadcast) due to unforeseen circumstances, and a work flow structured to accomplish a maximum number of tasks in a set amount of time. We conducted our first major Contextual Inquiry with an experienced Assignment Editor at a Pittsburgh News Broadcasting station.

BRIEF OVERVIEW OF PLANNING AND EXECUTION

The Assignment Editor is responsible for gathering story leads, escalating promising stories to the Producer, and managing reporters, photographers, and equipment. Turning a story from an initial snippet of information into an anchored news broadcast requires as many as ten roles and generates a variety of collaborative physical and digital artifacts. This process is served significantly by the use of a single integrated planning system, Essential News Production System (ENPS).

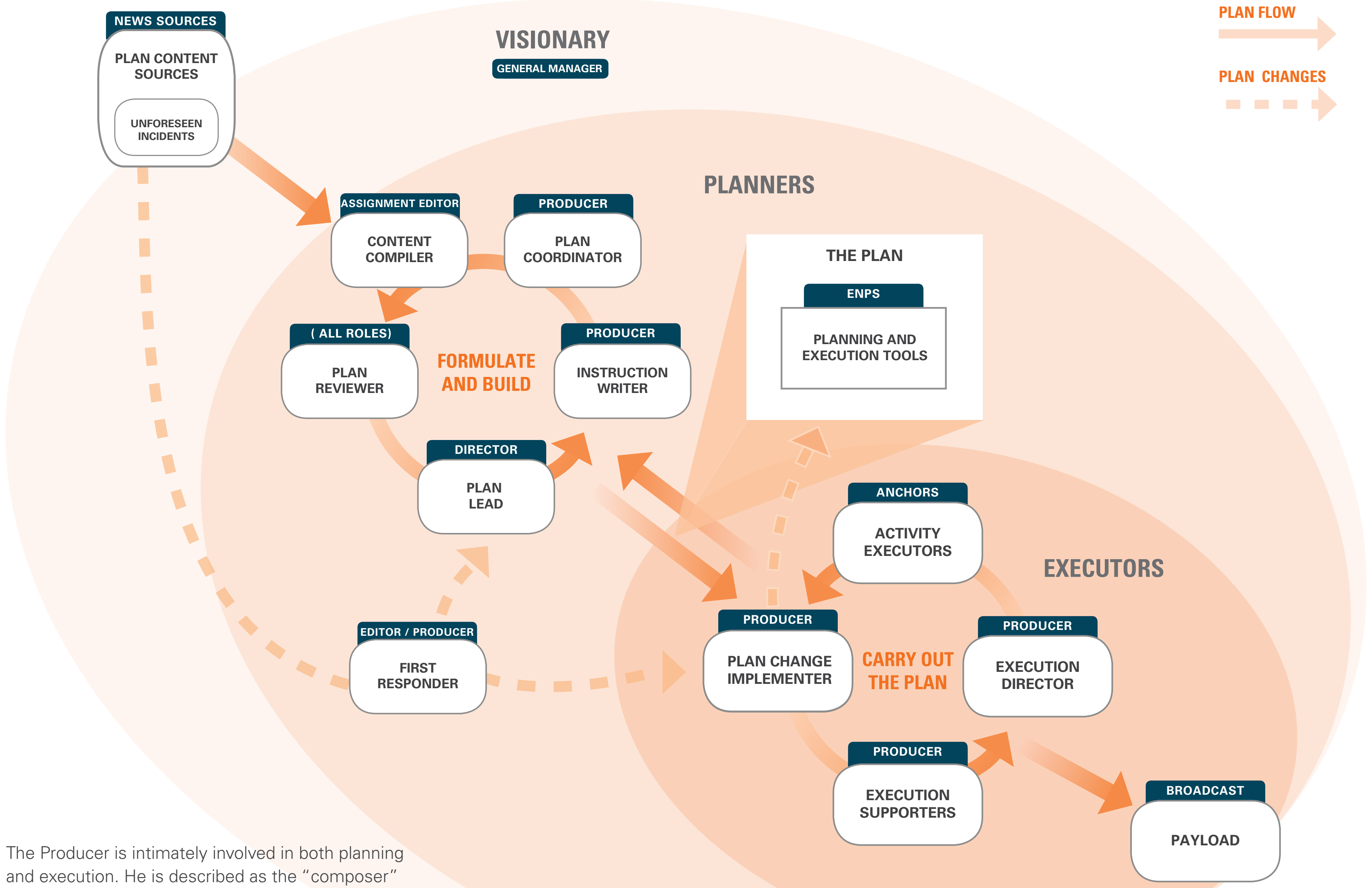
KEY OBSERVATIONS

1. Public displays play a crucial role in establishing shared understanding and situational awareness amongst the planning roles.
2. Many of the hard and soft constraints affecting planning are managed in the planner's head.
3. A single tool is used to organize the plan and facilitate collaboration between different roles across both planning and execution.
4. The use of a single tool bridges the divide between stages of planning and execution and increases efficiency when real-time re-planning occurs.

See Appendix C for further details.

Katy watches the Assignment Editor juggle many tasks using different artifacts such as paper notes and software.

ENPS: Essential News Production System



The Producer is intimately involved in both planning and execution. He is described as the "composer" of the broadcast and works in conjunction with the Director, who is the "conductor" of the broadcast.

SURGICAL WARD

Planning at the Surgical Ward has many parallels with planning for human space missions: staff coordination, equipment sharing, unforeseen circumstances, and real-time re-planning. For our second major Contextual Inquiry, we observed a veteran Charge Nurse at a large Pittsburgh Surgical Ward.

BRIEF OVERVIEW OF PLANNING AND EXECUTION

The Charge Nurse is main planner in the Surgical Ward, tasked with forming surgical teams, updating the daily plan of operations, and accommodating plan changes. Additionally, this role coordinates human and equipment resources for each case, directly manages a staff of nurses and technicians, and also works with surgeons, anesthesiologists, and hospital administrators. When delegating tasks, the Charge Nurse must also consider union regulations as well as his staff's personal requests.

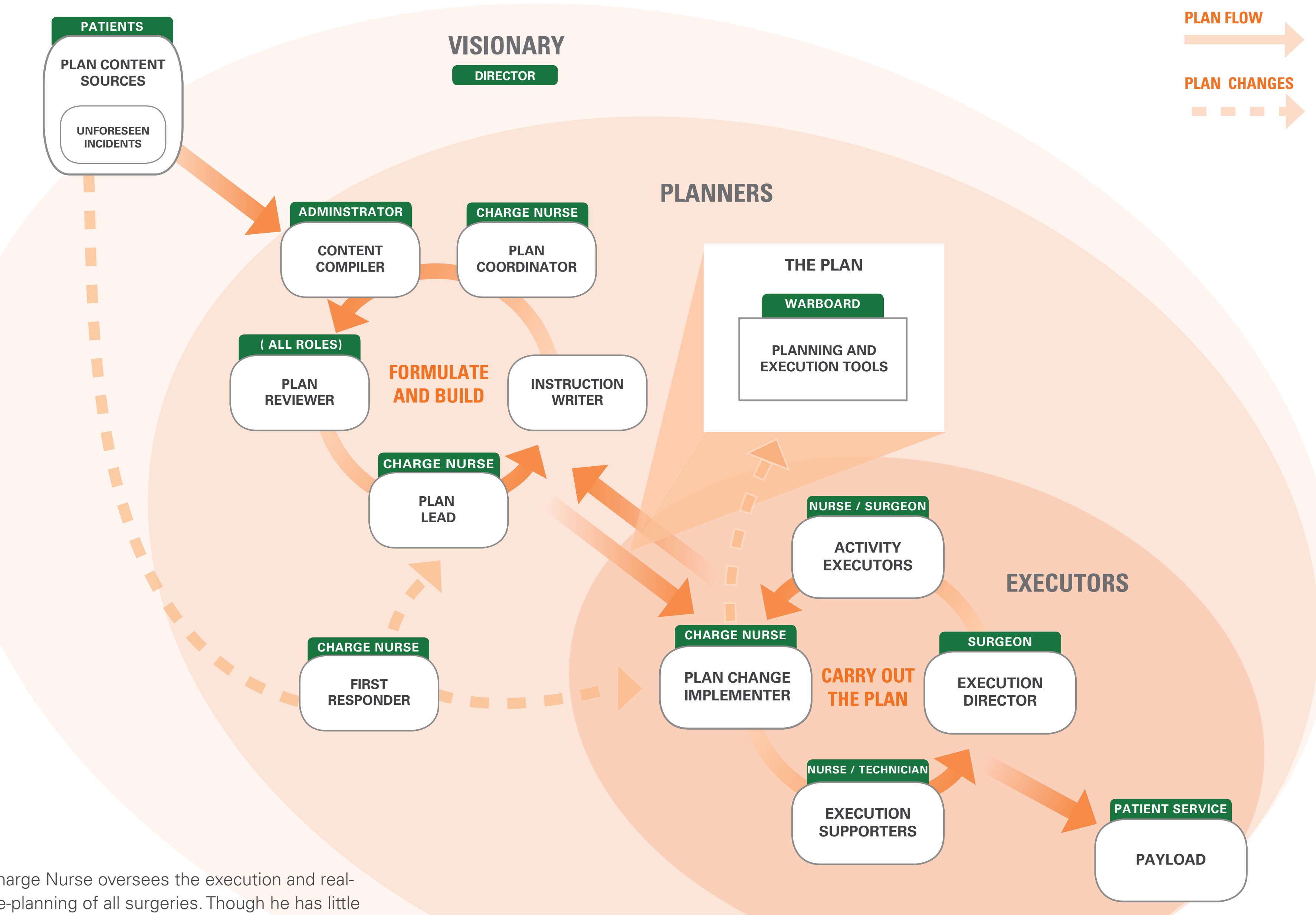
The Charge Nurse updates this warboard to inform surgeons of the status of operation rooms.

OR: Operating Room

KEY OBSERVATIONS

1. The Charge Nurse spends the majority of his time out of the office, making rounds and conversing with staff near the public plan displays.
2. The plan is often tracked and managed tacitly but externalized for the sake of communication through public artifacts tailored to each role's needs.
3. The plan is rarely executed to spec, with unforeseen incidents regularly upsetting the plan.
4. Many roles in the Surgical Ward rely on the Charge Nurse for reorientation during plan changes.
5. In addition to hard resource constraints, the Charge Nurse must also accommodate soft constraints such as personnel preferences when forming surgical teams.
6. Through a difficult and even thankless job, the Charge Nurse remains motivated by trying to achieve a higher purpose.

See Appendix C for further details.



The Charge Nurse oversees the execution and real-time re-planning of all surgeries. Though he has little control over the initial Operating Room (OR) schedule, he is responsible for forming surgical teams and responding to unscheduled "add-on" cases.

RESEARCH

SPACE

We concluded our user research with a week-long visit to the Johnson Space Center (JSC) in Houston, Texas. A behind-the-scenes investigation of the planning process for the ISS provided an opportunity to interview many of individuals involved.

BRIEF OVERVIEW OF PLANNING AND EXECUTION

International Partners, other NASA centers (e.g., Marshall) and science specialists outside of NASA are all sources for activities. The planning process starts out fairly lucid and gradually solidifies as the time of execution approaches.

Six months prior to execution, Long-Term Planners (LTPs) kick off the planning process by determining the activities for an International Space Station (ISS) increment. Two weeks prior to execution, the Week-Long Planners (WLPs) schedule activities at a high level. One week prior to execution, the Short-Term Planners (STPs) refine and solidify the plan. Three days prior to execution, the Real-time Planning Engineers (RPEs) ensure that links to all plan components (procedures, e.g.) are in place and valid. At this point, all changes to the plan must go through the formal change request process.

Both the astronauts onboard the ISS and flight controllers on the ground are responsible for executing the plan. They view the schedule, follow procedures, record results, and update activity status.

ISS: International Space Station

LTP: Long-Term Planner

WLP: Week-Long Planner

STP: Short-Term Planner

RPE: Real-Time Planning Engineer

TITAN: Telemetry, Information Transfer and Attitude Navigation

DOG: Daily Operations Group

The Flight Director maintains situational awareness by talking to other Flight Controllers, listening in on the loop, and watching the multiple displays on her desk.

KEY OBSERVATIONS

Exposure to a variety of individuals helped us gain insight into the planning and execution process.

To see planners in action, we performed Contextual Inquiries on **WLP** and **STPs** while they worked hard to incorporate activities into the plan for the current increment.

1. Planning is a hugely iterative, non-deterministic process.
2. Tools can only account for hard constraints.

For a better sense of real-time planning, we observed a **RPE** working in concert with the Ops Planner in the Flight Control Room to implement Planning Product Change Requests (PPCRs).

1. Planning roles are highly siloed.
2. Tools and processes assume that planning and execution progress linearly, but that is not reality.

We interviewed a **former astronaut** and a Daily Operations Group **(DOG) trainer** to find out more about plan execution aboard the ISS.

1. Different roles need different kinds of information from the plan.
2. Executors often view the plan as a suggestion.

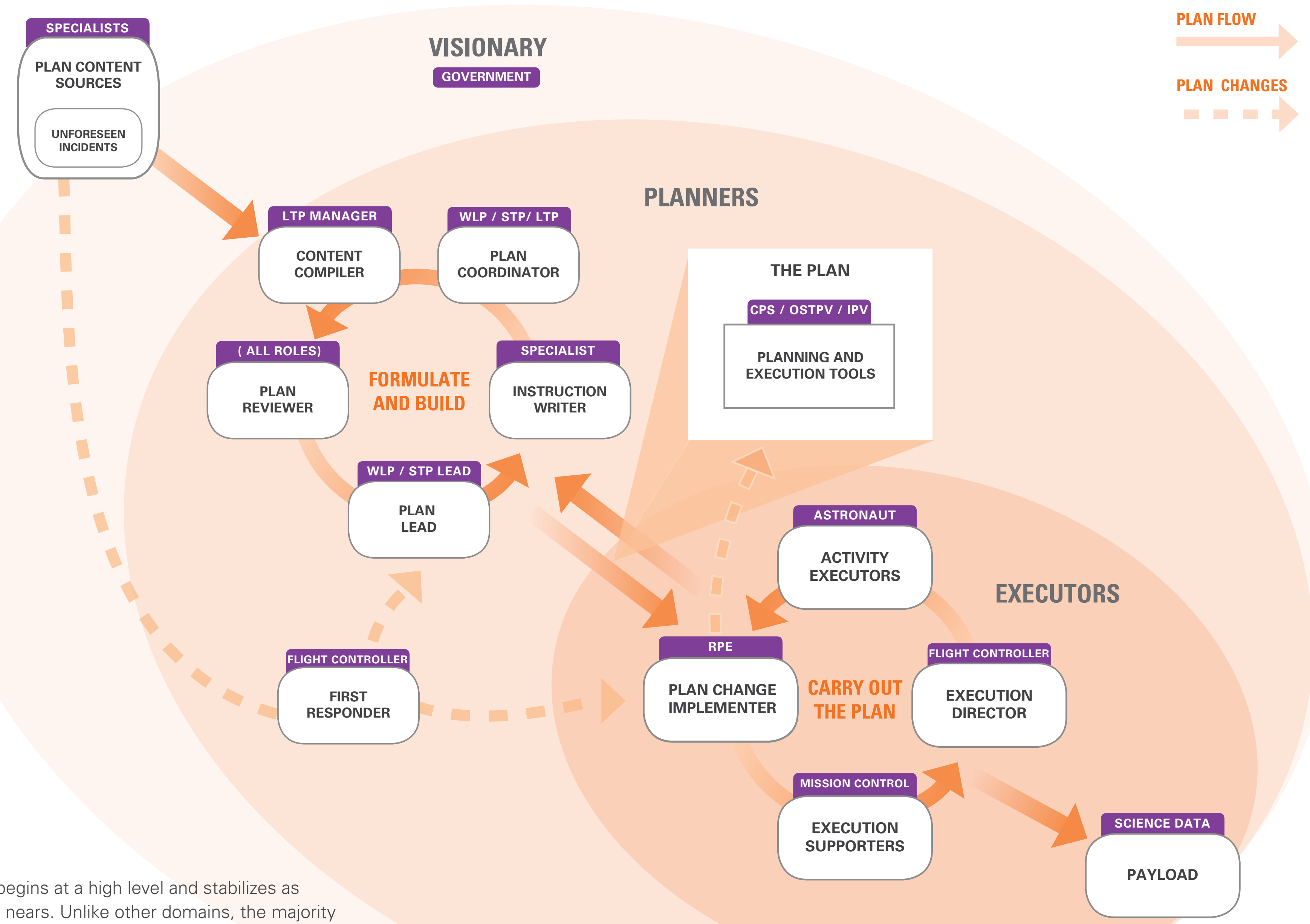
The Flight Controller working at the Telemetry, Information Transfer and Attitude Navigation (**TITAN**) console allowed us to sit with him during one of his shifts. He is responsible for maintaining contact with the ISS in order to keep track of the crew's progress.

1. Shift handoffs allow for information transfer between similar roles before executing the plan.
2. The TITAN does "detective work" to prepare for unforeseen circumstances.
3. Every role in the Flight Control Room requires situational awareness.

Finally, a **science specialist** gave us good insights into activity payloads.

1. Researchers must entrust the specialist groups to execute their experiments faithfully.
2. The ultimate artifact of the planning and execution cycle is the payload.

See Appendix C for further details.



The plan begins at a high level and stabilizes as execution nears. Unlike other domains, the majority of the roles are highly specialized and temporally exclusive.

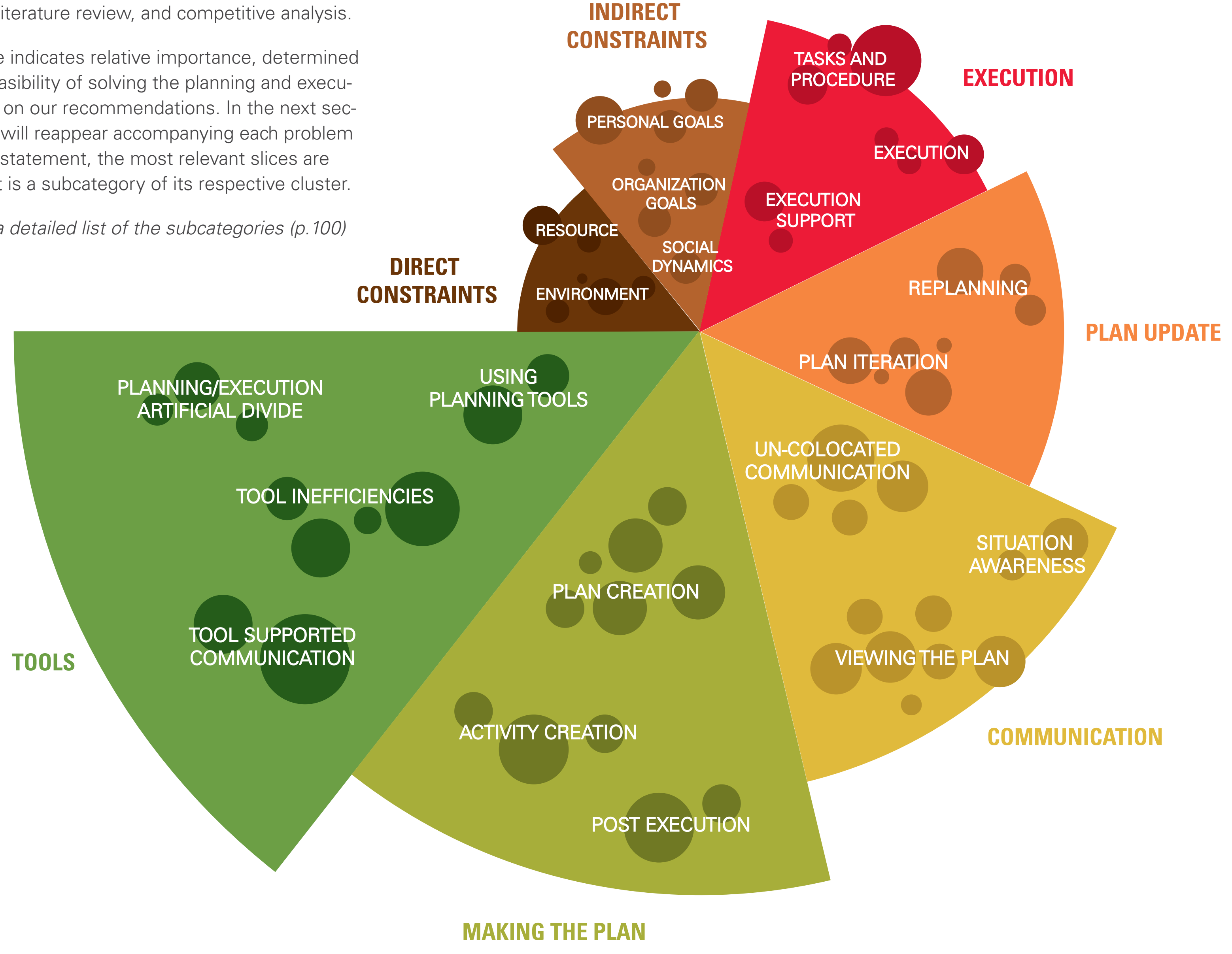
RESEARCH

SUMMARY

This framework is an abstracted, categorized view of all findings from user research, literature review, and competitive analysis.

The size of each slice indicates relative importance, determined by the impact and feasibility of solving the planning and execution problems based on our recommendations. In the next section, this framework will reappear accompanying each problem statement. For each statement, the most relevant slices are highlighted. Each dot is a subcategory of its respective cluster.

See Appendix C for a detailed list of the subcategories (p. 100)



PROBLEMS & OPPORTUNITIES

From our consolidated research summary, we extracted five central planning challenges that touch all domains of investigation. In each section, we present a description of the problem, evidence from our research, and high-level recommendations aimed at improving NASA's current workflow. Supportive data cited in each finding can be found in the appendices, which contain literature reviews, competitive analyses, detailed research findings, and work models.

1. **Inflexible plans** fail to capture the variable nature of execution.
2. The difficulties of **communicating experiential and *in situ* knowledge** result in uninformed plan making.
3. **Shift handoffs** within roles often involve poor information transfer, resulting in poor situational awareness and increased operating expense.
4. Dependencies between **highly siloed roles ungracefully accommodate human error**, which has cascading effects.
5. Any **single representation of the plan** fails to accommodate the varying needs and responsibilities across roles utilizing the plan.

1 **Inflexible plans** fail to capture the variable nature of execution.

[1] Crew Flow Model, p. 115

[2] Crew Flow Model, p. 115

[3] Specialist Flow Model, p.118

[4] WLP/STP, RPE Flow Model, p. 107, 109

[5] RPE Flow Model, p. 109

[6] SPIFe Competitive Analysis, p. 67

ISS: International Space Station

WLP: Week Long Planner

OSTPV: Online Short-Term Plan Viewer

RPE: Real-time Planning Engineer

DESCRIPTION

When planning is utilized to structure work, assign responsibility, and manage resources in an organization, plans are often deliberately inflexible. More often than not, however, discrepancies arise between the created plan and actual execution. Generalizing from our user observations, this divergence occurs in part due to the rigidity of the plan that tools create, and the failure to capture the "fuzzy" nature of execution. Unavoidable unexpected incidents do occasionally occur; more often, however, the plan simply fails to anticipate how execution actually unfolds.

The interview with a former astronaut offered insight into this planning/execution divide. He notes that execution on the ISS is analogous to driving across town. While this task is unremarkably predictable, the traveler must accommodate a wide array of unpredictable occurrences along the way, from stoplights and traffic, to finding keys and parking. Any map or set of directions will fail to expose these relatively banal occurrences. Timelines for the ISS are similarly unable to accurately reflect the idiosyncrasies of execution.

> *"The plan is just a suggestion."*
>
> *Former Astronaut (3/1/2010)*

Considering this reality, astronauts typically regard the plan as a "suggestion," executing some activities that aren't time constrained out of the originally-planned order [1]. What results is a visible cultural divide between how planners and executors view the plan. The former treat it more like a contract while the latter see it as a well-meaning suggestion.

The reality of planning is that there is never enough information contained even in a well vetted plan to fully anticipate how execution will transpire. In addition to this lack of information, planning tools are not equipped to support the creation of flexible plans. Consequently, inflexible plans often create large discrepancies between the plan and the actual execution, and wide cultural divides form between planners and executors.

EVIDENCE

Procedures utilized at NASA are salient examples of inflexible planning artifacts. Procedures are typically static documents that outline the exact steps that ISS astronauts must follow to carry out an activity. However, some astronauts skim procedures and do not execute the steps to spec, partly because they must continuously refer back to a static screen that displays the procedure away from the location of execution [2].

A more notable constraint, however, is the inability to change or update procedures in real time to reflect plan updates and unanticipated incidents. These inflexible execution tools contribute in part to the need for a support team to monitor astronaut execution and provide expertise when needed [3]. Because experiments aboard the ISS require a high degree of control, Specialist Engineers and Operation Planners sit in the Flight Control Room, solely to handle plan updates and unforeseen incidents (e.g., equipment breakdowns), and make sure procedures are executed faithfully.

Apart from executors, many of the desired tool features expressed by planners suggest a desire for a more flexible plan creation and iteration process [4]. Using OSTPV as an example, planners were frustrated with their inability to reassign activities from one crew member to another, without recreating the activity from scratch. Specifically, the interface does not support a drag-and-drop responsibility reassignment feature because constraint modeling is not handled properly.

The burdensome process of updating the plan in real time provides another example of inflexible plan iteration at NASA. To implement a plan change request, the RPE must maintain and reconcile 3 versions of the plan: the onboard plan viewed by executors, the interim updated plan, and the current flawed version of plan, viewed by the entire organization [5]. In the new SPIFe system, the NASA HCI group is taking steps to incorporate these desired tool features. For example, they are implementing a "merge editor" that functions to reconcile several partial plans using intuitive drag-and-drop functionality [6].

[7] RPE CI 2/24/2010

[8] TITAN Follow-Up Interview 4/6/2010

[9] WLP/STP CI 2/23/2010

[10] OSTPV Activity Dialog Artifact Model, ENPS Artifact Model, p. 123, p. 64

[11] Activity Dialog Artifact Model, p. 123

[12] Microsoft Project, EASY Project .Net Competitive Analysis, p. 76, 85

LTP: Long-Term Planner

TITAN: Telemetry, Information Transfer, and Attitude Navigator

The relatively laborious real-time plan iteration pales in comparison to creation process owned by the LTPs and WLPs. Within these roles, the plan undergoes rigorous reviews for mistakes and violations. To these planners, the plan is the result of many people's hard work and the consensus after countless meetings. In fact, the plan is treated as a contract as execution draws near; every change request, from a small typo to an activity addition, must go through a formal approval process, including a nod from the Ops Planner in the Flight Control Room [7].

> *Planners and stakeholders see the plan as a contract.*

Not only do the planners and stakeholders see the plan as a contract, it is a contract written assuming the ideal execution conditions. As described by a TITAN, "The plan placed on-board is written in a way that pretty much assumes that everything is going to work right, that the crew member is sufficiently trained or well versed in the activity, that all of the equipment is placed in the right location, and that the crew member is alert and feeling well. Let's just say the plan is always "success oriented"." [8].

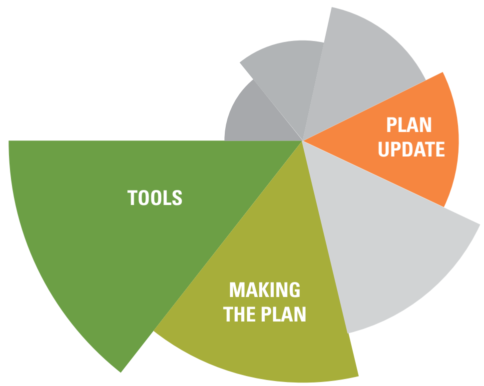
The variable nature of execution suggests that the amount of scrutiny and stress planners assume creating the "ideal" plan is not strictly necessary. Introducing a more flexible plan could help planners feel more valued and empowered. During the WLP/STP CI, one of the planner's biggest wish is to be "less of a secretary." [9]

The plan remains inflexible, however, necessitating workarounds to handle exceptions to the normal workflow. One common tool workaround accommodates variable execution in inflexible plans by allowing free-form text inputs for status updates. In the domains we investigated, task statuses are demarcated with a predefined set labels, such as "scheduled," "completed," "initiated," and "failed." [10] These categories, however, often fall short of wholly reflecting task completion status, which really requires more free-form qualifications. Astronauts use crew notes to more accurately communicate the status of tasks,

> *"[The plan] is written in a way that is... very success oriented."*
>
> *TITAN Follow-Up Interview (4/6/2010)*

while the news broadcasting team primarily tracks the status of stories with free-form notes [11].

Many project management tools, such as Microsoft Project and Easy Project .Net, utilize a numerical task completion scale (such as 0-100%). Both products, nevertheless, tellingly support the ability to add notes to task statuses [12].



RECOMMENDATIONS

[1] Appendix A, p. 58

Support continuous planning with in-context communication.
While NASA currently maintains a strict division between the planning and execution phases, the evidence articulated above suggests that execution typically involves continuous adjustment of the plan throughout execution. Promoting "Continuous Planning," where planning extends throughout execution, could therefore better capture the variable nature of execution [1]. Increased coordination, communication, and articulation of work between executors and planners is required for a proper support of continuous planning. While status updates begin to communicate work progression, a more direct and synchronous dialogue of work, that better captures the context of execution, would support more flexible tools that plan through execution, and reduce the need to "plan ahead."

Allow executors to schedule time insensitive activities.
Continuously planning through execution calls upon executors to schedule some activities based on the suitability of the context. In human space missions, there is already a large amount of informal executor autonomy. Activities that are not time constrained are often not executed according to the original schedule, resulting in execution divergence. To accommodate this workflow, activities that are unconstrained by time or predecessor should not be tied to the schedule (i.e., not specified with a duration). Allowing executors to estimate the duration of tasks may result in more accurate scheduling, less divergence, and better communication. Supporting a more flexible execution schedule, co-managed by executors, will alleviate burdens cause by the invariable nature of the plan.

Give each discipline a slice of the schedule to own.
In place of a designated team of planners integrating all activities for an increment, it could be beneficial to slice up the plan and have planners from each discipline plan their respective activities. These discipline-specific planners would have better knowledge about their respective domains and be charged with planning their slice of the plan and implementing all changes, regardless of time to execution. Of course, to prevent siloing, these per-discipline planners should have regular tag-ups to make sure that the high-level goals of the increment are satisfied. As explained by one of the planners, this strategy is currently not possible because the tools do not support concurrency. JSC should invest in developing support for concurrency or ensure that the next generation tool is capable of it.

> *"We want to send up a plan that they can execute, while giving them autonomy."*
>
> *Real-Time Planning Engineer (2/23/2010)*

Streamline the PPCR process.
At NASA, real-time plan changes are processes as Planning Product Change Requests (PPCRs). PPCRs are a hassle to file, laborious to approve, and a burden to implement. The amount process surrounding PPCRs may unintentionally cause planners to make haphazard changes to the plan right before it transitions to OSTPV.

Instead of implementing PPCRs one by one, the RPE should be able to create a "working draft" copy of the plan and implement batches of PPCRs at their discretion. At regular intervals the Ops Planner and other decision makers should approve the working copy. This strategy takes advantage of an experienced RPE's knowledge, decreases the amount of the busy-work, and avoids the situation where a later change overrides the work done for a previous change. When approving, the Ops Planner would review the new version of the plan, rather than disjointed plan changes. This provides context to the Ops Planner and allows him to focus on the more influential changes, instead of typos.

JSC: Johnson Space Center

PPCR: Planning Product Change Requests

A Short-Term Planner (STP) working on next week's activities on three monitors running on two PCs (a Windows machine and a Linux machine.)

❷ The difficulties of **communicating experiential and *in situ* knowledge** result in uninformed plan making.

[1] News Broadcasting Cultural Model, p. 138

[2] Surgical Ward Cultural Model, p. 132

[3] Crew Cultural Model, p. 116

[4] News Broadcast CI 2/10/2010

[5] Surgical Ward CI 2/19/2010

[6] WLP/STP CI 2/23/2010

DESCRIPTION

In our observations, we witnessed a remarkable reliance on intangible or tacit knowledge in the plan creation process. This knowledge came in three forms.

Process knowledge
Though planners in each domain examine plans carefully to manually check for errors, none could articulate exactly how they knew what to look for. Seemingly, the vast majority of planning knowledge comes from experience. The same phenomenon was observed during the planner's daily workflow. Without any formalized task list or daily structure, they move seamlessly from one activity to the next without hesitation, relying on years of experience to determine their next action.

Planning knowledge
Planners also have situational knowledge of direct (hard) and indirect (soft) constraints. Direct constraints, such as task and resource distribution, safety regulations, and the sequencing of activities in a timeline are concrete, strict, and easy to communicate. Indirect constraints are much harder to account for. They include personal motivations and goals, organizational standards, social considerations, skill disparities and other cultural issues. This type of information is often too sensitive to externalize or include in an interface, but its incorporation is critical. It increases worker satisfaction and therefore improves the efficiency of a work practice.

Real-time response knowledge
When unforeseen events occur, it requires just the right blend of experience, teamwork, and skill to tackle the problem correctly. Unfortunately this formula is difficult to articulate or document, and is consequently impossible to learn except through experience.

The difficulties in communicating these three forms of experiential and *in situ* knowledge result in uninformed plan making.

ISS: International Space Station

WLP: Week-Long Planner

STP: Short-Term Planner

RPE: Real-Time Planning Engineer

EVIDENCE

Though some of the soft constraints are considered peripheral or insignificant, others are critical components in the planning process. Though differences in executor skill level are often awkward to externalize, they must factor in to the delegation of tasks.

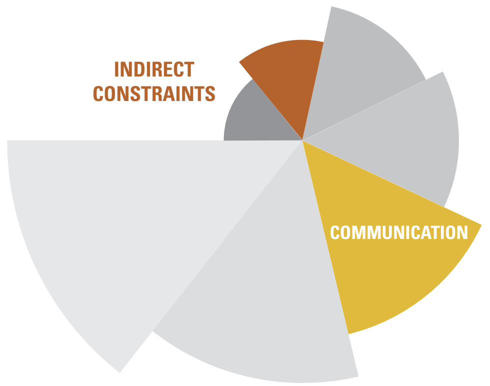
At the news broadcasting outfit, one particular photographer was notoriously unskilled at shooting live footage [1]. As a result, she was consistently scheduled to work earlier shifts that did not overlap any broadcast times. The Charge Nurse also uses his years of experiential knowledge of available of skill sets, strengths and weakness among the executors (nurses, surgeons, and anesthesiologists) to appropriately plan cases [2]. On the ISS, some crew members adhere to procedures more strictly than others, which occasionally disrupts the predetermined timing of activities [3]. Planning systems fail to incorporate these indirect constraints that experienced planners have internalized. As a result, rationale is lost and they can be easily overlooked when revisions are made.

In addition, the internalization and lack of documentation of experiential knowledge creates a huge learning curve for new planners. At the News Broadcast, it was impossible for the part-time intern to contribute because she lacked the requisite experiential knowledge to sustain a beneficial workflow. At the hospital, we saw that Charge Nurses and surgeons were often paired with mentors, allowing new planners and executors to learn through observation [5]. At NASA, the WLPs, STPs, and RPEs often had previous experience on the Shuttle program where some of the experiential knowledge carried over to reduce the learning curve [6]. This model is effective but perhaps unsustainable, as a need for new planners will eventually arise.

> *"I'm the most junior person here and I've been here for eight years."*
> Assignment Editor (2/10/2010)

The Multipurpose Support Room (MPSR) is where the Real-time Planner (RPE), Operations Data Format (ODF) staff, and Orbital Communications Adaptor (OCA) officer sit. The collocation of these roles ensures better support for the Flight Control Room.

> *"I used to be a planner for the Shuttle program, but they needed me in station instead. There's a surprising amount of overlap."*
> Short-Term Planner (2/22/2010)



RECOMMENDATIONS

[7] TITAN Follow-Up Interview 4/6/2010

[8] Soloway, Guzdial, and Kenneth E. Hay, Interactions Magazine 1994

Internalization of soft constraints gained from experiential knowledge supports a very efficient workflow for experienced planners. However, it creates difficulties for new planners. The challenge, therefore, becomes finding the right balance between the externalization of this information and the effort required outside the normal workflow.

> *"[The CAPCOM]'s really good at the happy words, making the crew feel comfortable."*
>
> *RPE Support (2/23/2010)*

Spread knowledge through shared work context.
The only way to gain tacit knowledge of another role is through experience of their work practice. Rotating personnel between similar roles (like WLP, STP, and RPE) may help create a better understanding of different work. Similarly, working in close proximity to equivalent practitioners may yield insights into the different mental models of the problem space.

Mentorship, as seen in all of the domains, is a successful practice and increased effort in this direction will to help build and maintain consistency in planning workflow. This can be encouraged through online forums and mailing lists for tool support and general advice. Tips and frequently asked questions would also give planners the opportunity to share information.

Capture and expose knowledge where possible.
NASA's console logs contain valuable execution information that is only occasionally audited by Flight Controllers at the Mission Control Center. Through this effort they can create 'templateized' activities that help Increment Leads reduce repetitive busy work for the planning team [7]. It could also be beneficial to allow executors to annotate console logs with additional information. Possible annotations could include thoughts on the quality of the execution, or brief suggestions for the next scheduled attempt.

Though some are too sensitive, other soft constraints can be externalized in a culturally acceptable way. For example, the Assignment Editors at the news broadcast were unwilling to externalize variances in skill level among the staff. Reading speed of the different anchors, however, was explicitly built into ENPS as a time constraint.

Obviously, not all executor-specific information is too sensitive to capture. At NASA, however, it would be much very awkward to publicize information about how closely each crew member follows procedures. The Charge Nurse circumvented this social concern by keeping the soft constraint information in a private binder. The binder contained constraint information about social preferences but was only seen or used by the Charge Nurse. An interface to support these indirect constraints should consider the balance between appropriateness and the benefit of its inclusion.

CAPCOM: Capsule Communicator

ENPS: Essential News Production System

Offer contextual help to novices.
Scaffolding is a technique that teachers use to provide support to learners of a new task. As a student gains expertise, a good teacher provides less and less coaching. Thus, the scaffolding fades as the learner becomes more experienced and is ready to be in full control [8]. Planners at NASA could use this technique to reduce the learning curve of new technologies and save training costs. There is an opportunity to incorporate unique indirect constraints for novices by building tips about how to handle frequent problems and suggestions for next steps in editing the plan. These tips could come directly from the expert's hands. Experiential knowledge comes into play by learning from the past mistakes of others and benefitting from previous plans, which is something that no system did especially well.

Jenn and Noah observing Short-Term Planners (STP) having an impromptu discussion about the schedule.

❸ **Shift handoffs** within roles often involve poor information transfer, resulting in poor situational awareness and increased operating expense.

[1] Surgical Ward Cultural Model, p. 132

[2] News Broadcasting Cultural Model, p. 138

[3] TITAN Interview (4/24/2010)

[4] Operations Planner Interview (4/26/2010)

DESCRIPTION

In a large organization where smooth operation depends on strict adherence to a well-planned schedule, the transfer of information between different individuals within the same role is crucial. Because knowledge of the events of a previous shift affects decision making in the next, 'shift handoffs' are a common mechanism to facilitate the transfer of information between individuals. The purpose these handoffs is to ensure that the new shift has the knowledge necessary to complete their tasks.

Problems often occur during information transfer because of inefficient communication. There are two main issues prevalent across the research domains that were found to greatly affect workflow:

1. Preparing for and executing shift handoffs requires heavy time and resource consumption.

2. The unstructured delivery of handoffs undermine information transfer.

EVIDENCE

Shift handoffs are problematic in all three domains. In the Surgical Ward, the Charge Nurse found himself so busy that he had to find a quiet place in a corner of a small secluded room to create shift handoff artifacts. He told us, "This is my secret hiding place. I get interrupted too frequently if I'm out there. Work is important but it's also critical that my relief knows what to do when she comes in." The Charge Nurse also expressed that he had to expend extra effort to make things easier for his relief because he felt the night shift was "incompetent" [1].

In a similar situation at the News Broadcasting, the Assignment Editor had to spend extra time to decipher the notes in the handoff artifact left by the previous shift. She was consistently frustrated by poor notes left by the previous shift, requiring significant time and effort on her part to understand the status of resources [2].

At NASA, shifts are deliberately scheduled to allow time to prepare and execute a proper handoff. Different disciplines at NASA have differing methods and spend different amounts of time on this process. In the Flight Control Room, there is a one hour overlap between shifts that is dedicated solely to the shift handoff [3]. An interview with an Operations Planner at the Human Research Group revealed that shift handoffs often occurred during brief conversations at the water cooler or in informal emails, resulting in poor information transfer between roles [4]. Generally, poor clarity in information between non-collocated parties can introduce incorrect or incomplete information into the planning life cycle. Evidence from all domains points to incomplete information transfer during handoffs as the cause of poor temporal coordination of personnel and resources across shifts.

> *"I leave the overnight staff very detailed notes because I don't see them and they need to know what's going on."*
>
> *Assignment Editor (2/10/2010)*

TITAN: Telemetry, Information Transfer, and Attitude Navigation

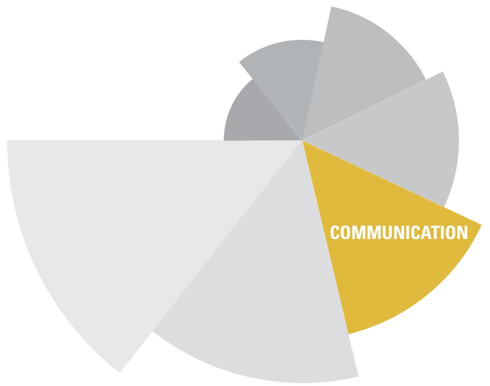
RECOMMENDATIONS

Streamline shift handoffs.
Providing a standardized format for the delivery of shift handoffs reduces ambiguity in the information presented, especially when shifts do not overlap to facilitate in-person discussions. This addresses the problem of unclear information transfer from the previous shift, an issue across all of the domains that we investigated. Another problem with shift handoffs was the overload of information presented to the next shift [5]. These processes must be done quickly, but the individual must parse the information to mentally organize by relevancy and priority. Shift handoffs are most efficient when they are structured around what is relevant to the next shift. Displaying open items and highlights that are pertinent to the current shift will reduce the inefficiencies and resources used in obtaining situational awareness.

Foster understanding between shifts.
Many of the problems found in poor information transfer are in the abundance of irrelevant information that creates poor understanding between shifts. Activities that occur in a prior shift often affect the status of activities in the next. Misunderstandings due to unawareness of activities in other shifts generate frustration and tension between individuals. In addition, time and resources are consumed in the process. To alleviate this problem, the current shift should be able to elicit feedback from the next shift and request information pertaining to their work and activities. This fosters feedback to reduce problems and tensions in the workflow, and promotes fuller situational awareness between shifts.

Automatically integrate shift handoffs during execution.
Handoffs are essentially highlights and notes of the shift's execution. Expenditure of time and effort for these handoffs can be reduced if software automatically creates handoff artifacts. With these artifacts as a starting point, a worker could quickly mark significant activities and decisions that require follow-up.

[5] News Broadcasting Flow Model, p. 137



4 Dependencies between **highly siloed roles ungracefully accommodate human error**, which has cascading effects.

DESCRIPTION

From planning to execution, the plan requires multiple roles and tools, which often result in input error that later impacts execution. Unforeseen incidents are often internally originated as incorrect information is fed into the planning life cycle. Many domains including News Broadcasting and NASA maintain a workflow requiring many roles to update the plan, which in turn offers many opportunities for human error to create execution discrepancies. In addition to multiple roles, a plan scattered across many tools in an organization prevents systematic and unified updates. Of all the domains we observed, NASA suffers the most from the use of too many tools, which results in reconciliation issues between different versions of the plan. The multiple roles and tools required to update inflexible plans promote input errors that go unnoticed until execution is impacted.

[1] RPE Flow Model, p. 109

[2] WLP/STP Cultural Model, p. 108

[3] News Broadcasting Flow Model, p. 137

[4] STP Interview 2/22/2010

IMS: Inventory Management System

ISS: International Space Station

PPCR: Planning Process Change Request

WLP: Week-Long Planner

STP: Short-Term Planner

OSTPV: On-board Short-term Plan Viewer

EVIDENCE

The Inventory Management System (IMS), which is responsible for tracking the locations and state of equipment aboard the ISS, provides one salient example of human error affecting planning on the ISS. At NASA, procedure writers assume that the IMS group has accurately inventoried the locations of ISS equipment. During execution, however, IMS inaccuracies impact the smooth execution of procedures and therefore impact the overall plan [1]. Interestingly, the human error in this case often originates from the executors themselves, who fail to return equipment to the appropriate location, or indicate a new location for an item. A related problem found to affect the workflow in planning is the process of filling out Planning Product Change Requests (PPCRs). According to the STPs, filling out PPCRs is a tedious process that occurs when changes need to be made to the plan one week before execution [2]. The STPs expressed frustration with the laborious process of filling out PPCRs for minor changes like typos.

Similarly, input errors resulting in resource tracking breakdowns occur at the news broadcasting outfit. The Assignment Editors are largely responsible for managing trucks, reporters and photographers in the field. To track the status of these parties, they utilize a public whiteboard to mark which resources are deployed. During our Contextual Inquiries at the station, we observed a breakdown when a truck driver returned to the office claiming that the truck he was assigned was not found in the lot [3]. The whiteboard indicated otherwise, and the Assignment Editor had to track down the missing equipment. Ultimately this breakdown originated from erroneous management of the whiteboard and as a result, execution was jeopardized.

At NASA, WLPs and STPs use different formats for the same plan information. "It's just easier to look at," they told us when asked about the difference [4]. They also use an excel version of the same plan to view it exactly as displayed in the On-board Short-Term Plan Viewer (OSTPV). However, the unintegrated nature of the plan often causes disparity in the information and often results in errors due to human input.

> *"The meteorologist sometimes doesn't listen to constraints, and it becomes a big problem because other stories can get cut."*
>
> *Assignment Editor (2/10/2010)*

RECOMMENDATIONS

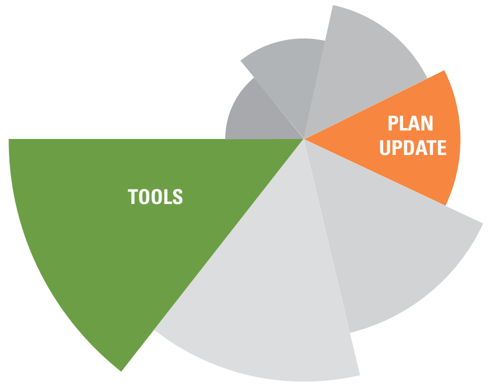
Reduce diffusion of responsibility. Because the plan review process at NASA involves so many individuals and filters, reducing the number of reviews can reduce the amount of erroneous data entering the plan. Since many individuals are involved in the review process, there is a diffusion of responsibility. This creates a dependency on the next person in the review process to catch any inaccuracies. In addition, allowing anyone within the same discipline to look at any part of the plan, rather than just the part they are responsible for, would facilitate fuller understanding by providing 'the big picture.'

Consolidate tools to reduce human error. The planning tools at NASA are highly dependent upon each other, which increases the chance of human error. Duplicate information is often displayed in different formats, which leaves room for errors during transfer of information between the different artifacts [5]. Consolidation of tools that allow for multiple configurations of the same data will reduce the occurrence of inaccurate information transfer.

Establish understanding and awareness between different roles. Many of the problems occur because of misunderstandings and miscommunication between different individuals involved. The rotation of roles allows for a fuller understanding of the consequences and impact of their actions, and reduces the 'silo' effect.

> *"It's embarrassing when you get things wrong, [broken links are] usually so simple to fix."*
>
> *RPE Support (2/23/2010)*

[5] OSTPV Artifact Model, p. 122



5 Any **single representation of the plan** fails to accommodate the varying needs and responsibilities across roles utilizing the plan.

[1] ENPS Artifact Model, p. 144

[2] RPE Physical Model, p. 111

[3] Daily Assignment Artifact Model, p.135

[4] OR Schedule Artifact Model, p. 136

CPS: Consolidated Planning System

ISS: International Space Station

OSTPV: On-line Short-Term Plan Viewer

ENPS: Essential News Production System

RPE: Real Time Planning Engineer

DESCRIPTION

Primarily intended as a communication device, the plan is an abstract representation of an intended future. However, the plan often does not match how plans are naturally conceptualized, and so, creates problems for users. As the plan is created, refined, reviewed, updated, and executed, it is viewed, interpreted, and updated by many different roles. Each of these interactions intends a different set of goals, requires a different set of information, and benefits from a different representation structure.

Furthermore, because tools must accommodate such a disjointed assortment of scenarios and goals, they fall short of serving any of them well. An inflexible level of information and visualization adaptability, leads to information irrelevancy during the plan creation, iteration, and execution processes, a non-obvious mapping of language and coding, and inappropriate plan structure for specific roles.

EVIDENCE

Although there are many roles at NASA with the word "plan" in their title, each interact with the plan at very different points in the process and are tasked with a different set of responsibilities. However, both of the core planning artifacts, CPS and OSTPV, structure the plan as a timeline-based, activity scheduling platform. Other domains we investigated extend more flexible plan displays.

Our research of News Broadcasting revealed that the integrated planning system, ENPS, displays different views of the plan for different roles. The Assignment Editor, responsible for gathering leads, managing resources, and escalating worthy stories to the producer, uses an interface that is devoid of broadcast scheduling concerns, and focuses on the allotment of resources and the status or completeness of each line item. The Producer, however, uses a timeline-based interface, appropriate to his responsibility as the scheduler, with visual indicators of the status of tasks before the plan can be executed. Similarly, Anchors are presented only with the script for the broadcast, and are not concerned with extraneous information, irrelevant to their task.

Creating interfaces specific to the tasks and responsibilities of each role, users can easily forage through the information provided to find what is important to their task, and more easily and efficiently accomplish their goals [1].

In many of our user investigations we observed a non-obvious mapping between real-world objects, elements, and people and their associated representations in tools. For example, ISS crew members are represented with ambiguous naming conventions in planning tools, requiring some Real-time Planning Engineers (RPEs) at NASA to affix a note on their desktop monitor translating the tool's naming convention to the associated crew member's name [2]. Furthermore, RPEs consult an informal binder of reference information to support workflow. The binder consists of color-coding translations, naming conventions, crew preferences, formatting guidelines, and tried-and-true breakdown workarounds. These workarounds suggest that the plan at NASA does not obviously map to reality such that plan iteration process is transparent.

In addition to creating the plan in more natural manner, different roles represent the plan in ways that more naturally accommodate specific workflows. The plan can be structured and displayed by time, resource, personnel assignment, or other dimensions.

At the Surgical Ward, the plan was displayed along varying dimensions across multiple artifacts, in part because different roles prefer distinct orientations of the plan. For example, surgeons spend most of their day in one operating room, and are most interested in seeing the daily plan sorted by patient information, rather than by resource [3]. Alternatively, nurses often occupy multiple operating rooms during a shift, acting as execution support for multiple surgeons, and typically view the plan organized by time and responsibility [4]. These observations suggest that different roles conceptualize plan differently, to better inform them of their goals relevant to their workflow.

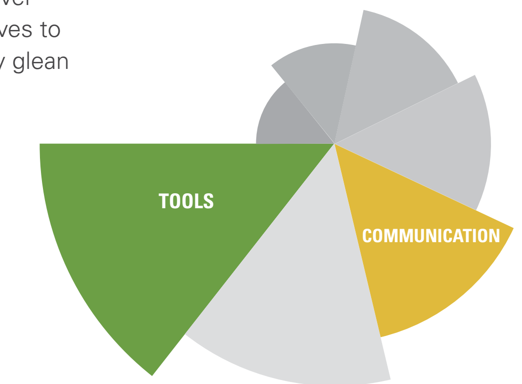
> *We observed a non-obvious mapping between real-world objects, elements and people, and their associated representations and tools.*

[5] OSTPV Artifact Model, p. 122

RECOMMENDATIONS

Tailor the plan structure to role.
Though the ISS plan invariably takes the form of a timeline, plans should be structured to reflect the needs and goals of the person viewing the plan. At the Surgical Ward we saw three different structures of the plan maintained (by time, by resource, and by personnel assignment). At the News Broadcast, we saw the plan organized by broadcast order and by open issue. Tailoring the plan display to different roles may increase usability and efficiency of the plan by allowing different roles see the plan organized in a way that helps them quickly understand the information relevant to their task. For an executor, a timeline-based rundown of activities may be the most appropriate mapping to workflow, while for planners like WLPs, STPs, and RPEs, a more tailored plan would be structured around the tasks they have to complete.

Allow individualized interface customization.
Personalization and customization of planning interfaces could enhance the glance-ability of information relevant to role-specific tasks. One salient example of customization utilized at NASA is the ability of ISS crew members to selectively hide activities that aren't assigned to them [5]. There are plenty more opportunities, however, to visually customize the plan. Examples might include the ability to convey extra meaning by increasing the size of elements of importance, or customize the way names or acronyms appear. In addition, support for Macros could allow roles to more efficiently streamline individual workflows. It is important, however, to preserve a common view of the plan, since it must present a common language in order to serve as a communication artifact. View personalization should serve as a lens over the underlying plan data that serves to increase a user's ability to quickly glean pertinent information.



COST-BENEFIT COMPARISON

Using our findings, we performed a cost-benefit analysis of each problem. The cost of fixing a problem is based on the monetary cost incurred to implement the recommendations and the workflow disruptions those implementations may cause. The benefit is defined as the improvement in task efficiency as well as worker satisfaction.

For example, addressing **Inflexible Plans** is the most costly because the recommendations involve both tools and process changes. A tools overhaul will improve efficiency by reducing busy work and the process change will help empower planners and executors alike.

On the other hand, **Experiential and *In Situ* Knowledge** is less costly but does not derive as much benefit as the former. It is also asymmetrical in worker satisfaction because any additional process to encourage knowledge sharing will benefit new employees more than the veterans. Because planners are generally very busy, taking time to externalize knowledge may be burdensome.

The recommendations in **Shift Handoffs** and **Siloed Roles** generally suggest relatively small process changes like information exchange optimization and role rotation. However, these small process changes can greatly improve team work and communication amongst roles.

Assuming that the current customization feature of OSTPV is extensible, **Single Representation of the Plan** is the least costly. Given the variety of roles that interact with OSTPV, it is far more worthwhile to concentrate development efforts on a scalable customization system rather than a "one size fits all" solution.

NEXT STEPS

Our design process will focus on creating a prototype for **NASA's Desert Research and Technology Studies (RATS) project,** which investigates surface operation concepts, including manned rovers, EVA timelines, and ground support. Specifically, we will assist Desert RATS in prototyping a mobile execution tool for astronauts performing extra-vehicular activities on a planetary surface.

The wealth of knowledge and experience gained through our research provides our team with the insight necessary **to create a compelling and useful execution tool**. In particular, the five planning problems described afford many exciting design opportunities to produce an innovative solution addressing the unique needs of human space missions.

APPLICABLE DESIGN RECOMMENDATIONS

Many of the stated recommendations apply to the design of a mobile execution tool for Desert RATS:

Tailor plan structure to role.
Plans should be structured to reflect the unique needs and goals of roles executing off a mobile device during extra vehicular activities.

Allow individualized interface customization.
Customizing an interface to individual workflows would enhance the execution efficiency.

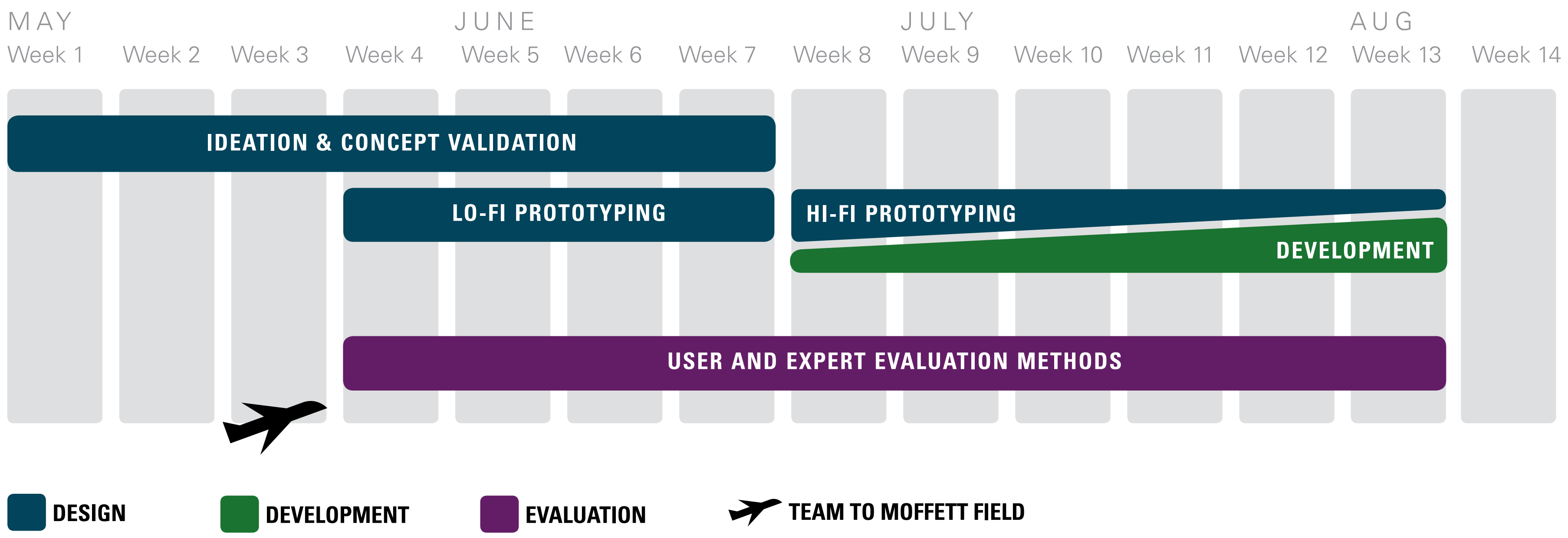
Allow executors to schedule time insensitive activities.
Continuous planning requires executors to schedule some time insensitive activities.

Offer contextual help to novices.
Accommodate varying skill levels by selectively displaying support (e.g., tips) for frequent or reoccurring problems.

Establish understanding and awareness between different roles.
Expose role-specific workflows to both planners and executors to reduce misunderstandings and miscommunication during execution.

DESIGN PROCESS

The summer semester is structured around an iterative design process, culminating in a high-fidelity prototype representing our final design solution for the Desert RATS project. Ideation sessions will take place during the months of May and June, resulting in many potential approaches to an execution tool. Next, we will perform concept validation through persona- and scenario-driven low-fidelity prototyping. User evaluation methods, such as Think Aloud studies will help us refine our prototypes towards a single design. The prototypes will undergo an iterative process with usability testing in July, resulting in a well-vetted final prototype, ready for NASA's operational readiness tests in August.



APPENDICES

APPENDIX A

LITERATURE REVIEW

A literature review allowed us to explore planning in analogous domains and gain sufficient background knowledge in preparation for our CIs. We reviewed existing ethnographic accounts in the Airline, Surgical Ward, and Space domains in addition to relevant research in Cognitive Science.

Our research revealed distinct planning challenges and unique approaches to structuring work and managing resources. In addition, we discovered common planning problems, and methods for addressing these problems, across all domains that contributed to our research findings.

AIRLINES

INTRODUCTION

There is a significant overlap between planning for airlines and planning for human space missions. Among these similarities, it is worth exploring a few key concepts to help draw design solutions for NASA:

SUMMARY

- **Incremental Planning (Use of Pre-Existing Schedules)**
  a. Uses historical booking to forecast data
  b. Provides consistency and routine
- **Maximization of Resources in a Given Day**
  a. Supply / Demand Market
  b. Mostly Profit Driven
- **Different Types of Resource Constraints**
  a. Thresholds: Fuel, Maintenance, # of aircraft
  b. Personnel: Crew Restrictions, # of people
- **Agent-based Automation***
  a. User-supplied heuristics
  b. Constraint bidding
  c. Manual user override
- **Safety Considerations**
  a. Upmost concern
  b. Main competitor to profit when making decisions
- **Decentralized Software**
  a. Different tools for different portions of the planning process

*Not currently implemented, but heavily suggested in research

APPENDIX A: LITERATURE REVIEW

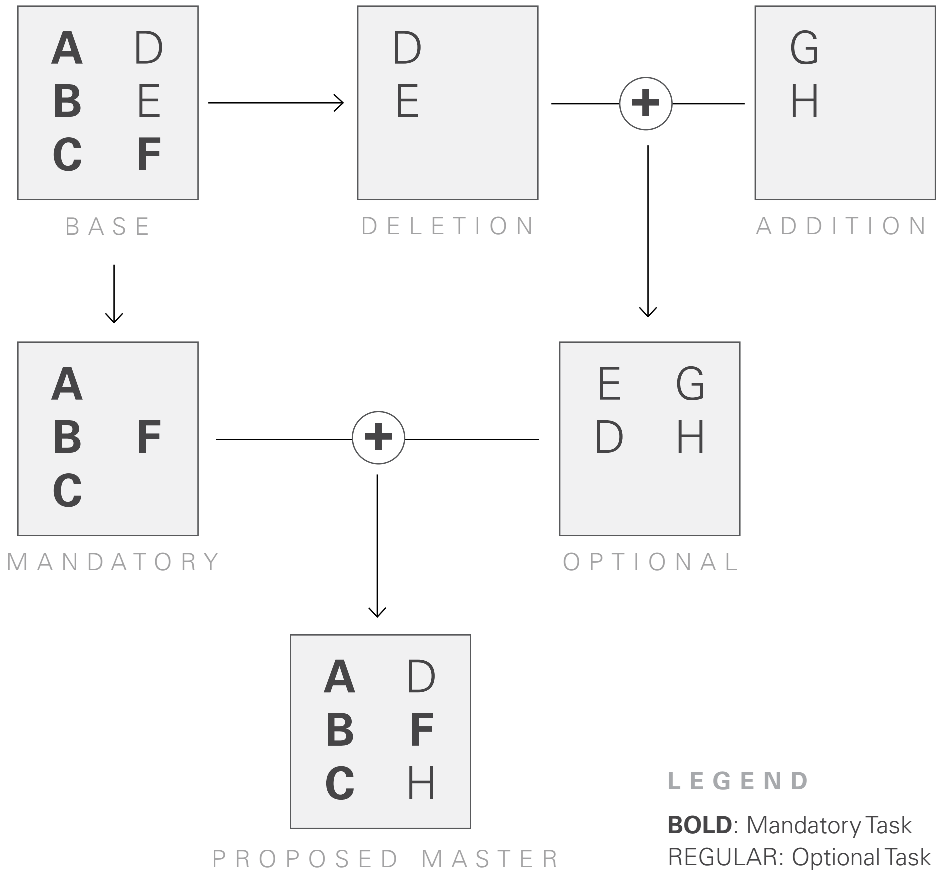
AIRLINES: STARTING SIMPLE

Building the next season's schedule from previous ones allows airlines to:

1. Use historical booking to forecast data
2. Save time and planning efforts
3. Provide consistency for both customers and crew

Working with a base schedule allows planners to propose changes to the list using a relatively simple model (shown to the right), resulting in a proposed master list [1].

To reduce problem complexity, there are three popular techniques. Variable Elimination removes any non-crucial variables. Exploitation of Dominance replaces multiple constraints with the dominating constraint. Finally, Variable Disaggregation breaks up complex constraints into smaller, solvable constraints [2].



LEGEND
BOLD: Mandatory Task
REGULAR: Optional Task

[1] [2] Barnhart, et al., *Airline Schedule Planning, Manufaturing & Service Operations Management*, 2002

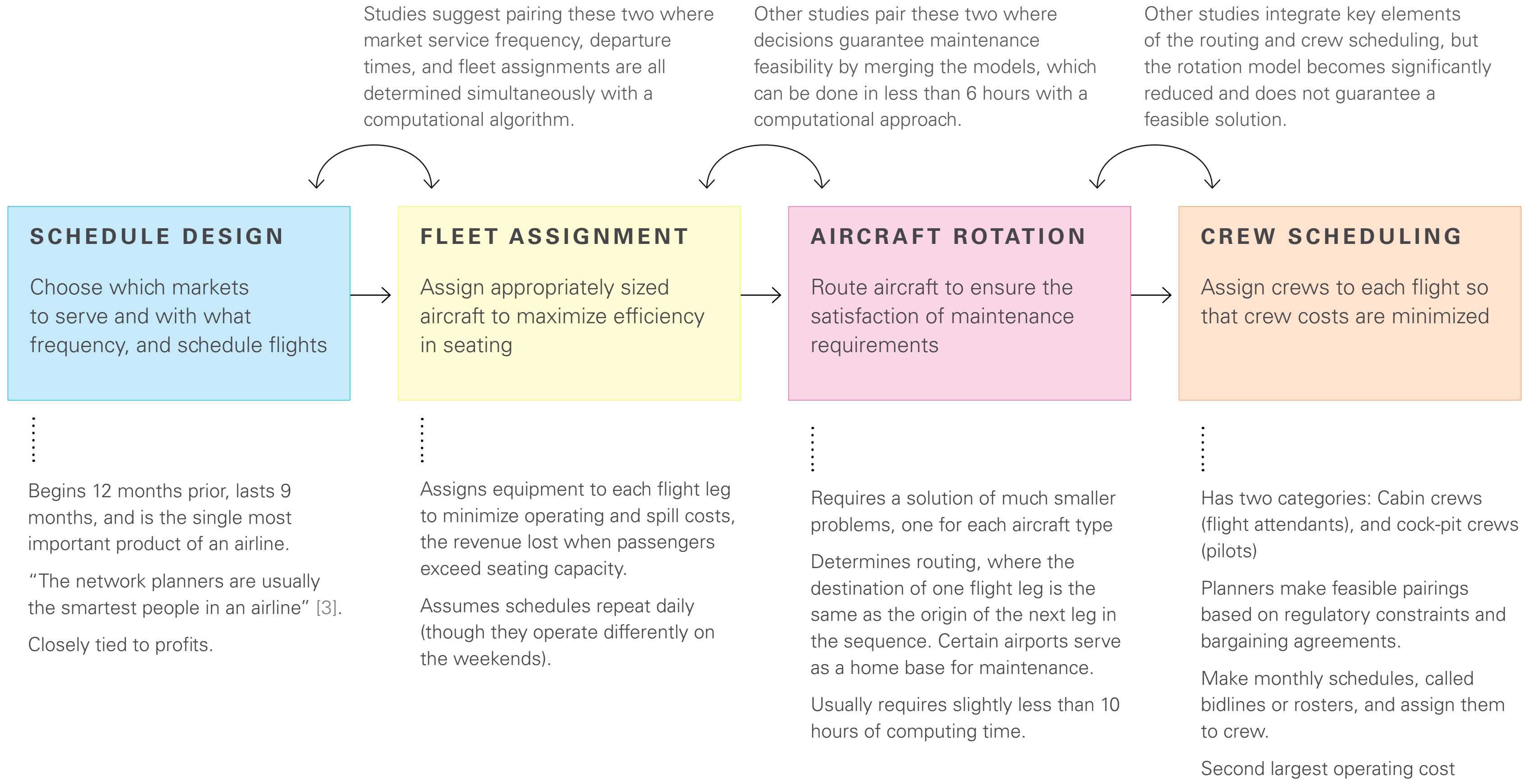
AIRLINES: SEQUENTIAL PROBLEM SOLVING

[1] [2] Sandhu et al., *Integrated Airline Planning.* University of Illinois, 2005

[3] Cook, *Creating Competitive Advantage Using Model-Driven Support Systems.* Cambridge, 2000

Currently, airlines have extremely complex scheduling problems. Collectively, these problems are characterized by numerous and well-defined constraints totalling in billions of decision variables, which means that the problem cannot be solved using one model. As a result, airlines have employed a decomposition approach, breaking up the large problem into a series of smaller ones to be solved sequentially [1].

However, sequential problem solving results in choosing increasingly less optimal solutions as one moves down the tree, because it is difficult to predict the later steps. To tackle this issue, many airlines have adopted partially integrated planning approaches, where multiple parts of the problem are solved in parallel [2].

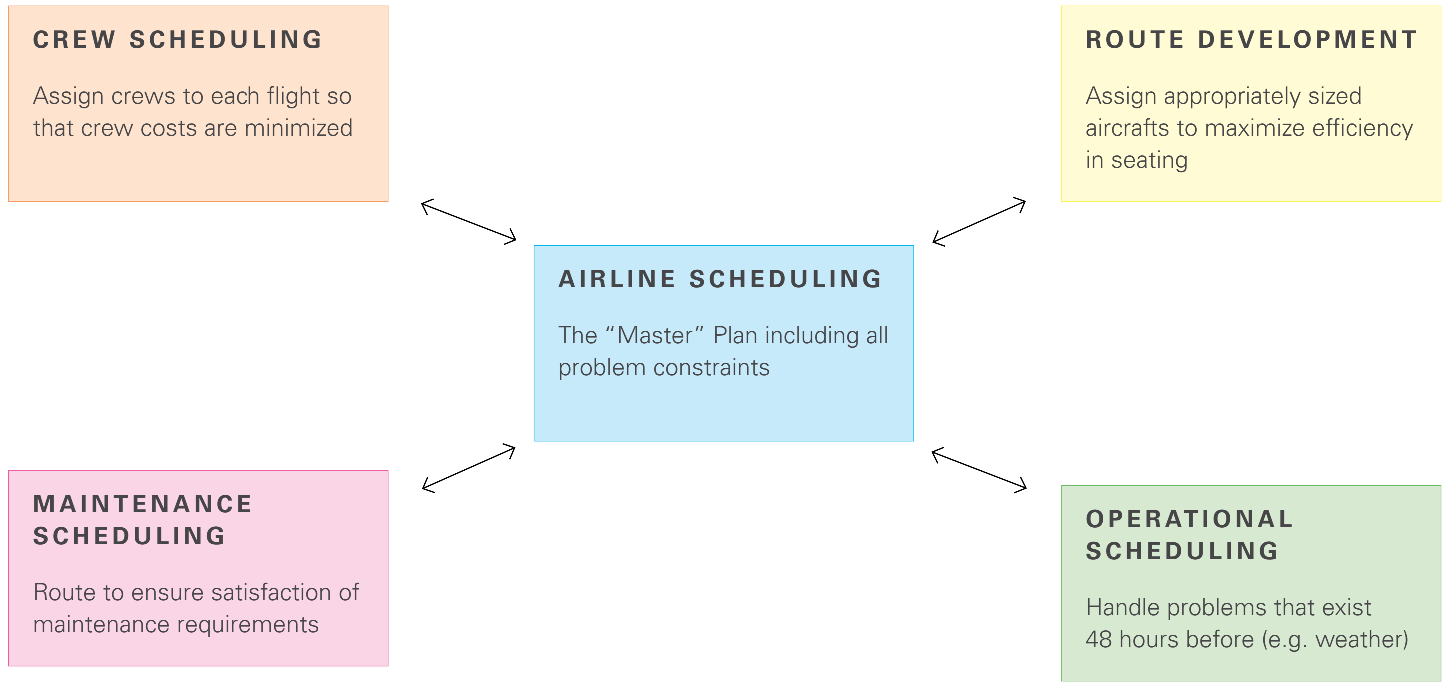


AIRLINES: AGENT-BASED APPROACH

[1] Langerman et al., *Agent-Based Airline Scheduling,* Rand Afrikaans University, 1997

The Airline scheduling problem can be reframed around the "free market" concept, where different 'agents' bid their constraints against each other to generate the best schedule possible [1]. Here, a master planner can override any plan, and the system will learn based on the planner's decisions to speed up the process.

The user can also apply heuristics and user-weighted problem constraints to help the system prioritize different possible solutions.



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Sandhu, R. and Klabjan, D. Integrated Airline Planning. University of Illinois, 2005.

SURGICAL WARD

INTRODUCTION

Healthcare can be considered a "high-hazard" industry, similar to aviation, military operations, and nuclear power. These domains typically exhibit risky and complex workflows that must anticipate future events and accommodate evolving situations under resource constraints. Similar to counterparts, healthcare planners often possess deep experiential and domain knowledge that allow a continuous coordination of tasks and resources under time pressure [1]. Surgical Wards exhibit unique challenges for planning and execution, requiring multiple roles to carry out daily complex plans under the constraints of authority tensions, remote communication, resource management, and urgent re-planning. For these reasons, the Surgical Ward proved to be a close analog to human space missions.

SUMMARY

- Daily cases in the OR are rarely executed to plan, with 67% of planned operations substantially changed on the day of surgery.
- Workarounds are commonly used to handle exceptions to normal workflow, though commonly reduce OR performance.
- The Charge Nurse is tasked with updating the daily plan to accommodate plan changes, requiring many complex cognitive tasks.
- The plan acts as a contract between OR personnel; the Charge Nurse modifies this contract, balancing the unique needs of plan changes with the personal desires of the execution staff.
- The Warboard is a public planning artifact, managed by the Charge Nurse, which increases situational awareness.
- The OR utilizes a variety of planning artifacts that all work in concert to display different views in varying contexts of ultimately the same information.

[1] Nemeth et al., *Cognitive Artifacts' Implications for Health Care Information Technology: Revealing How Practitioners Create and Share Their Understanding of Daily Work*, 2005

Image Credt: Bardram et al. (2010)

OR: Operating Room

SURGICAL WARD: ARTIFICIAL DIVIDE

[1] [2] Bardram et al., *Why the Plan Doesn't Hold - a Study of Situated Planning, Articulation and Coordination Work in a Surgical Ward*, 2010

Similar to other domains, the plan is rarely executed to spec in the Surgical Ward. While unavailable staff members and technology breakdowns occasionally disrupt the daily plan, patients more often compromise the plan by becoming ill or responding to treatments unpredictably.

67% of planned operations are substantially changed the day of the surgery (see Table 1). The majority of these cases involved moving an operation forward or back more than 30 minutes (see Table 2). Additionally, only 56% of all operations are planned ahead, meaning that 46% are acute cases (i.e., emergency surgeries) that are scheduled in an ad hoc manner [1].

Considering these planning challenges, the Surgical Ward should approach the workflow as "continuous planning," properly supporting rescheduling, coordination, and crucial communication to re-plan with a minimum reduction in performance [2].

Table 1. Scheduled, Acute, and Cancelled Operations.

	Total	%
No. of days (D)	133	
Total no. operations (N)	3,221	100%
No. operations executed (E)	2,979	92%
No. elective operations (S)	1,801	56%
No. acute operations ($A = N - S$)	1,420	44%
– day shift (07:00–16:00)	646	20%
– night shift (16:00–07:00)	488	15%
– weekends	286	9%
No. cancelled operations ($C = N - E$)	242	8%
No. operations executed pr. day (E/D)	22.4	
No. cancellations pr. day (C/D)	1.82	

Table 2. Changes to Operations.

	Total	%
Total no. of changed operations:		
– start/stop time +/- 30 min.	2,172	67%
– start/stop time +/- 60 min.	1,990	62%
No. of minor changes	167	5%

Graphic Credt: Bardram et al. (2010)

SURGICAL WARD: THE CHARGE NURSE

Accommodating last minute plan changes to the plan requires complex problem solving.

The authority to change the plan during execution belongs to the Charge Nurse [1]. The Charge Nurse encounters situations with little room for error, little time to react, and often insufficient information about how to act. The cognitive tasks required for this type of complex problem solving are not trivial. When re-planning, the Charge Nurse must rapidly comprehend the nature of the unforeseen incident, including the number of changes to the plan may be required, and the significance of these updates. Additionally, the reasons for plan changes must be understood and articulated, and the consequences of the changes must be anticipated. Lastly, the Charge Nurse must utilize various cultural strategies to assist the team in coping with the change.

The OR schedule is a contract between stakeholders with varying interests.

The operation schedule (i.e., daily plan) acts as a contract between stakeholders involved, including the nurses, surgeons, and anesthesiologists [2]. Modifying this contract may result in staff having to work overtime, patients having to wait, and operations being cancelled. The Charge Nurse, therefore, must balance the requirements, needs, and urgency of the unforeseen incidents with the cultural needs of the office. Many groups in the OR have cross cutting agendas. For example, a surgeon's desire to generate revenue may conflict with an anesthesiologist's need to manage resources most economically [3]. The Charge Nurse has the difficult job of reconciling effective and efficient planning and re-planning, with the personal desires of the execution staff. Ultimately, updating the plan requires a collaborative effort from every component in the OR system.

[1] Kobayashi et al., *Work Coordination, Workflow, and Workarounds in a Medical Context*, 2005

[2] Bardram et al., *Why the Plan Doesn't Hold - a Study of Situated Planning, Articulation and Coordination Work in a Surgical Ward*, 2010

[3] Nemeth et al., *Regularly irregular: how groups reconcile cross-cutting agendas and demand in healthcare*, 2005

Image Credt: Bardram et al. (2010)

OR: Operating Room

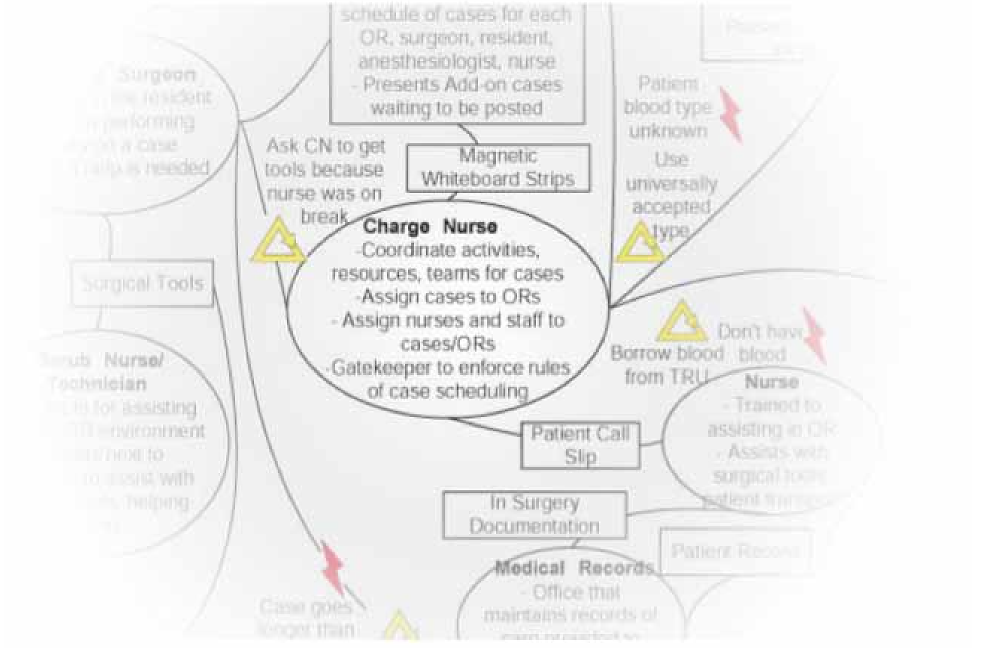
SURGICAL WARD: WORKFLOW WORKAROUND

[1] [2] Kobayashi et al., *Work Coordination, Workflow, and Workarounds in a Medical Context*, 2005

Because of the prevalence of plan updates, workarounds are commonly utilized to handle workflow exceptions [1].

Typical workarounds include keeping a patient sedated during a prolonged case, using universally accepted blood type when the patients blood type is unknown, and asking the Charge Nurse to retrieve tools when other nurses are on break. While workarounds draw on the tacit knowledge of coworkers and other's willingness to help, they can have cascading effects in the entire system.

A single workaround can result in a chain of other workarounds before the operating room has returned to normal operations. For example, there was an incident of personnel substituting the universal donor blood type for a patient while relying on a second workaround of borrowing the blood from a neighboring facility, resulting in a shortage [2]. While workarounds are common techniques for accommodating plan updates, the workflow exceptions often impact the ability to return to normal operating conditions.



Graphic Credits: Kobayashi et al. (2005)

SURGICAL WARD: ARTIFACTS

The Warboard

Among the many physical artifacts employed in the OR to assist planning, the "warboard" is perhaps the most utilized execution tool throughout a shift. The warboard is a large public whiteboard that displays the patients' room and bed numbers, the schedule of cases for each operating room, and the surgeon, nurse, and anesthesiologist assignments. Additionally, this artifact provides a status overview of surgeries, utilizing task categories of "not-started", "commenced", and "completed" communicated with magnetic strips [1]. The Charge Nurse has the critical responsibility of maintaining the warboard as accurately as possible.

The Work Schedule

The work schedule is the main planning artifact of the OR, providing an overview of the available staff for the current shift. The printed paper document displays a list of the operating rooms and the patients' respective bed numbers, with assigned surgeons, nurses and support staff. The staff members primarily use the work schedule to view their responsibilities and assignments for the shift.

A Web of Coordinating Artifacts

In conjunction with the whiteboard and work schedule, the OR utilizes a variety of other artifacts, including personal notes, examination sheets, and post-it notes, which all play multiple roles and display different views of the same information. Some artifacts are more useful in specific context, highlighting more appropriate information. This "Web of Coordinative Artifacts," provide situational awareness, continuous coordination, cooperative planning, and status overview [2]. Generally, the web of artifacts provides an overview of the state of work process, the location and status of staff and resources, and a documentation for cooperative planning.

[1] [2] Bardram et al., *A Web of Coordinative Artifacts: Collaborative Work at a Hospital Ward*, 2010

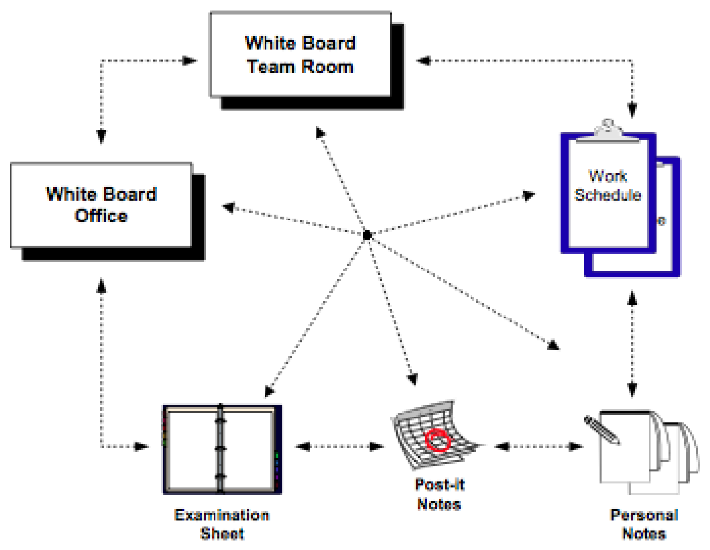


Figure 2: The network of artifacts

Graphic Credits: Bardram et al. (2005)

OR: Operating Room

SURGICAL WARD: REFERENCES

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SPACE

INTRODUCTION

The complexity of human space missions requires the integration of information from sources, the expertise of individuals, and the support of software tools. On top of hard constraints like electricity usage thresholds, there soft constraints like cultural differences between international partners [1]. Better tool support is a must. Process wise, successful case studies like Extreme Collaboration can perhaps offer some insights [2].

While machine planning has benefited greatly from advancements in artificial intelligence in recent years, human planning has not. Compared to machine planning, human planning is wildly unconstrained, highly conditional, and highly ambiguous at times. "The representation of plans for execution by people, and the design of software decision aids supporting a human [...] pose different challenges than representation of plans for execution by machine." [3] This is not to say, however, that human planning cannot learn selectively from concepts that have improved machine planning. Concepts like rapid, iterative repair to the plan (as opposed to batch repairs) have shown promise for machine planning and may have parallels in human planning [4].

SUMMARY

- Both hard and soft constraints must be considered for effective planning.
- Poorly integrated tools degrade efficiency and create cognitive overload by destroying context.
- Empowering planners and alleviating siloed roles can greatly improve efficiency and accuracy.
- Iterative repair works well for machine planning.

[1] Sylver Consulting, *Defining Collaboration in the International Space Station (ISS): Planning Process and Developing Tools to Support It*, 2006

[2] Mark, *Extreme Collaboration*, 2002

[3] Frank, *When Plans Are Executed by Mice and Men*, 2009

[4] Chien et al., *Using Iterative Repair to Improve the Responsiveness of Planning and Scheduling*, 2000

SPACE: PLANNING CONSTRAINTS

Both hard and soft constraints must be considered for effective planning.

[1] Frank, *When Plans Are Executed by Mice and Men*, 2009

[2] Sylver Consulting, *Defining Collaboration in the International Space Station (ISS): Planning Process and Developing Tools to Support It*, 2006

Consolidated Planning System (CPS), the planning software used by the Long-Term Planners, is capable of understanding hard constraints like S-band usage and electricity usage thresholds, but it is not used throughout the planning process. One week prior to execution, the plan is transferred to the Onboard Short-Term Plan Viewer (OSTPV) which provides a more user-friendly view, but strips the plan of all constraint data. As a result, any planners touching the plan after that must backport changes to CPS, but also be highly cognizant of constraints. The Ops Planner sitting in the Flight Control Room oversees the progression of plan execution and must maintain situational awareness of everything that is happening both on the space station and on the ground. When unforeseen events occur, he works with the Real-time Planning Engineer (RPE) in the Multi-Purpose Support Rooms to implement changes to the plan [1].

There are also many soft constraints surrounding planning that have no tool support. The Ground Rules and Constraints document contains rules such as "No exercise activity less than 75 minutes after eating, but may overlap 15 minutes between crew members." Procedures for activities are meant to be multi-use and are therefore written in a very general fashion, with many contingencies. Flight Controllers maintain the Electronic Flight Notes, to communicate deviations from these procedures, such as a change of the location of a piece of equipment on the ISS. If these changes effect a plan that is less than one week from execution, they must be reflected in OSTPV and then backported to CPS. Lastly, planning for the ISS requires collaboration among different NASA centers and international partners. "Collaboration equals negotiation," [2] and negotiation means meetings. Not only must planners heed hard constraints as described above, they must also consider cultural differences. For example, Americans are motivated by positive wording while Germans are motivated by negative wording.

CPS: Consolidated Planning System

OSPTV: Onboard Short-Term Plan Viewer

RPE: Real-time Planning Engineer

SPACE: TOOL INTEGRATION & TEAMWORK

TOOL INTEGRATION

Poorly integrated tools degrade efficiency and create cognitive overload by destroying context.

Tools perform distinct functions and thus only contain certain information [1]. OSTPV shows the crew the planned activities, but other required meta-data, such as procedures, are located in IPV. The crew can easily click from an activity in OSTPV to the referenced procedure in IPV, but the reverse is impossible. It thus becomes a chore for the Procedure Writer to consider of activity dependencies and adjustment accordingly. When there are changes to the plan, like an activity status update or crew note, the changes are manually integrated from the on-board OSTPV to the ground OSTPV, using data downloaded by the Orbital Communications Adaptor (OCA) Officer. Changes are then backported to CPS to keep all copies of the plan in sync. CPS runs on Linux only while many of the other tools run in Microsoft Windows. Switching back and forth between these tools and others destroys context and creates immense cognitive overload. It is easy for planners and executors to lose track of what they are doing.

TEAMWORK

Empowering planners and getting rid of the silos can greatly improve efficiency and accuracy.

Extreme Collaboration can be highly efficient because it makes good use of the human network by collocating team members [2]. These team members are highly qualified individuals in their domain and work together in a war room atmosphere. A team leader keeps everyone on schedule and focused on the goals. Public displays around the war room help everyone maintain situation awareness. Everybody can see everybody else's monitors by walking around the room. Spontaneous conversations happen all the time, and via the cocktail effect, people can join in when they hear relevant keywords. Information is disseminated via a publisher-subscriber mechanism. Raw data, rather than polished results, is available for everyone in a shared spreadsheet. Any interested party can subscribe to the data.

Extreme Collaboration is not for everyone, but it is highly efficient and accurate. It works particularly well when team members are highly dependent on each other, like in mission planning.

Team X at Jet Propulsion Laboratory used Extreme Collaboration methods to plan 13 missions. The team predicted the final cost of seven completed missions to within 5% of the actual cost. What's even more impressive is the high job satisfaction team members experienced - average 9.4 / 10. This case study and others show that for certain tasks, it works well to group highly motivated individuals in the same room, and trust everyone with access and responsibility. Certainly for problems with high interdependency, extreme collaboration wins over a pipeline of individuals with varied skills levels, varied access, and limited communication.

[1] Frank, *When Plans Are Executed by Mice and Men*, 2009

[2] Mark, *Extreme Collaboration*, 2002

OSPTV: Onboard Short-Term Plan

IPV: International Procedure Viewer

CPS: Consolidated Planning System

SPACE: PLANNING STRATEGY

[1] Chien et al., *Using Iterative Repair to Improve the Responsiveness of Planning and Scheduling*, 2000

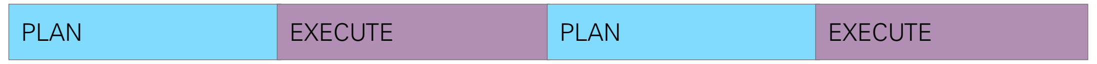
Iterative repair works well for machine planning.

For better efficiency and response to unforeseen circumstances, Continuous Activity Scheduling Planning Execution and Replanning (CASPER) employs "iterative repair" in the planning and execution process [1]. Shrinking budgets and a growing number of autonomous spacecraft and robotic mission create a need for onboard software that provides knowledge and reasoning procedures appropriate during execution. When designing this software, the "batch" method is straight forward but has severe drawbacks:

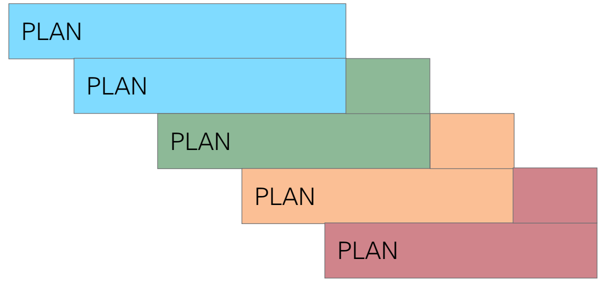
- Planning and execution are nonconcurrent. If a plan fails during execution or finishes early, the machine sits idle until the next planning phase.
- It is difficult to project the "future state" before execution finishes.

The "iterative repair" approach, on the other hand, overlaps planning and execution. To make sure that the two stay in sync, the state of the system is continuously monitored and estimated. The system will invoke re-planning as a result of certain changes, like errors or completion status updates. The new plan will include portions of the old plan, if appropriate, in addition to changes that account for the new state of the world.

Batch
Planning and execution are done in a mutually exclusive fashion.



Iterative Repair
Planning is interleaved with execution. Each new plan is partly new and partly old.



CASPER: Continuous Activity Scheduling Planning Execution and Replanning

SPACE: REFERENCES

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COGNITIVE SCIENCE

INTRODUCTION

The term "planning" has been used to account for so many diverse aspects of human cognition and functions that the definition has become quite vague, accommodating many different qualifications [1]. The activity of planning synthesizes several different cognitive processes and levels of function under one umbrella, and is heavily related to problem solving, strategizing, and metacognition. Generally, most researchers agree that planning incorporates representing the environment, anticipating solutions to problems, and monitoring the execution of strategies in service of solving the problem and following the plan [2]. Following this model, planning is very much a "goal-directed preparation for the future." [3]

There is a rich history of cognitive scientists attempting to operationalize human planning. Some researchers focus on how participants build and execute plans in response to the proposition of a well-defined task, such as a maze, a game of chess, or the Towers of Hanoi [4]. Alternatively, other researchers have investigated the planning life cycle in domains of everyday problem solving that are often ill-structured and lack clear steps to achieve goals, such as errand running [5] and party planning [6].

Ultimately, individual planning is a self-organizing, conscious, and reflective process, where individuals attempt to achieve satisfactory future states by representing problems, choosing goals, formulating goals and subgoals, executing and monitoring the plan, and lastly learning from the plan [7].

SUMMARY

- Planning is an activity that utilizes several cognitive processes, including problem solving, strategizing, and metacognition.
- Typically, individuals plan to achieve satisfactory future states though representing problems and formulating intermediate goals.
- Planning research has focused on both well-defined domains of planning such as games, and domains with no explicit intermediate steps to achieve a goal, such as errand running and party planning.
- While cognitive science literature provides a theoretical frame to understanding planning, the Model Human Processor model is perhaps the most actionable literature that will guide the design and evaluation process of HCI systems.

[1] [2] Friedman et al., Blueprints for thinking: The role of planning in cognitive development, 1987

[3] Scholnick et al., Planning in context: Developmental and situational considerations, 1993

[4] Friedman et al., Blueprints for thinking: The role of planning in cognitive development, 1987

[5] Hayes-Roth, A cognitive model of planning, 1979

[6] Chalmers et al., *Investigating the effects of planning aids on adults' and adolescents' organization of a complex task*, 1993

[7] Friedman et al., Blueprints for thinking: The role of planning in cognitive development, 1987

COGNITIVE SCIENCE: PLANNING BEHAVIOR & IMPACT

OBSERVING PLANNING BEHAVIOR

Three main factors to consider when observing planning behavior are the complexity of the problem, individual and group differences, and the problem solving environment [1].

In addition to these factors, planning behaviors also depend on the nature of the plan. Generally, there are two types of planning for problems: initial and concurrent. Initial planning is goal directed and hierarchical. The plan is created well in advance of the actual act of problem solving, and organized to be implemented in a specific order. Concurrent planning is opportunistic and non-hierarchical. These plans are implemented as needed and can be postponed if additional information is required [2].

DESIGN IMPACT

While planning theory provides an informative background in modeling human planning, complex problem solving required by our design will mostly be evaluated through user testing and evaluation, rather than adherence to theory.

However, the most appropriate and actionable literature we reviewed that could inform design decisions for a planning tool is the Model Human Processor [3]. The Model Human Processor considers the fundamentals of human cognition, including memory, perception, and attention, to derive a set of "Principles of Operation" that guide HCI. Among these principles are the optimization of perception and memory to enhance visual search, the capabilities of working memory, and Fitts' Law. Considering the necessity safe, dependable, and intuitive tools in human space missions, utilizing Model Human Processor as an evaluation technique will improve and validate our final design.

[1] [2] Davies, *Planning and Problem Solving in Well-defined Domains*, 2005

[3] Card et al., *The Model Human Processor: An Engineering Model of Human Performance*, 1986

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APPENDIX B

COMPETITIVE ANALYSIS

To broaden our understanding of current planning and execution practices in industry, we examined several project management software packages, and three industry-specific planning tools. Microsoft Project, Easy Project .NET, and Primavera are critical path project management tools marketed towards IT organizations. In addition we examined three planning tools utilized in the Airline, News Broadcasting, and Space industries.

The consolidated analysis revealed important aspects of project planning support across tools and improved our understanding of current methods and terminologies. In addition, the exploration of industry-specific tools exposed different approaches to tailoring planning and execution to the specific needs and requirements of a domain. Results from the competitive analysis, summarized below, ultimately influenced our research findings.

ENPS: SUMMARY

The Associated Press's Essential News Production System (ENPS) is the world's most popular news production system. It's used by over 50,000 news makers in 57 countries. This tool coordinates the efforts of the assignment editors, producers, reporters, photographers, crew, and anchors as they track story status, stack broadcasts, and allocate personnel. It is used in multiple stages of planning and produces several different artifacts for real time execution.

http:www.enps.com/

Domain:
News Broadcast

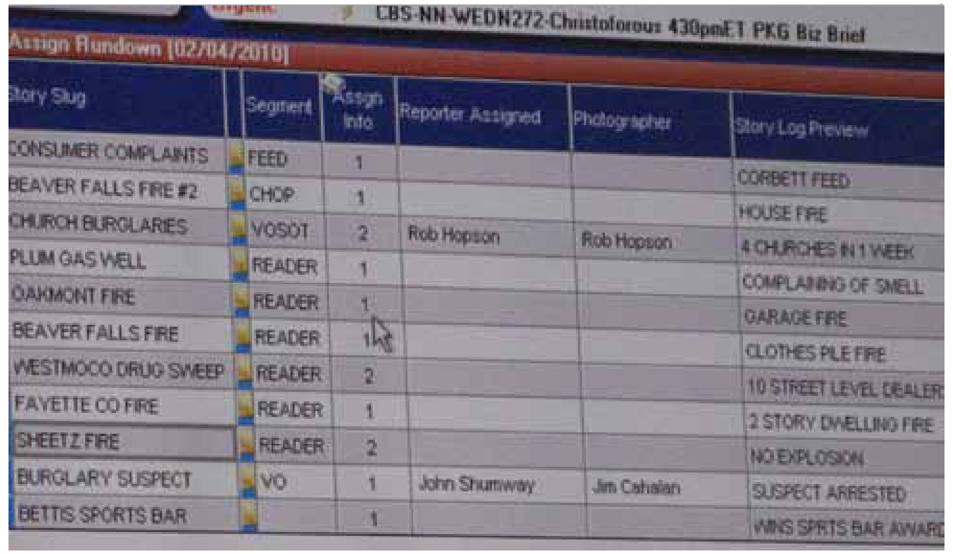
Target Users:
Producers, Editors, Directors, Reporters

Key Features:
Integration, Multi-User Collaboration, Role-Specific Views.

THEME	RELEVANCE	DESCRIPTION
Multi-User Collaboration Allowing multiple people to create edit and execute portions of a plan	●●●●○	Assignment editors can leave notes for themselves and others as a story matures. User-to-user and group-based top-line messaging allows instant communication. Different views allow different roles to collaborate, while focusing on what is important to them.
Issue Tracking Identifying problems in a plan and assigning responsibilities to resolve	●●●●○	Assignment editors can track issues and activity statuses in free form notes as stories develop. The user can write updates, log actions taken, and track necessary tasks associated with the story. It is not a formal system, but these notes work well in communicating story statuses to others.
Execution Management The real-time plan execution interface	●●●●○	For each broadcast, the producer creates a "Rundown" which lists the stories in order for the broadcast. The tool can generate execution steps for the crew, feed the teleprompter with the script for the anchors, and allow the producer to monitor and dynamically replan as the broadcast airs.
Progressive Granularity Viewing and managing the plan at increasing resolutions over time	●○○○○	The system does not track the news plans as they increase in granularity. It does however, aid the producer in paring down the story ideas to a final set that makes it into the broadcast.
Version Control Viewing and duplicating previous stages of a plan; tracing the life-cycle of a plan	●○○○○	No specific version control is provided, but there is an archive of previous day's plans. These are saved along with an "as aired" version of the rundown.
Task Dependencies The ability to create contingent relationships between tasks	●●○○○	Task dependencies don't often come into play in news broadcast scheduling. However, the script often heavily depends on story order. When the script changes due to overages or underages during broadcast, the producers must rewrite it in real-time.
Resource Management The allocation of personnel and equipment	○○○○○	Resource management is definitely a factor of news broadcast planning. However, we did not see anyone using ENPS for this task. Assignment editors relied heavily on extensive experience and other artifacts to track and manage resource constraints.

ENPS FEATURES & SCREENSHOTS

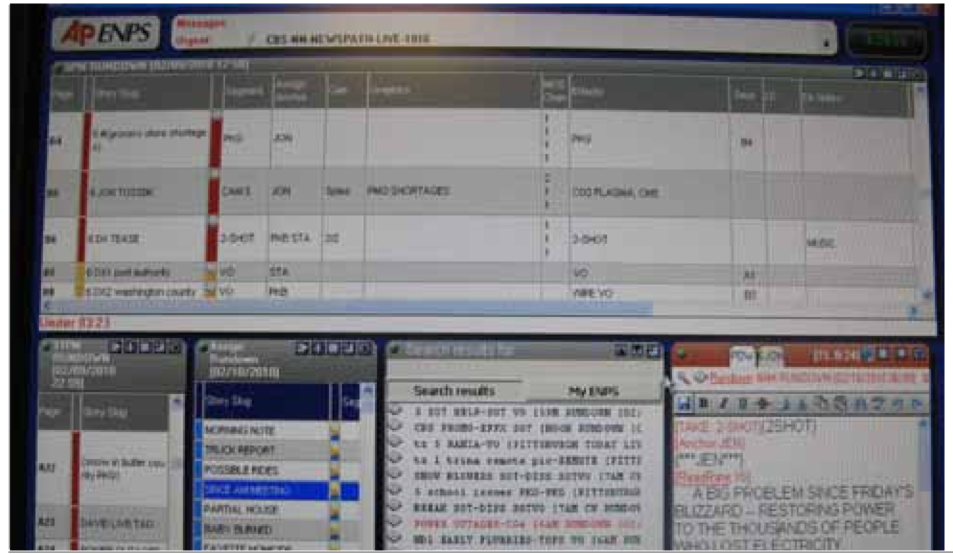
PLANNING VIEW



SUMMARY

The planning view is used to record/communicate personnel assignments, enter updates on story progress, and keep track of story status. Each story is entered as a "slug" which warrants its own row. Each "slug" contains notes from the assignment editor, and shows which resources are devoted to it.

EXECUTION VIEW



SUMMARY

This view is used by the producer and director during the news broadcast. The top window shows the story order, or the "rundown," for the 11 pm broadcast. As the broadcast airs, the row of the current segment is highlighted yellow help keep the producer aware as he is constantly changing and rewriting the broadcast. Each segment has a script, which feeds the teleprompter directly, and can be pulled up in the lower right hand window. There is a text indicator to show the producer how long or short the broadcast is currently running, and with that information the producer is constantly at work rewriting, adding, and cutting segments. When a story is cut, it remains in the rundown highlighted in red, so that it is easy to add back at a moment's notice.

ENPS: NOTES

NOTES	DESCRIPTION
Powerful Search	Instant indexing of every word allows powerful search through active, archived, linked, and web content.
Drag-and-Drop Windows	Drag-and-drop increases productivity by allowing users to maximize use of multi-monitor displays.
Integrated System	The single integrated system increases productivity creating faster turnaround during real-time re-planning. Also, there is no need to replicate changes through multiple systems.
Shortcuts	ENPS contains keyboard shortcuts that allow for the programming of user-defined macros to help individuals become more productive in their roles.
Follow-Me Messaging	Follow-me messaging allows ENPS messages to be sent to mobile devices of contributors that have left the newsroom.

SPIFe: SUMMARY

The Scheduling and Planning Interface for Exploration (SPIFe) was designed by the HCI group at NASA Ames to assist the plan making process around human space missions. The tool solves many of the pain points and breakdowns observed in current the planning workflow and while SPIFe achieves a considerable improvement in human space mission planning, the tool does not currently support plan execution. Europa, an automatic plan advisor, uses intelligent algorithms to provide relevant advice.

Domain:
Human Space Missions

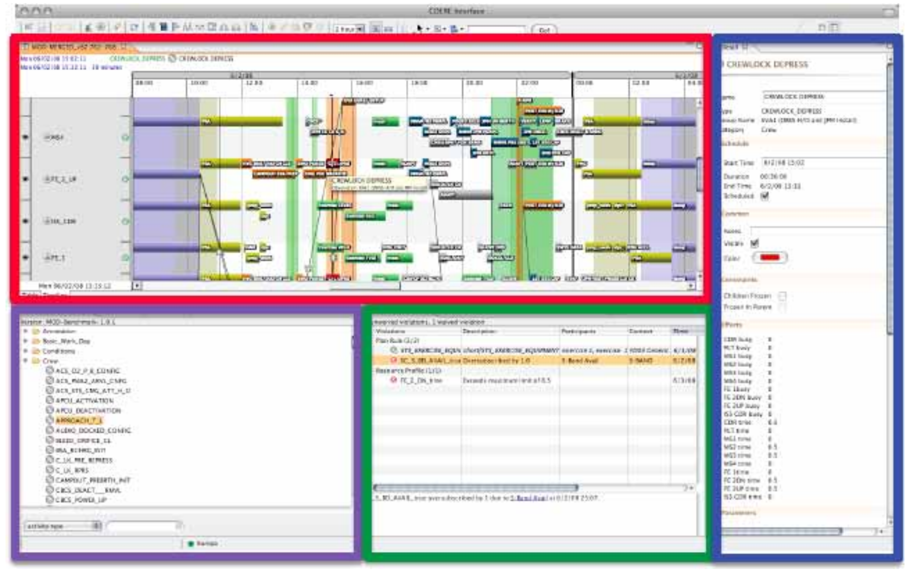
Target Users:
Long-Term Planners

Key Features:
Timeline, Merge Editor, Plan Advisor, Resource Modeling

THEME	RELEVANCE	DESCRIPTION
Multi-User Collaboration Allowing multiple people to create edit and execute portions of a plan	●●●○○	SPIFe supports multi-user collaboration through the merge editor, which may be a bit slower than real-time collaboration.
Issue Tracking Identifying problems in a plan and assigning responsibilities to resolve	●●○○○	It does not appear that SPIFe allows for issue tracking explicitly in the system, though Europa may help do much of this.
Execution Management The real-time plan execution interface	○○○○○	
Progressive Granularity Viewing and managing the plan at increasing resolutions over time	○○○○○	
Version Control Viewing and duplicating previous stages of a plan; tracing the life-cycle of a plan	●●●●○	The merge editor resolves conflicts in multiple versions of the plan, preventing the accidental override of important changes.
Task Dependencies The ability to create contingent relationships between tasks	●●●●●	Constraint mapping is one of SPIFe's strongest features. Europa can operate from a specified list of activities and constraints, or this can be done manually. Also, the "pin task" feature allows the user to exactly specify a time for an activity.
Resource Management The allocation of personnel and equipment	●●●●●	SPIFe includes a resource modeling visualization integrated on the timeline. Resource Profiles provide an overview of the information captured.

SPIFe: FEATURES & SCREENSHOTS

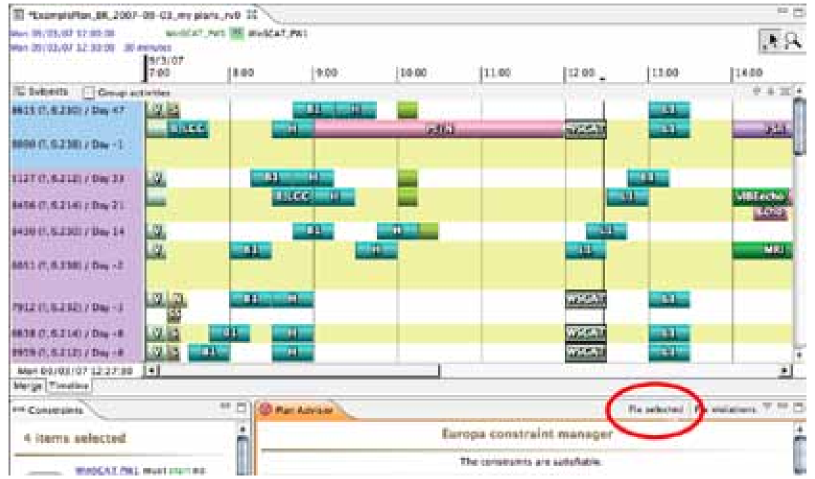
INTERFACE OVERVIEW / MULTIPLE PANELS



SUMMARY

The primary components are: Plan Editor, Activity Dictionary, Plan Advisor (Europa), and Detail view. These are displayed in different 'panels,' where the user can modify the view to help facilitate their unique planning process. The Plan Editor includes the table and timeline, the Activity Dictionary provides a searchable master list of activities and resource information, the Plan Advisor gives the feedback on the current plan, and the Detail View explains properties of the current selection (times, parameters, detailed notes).

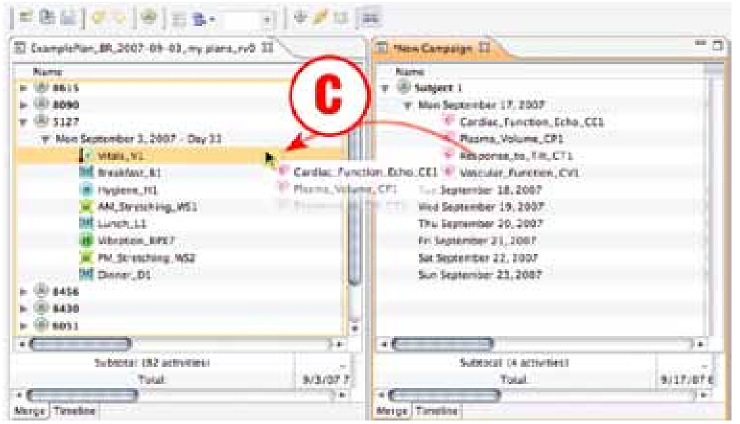
EUROPA AUTOMATED PLANNER



SUMMARY

After the user selects a set of activities, the Europa automated planner can attempt to repair problems or offer suggestions. Europa provides suggestions to resolve conflicts and allows a user to reject individual suggestions.

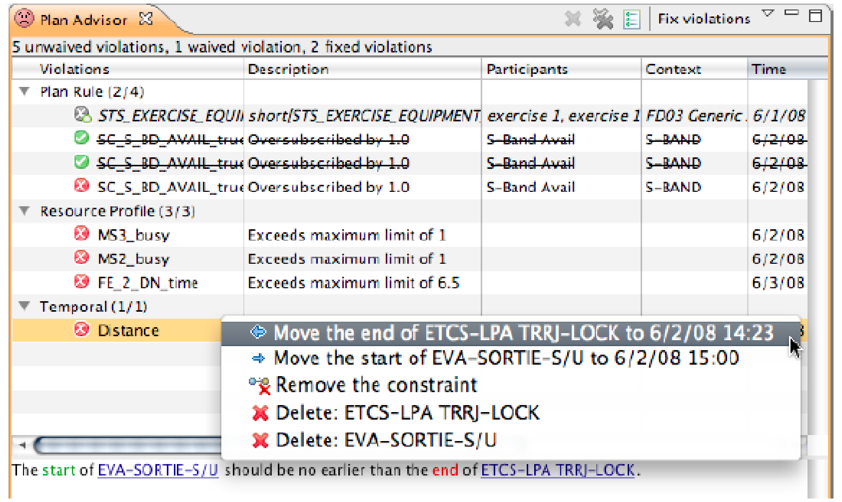
THE MERGE EDITOR



SUMMARY

SPIFe allows for several partial files to be arranged and merged into one plan using drag-and-drop or copy-paste. The Merge Editor gives feedback on resources, priorities, and constraints, and can be customized to show only relevant tasks.

THE PLAN ADVISOR



SUMMARY

The plan advisor is the heart of the user's interaction with the constraints engine. It never prevents a user from manually editing the plan, but instead passively updates its suggestions when the plan changes. It marks constraint violations and gives quick suggestions for simple optimizations.

SPIFe: NOTES

NOTES	DESCRIPTION
Undo and Redo Support	Full undo and redo support is not common in NASA software, but is strongly desired by many. SPIFe supports this, which gives users the confidence to explore various planning scenarios.
Multiple Selection / Drag-and-Drop	The ability to select and manipulation multiple portions of the plan increases the efficiency of assigning tasks and re-planning.
Integration with older software	SPIFe integrates with legacy systems to incorporate past versions of the plan.
Plan Automation	Europa allows the user to specify a partial set of constraints against which a plan can be generated or evaluated.

LUFTHANSA SUITE: SUMMARY

Lufthansa Systems offer a suite of tools for flight planning and performance monitoring. The FlightOps suite provides a web interface to specify the operational parameters for an entire flight schedule (or an individual flight) and finds the most efficient flight path, incorporating information like flying conditions, airport weather, and NOTAMs (Notices to Airmen). Used by small and medium-sized airlines, the Lufthansa Suite aides both planners on the ground, and pilots in-flight on a laptop or electronic flight bag.

http://www.lhsystems.com

Domain:
Flight scheduling and optimization for airlines

Target Users:
Planners and pilots for small to medium-sized airlines

Key Features:
Integrated flight info, auto scheduling, and performance tracking

THEME	RELEVANCE	DESCRIPTION
Multi-User Collaboration Allowing multiple people to create edit and execute portions of a plan	●●●○○	Multi-level user authorization schemes and access controls support collaboration for large scheduling departments. All data is managed in a relational database, which serves as a central data repository for the airline.
Issue Tracking Identifying problems in a plan and assigning responsibilities to resolve	○○○○○	
Execution Management The real-time plan execution interface	●●●●○	Lufthansa's software suite includes both planning and execution tools. While they share the same data, they do not always use the same interface.
Progressive Granularity Viewing and managing the plan at increasing resolutions over time	○○○○○	
Version Control Viewing and duplicating previous stages of a plan; tracing the life-cycle of a plan	●●○○○	All schedule changes applied by the user are held in a hypothetical mode until released, allowing planners to reverse changes step-by-step. The system automatically maintains an audit trail of schedule changes.
Task Dependencies The ability to create contingent relationships between tasks	●●●○○	The planning software provides suggestions based on related tasks such as weather constraints, and rotation optimizer observes operational constraints. Local Fleet Assigner takes forecasts of passenger counts, revenues, and costs.
Resource Management The allocation of personnel and equipment	●●●○○	The Aircraft Management portion of the suite suggests daily routine maintenance procedures based on necessity. It also provides information on passenger counts and aircraft peculiarities.

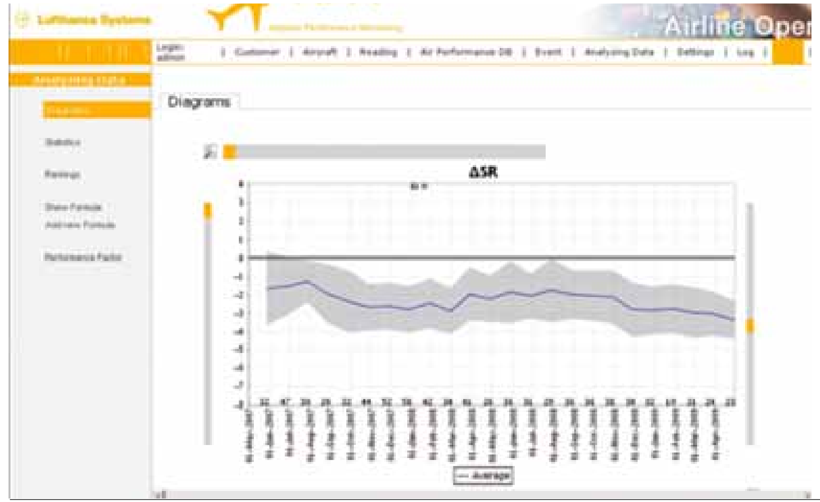
LUFTHANSA SUITE: FEATURES & SCREENSHOTS

NETLINE SCHED

SUMMARY

Aircraft rotations can be viewed and updated in a Gantt Chart format. The Flight List visualizes schedule information according to flight number in a textually abridged format and also facilitates individual flight updates as well as mass changes to the plan.

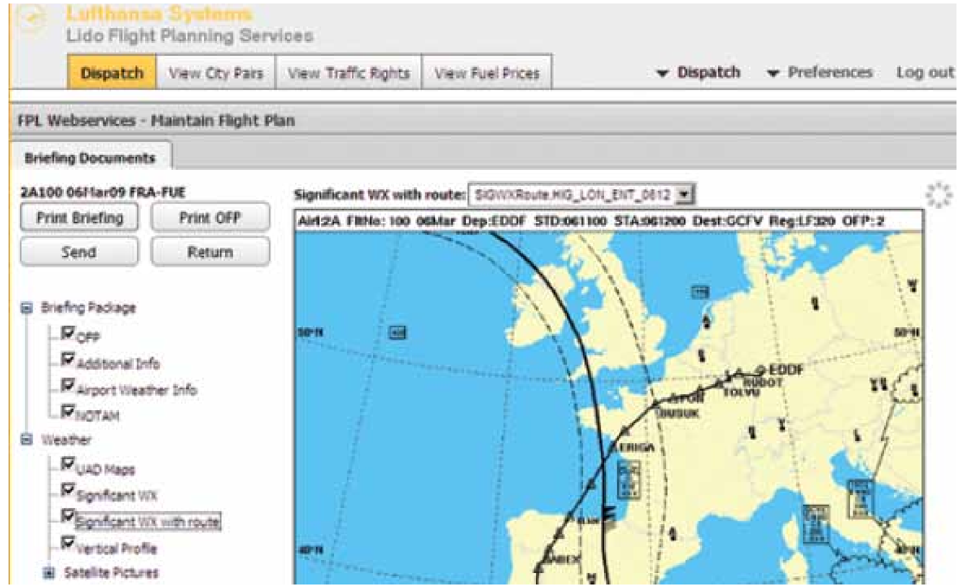
LIDO / AIRPLANE PERFORMANCE MONITORING



SUMMARY

Lido monitors an aircraft's performance during flight, providing information such as fuel consumption, which helps airlines to extend the lifetime of an aircraft and conduct operations in the most efficient and ecological manner possible.

FLIGHT PLANNING SERVICES INTERFACE



SUMMARY

Lido eFlightBag integrates onboard and ground applications as well as individual airline systems. Not only pilots, but also dispatchers, performance engineers, and navigation experts can use a single solution.

LIDO TAKEOFF

SUMMARY

Pilots enter relevant data during take-off preparations and Lido Takeoff calculates optimal settings for variables including thrust, flap orientation, and speed, taking aircraft-specific limitations into account.

FLIGHT PLANNING SERVICES INTERFACE

SUMMARY

The paperless briefing package provides crew with all flight-related documents and data. Pilots, dispatchers, operations engineers, navigation experts, performance engineers, and maintenance technicians use the consolidated data.

The Library Document Viewer in the Electronic Flight Bag (EFB) contains all generic documents such as operational manuals, equipment lists, airline operating policy manuals, and more. The clipboard allows quick access to the most important documents.

LIDO TAKEOFF

SUMMARY

The Lido eRouteManual allows pilots to access en-route aeronautical information. Highlights of the charts, which are drawn to scale and oriented magnetic north up, and follows the Volpe Human Factor Recommendation for electronic charts.

LUFTHANSA SUITE: NOTES

NOTES	DESCRIPTION
Planning and Execution	Lufthansa's software provides functionality for planners to create flight plans and for pilots to execute off of them.
Efficiency Checker	The NetLine/Sched tool uses a Tactical Profitability Evaluation Model to evaluate full schedules as well as schedule scenarios from an economic perspective. This check occurs just before publication / close-out date.
Search	Global search allows users to find information anywhere in the system and saves time during flight preparation.
Web-based User Portal	The user portal enables pilots to gain access to all data worldwide via the Internet. The web flight book is identical in the ground applications and onboard devices so the pilot can prepare his flights while on the ground.

EASY PROJECTS .NET: SUMMARY

Easy Projects .NET is a web-based project management and collaboration tool. Primary features include an interactive Gantt chart, asynchronous communication, real-time online conferences, multi-user collaboration, and resource tracking.

http://www.easyprojects.net

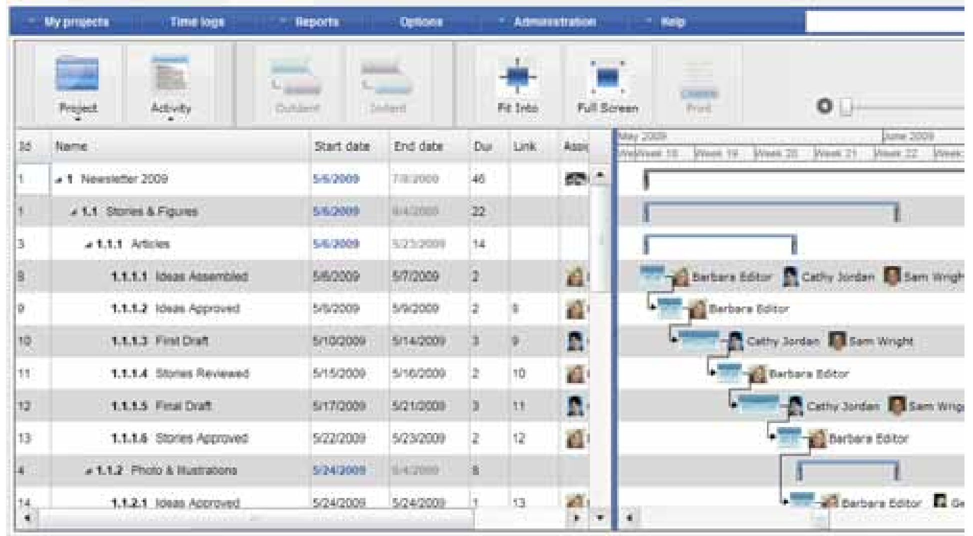
Domain:
IT organizations and companies employing information workers

Target Users:
Project Managers

THEME	RELEVANCE	DESCRIPTION
Multi-User Collaboration Allowing multiple people to create edit and execute portions of a plan	●●●○○	The tool supports screen sharing, virtual team meetings, and webinars for up to 10 participants. Text chat messages and VOIP are also available. However, users cannot communicate asynchronously on an activity or task level.
Issue Tracking Identifying problems in a plan and assigning responsibilities to resolve	●●●○○	Each task can be tagged with problem or issues. Roles responsible are assigned to tasks, and consequently are responsible for any related issues.
Execution Management The real-time plan execution interface	●●●○○	Tasks and activities are assigned a completion status on a 0-100 scale. An interactive Gantt chart indicates which activities are behind, on, or ahead of schedule.
Progressive Granularity Viewing and managing the plan at increasing resolutions over time	●●●●○	Calendar views display a project's history and future over the total length of the project. Gantt views can zoom in on the plan down to the day level.
Version Control Viewing and duplicating previous stages of a plan; tracing the life-cycle of a plan	○○○○○	
Task Dependencies The ability to create contingent relationships between tasks	●●●○○	An interactive Gantt chart supports sequential task dependencies.
Resource Management The allocation of personnel and equipment	●●○○○	Easy Project .NET has dedicated personnel tracking, including workload distribution at the project and individual worker levels. Equipment resources are not tracked.

EASY PROJECTS .NET: FEATURES & SCREENSHOTS

INTERACTIVE GANTT CHART



SUMMARY

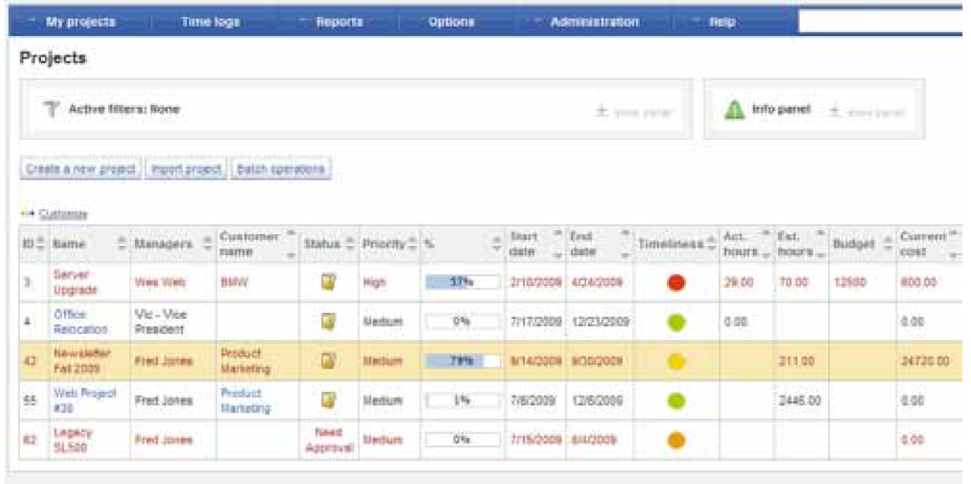
The Interactive Gantt Chart supports the creation and update of activities using simple drag-and-drop controls. Users can also edit activity names and the start/end dates for activities in line. The interface allows managers to assign responsibilities to activities using workers' photos.

ACTIVITY TRACKING

SUMMARY

An activity details the status of tasks required to complete it. The activities interface displays assigned personnel, task completion status on a 0-100 scale, and the estimated or actual hours to completion. This interface also supports in-line editing. In addition, activities can be created at different hierarchies or levels.

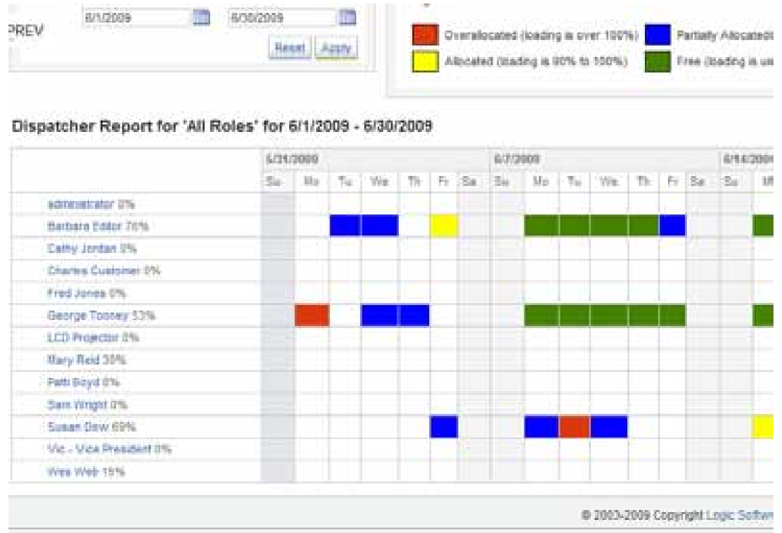
PROJECT TRACKING



SUMMARY

Similar to the Activity Tracking pane, the Project Tracking pane displays the completion status of projects on a 0-100 scale, and the estimated or actual hours to completion. Project managers, associated costs, and customers can be specified. In addition, contextual menus allow users to view associated activities, export to Microsoft Project, and view project communication / messages.

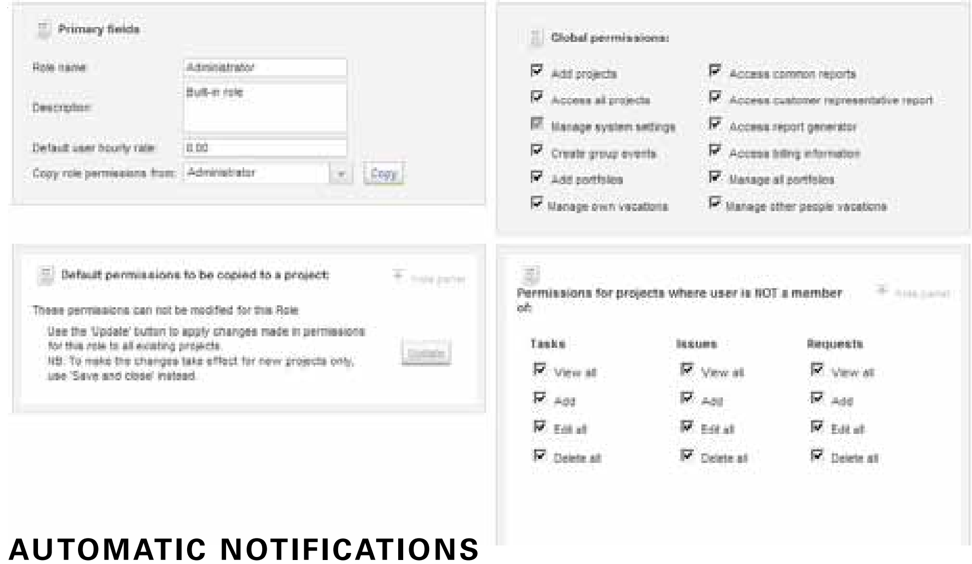
RESOURCE/PERSONNEL MANAGEMENT



SUMMARY

Personnel tracking allows managers to view how activities and tasks are spread over roles within a selected period of time.

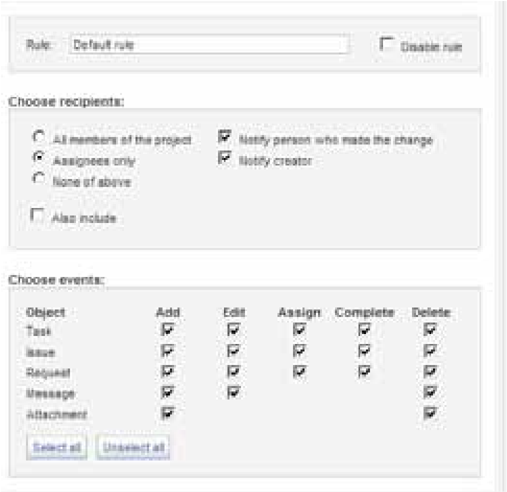
PERMISSIONS



SUMMARY

Permissions allow managers to tailor the interface to specific and definable roles. Typically this is used to grant or restrict access to features.

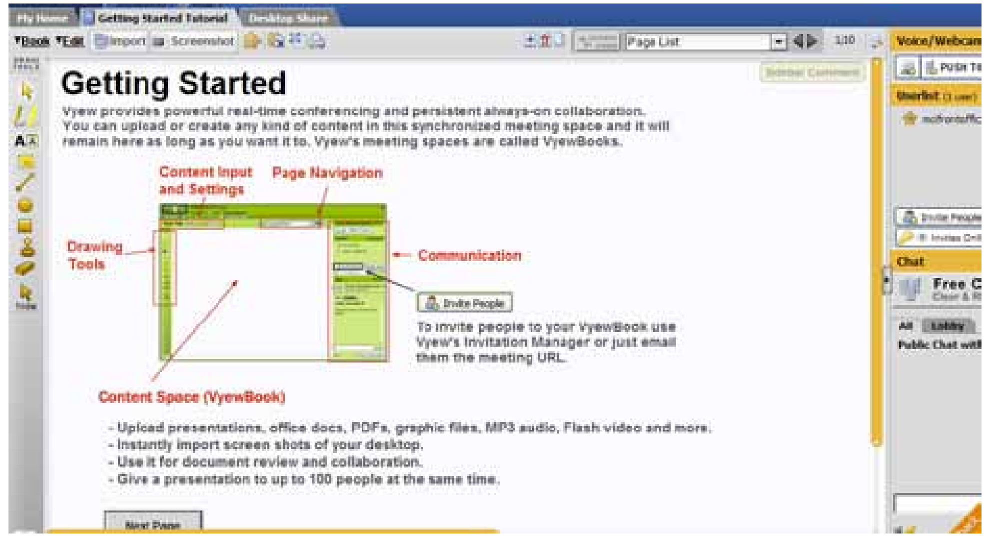
AUTOMATIC NOTIFICATIONS



SUMMARY

Users can specify recipients for automatic notifications of task status updates.

REAL-TIME CONFERENCING



SUMMARY

Real-time presentations, webinars, and team meetings with up to 10 participants along with instant messaging, screen sharing, and VOIP.

PRIMAVERA: SUMMARY

Primavera is an enterprise class Project Portfolio Management tool that allows project managers to balance resources and project risk across multiple projects within an organization. It scales from tracking a single project for a small team to managing hundreds of projects involving thousands of users for an entire organization. Primavera utilizes the Critical Path Method which models a project in terms of the activities required to complete the project, the duration each activity will take to complete, and the dependencies between activities.

http://www.oracle.com/primavera/index.html

Domain:
Large IT corporations

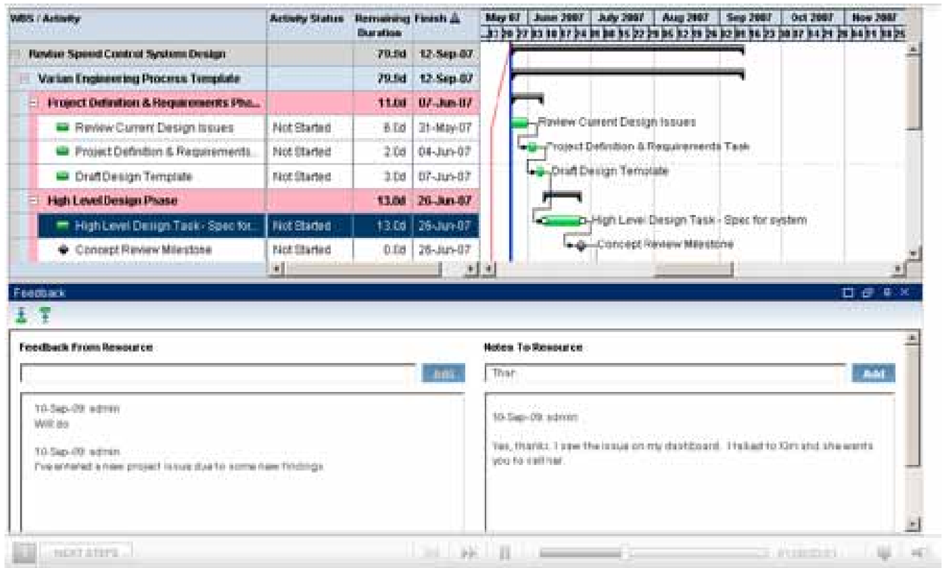
Target Users:
Project Managers, Executive staff

Key Features:
Critical Path Method, Gantt Chart view for projects & activities

THEME	RELEVANCE	DESCRIPTION
Multi-User Collaboration Allowing multiple people to create edit and execute portions of a plan	●●●●○	Primavera gives all members of the project team access to their project information via a web interface. The tool also supports bi-directional communication to aid team collaboration.
Issue Tracking Identifying problems in a plan and assigning responsibilities to resolve	●●●●○	Primavera focuses heavily on tracking the activities required to complete a project, using a Gantt Chart with a Critical Path visualization to track "Activity Status." Teams can use asynchronous communication to help resolve issues that arise.
Execution Management The real-time plan execution interface	●●●○○	A Gantt chart provides a current overview of activities statuses and dependencies. However, Primavera users can only mark activities as "Started" or "Completed" allowing no further resolution of the real-time status of activities.
Progressive Granularity Viewing and managing the plan at increasing resolutions over time	●●●●○	Primavera is useful for viewing a wide snapshot of the state of organization, including long-term projects, resource availability, financial state, and fundamental business strategy. However, the tool can also be used to view specific plan activities on the scale of days.
Version Control Viewing and duplicating previous stages of a plan; tracing the life-cycle of a plan		
Task Dependencies The ability to create contingent relationships between tasks	●●●●○	Primavera emphasizes task dependencies in a Gantt Chart view. Sequence dependencies are particularly salient in the Critical Path visualization.
Resource Management The allocation of personnel and equipment	●●●○○	Users of Primavera are encouraged to provide task status through the tool to provide managers with better visibility into personnel resources.

PRIMAVERA: FEATURES & SCREENSHOTS

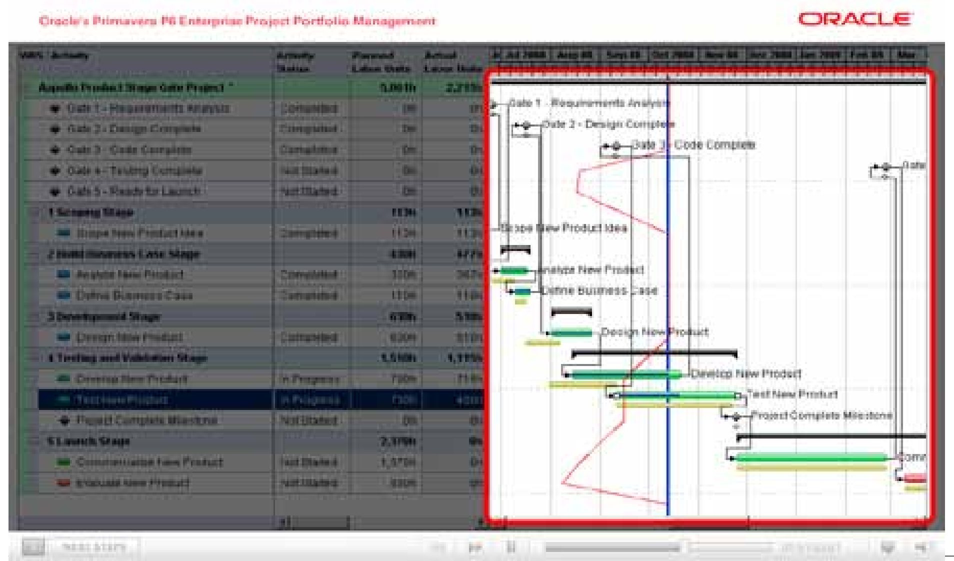
ASYNCHRONOUS COMMUNICATION



SUMMARY

The tool supports asynchronous communication at the activity level. This screen shot displays two users discussing an issue related to a project.

GANTT CHART (ACTIVITY)



SUMMARY

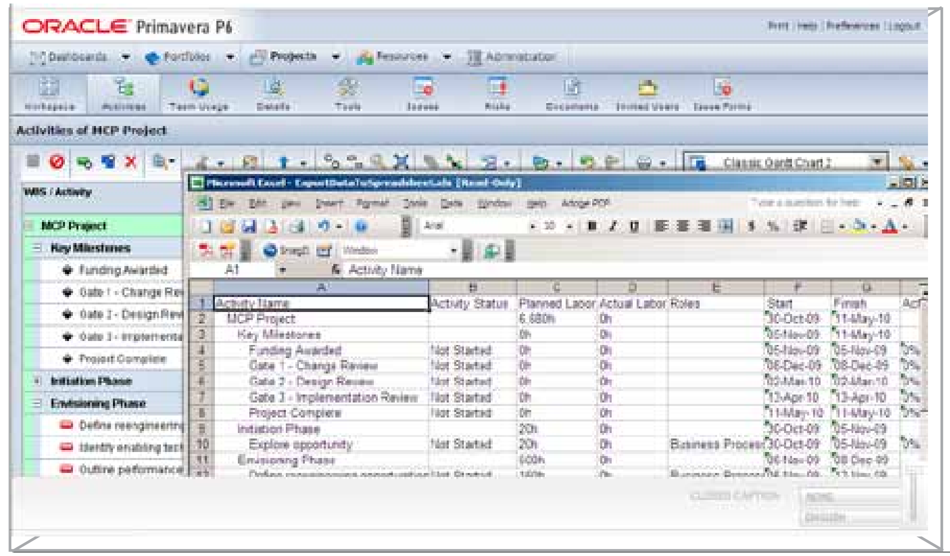
This Gantt Chart displays the start and end dates for activities in a project. The vertical blue line indicates whether activities are ahead or behind schedule. The horizontal blue line within a band indicates the progress of that activity.

GANTT CHART (PROJECT)

SUMMARY

This Gantt chart provides a real-time view of project performance, that is, the relative status as compared with the schedule.

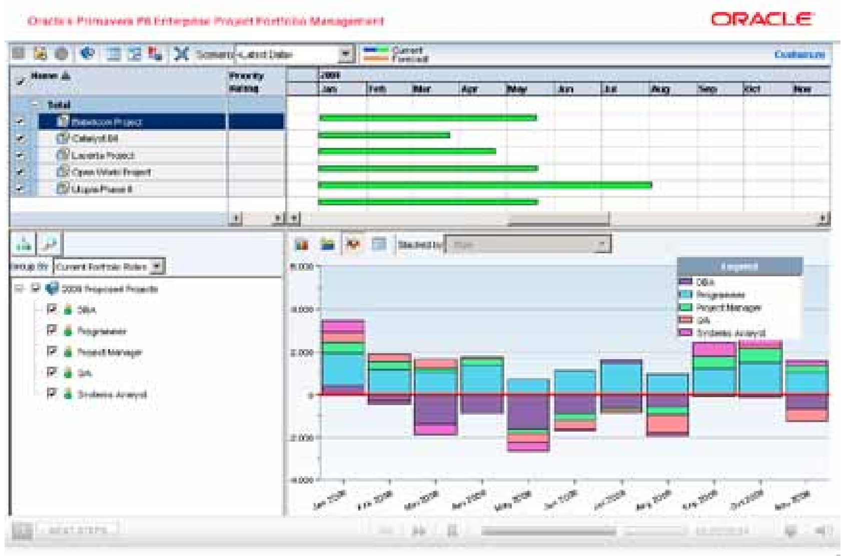
EXCEL IMPORT

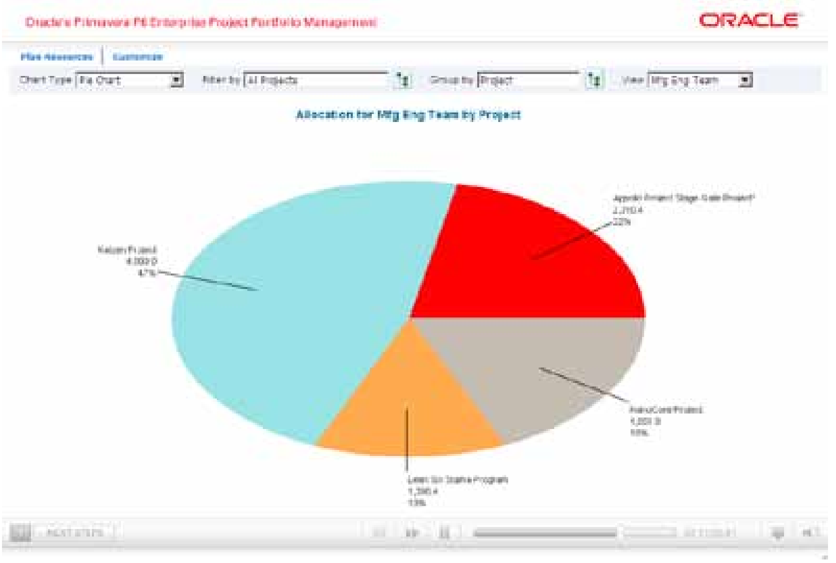


SUMMARY

Primavera supports an excel import / export functionality, to help manage and extend projects.

RESOURCE ALLOCATION





SUMMARY

The resource allocation tool provides an overview of resources usage, across all programs and projects.

Resource allocation charts provide another view into resource demand & capacity.

MICROSOFT PROJECT: SUMMARY

Microsoft Project, part of the Microsoft Office family, is considered the dominant project management application with a majority of the market share. It offers the standard suite of project management features including Gantt Charts, Critical Path visualizations, resource allocation tools, and task management. Microsoft Project is set apart from other competitors, integrating tightly with other Microsoft Office products, including Excel, Visio, SharePoint, and Project Server.

http://www.microsoft.com/project

Domain:
Not targeted to one specific domain

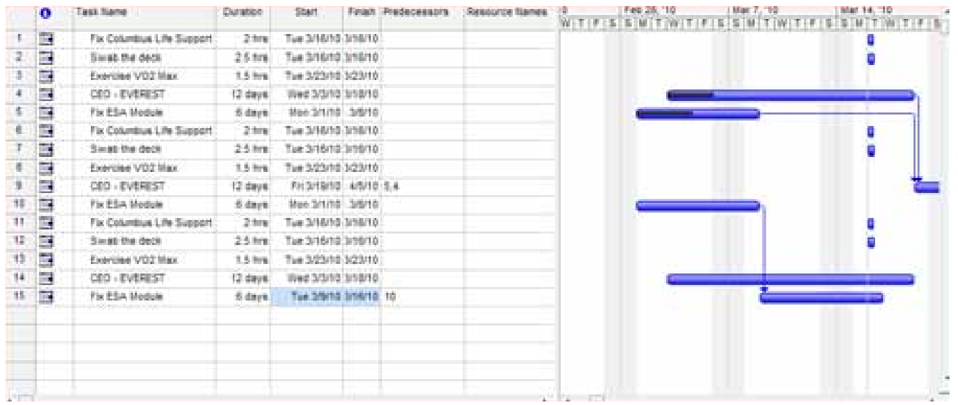
Target Users:
Project Managers

Key Features:
Gantt Chart, Resource Allocation, Microsoft Office Integration

THEME	RELEVANCE	DESCRIPTION
Multi-User Collaboration Allowing multiple people to create edit and execute portions of a plan	●○○○○	The Microsoft Project client application alone does not support multi-user collaboration. However, Microsoft Office Project Server provides a web interface and a centralized database.
Issue Tracking Identifying problems in a plan and assigning responsibilities to resolve	●●●○○	Generalized "Notes" can be added to tasks to track task-specific issues, in addition to custom fields. Project has special visualizations that display task that are behind, or scheduled to consume unavailable resources. However, there is no pre-built "issues" field for tasks in the product.
Execution Management The real-time plan execution interface	●●●○○	Various Gantt chart views are available, including a diagram view which displays current tasks and activities in a flow chart diagram. In addition task status can be configured and communicated. However, no other real-time reminders, timers, execution features are available.
Progressive Granularity Viewing and managing the plan at increasing resolutions over time	●●●●○	Plans and the associated tasks and activities can be viewed at a high level providing an overview of the entire plan, or at a highly detailed level, on the order of days, hours and minutes.
Version Control Viewing and duplicating previous stages of a plan; tracing the life-cycle of a plan	●●●○○	Project supports multiple levels of undo which allows users to experiment with multiple "what-if" scenarios. However, Project has no plan versioning beyond the ability to save multiple files to save several versions of the plan.
Task Dependencies The ability to create contingent relationships between tasks	●●●●○	Project supports the sequential tasks dependencies afforded by a Gantt chart, including duration and predecessor constraints. Also, tasks can be configured to be dependent on resource availability.
Resource Management The allocation of personnel and equipment	●●●●●	Project supports resource management and leveling, allowing users to examine unbalanced use of personnel and resources across tasks, and help resolve over-allocations.

MICROSOFT PROJECT: FEATURES & SCREENSHOTS

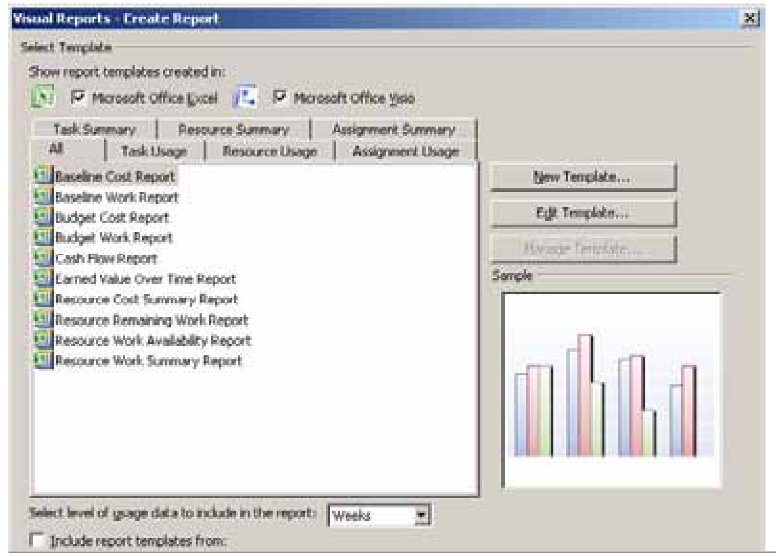
GANTT CHART



SUMMARY

Project supports a dual-pane view of the task list and Gantt Chart, which aligns tasks and activity bands in horizontal rows. The Gantt Chart supports drag-and-drop linking of tasks, and displays the typical visualization of task start and end information. In addition, the chart supports full formatting of color, shape, pattern, height, etc.

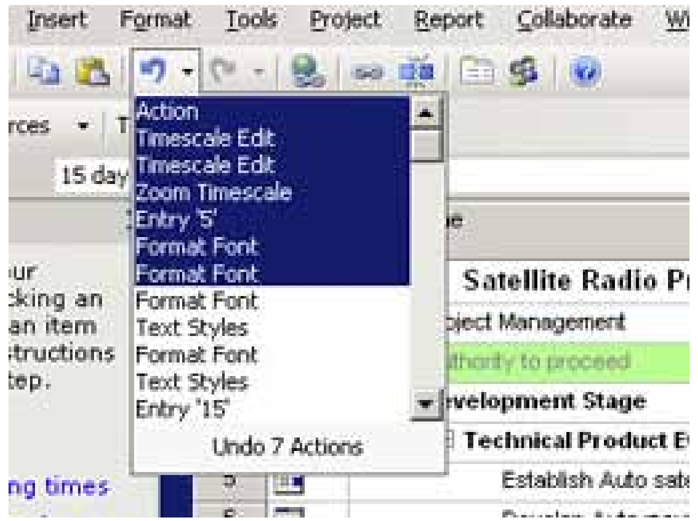
EXCEL & VISIO INTEGRATION



SUMMARY

Project allows users to leverage integration with the Office Suite to create Excel charts and Visio diagrams. Built-in charts include task summaries and resource usages.

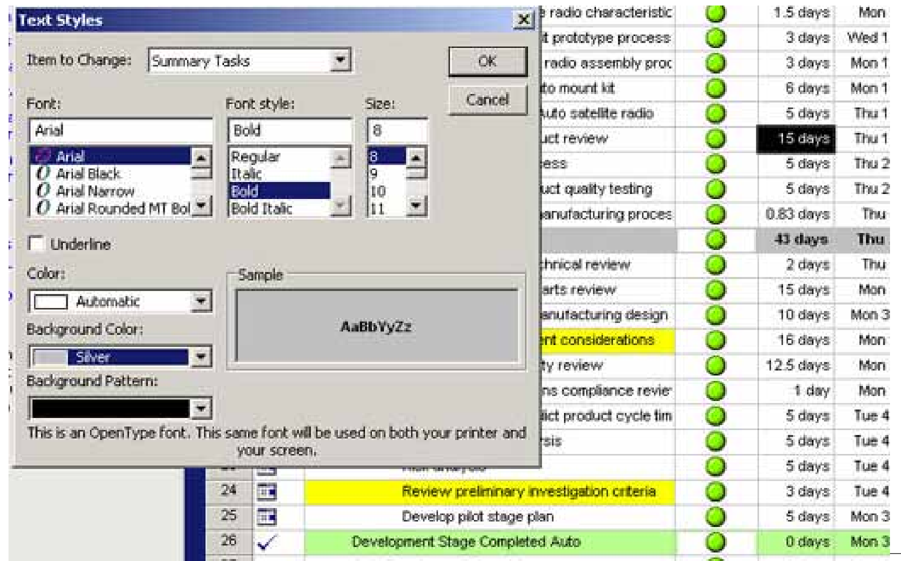
MULTIPLE LEVEL UNDO



SUMMARY

Multiple levels of undo allow users to experiment with "what-if" scenarios. Users can undo the most recent action or entire sets of actions at once.

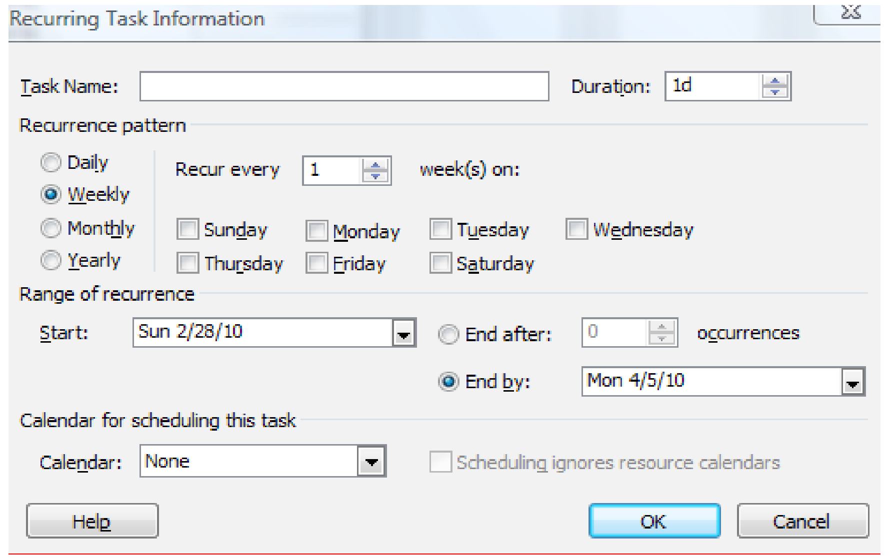
CUSTOM FORMATTING



SUMMARY

Users can change the formatting of cells and rows in the task lists (including background color and font), to convey additional meaning.

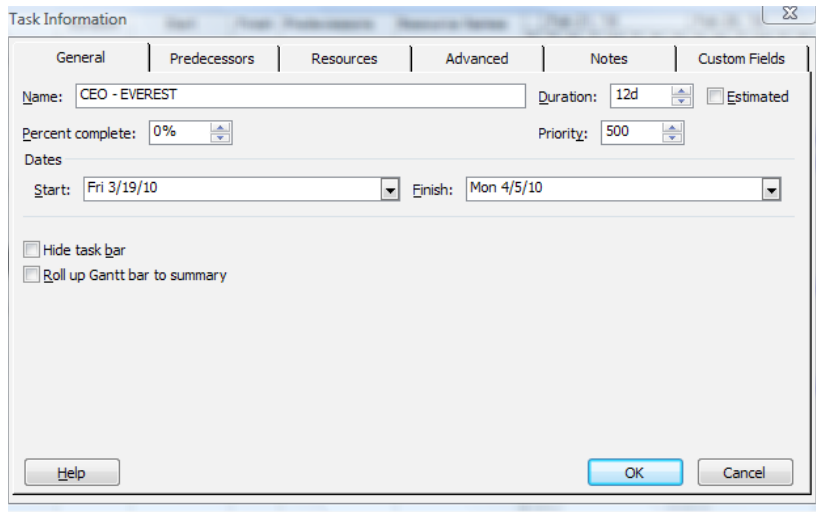
RECURRING TASKS DIALOG



SUMMARY

Recurring tasks can be specified using a specialized dialog.

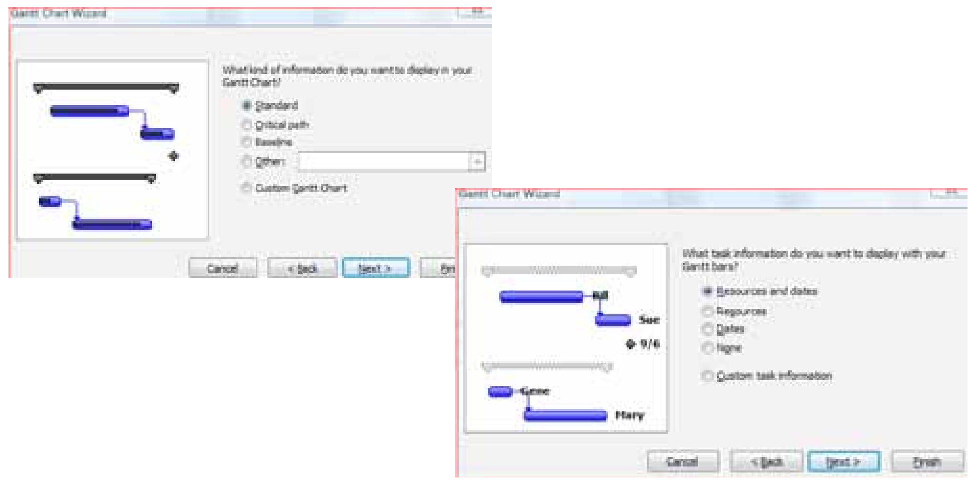
TASK INFORMATION DIALOG



SUMMARY

The "Task Information" dialog allows users to edit task parameters such as start and end dates, completion percentage, required resources, notes, custom fields, and predecessor information.

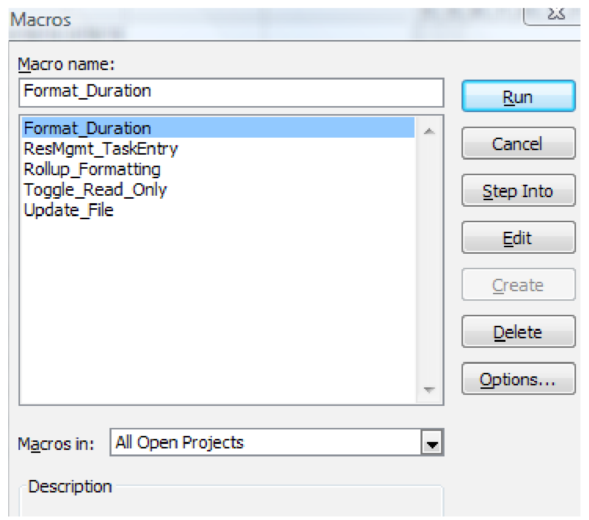
GANTT CHART WIZARD



SUMMARY

A Gantt chart wizard structures the chart creation process, allowing users to specify what type of information to display.

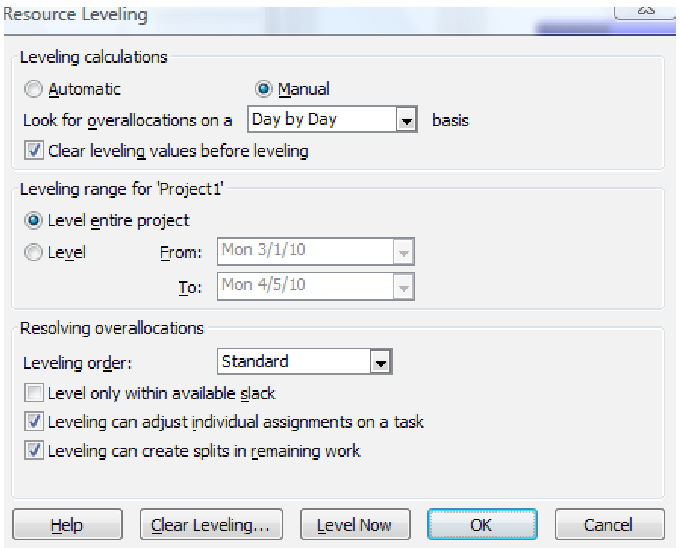
MACRO SUPPORT



SUMMARY

Project supports Macros, allowing users to create personalized scripts to access application features.

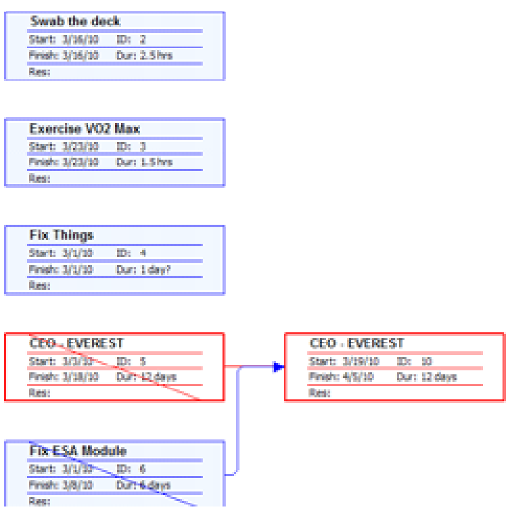
RESOURCE LEVELING



SUMMARY

Built-in resource leveling allows Project users to examine unbalanced use of personnel or resources across tasks, and help resolve over-allocations.

SPECIALIZED GANTT VIEWS



SUMMARY

Project supports a “diagram view” of the Gantt Chart, which overlays activities & tasks within the chart as activity bands.

APPENDIX C

DETAILED RESEARCH FINDINGS

The following is an in-depth analysis of every key observation we found during our contextual inquiries.

NEWS BROADCASTING: ASSIGNMENT EDITOR

[1] News Broadcasting Whiteboard Artifact Model, p. 145

[2] News Broadcasting Flow Model, p. 137

[3] News Broadcasting Sequence Model, p. 139

[4] News Broadcasting ENPS Artifact Model, p. 144

[5] News Broadcasting Flow Model, p. 137

1. Public displays play a crucial role in establishing shared understanding and situational awareness amongst the planning roles.

Among the different Assignment Editors, and the other roles involved in planning (Producers, News Director, Anchors), effective collaboration and shared understanding is crucial to the planning process. The most prominent collaboration artifact is surely the news desk whiteboard [1]. The Assignment Editors use this public display to communicate the current allocation of resources.

2. Many of the hard and soft constraints affecting planning are managed in the planner's head.

For efficiency, the Assignment Editors track most of the hard constraints in their heads [2], but occasional oversights cause major breakdowns [3]. During our observation, an omission on the whiteboard led the Assignment Editor to accommodate an equipment request by assigning a driver to a truck that was not in the garage. In addition, the planners keep track of soft constraints, like the expertise and skill level of each reporting staff. Such information can be culturally sensitive, and cannot be made explicit or public, so Assignment Editors must internalize this information over years of experience.

3. A single tool is used to organize the plan and facilitate collaboration between different roles across both planning and execution.

Throughout the day, the news desk sifts through large amounts of data from a large number of sources, crafting legitimate stories from scattered tidbits of information. Assignment Editors track the status of these stories and next steps, in ENPS, their integrated planning tool [4]. Because stories develop over time and often cross shift boundaries, this helps them communicate and collaborate. Another feature that facilitates communication of story status is the ENPS messaging system. This integration facilitates a contextual conversation about plan items.

> *Throughout the day, the news desk sifts through large amounts of data from a large number of sources, crafting legitimate stories from scattered tidbits of information*

4. The use of a single tool bridges the divide between stages of planning and execution and increases efficiency when real-time re-planning occurs.

One theme that emerges in all of our research, the artificial chronological divide between planning and execution, is quite prevalent in this domain. ENPS provides excellent support for the re-planning cycle during execution [5]. The producer sits in the control room during broadcast, continuously tinkering with the rundown and script in order to ensure that the broadcast is the proper length. He monitors real-time progress and has ultimate authority over plan changes. ENPS provides him with the situational awareness that he needs for this task. Most of the screen real-estate in the execution view is devoted to the "rundown," the ordered list of stories to air in broadcast. However, several panes are available to display detailed information about a selected story. A yellow Marcus-Bains-esque line highlights the current story during the broadcast. This bar creates in-context awareness of the current status of execution. As the bar advances, estimated duration for each completed story is replaced with the actual duration, and a running overage/underage count is updated. This provides the information necessary to add/cut stories and/or update scripts for the teleprompter. When a particular story is cut, it remains inline in the rundown, highlighted in red, so that it could be uncut at any moment, if more re-planning becomes necessary.

ENPS: Essential News Production System

Because every execution artifact is born out of ENPS, digital artifacts, such as the teleprompter are updated automatically. However, re-planning creates an artifact breakdown for the printed schedules that are used by the crew. They must continuously scratch-out, erase, and otherwise annotate on their printed copies of the plan as the producer calls them [6]. However, the features of ENPS come together to provide in-context situational awareness for the producer so that he can easily make confident and informed re-planning decisions quickly.

[6] News Broadcasting Flow Model, p. 137

A live news broadcast in progress. Backstage, the producer acts as the composer while the director acts as the conductor.

SURGICAL WARD: CHARGE NURSE

[1] Surgical Ward Flow Model, p. 131

[2] Surgical Ward Flow Model, p. 131

[3] Surgical Ward Warboard Artifact Model, p. 134

[4] Surgical Ward Daily Assignment Artifact Model, p. 135

[5] Surgical Ward Sequence Model, p. 133

[6] Surgical Ward Sequence Model, p. 133

1. The Charge Nurse spends the majority of his time out of the office, making rounds and conversing with staff near the public plan displays.

One of the Charge Nurse's main responsibilities is to maintain situation awareness of each surgery's progress. [1] As he walks around the surgical floor, the surgical teams can communicate progress through a small window on the door. He is a trained nurse himself and has many years of experience, so it is easy to communicate status through the use of simple gestures. For example, a hand doing a threading motion means "closing", indicating that the surgery is near completion.

> *He is a trained nurse himself and has many years of experience, so it is easy to communicate status through the use of simple gestures.*

2. The plan is often tracked and managed tacitly, but externalized for the sake of communication through public artifacts tailored to each role's needs.

The Charge Nurse keeps the progress of every operating room in his head, where he can most easily access it. However, he externalizes that information in three different ways to communicate with his director, with the surgeons, and with the nurses and technicians [2].

The director needs a high-level status overview. For her, he creates a blue copy of the day's scheduled surgeries, which is kept near the Nurses Station. Throughout the day, he will make notes on that schedule, often in symbols and shorthand, to communicate the status of each case. For example, canceled surgeries are marked out with an "x."

For the surgeons and anesthesiologists, he maintains a warboard of the day's cases, organized by operating room. Few of the operating rooms are general purpose and most are specialized, just like surgeons. For example, the Cardiac Surgeon is likely to stay in the operating room with the specialized cardiac equipment. Therefore, the surgeons are most interested in seeing the run-down of the day's cases by operating room [3].

For the nurses and technicians, he prints a paper assignment sheet indicating the OR and duty assignments. In contrast to surgeons, the nurses and technicians frequently travel between operating rooms, according to the requirements of the day. The Charge Nurse writes up the assignment sheet in pencil, shortly before each shift. He also uses the assignment sheet to assign lunch breaks [4].

3. The plan is rarely executed to spec, with unforeseen incidents regularly upsetting the plan.

Add-ons, unscheduled additions to the plan, are very frequent at the surgical suite. We observed an emergency add-on when a patient suddenly became septic and required immediate surgery. However, a less urgent add-on might be a biopsy request from an attending physician. Regardless of urgency, the Charge Nurse must work hard to accommodate these add-ons. In the emergency example above, he was able to locate an available operating room and put together a surgical team within 30 minutes [5].

4. Many roles in the OR rely on the Charge Nurse for reorientation during plan changes.

The surgical staff has a pretty good idea how often the Charge Nurse updates the public display and will loiter around the warboard in anticipation. In addition to the management of public displays, people rely on the Charge Nurse to orient themselves when the unexpected happens. During the case of the septic patient, the anesthesiologist came directly to the Charge Nurse to find out which operating room to go to. The surgeon who needed to perform a biopsy as an add-on depended on the Charge Nurse to track down a special piece of brain imaging equipment needed for the biopsy [6].

OR: Operating Room

[7] Surgical Ward Flow Model, p. 131

[8] Surgical Ward Cultural Model, p. 132

5. In addition to hard resource constraints, the Charge Nurse must also accommodate soft constraints such as personnel preferences when forming surgical teams [7].

Nurses and technicians have specialties, similar to the surgeons. Not all nurses and technicians are certified to assist in all surgeries. Different staff members have different work styles and priorities, too. A new hire might be very eager for assignment opportunities while others shy away from extra work. Furthermore, surgeons often have preferences for particular personnel and operating room prep style. The Charge Nurse has a binder for each surgeon to keep track of their preferences, but rarely refers to it.

6. Through a difficult and even thankless job, the Charge Nurse remains motivated by trying to achieve a higher purpose [8].

It is the Charge Nurse's higher goal of helping patients that sustains him through the politics and unpleasantries. When something goes wrong, like an error in recording which surgeon performed which surgery, the Charge Nurse becomes the scapegoat even if he was simply informed incorrectly. After all the hard work the Charge Nurse puts into coordinating the surgeries, a surgeon can change everything due to personal preferences. For example, the Charge Nurse had to redo the entire assignment sheet because a surgeon requested to do the surgeries in a different order at the last minute [9]. Sometimes his own staff are uncooperative, too. Since the unions limits the number of hours worked, some staff members will refuse assignments that go over that limit.

The entrance to the OR. Just beyond the double doors are the nurses's station and the Charge Nurse's office. It is a high traffic area for all OR personnel.

SPACE: WLP, STP, and RPE

[1] WLP/STP CI 2/23/2010

[2] WLP/STP CI 2/23/2010

[3] WLP/STP Flow Model, p. 107

[4] RPE Flow Model, p. 109

[5] RPE CI 2/24/2010

WLP: Week-Long Planner

STP: Short-Term Planner

IP: International Partner

RPE: Real-time Planning Engineer

CPS: Consolidated Planning System

OCA: Orbital Communications Adaptor

ODF: Operations Data Format

OSTPV: Onboard Short-Term Plan Viewer

WLP/STP

1. Planning is a hugely iterative, non-deterministic process [1].

The planning team follows a very rigorous weekly schedule in order to deliver a weekly plan on schedule. An initial lot of plan proposals come in at the beginning of the week, but additional activity requests continue to arrive throughout the week. Plans are sent out to IPs every Tuesday - Thursday night for review. These manual reviews the primary method of verifying a plan; it is labor intensive and slips often happen. Some planners mentioned that their busy schedules and full plates often prompt them to sign off without performing a full review. Planning meetings with IPs are also held three times a week to review the latest plan, during which priorities often change. The plan is in perpetual flux throughout the entire planning and execution process.

2. Tools can only account for hard constraints.

Every planning team in the back room has at least one senior member with at least five years of experience. This senior member has a wealth of experiential knowledge about he softer constraints in the planning process which are difficult to externalize. The WLP and STP team members are collocated in a U-shaped formation to facilitate both communication and the transfer of experiential knowledge [2]. The team leads set the pace each day and give direction to others on the team. When issues arise, the WLP and STP leads consult each other for advice. During schedule conflicts, for example, the leads collaborate to make decisions based on experience and the stated priorities [3].

RPE

1. Planning roles are highly siloed.

The job descriptions of various planning roles are highly specific [4]. The RPE is the implementor of change requests. He does not, however, coordinate the approval process; that is the job of the Ops Planner in the Flight Control Room. The RPE also integrates crew status updates into the plan, but the OCA officer is responsible for the actual downlink and uplink of data to and from the ISS. The ODF team is solely responsible for maintaining the IPV, but is not involved in the procedure creation process. The crew executes the planned activities but is rarely directly involved in the scheduling of those activities. Specialists from various disciplines that submit activities are not involved anywhere in the actual planning or execution processes.

2. Tools and process assume that planning and execution progresses linearly, but that is not reality [5].

As the planning process unfolds, the plan migrates from CPS through progressive versions of OSTPV. Many integration tools (Myrmo, Mr. Planner *et al.*) export the plan forward, but the reverse is more difficult. The process to backport changes from OSTPV to CPS is essentially manual. To make matters worse, CPS runs only on Linux and copy-paste does not work across platforms. As previously mentioned, there is little tool support for execution history and *in situ* planning knowledge. Crew cannot easily feed execution history back to the planners so the history does not inform the next iteration of planning. Planners utilize activity templates, but there is no support to externalize something like the "best" frequency for an activity. That kind of knowledge is only gained through experience.

> *There is little tool support for execution history and in situ planning knowledge. Crew cannot easily feed execution history back to the planners so the history does not inform the next iteration of planning.*

SPACE: CREW. DOG TRAINER, and TITAN

CREW + DOG TRAINER

1. Different roles need different kinds of information from the plan.

Constraints (like daylight and communication availability) and the relationships between activities are crucial during planning. Planners must maintain a bird's eye view of all the activities scheduled onboard, to ensure that resource constraints are satisfied [1]. Conversely, astronauts care most about their own schedule. OSTPV, the plan viewer used by both planners and executors, allows the user to customize the view, optimizing their timeline with information that is most relevant to their tasks. Vertical screen real-estate is precious to planners. Astronauts, on the other hand, prefer very targeted information and will often hide irrelevant information. An astronaut once made a request to view his schedule as a taskbar at the bottom of the screen, completely removed from the context of the timeline [2].

2. Executors often view the plan as a suggestion.

The plan represents countless hours of work. Planners work tirelessly to incorporate feedback from stakeholders. This "execution contract" is the result of many long negotiations. Conversely, astronauts view the plan as a flexible suggestion and take liberties with the plan when they feel it is appropriate [3]. They commonly complain about the inaccuracy of activity time estimates and the frequency of unsavory tasks, like cleaning the toilets. However, there is no formal system in place for this kind of execution feedback. No planner has ever been in space and no astronaut has ever been intimately involved with planning [4].

TITAN

1. Shift handoffs allow for information transfer between similar roles before executing the plan.

Each domain has some variation of a shift handoff, during which a planner or executor transfers relevant information to the next person coming on duty. We observed a shift handoff between a TITAN and the equivalent roles before him (ADCO, ODIN, CATO). During this time, he discussed the day's plan with the person leaving, face-to-face, during a scheduled overlap in shifts. After reviewing the day's plan, the TITAN received an overview of what he needed to know and was able to ask clarifying questions [5].

2. TITAN does "detective work" to prepare for unforeseen circumstances.

The TITAN feels responsible for anything that could go wrong with plan. To stay on top of the game, the TITAN looks ahead in the day's plan to identify potential problems [6]. He described this and many other the roles in the flight control room as playing "detective work" to make sure the plan runs smoothly. This includes formulating back-up plans and contingencies in the case of unforeseen events. For example, the TITAN knew that a particular method of routing was often unreliable. When it was unavoidable, he created a written back-up plan to make sure he could still record the execution.

3. Every role in the Flight Control Room requires situational awareness [7].

The TITAN expressed the need for constant situational awareness in the Flight Control Room (FCR). Because of this, many times FCR team members catch problems in the plan that may be tangential to their specific role. The Daily Planning Conference (DPC) and scheduled shift handoffs provide opportunities for different roles to communicate possible deviations from the current plan to the Flight Director and review any upcoming details. Using the Loop technology for this increases situational awareness and allows everyone feel comfortable proceeding with the plan.

[1] WLP/STP CI 2/23/2010

[2] DOG Trainer CI 2/25/2010

[3] Former Astronaut Interview 3/1/2010

[4] DOG Trainer CI 2/25/2010

[5] TITAN CI 2/24/2010

[6] TITAN FLow Model, p. 112

[7] TITAN Flow Model, p. 112

TITAN: Telemetry, Information, Transfer and Attitude Navigation

ADCO: Attitude Determination and Control Officer

ODIN: Onboard, Data, Interfaces and Networks

CATO: Communication and Tracking Officer

FCR: Flight Control Room

DPC: Daily Planning Conference

SPACE: SPECIALIST

SPECIALIST

[1] Specialist CI 2/26/2010

[2] Specialist Flow Model, p. 118

[3] Specialist Flow Model, p. 118

[4] OSTPV Artifact Model, p. 122

1. Researchers must entrust the specialist groups to execute their experiments faithfully [1].

Often, experiments aboard the ISS are commissioned by Primary Investigators (PIs),who are not affiliated with NASA and must bid for the chance to have experiments run by the ISS crew. The process is competitive and lengthy; PIs might wait upwards of 10 years to complete experiments [2]. Because they are not affiliated with NASA, they cannot directly oversee execution of their experiments. Instead, PIs must trust the respective specialist group at NASA to ensure that the crew executes their experiments faithfully. Everyone on the specialist team must carry that weight, especially the Experiment Support Scientist who is ultimately the PI's advocate for scientific concerns.

2. The ultimate artifact of the planning and execution cycle is the payload.

Although the planning process is ultimately about creating a communication artifact for the crew onboard the station, the goal of the execution of that plan is to create payload. This comes in the form of data that can be propagated back to the PI who conceived the experiment [3]. However, the planners and executors may have very little insight into the higher purpose of the experiments/activities. Planners can only observe the sequencing, physical, and resource constraints that are communicated to them, and much of that information is lost in the crew version of OSTPV [4]. As a result, astronauts are left with little insight into the motivation of the work they do and this can lead to unfaithful execution of the plan.

> *There is little tool support for execution history and in situ planning knowledge. Crew cannot easily feed execution history back to the planners so the history does not inform the next iteration of planning.*

Rocket Park, Johnson Space Center, Houston, Texas

SUMMARY CATEGORIES

TOOLS

TOOL INEFFICIENCIES
Tools' Current Problems
CPS Breakdown
Desirable Tool Features
Initiative To Improve Tool Inefficiencies

USING PLANNING TOOLS
Tool Dependence
Diff People Use Diff Tools

PLAN / EXE ARTIFICIAL DIVIDE
Unforeseen Circumstances
Planning And Execution Divide
Tool Compatibility And Interoperability

TOOL SUPPORTED COMM.
Communication Breakdown
Communication Techniques

MAKING THE PLAN

ACTIVITY CREATION
Activity Creation
Activity Content Sources
Source Breakdowns

POST EXECUTION
Execution History
Execution Post Mortem

PLAN CREATION
Automation
Plan Lead + Decision Making
Planning Constraints
Old Plan Templates
Structure Of Plan
Activity Scheduling

COMMUNICATION

UNCOLOCATED COMM.
Shift Handoff
Planner To Executor Comm.
Crew Ground Collaboration
Messaging

VIEWING THE PLAN
Different Views Of Plan
Screen And Monitors
Where Is The Plan?
On-Demand Info Display
Public Display
Plan Accessibility
Glanceability

SITUATION AWARENESS
Need for Sit. Awareness
Sit. Awareness Techniques

PLAN UPDATE

PLAN ITERATION
Version Controls
Plan Iteration + Evolution (General aspects)
Plan Iteration + Evolution (People)
Planning Experiment Tool Support
Plan Review

REPLANNING
Replanning Roles
Plan Changes
Change Notification And Approval

EXECUTION

TASKS AND PROCEDURE
Procedures For Activities
Status Update
Executor Training

EXECUTION SUPPORT
Execution Support (People)
Execution Support (Tools)

EXECUTION
Execution Expertise Level
Plan vs. Execute Discrepancy
Executing The Plan

INDIRECT CONSTRAINTS

PERSONAL GOALS
Astronaut = Rockstar
High Purpose Motivation
Personal Likes
Negative Motivation

SOCIAL DYNAMICS
Personal Interactions

ORGANIZATION GOALS
Visions + Goals
Standards
Organization Rules

DIRECT CONSTRAINTS

RESOURCE
Resource Management
Resource Constraints

ENVIRONMENT
Physical Environment
Physical Resources
Physical Space Breakdown
Safety