The Future of Space Mission Planning: AI-Integrated Decision Support System

Reimagining the Playbook Interface with AI-Powered Decision Support to Simplify and Enhance Mission Planning

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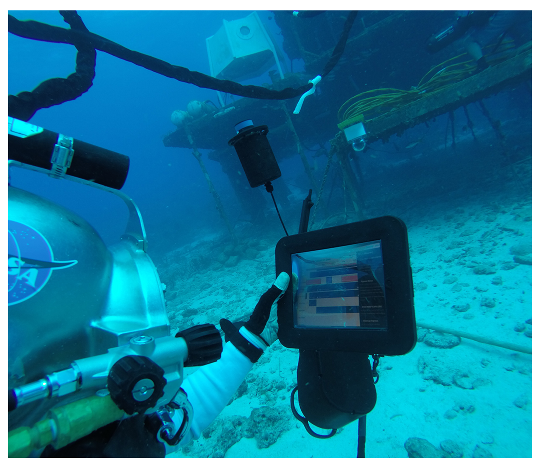
The purpose of this project is to create research-supported design concepts for a hypothetical, AI-driven mission planning and execution interface within Playbook, intended for future deep-space exploration missions. Playbook is a NASA software tool designed to enable mission planning, scheduling, and execution for human and robotic space missions. Our work involves utilizing AI to augment human decision-making, automate re-scheduling, and provide real-time support to both mission planners on Earth and crew members in space or analogous environments. By integrating AI into Playbook, we aim to reduce manual workloads, enhance situational awareness, and ultimately improve the effectiveness of mission planning and execution in the unique and high-stakes environment of space exploration.

What is Playbook?

Playbook is a user-friendly software developed by NASA's SPIFe team to support the plan ning, scheduling, and execution of space exploration missions. Playbook enables planners and crew members to create, modify, and execute mission timelines in feasible and intuitive ways. It features timeline scheduling with activity modeling, resource management, and con straint checking, as well as execution capabilities like procedure integration and activity status tracking. Playbook has been utilized in various NASA Space Exploration Missions, including:

- NASA Extreme Environment Mission Operations (NEEMO)
- Human Exploration Research Analog (HERA)
- Crew Health and Performance Exploration Analog (CHAPEA)
- Biologic Analog Science Associated with Lava Terrains (BASALT)
- Hawaií Space Exploration Analog and Simulation (HI-SEAS)

Additionally, it has been part of two International Space Station (ISS) Technology Demonstrations, contributing to the Exploration Systems Development Division (ESDM) and the Crew Autonomous Scheduling Test (CAST).



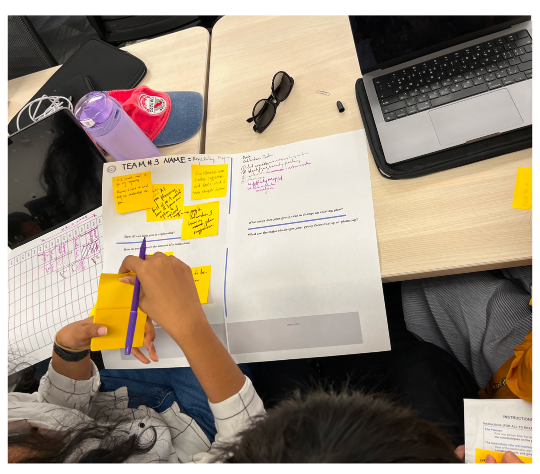
Left: Crew member on NASA Extreme Environment Mission Operations (NEEMO) utilizes Playbook during the undersea mission *(Credit: NASA)* **Right:** International Space Station (ISS) astronaut using Playbook on a touch device as part of the Crew Autonomous Scheduling Test (CAST) experiment *(Credit: NASA/NASA Johnson Space Center)*

Research

Preliminary Research

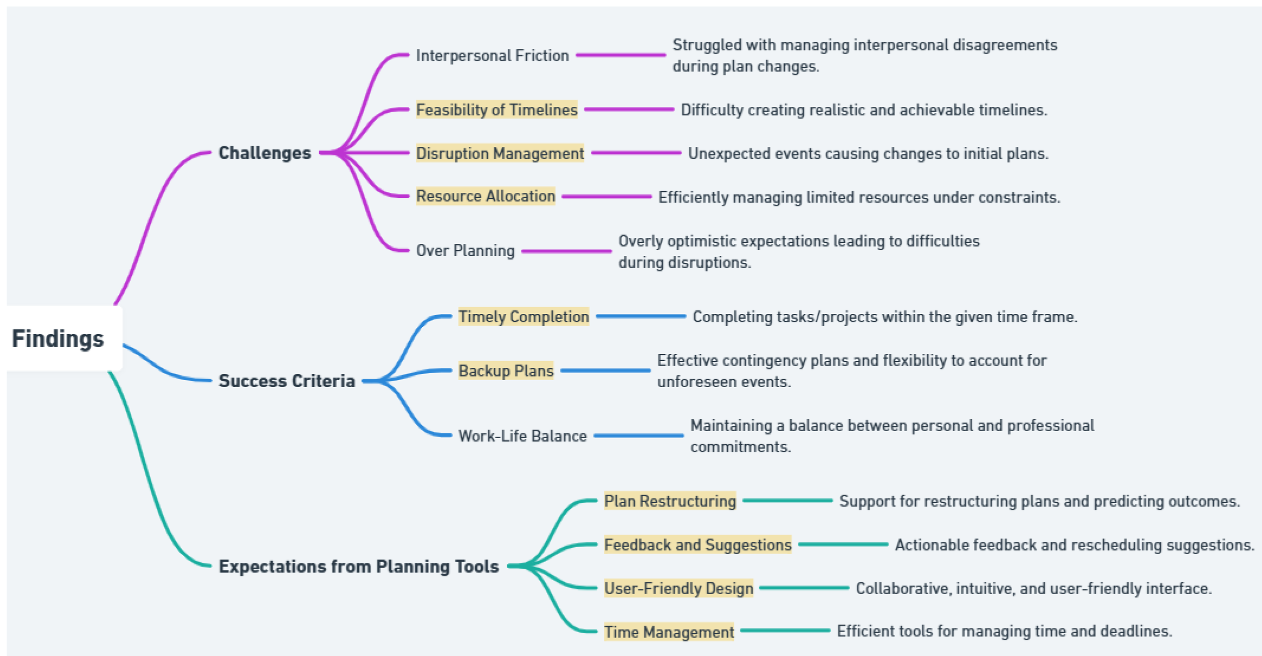
The preliminary research aimed to explore the general thought processes, challenges, and expectations individuals face during planning and rescheduling. This phase was instrumental in laying the groundwork for the research phase by providing a clear understanding of user behaviours, decision-making patterns, and the obstacles they encounter in general while decision-making and re-planning. The insights derived from this research were helpful to familiarize ourselves with the plan generation process itself and helped us formulate our primary set of research questions for our study.

Methodology: The research consisted of two main components: *open-ended unstructured interviews* and a *group replanning activity.* Qualitative insights from the interviews helped us understand how individuals approach planning and rescheduling routine tasks, time-critical tasks, personal strategies, and the challenges they face. Under group replanning activity seven groups, each consisting of 3–4 participants, were tasked with replanning their mid-quarter project timeline under specific constraints, including limited time (one week) and resources. This activity helped us to observe how participants collaborate and adapt to planning challenges in a group setting under constrained conditions.



Left: Manual data collection **Right:** Group Re-planning activity

Findings



Findings from a preliminary research

Domain Specific Qualitative Research

Building on the insights gained from the preliminary research, this research phase aimed to explore these four research questions broadly.

- What steps are involved in the mission planning process?
- What are the primary challenges encountered during mission planning?
- In what ways do various constraints influence and shape mission plans?
- How can decision support systems, including AI-driven tools, enhance the planning, scheduling, and replanning of both contingency and nominal operations by providing improved decision-making support?

Methodology: The research involved *semi-structured interviews* with subject matter experts (SMEs) from NASA's Ames Research Center, specifically those involved in the Playbook team and mission-critical operations. The interview process was designed to collect rich, in-depth data relevant to the research questions while remaining open-ended to explore unexpected insights and themes. The interviews explored participants' range of perspectives on mission-critical planning processes, challenges, and the potential role of technology, particularly AI, within the context of Playbook.

Findings

Navigating Constraints and Interdependencies: Effective mission planning hinges on the ability to manage constraints and interdependencies, which include technical, operational, and resource-based factors. Managing these complexities is critical for creating strong and feasible mission plans. This theme highlights the strategies employed by planners to navigate these difficulties and emphasizes the need for advanced tools to support this process. Participants consistently stressed the importance of identifying, prioritizing, and understanding various layers of constraints and dependencies to ensure effective mission planning. This includes considering how one activity influences or overlaps with others, as well as the technical and resource-based limitations involved. Despite these efforts, manually managing these dependencies poses significant challenges.

Mission Success through User-Centered Contingency Planning: This theme focuses on the critical importance of user experience (UX) in planning tools. The development of user-friendly and intuitive interfaces with functional features is essential to ensure accessibility and usability. Participants emphasized that interfaces must be designed to make navigation seamless and task management straightforward, especially for new users. Reducing the learning curve not only ensures accessibility but also empowers users to focus on mission-critical tasks without being overwhelmed by the complexity of the tool itself.

Human-AI Collaboration and Trust: This theme explores the potential of integrating AI into mission planning processes to enhance efficiency, support human planners, and address concerns about reliability. While AI-driven systems offer automation and adaptive capabilities, a balanced approach emphasizing collaboration and trust between humans and AI is critical for success. The theme is divided into four subthemes:

- **Automated Task Planning and Scheduling:** AI-driven systems have the potential to stream line task creation and scheduling by automating these processes based on user-defined parameters. This capability significantly reduces manual effort and enhances planning efficiency, freeing up human planners to focus on higher-level decision-making.
- **Continuous Monitoring and Adaptive Adjustments:** One of the possible key utilizations of AI in mission planning is its ability to monitor operations and make real-time adjustments continuously. This will ensure that plans remain current and aligned with mission objectives while enhancing flexibility and resilience. Continuous monitoring will also allow quick responses to unexpected disruptions, minimizing operational risks.
- **Data-Driven Predictions and Intelligent Suggestions:** AI systems excel at analyzing large volumes of historical and real-time data to provide predictive insights and intelligent suggestions. By offering context-aware recommendations, AI can support decision-making processes, optimize mission plans, and improve the accuracy and reliability of outcomes.
- **Balancing AI and Human Oversight:** While AI can offer significant benefits, participants emphasized the importance of maintaining human oversight in decision-making. Acknowledging AI's limitations and potential for errors, participants advocated for a collaborative approach where AI supports, rather than replaces, human planning. By combining AI's analytical strengths with human intuition and expertise, mission planning processes can achieve greater reliability and robustness.

Design

User Types

Two primary user types were identified based on their involvement in mission planning and execution:

Mission Planners:

- **Role:** Mission planners are the architects of mission operations, responsible for creating, managing, and validating mission schedules. They possess extensive expertise in planning, decision-making, and contingency management.
- **Key Needs:** Streamline the planning process, reduce manual workload, and support scenario-based decision-making.
- **Challenges:** Managing complex workflows, ensuring plans are executable, and addressing constraints under time-sensitive conditions.

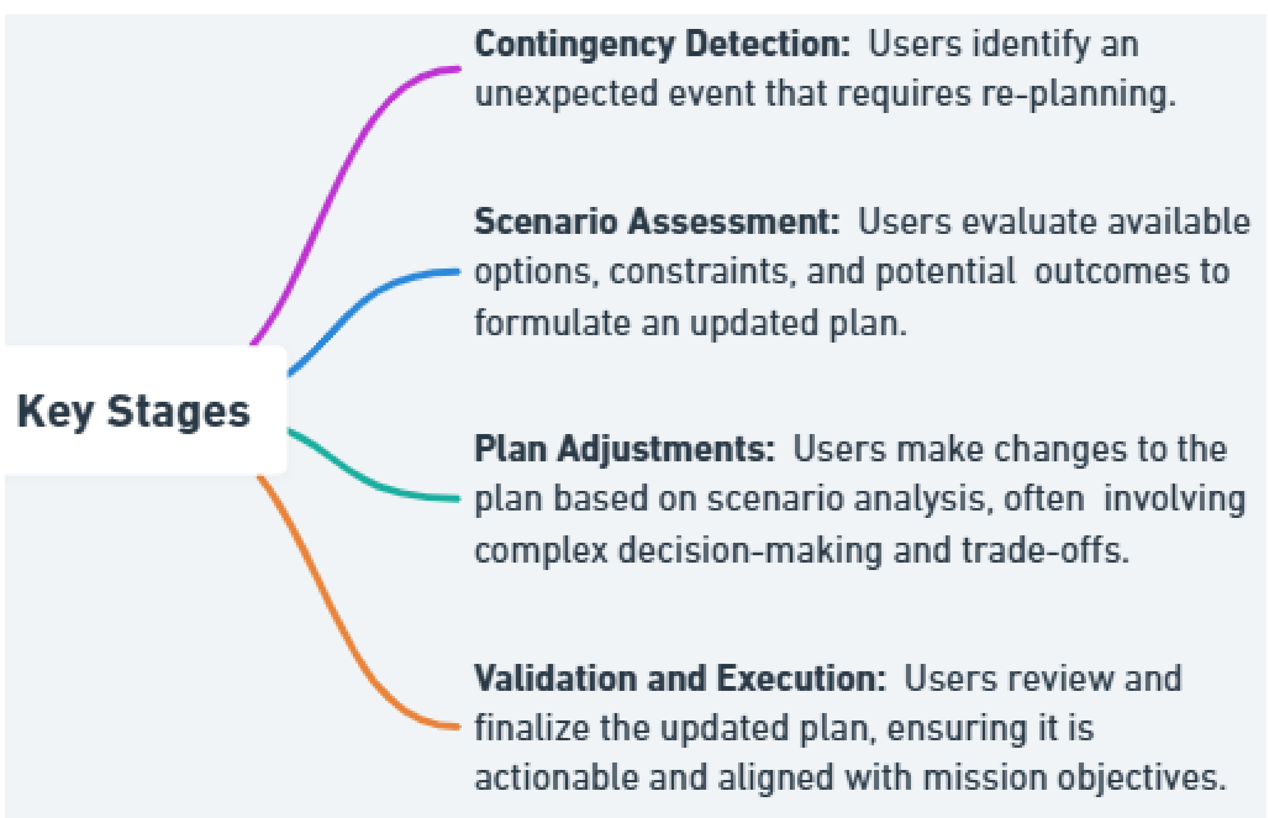
Crew Members:

- **Role:** Crew members are primarily responsible for executing the mission plan. They rely on the schedules and guidelines provided by mission planners and often need to adapt to real-time changes during the mission.
- **Key Needs:** Intuitive and clear plans that allow for adaptability, real-time decision support, and effective plans.
- **Challenges:** Understanding complex plans and adapting to unexpected changes.

User Flow Analysis

Purpose of User Flow Analysis: The user flow analysis aimed to map out the re-planning process and identify opportunities to address user challenges effectively. This process allowed us to:

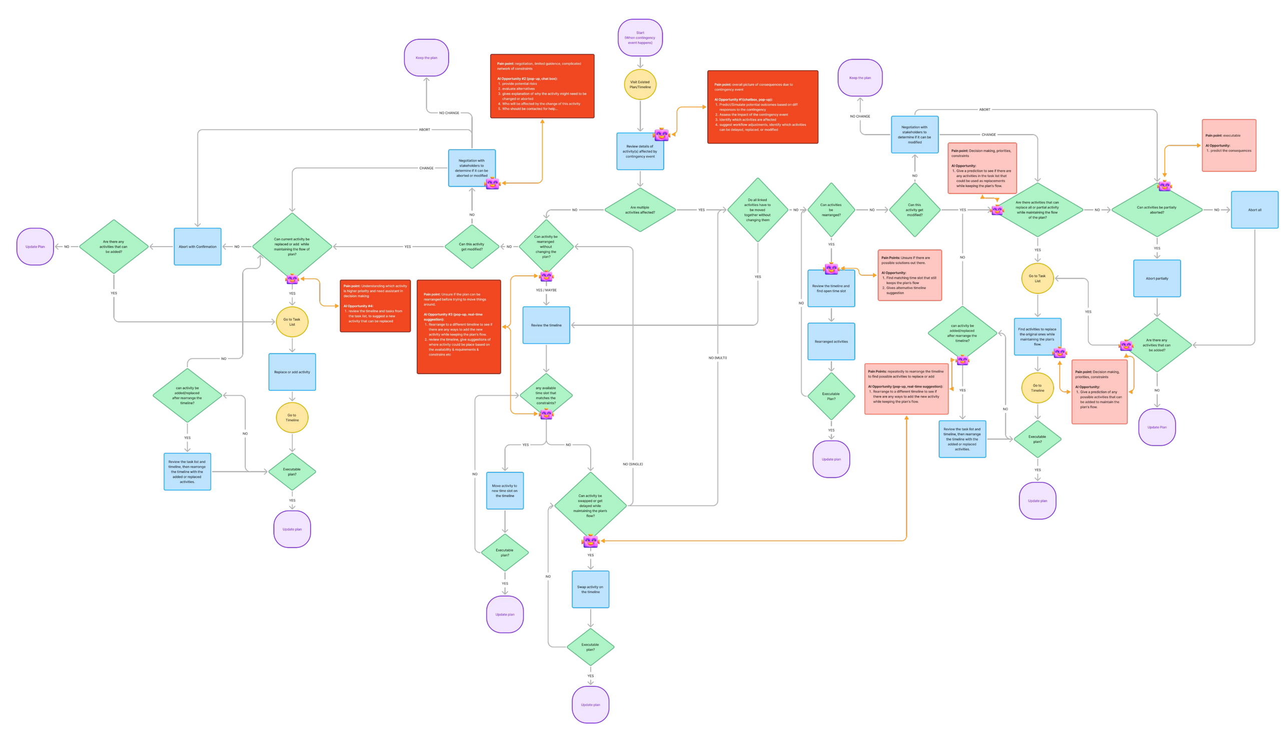
- Break down the workflow into distinct stages and identify where users interact most with the system.
- Highlight moments where users face challenges such as cognitive overload, hesitation, or frustration, particularly during complex decision-making tasks.
- Use insights to inform high-level design directions, ensuring the concepts address the critical needs of mission planners and crew members.



Four key stages

Insights from User Flow Analysis: The user flow analysis revealed that the **scenario assessment** and **plan adjustments** stages were the most critical for user engagement and decision-making. These stages aligned directly with the identified design directions:

- During **scenario assessment**, users will benefit most from *Pathways Exploration* features that will help them to evaluate and compare alternative options.
- In the **plan adjustments** stage, users need support in navigating *Simplified Constraints*, ensuring they can focus on solving problems without being overwhelmed by the information.
- Across all stages, **human and AI collaboration** is essential for creating a system that users can rely on for guidance, support, and adaptability.



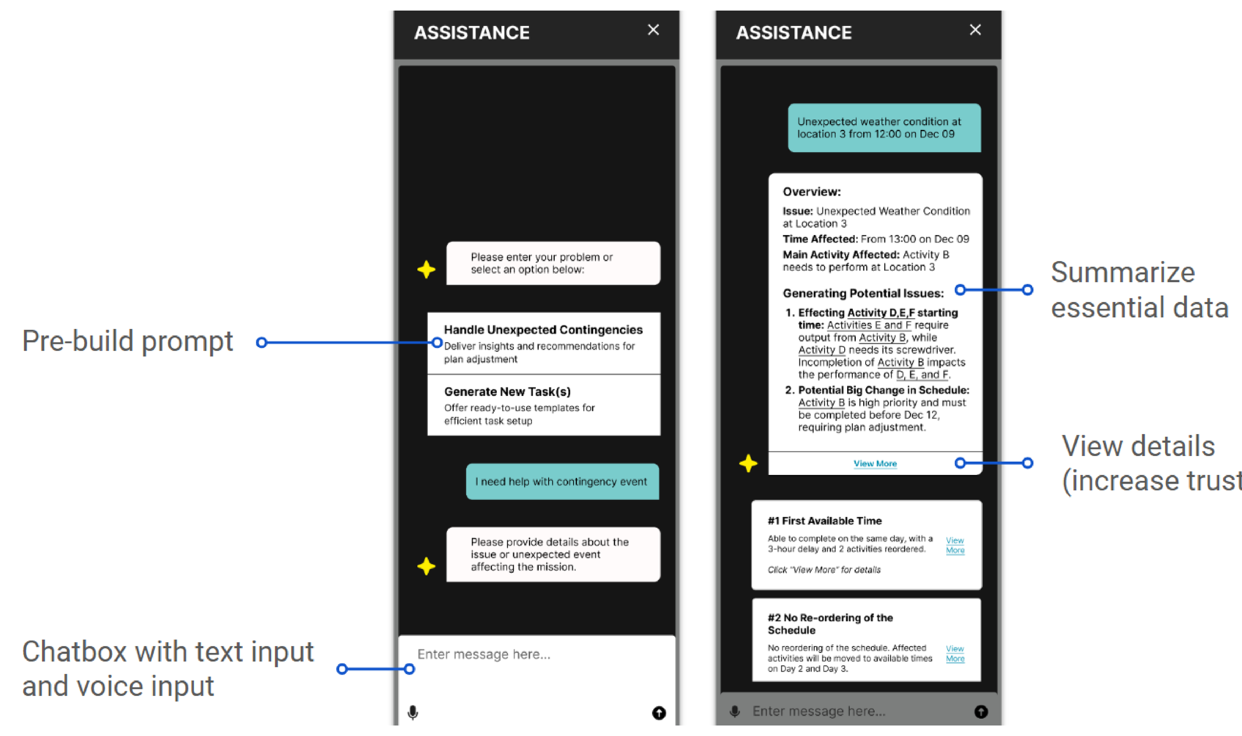
Four key stages in red highlights

Designs

The results of our research and iterative design process culminated in a set of robust features aimed at addressing the critical challenges of mission planning and execution. These features were developed based on user feedback, usability testing, and qualitative insights, ensuring a user-centered approach. Below is a brief overview of the key features integrated into the toolkit:

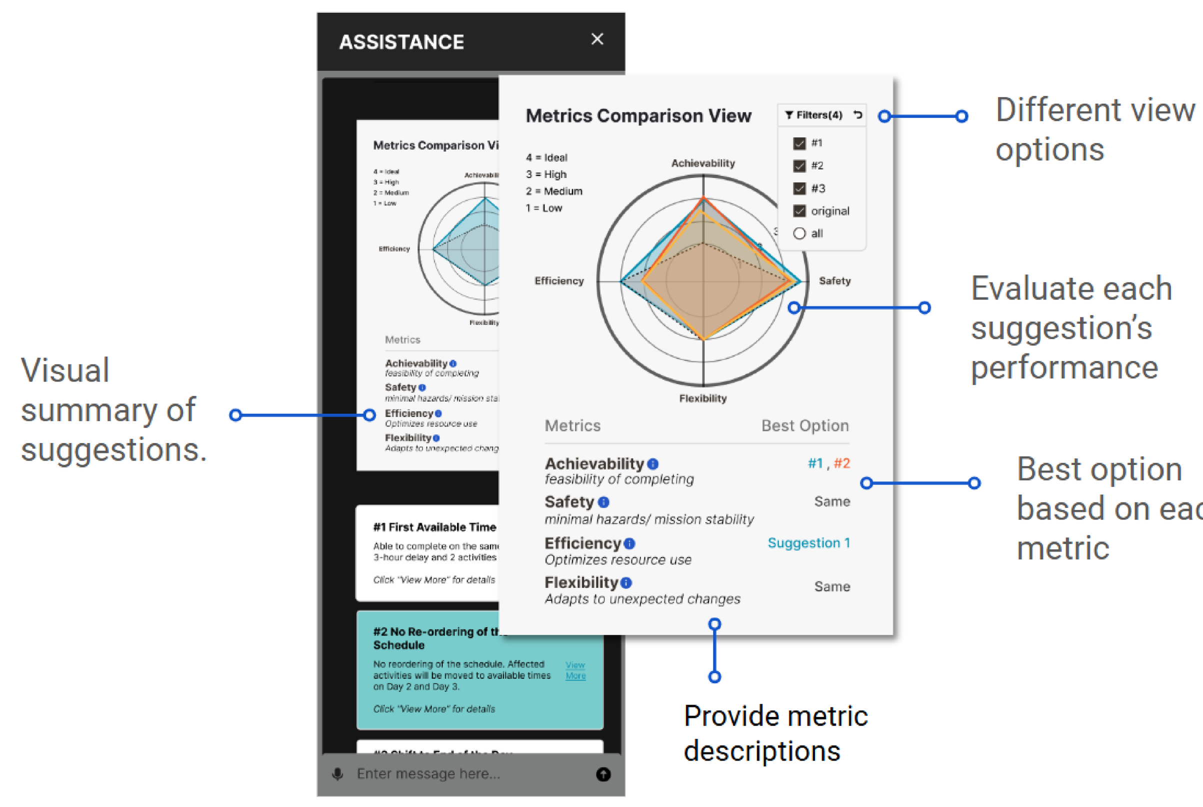
AI Assistance (for Planners)

The AI Assistance feature provides mission planners with decision-making support through pre-built prompts, chat-based interaction, and voice input. This tool allows planners to handle unexpected contingencies and generate new tasks efficiently. Key highlights include:



AI assistance for the planners

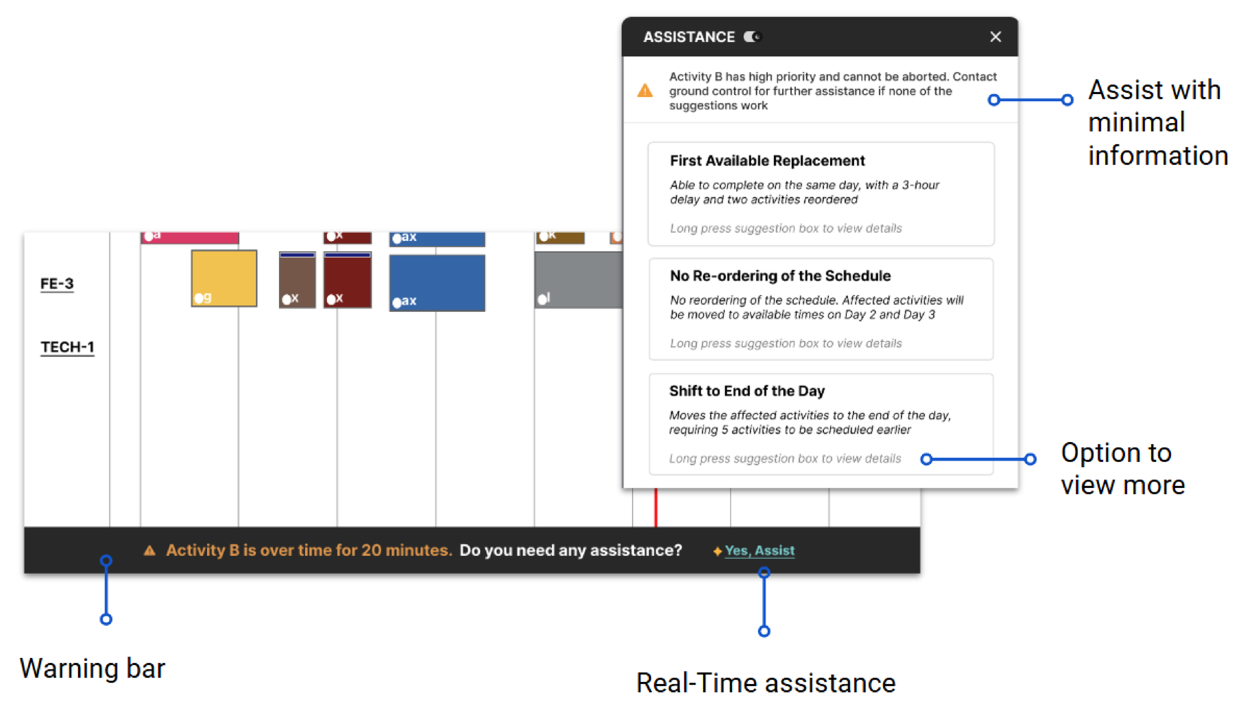
- **Pre-Built Prompts:** Enables quick access to issue-specific prompts, reducing cognitive load.
- **Data Summarization and Details:** Summarizes essential information while offering the option to dive deeper into the context, increasing user trust in the system.
- **Metrics Comparison View:** Provides a visual summary of suggestions, allowing users to evaluate each option based on key performance metrics such as efficiency, flexibility, and safety.



Metrics comparison view

AI Assistance (for Crew)

Designed to assist crew members during mission execution, this feature provides real-time assistance through:



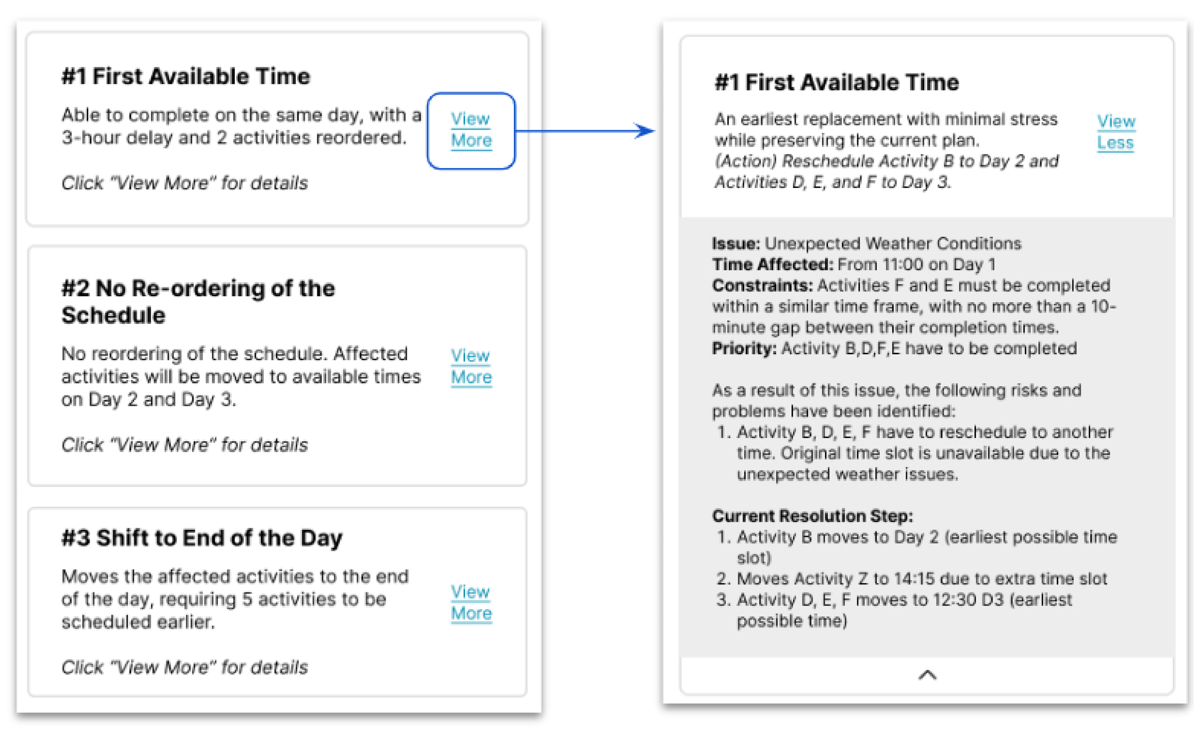
AI Assistance (Crew)

- **Warning Bar:** Alerts crew members when tasks exceed their allocated time, ensuring timely interventions.
- **Clear and Concise Assistance with an Option to Expand:** Offers concise suggestions for resolving issues, with the ability to view more detailed information if required.

Multi-Suggestions

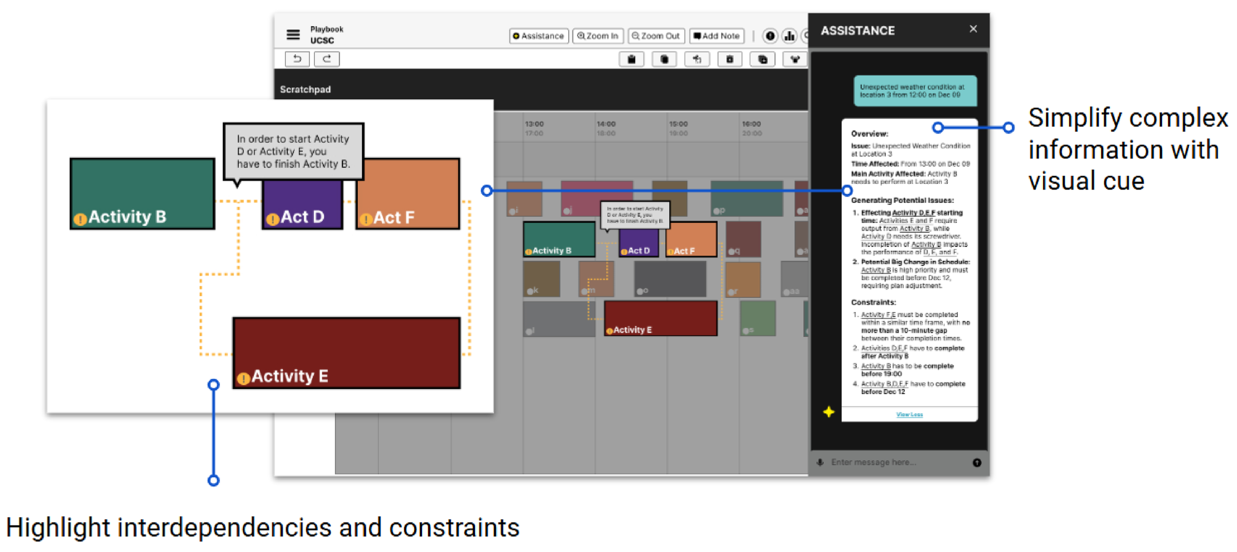
The multi-suggestions feature empowers users to explore multiple options for solving a problem. Each suggestion is ranked and accompanied by detailed information about constraints, impacts, and resolution steps:

- **First Available Time:** Presents the earliest viable replacement for activities while preserving the existing schedule.
- **No Reordering of Schedule:** Highlights non-disruptive alternatives to minimize changes.
- **Detailed Constraints and Steps:** Offers a comprehensive view of how each suggestion impacts the schedule and other activities.



Multi-Suggestions

Timeline Visualization (Hints Feature)



Timeline Visualization (Hints Feature)

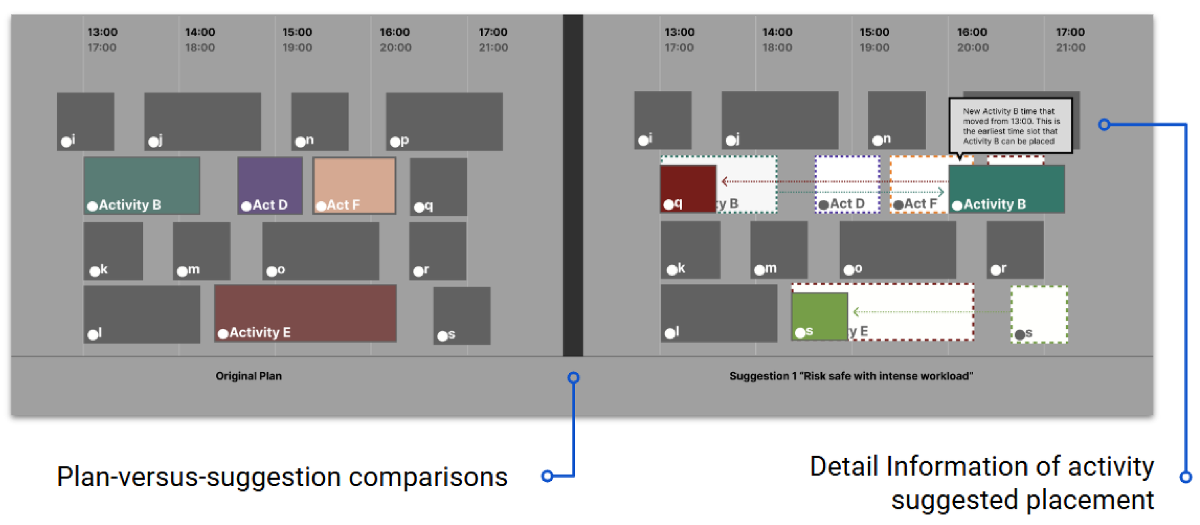
This feature simplifies complex dependencies and constraints through intuitive visual cues:

- **Highlighting Interdependencies:** Displays relationships between activities, helping users understand cascading impacts.
- **Simplifying Information:** Provides clear and concise explanations to improve decision-making during re-planning.

Timeline Visualization - Comparison View

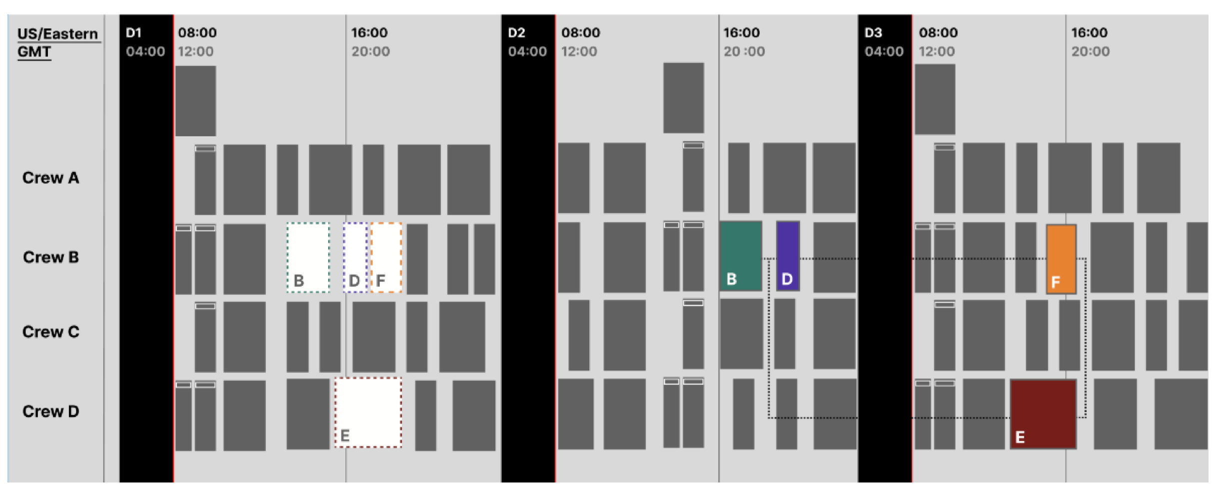
The comparison feature enables users to evaluate the differences between the original plan and suggested changes:

- **Plan vs. Suggestion:** Offers side-by-side visualizations, making it easier to assess the impact of proposed adjustments.
- **Detailing Suggestions:** Provides detailed information about the suggested placement of activities.



Timeline Visualization (Comparison View)

Timeline Visualization - Cascading Overview



Timeline Visualization (Cascading Overview)

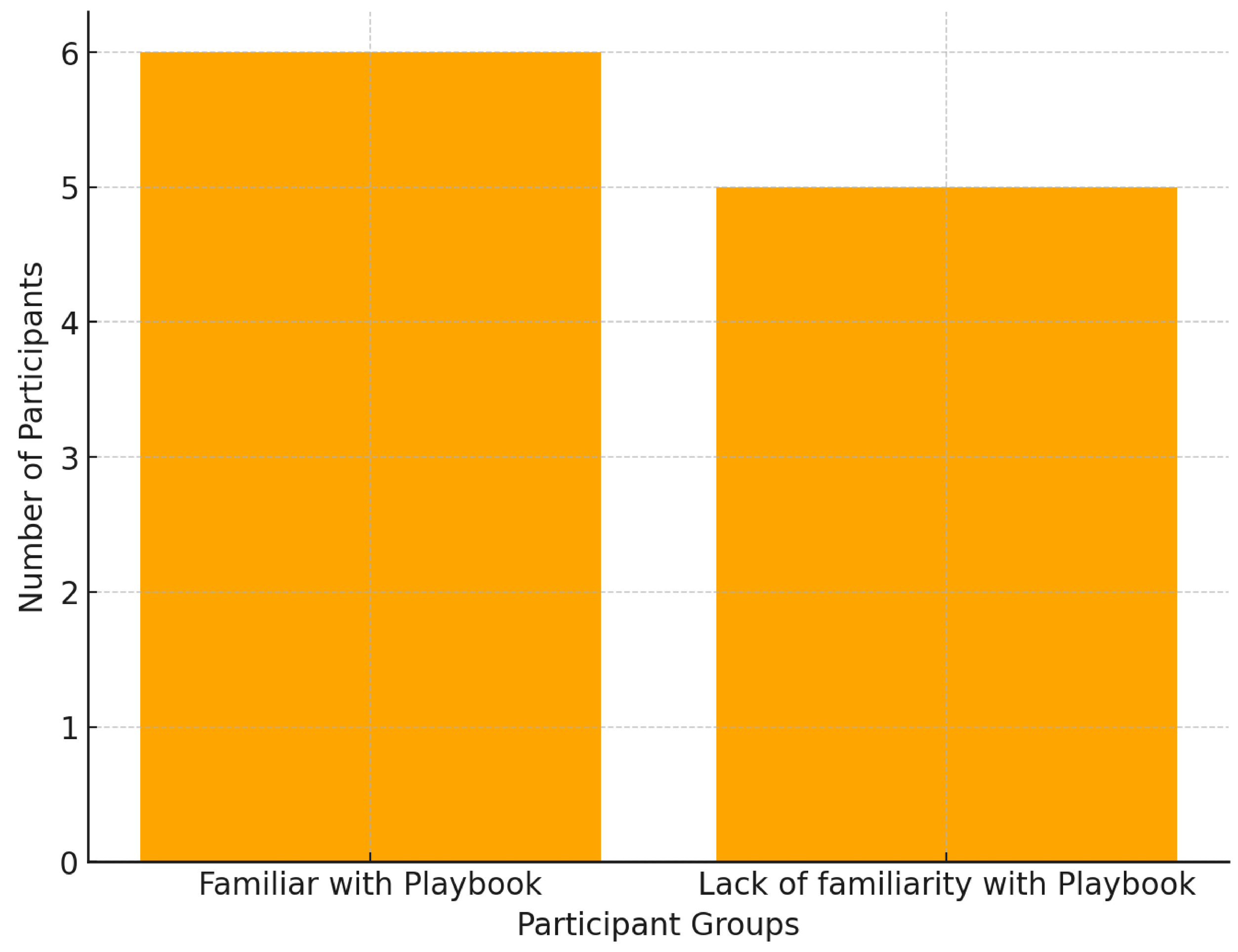
This feature provides a comprehensive view of cascading effects caused by activity delays or changes:

- **Multi-Day Overview:** Displays how changes on one day impact subsequent days and activities.
- **Simplified Navigation:** Highlights critical changes to reduce cognitive load and improve situational awareness.

Testing

Usability sessions

We conducted usability sessions with a diverse pool of participants to evaluate the effectiveness of our Lo-Fi, Mid-Fi, and Hi-Fi designs. All participants were from NASA, representing a mix of those familiar with the Playbook software and those who lacked prior familiarity. This balanced participant pool allowed us to capture a wide range of perspectives and usability feedback from the crew as well as the planner's point of view.



Participant Pool

Iterative Feedback and Design Refinement

The feedback gathered during these sessions played a critical role in shaping the designs:

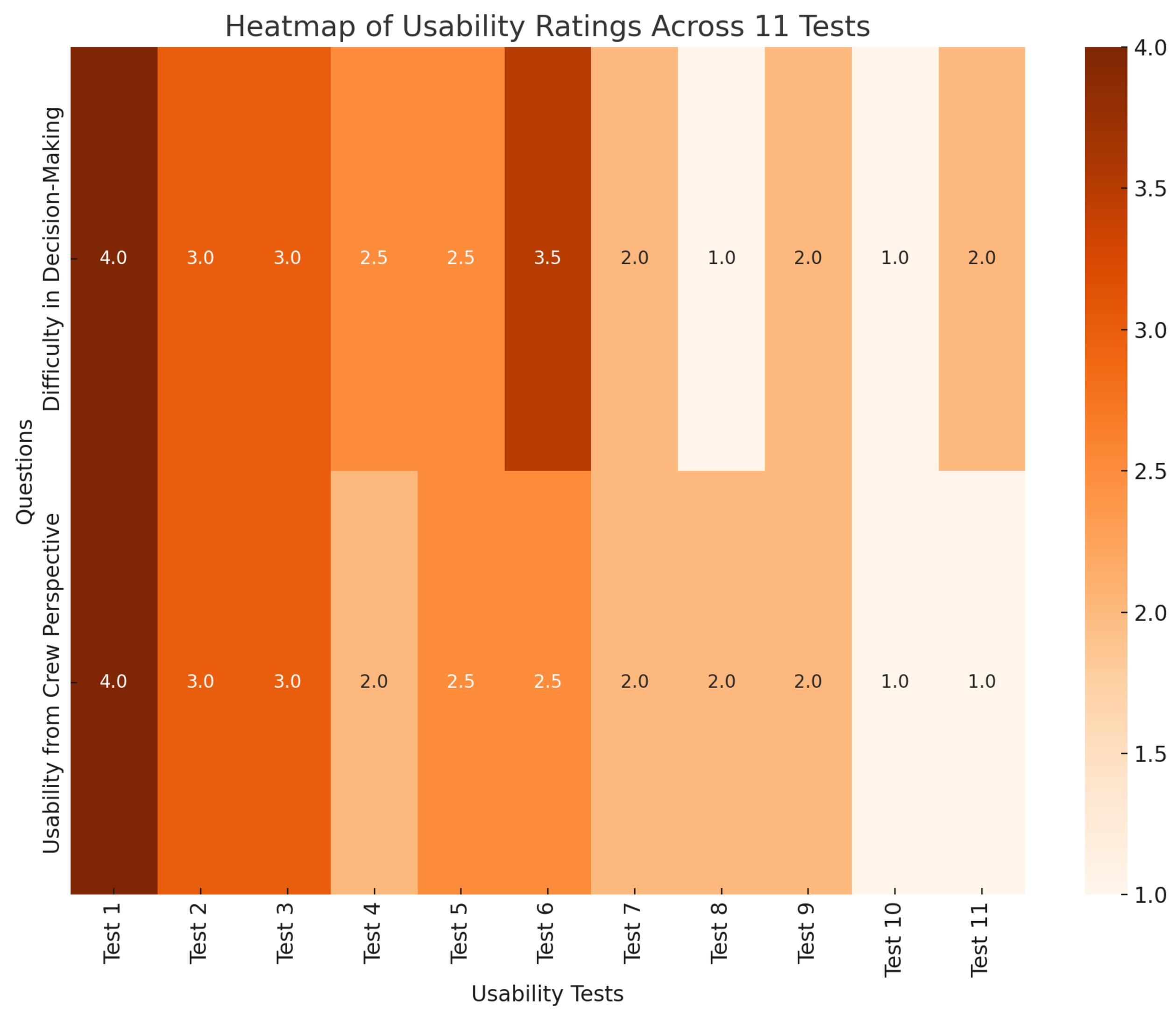
- **Familiar with Playbook:** Highlighted inefficiencies in workflows and provided detailed feedback on how to improve the integration of features like *cascading overviews and timeline visualizations*.
- **Not familiar with Playbook:** Identified areas where the designs lacked clarity or introduced unnecessary complexity, helping us refine the user interface for better accessibility, especially from the crew's point of view.

Quantitative Results

To evaluate the effectiveness and usability of the designs, a quantitative analysis was conducted based on usability ratings collected across 11 testing sessions. Participants provided feedback on two key metrics, rated on a scale from 1 to 4: The following key aspects were analyzed across the usability tests:

1. **Usability from Crew Perspective:** How intuitive and user-friendly the designs were for crew members.
2. **Difficulty in Decision-Making:** The level of difficulty participants faced while making decisions using the tools (with 4 indicating very difficult and 1 being very easy).

The heatmap illustrates the variation in ratings across the 11 tests:



Usability Ratings

Findings

1. **Usability from Crew Perspective:**
   - **Initial Tests:** Usability ratings ranged from 4.0—3.0 during Tests 1–3, indicating that the designs were not intuitive for crew members and required significant effort to navigate.
   - **Final Tests:** Ratings dropped to 1.0 in Tests 10 and 11, reflecting substantial improvements in the design's accessibility and user-friendliness after multiple iterations.
2. **Difficulty in Decision-Making:**
   - **Challenges in Initial Tests:** Early tests (Tests 1–6) recorded moderate to high difficulty ratings (2.5–3.5), revealing that participants struggled with the decision-making workflows and found certain tasks overly complex.
   - **Reduced Difficulty in Later Tests:** Tests 8 and 10 scored 1.0, demonstrating significant reductions in decision-making complexity, achieved by providing clearer guidance and simplifying workflows.

Qualitative Analysis

In addition to the two-point quantitative evaluations, we conducted a qualitative analysis of participant transcripts to gain in-depth insights into user expectations, pain points, and overall confidence in interacting with the proposed designs. This analysis provided a richer understanding of user behaviors, preferences, and challenges that quantitative metrics alone could not capture.

Usability Analysis

Methodology

The qualitative analysis involved systematically coding participant feedback during usability sessions. Insights were categorized into three main themes:

- **Red: User Uncertainty or Lack of Confidence**
- **Blue: User Expectations**
- **Green: User Confidence**

Each theme was analyzed to identify recurring patterns and specific areas for improvement in the designs. The findings were further supported by relevant examples and contextual details from user interactions.

Findings

User Uncertainty or Lack of Confidence (Red)

Participants frequently expressed uncertainty and confusion during early iterations of the designs. Key issues included:

- **Terminology Confusion:** The use of terms such as *"contingency event"* and *"assistant prompts"* did not align with user expectations, leading to hesitation and difficulty in proceeding with tasks.
- **Complex Visualizations:** Features like the timeline visualization were described as overwhelming due to unclear color-coding and numbering systems, making it difficult to interpret cascading impacts or identify dependencies.
- **Risk Overview Challenges:** The risk overview feature was perceived as cluttered and lacking clarity, with participants struggling to locate actionable information quickly.

For example, one participant noted:

> *"The numbering system used in the assistant's response was confusing—it wasn't clear without hovering over it what those numbers represented."*

These findings highlighted the need for simplification and better contextual explanations in the designs.

User Expectations (Blue)

Participants provided valuable insights into what they expected from the features to make them more effective and user-friendly:

- **Proactive Assistance:** Users desired a more proactive AI assistant that could recognize potential issues (e.g., weather-related problems) and suggest solutions without requiring user initiation.
- **Simplified Overview and Visualization:** Participants expressed a need for clean and focused visual representations that highlighted only directly relevant activities or cascading effects.
- **Streamlined Processes:** Many users expected quicker workflows with fewer steps for common tasks like rescheduling or adjusting timelines.

For instance, a participant mentioned:

> *"I want to see a simplified view that shows only the directly impacted activities and how they connect to others. Too much information makes it harder to focus."*

These expectations informed several iterative improvements to the design, such as reducing manual input requirements and highlighting essential details.

User Confidence (Green)

The qualitative feedback also revealed areas where users demonstrated confidence and ease of interaction, particularly in later iterations:

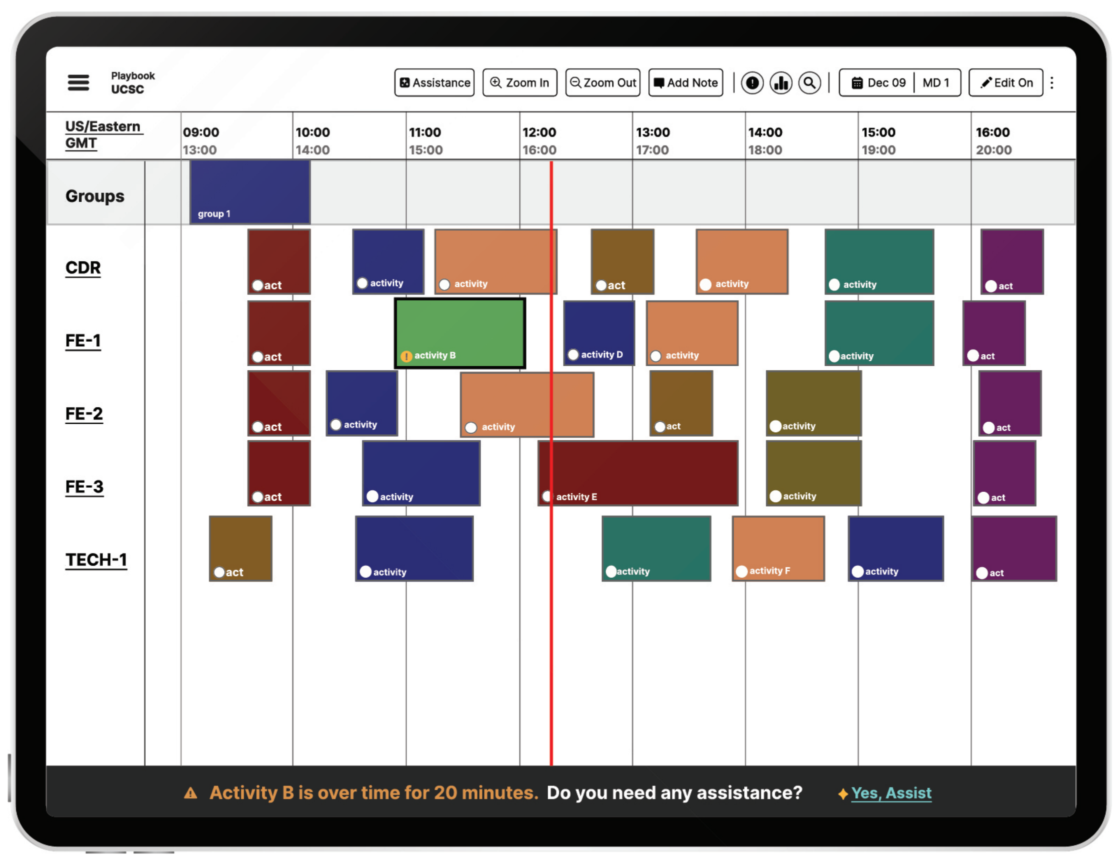
- **Chat-Like Interface for AI Assistance:** Participants found the chat-based AI assistant intuitive and approachable, providing familiarity and reducing cognitive load. However, confidence decreased when the assistant lacked contextual clarity or generated generic suggestions.
- **Improved Comparison Features:** The side-by-side timeline comparison was well-received, as it enabled users to evaluate original and suggested plans more effectively.
- **Refined Sliding Bar for Suggestions:** Users appreciated features like the sliding bar for accessing additional details, which made it easier to navigate through options without overwhelming the interface.

One participant remarked:

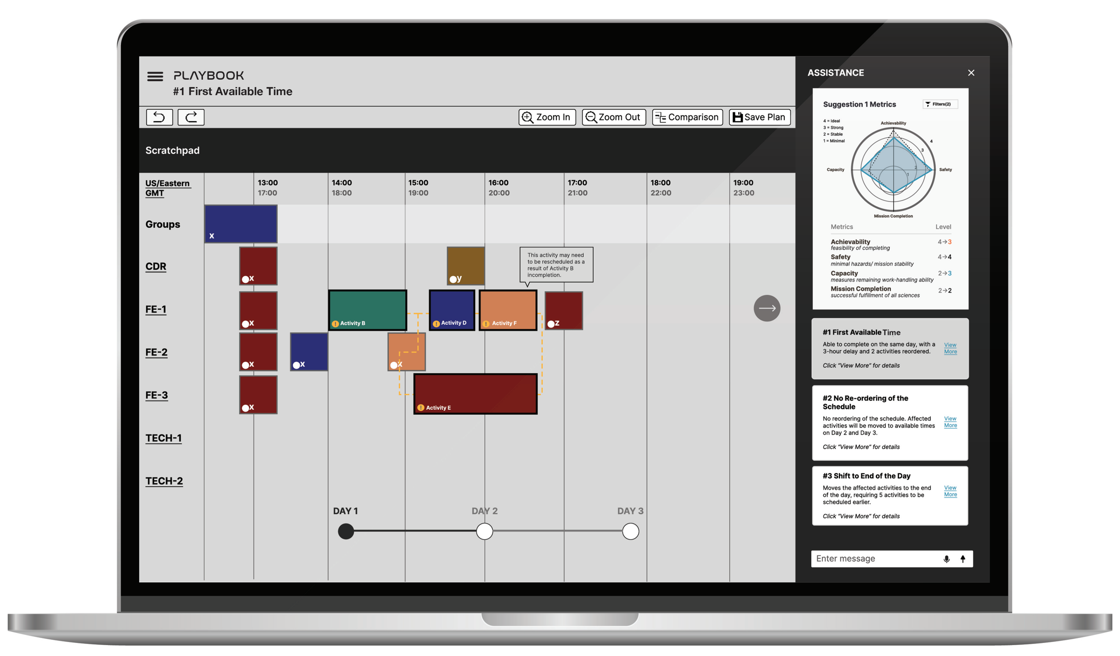
> *"The comparison view was relevant and interesting—it allowed me to see the changes clearly and understand how they might impact the overall schedule."*

These findings validated many of the refinements made during the iterative design process. The qualitative analysis was instrumental in identifying nuanced user challenges and expectations that informed the iterative refinement of the designs. By addressing the themes of user uncertainty, expectations, and confidence, the final designs were able to achieve greater clarity, usability, and effectiveness in meeting the needs of mission planners and crew members.

Discussion



Interface for Crew



Interface for Planners

The features developed in this AI-driven mission planning and execution toolkit signify a transformative shift in managing complex and high-stakes operations. By leveraging user-centered design principles and iterative usability feedback, the toolkit addresses critical challenges faced by planners and crew members under contingency scenarios. Traditional mission planning often relies on highly manual workflows, leading to delays and potential errors in decision-making during crises. This toolkit overcomes those limitations by introducing AI-driven solutions that enhance the adaptability, efficiency, and clarity of planning processes. Features such as *AI assistance, multi-suggestions, and timeline visualizations* ensure that users are equipped with actionable insights tailored to their roles and the situational demands of the mission.

For mission planners, the *AI assistance* feature represents a proactive partner in decision-making. The tool not only identifies potential disruptions but also offers ranked alternatives based on predefined metrics like *efficiency, flexibility, and safety.* This level of transparency fosters trust in the AI's recommendations, enabling planners to make informed decisions with confidence. By reducing the cognitive load required to interpret and evaluate cascading impacts of delays, features like the *cascading overview and metrics comparison view* ensure that even the most complex scenarios can be navigated with ease. Additionally, *multi-suggestion* functionality provides flexibility, allowing planners to choose the most suitable resolution based on mission priorities and constraints. These features collectively redefine how planners engage with uncertainty, empowering them to focus on strategic goals rather than operational bottlenecks.

For crew members, the toolkit introduces *real-time assistance* designed to deliver timely and concise support. Features such as the *warning bar* and minimal intervention prompts ensure that the crew can respond effectively to time-sensitive disruptions without being overwhelmed by excessive details. By offering quick resolutions and the option to explore more detailed suggestions when needed, the system strikes a balance between simplicity and depth. This is particularly valuable in environments where crew members are isolated and must make autonomous decisions with limited support from ground control. The seamless integration of AI-driven insights into their workflows bridges the gap between planning and execution, ensuring that contingency scenarios are managed with minimal disruption to mission objectives.

The visualization features in the toolkit serve as a cornerstone for enhancing situational awareness and collaboration between planners and crew members. The *timeline visualization feature*, including the *hints, comparison, and cascading overview functionalities,* simplify the complexity of task dependencies and constraints. For instance, the ability to visually compare the original plan with suggested changes allows users to evaluate the trade-offs of each adjustment, ensuring alignment with mission goals while minimizing unnecessary disruptions. The cascading overview, on the other hand, highlights the ripple effects of task delays across multiple days, providing a comprehensive understanding of how a single decision can impact the broader mission timeline. These tools not only streamline decision-making but also enhance collaboration by ensuring that both planners and crew members operate with a shared understanding of mission priorities and constraints.

Looking ahead, the features developed in this toolkit are poised to have far-reaching implications beyond space exploration. In an era where operational complexity continues to grow across various industries, the ability to integrate AI-driven tools for adaptive planning and decision-making is becoming increasingly essential. The principles of this toolkit can be applied to fields such as disaster management, healthcare operations, and military logistics, where the stakes are high and timely interventions are critical. By fostering a collaborative relationship between humans and AI, this toolkit exemplifies how technology can augment human capabilities, ensuring that planning and execution processes are not only efficient but also resilient in the face of uncertainty.

Limitations and Future Work

Limitations

While this project introduced a robust AI-driven toolkit for mission planning and execution, certain limitations impacted the development process and final outcomes. These include:

1. **Limited Access to the Playbook Tool:**
   As Playbook served as the primary platform for this project, restricted access to its full functionality and capabilities posed challenges in integrating and testing the proposed features seamlessly. This limitation constrained our ability to simulate real-world mission planning scenarios fully.
2. **Restricted Access to End-Users:**
   Direct interaction with end-users, such as astronauts and mission controllers, was not feasible during this project. Consequently, the feedback relied heavily on indirect stakeholders, which may not fully capture the specific needs and preferences of the primary users.
3. **Assumed AI Capabilities:**
   The design process treated AI capabilities as assumptions, excluding considerations of current technical limitations. While this approach allowed for conceptual exploration of features, it may require significant adaptation when aligning with actual AI performance and technical feasibility.

These limitations underscore areas for improvement in future iterations, particularly in engaging with end-users and aligning designs with real-world constraints.

Future Work

The outcomes of this project open several avenues for future exploration and refinement. Key directions for future work include:

1. **Conducting Usability Testing with Crew:**
   Engaging astronauts and mission controllers in usability testing will provide first-hand feedback, enabling the refinement of features based on real-world use cases. This will help bridge the gap between conceptual designs and practical applications.
2. **Evaluating Features Across Devices:**
   Testing the toolkit on various devices, such as mobile phones, tablets, and other small-form-factor devices, will ensure that the features remain accessible and functional across different platforms. This is particularly important for scenarios where users may not have access to full desktop interfaces.
3. **Investigating Alternative Approaches to Metrics:**
   Exploring alternative methods for calculating and presenting relevant metrics, such as efficiency and safety, will improve the clarity and usability of the Metrics Comparison View. This could include experimenting with visual representations or simplifying complex data into actionable insights.
4. **Understanding AI Capabilities and Refining Designs:**
   As AI technologies continue to evolve, revisiting the designs to align with current capabilities will be crucial. This includes refining features like multi-suggestions and real-time assistance to leverage advancements in AI-driven prediction, decision-making, and adaptability.

Acknowledgments

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