Crew Autonomy Through Self-Scheduling: Scheduling Performance Pilot Study

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Introduction

- Crew scheduling for International Space Station remains a human-driven planning task by Ops Planners
- As NASA considers long-duration exploration missions the shift of some planning and scheduling tasks from Ops planners to crew members are required
  - Time delay
  - Crew autonomy
- This study aimed to evaluate non-expert human performance for the task of planning & scheduling
  - Plan complexity
  - Scheduling task difficulty
  - Plan constraints

Background

- Aboard the ISS, astronauts are tasked with complex and demanding daily schedules
- Daily schedules for missions are usually developed up to six months in advance by planning specialists (Ops planners)
- Ops planners have years of experience creating a schedule that meets all of the program's requirements, spacecraft constraints, and crew member availability and ability (Barreiro, Jones, & schaffer, 2009)
    - Astronauts do not have scheduling experience
    - They do not have insight to the numerous constraints and requirements that need to be met
- Self-scheduling needs to be supported for future spaceflight
    - Violation-free timelines
    - Without imposing additional workload

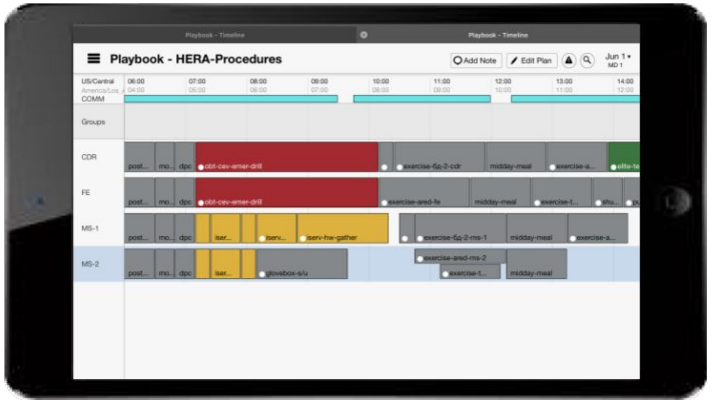
Playbook

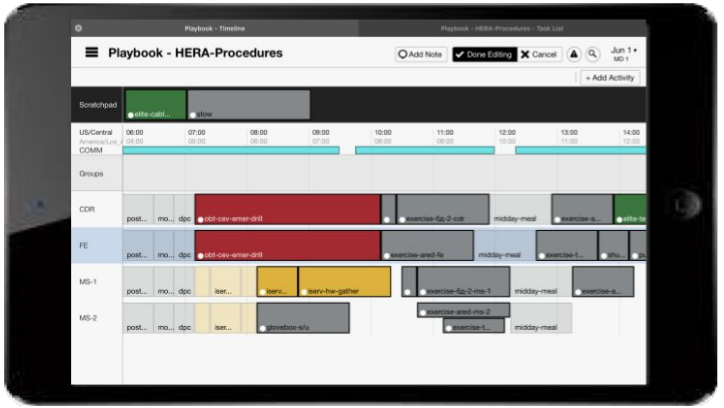
- Playbook is a next generation, easy-to-use, mobile, web-based planning tool
- Used in dozens of Earth analog missions
- Built upon space operation heritage tools for space exploration
- Allows astronauts to complete lightweight plant editing & execute their assigned activities



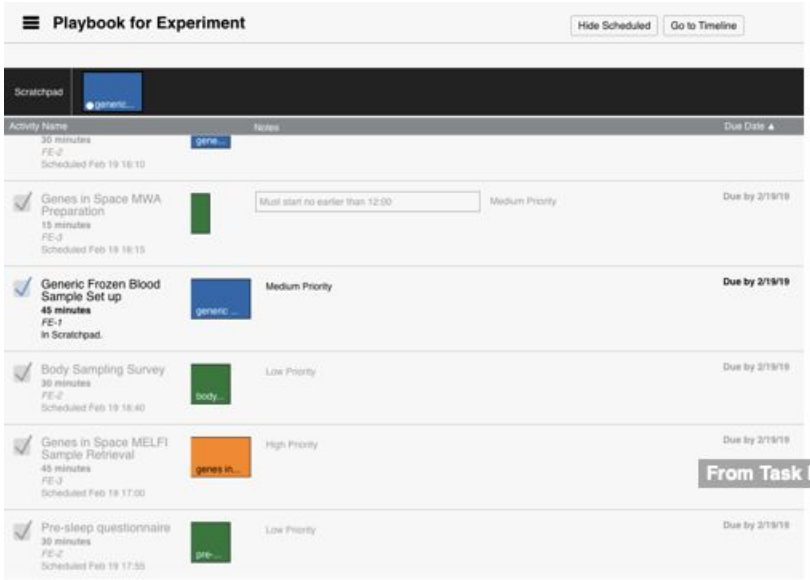
Playbook Timeline

- Crewmember bands
- Activities, activity details
- Visualized constraints
  - Claimables
  - Time-of-day requirements
  - Resource constraints
  - Temporal relationships
- Violations
  - If constraints are not met
- Editing mode

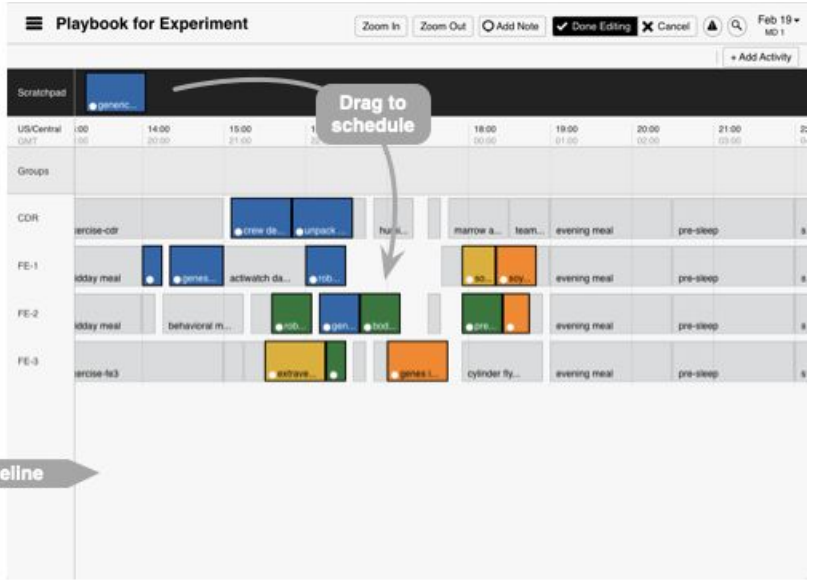




Scheduling in Playbook



From Task List to Timeline



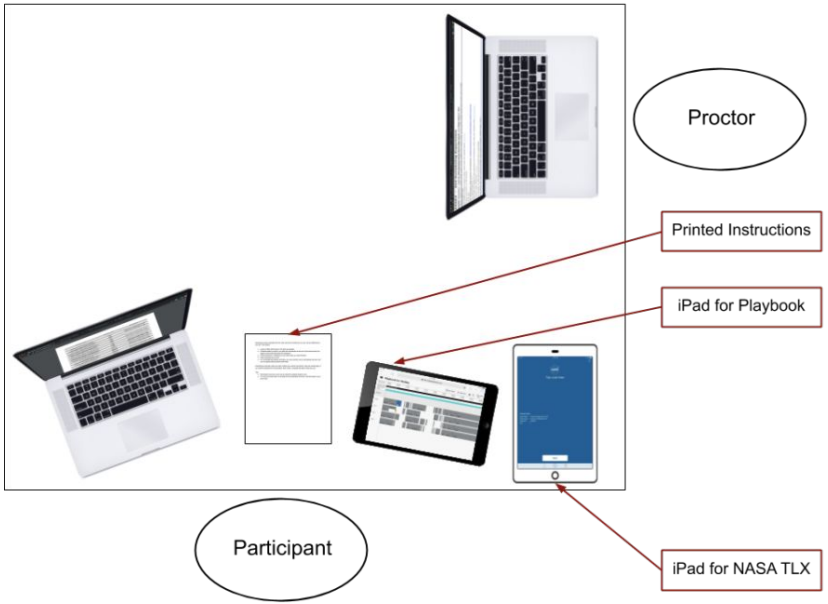
Experiment Design

- 3 x 3 within subjects design
  - Number of activities to schedule (12, 24, 36)
  - Percentage of activities with constraints (0%, 33%, 66%)
- Efficiency
  - Time on task
  - Time to resolve violations
- Plan effectiveness
  - Number of violations
  - Number of activities left unscheduled
  - Margin (white space left in the plan)
- Priority level of activities left unscheduled
- Situation Awareness (SPAM)
- Workload (NASA TLX)

Constraints	Activities		
	12	24	36
0%	act12-con0	act24-con0	act36-con0
33%	act12-con33	act24-con33	act36-con33
66%	act12-con66	act24-con066	act36-con66

Procedure

- 9 playbook-naive and non-expert planners were recruited
- Sign consent form
  - Complete demographic questionnaire
- Playbook training
- Training plans (4)
- Experimental trials (9)
  - 2 Situation awareness questions (SPAM)
  - NASA TLX (Hart & Staveland, 1988)
- System trust scale (Jian, 2000)
- User Experience Questionnaire



Laboratory Experiment Configuration

Task

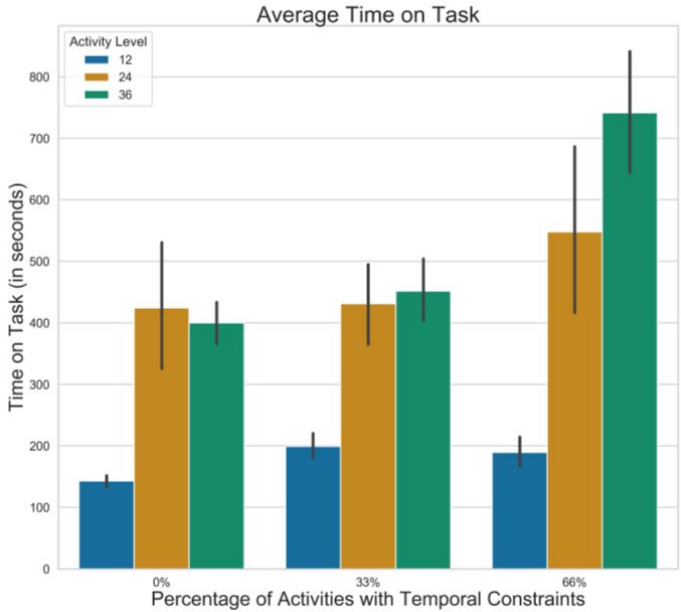
- Scheduled as many activities from the Task List to the Timeline as quickly as you can
- Schedule by priority
  - Activities left unscheduled should not be a higher priority than an activity that is scheduled
  - The task was designed so that no participant could schedule all activities
- Verbally inform the researcher that you have completed the task
- Participants were given only 1 type of constraint per activity, and one constraint per activity
  - In the real world, an activity could have multiple constraints, and multiple types of constraints
  - We used an earliest/latest constraint
  - “This activity must start no earlier than 1400 and end no later than 1700”
- Do not leave any violations in the plan when you are finished
- All participants completed all 9 trials in the same order

Results

- Observed a linear relationship between time on task and each independent variable
  - Potential order effects
- An observed compounding effect on time on task when considering both number of activities and percentage of constraints
- More violations were created when there were more activities with constraints to schedule
  - More opportunities to create violations
  - All participants left no violations in their plans
- Participants experienced higher workload when there were more activities to schedule as well as more constrained activities to schedule

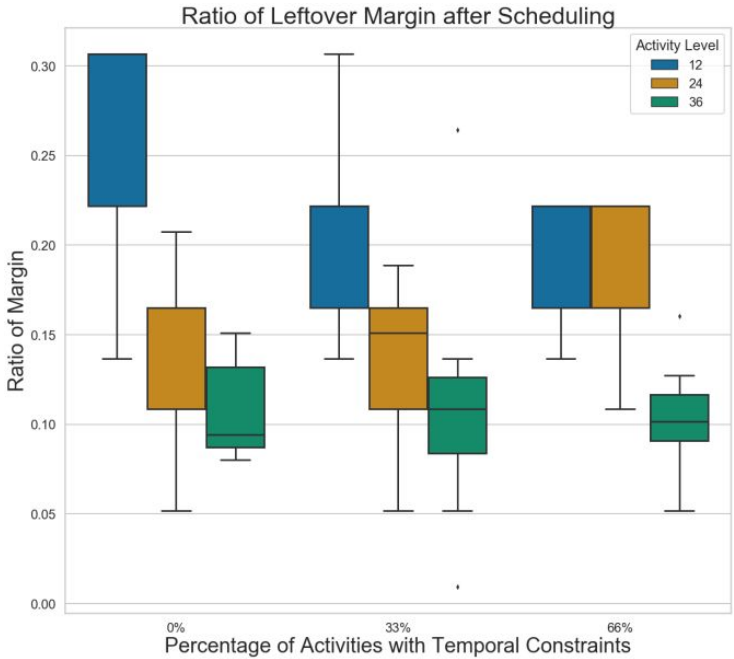
Efficiency

- Time on Task
  - Friedman's ANOVA was conducted
  - The results show there was a significant effect on increasing time on task $F(2.173, 19.553)=6.034$, $p=.008$.
- Time to resolve violations
  - Average across all conditions were 8.14 seconds
  - No observed trend



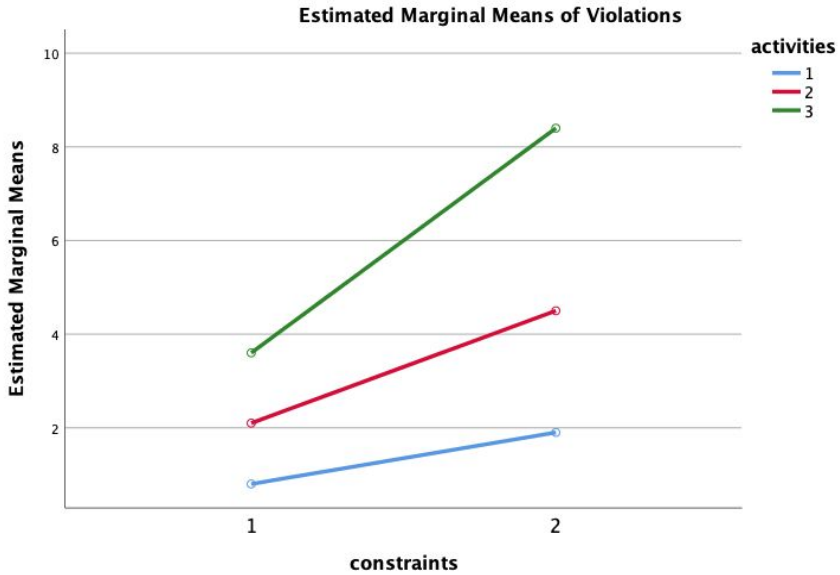
Plan Effectiveness

- Margin
  - The amount of available ‘white space’ in the finished plan(i.e., the sum of the time between the scheduled activities)
  - Calculated as a ratio between initial white space and the final white space
  - More white space left in 12 activity conditions
  - Not a good metric for plan effectiveness
- Violations
  - No participants left any violations at the end of each trial



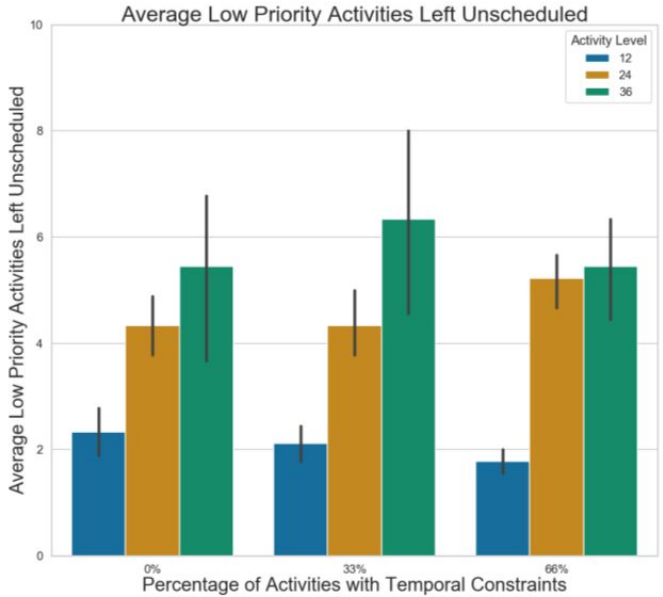
Violations created over time

- Only observed 33% and 66% constrained conditions
- Repeated measures Friedman ANOVA was conducted
  - Results show that the number of activities had a significant effect on the number of violations created $F(1.124, 10.117)=9.234$, $p=.011$, while interactivity was not significant $F(1.275, 11.475)=1.505$, $p=.253$.
  - The larger percentage of constraints, the more violations that were created



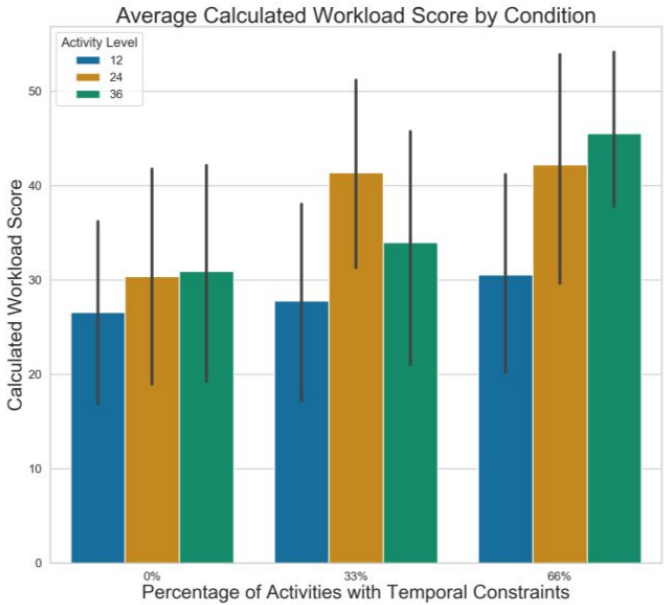
Priority level of activities left unscheduled

- All participants scheduled all High Priority level activities were scheduled for all trials
- Participants who left Medium Priority activities unscheduled on average left less than 1 activity
- Low priority activities left unscheduled were analyzed
    - Wilcoxon test were conducted per condition with a Bonferroni correction
    - Approached significance between 12 & 36 activity conditions
    - No significant difference between the percentage of constraints within each activity level



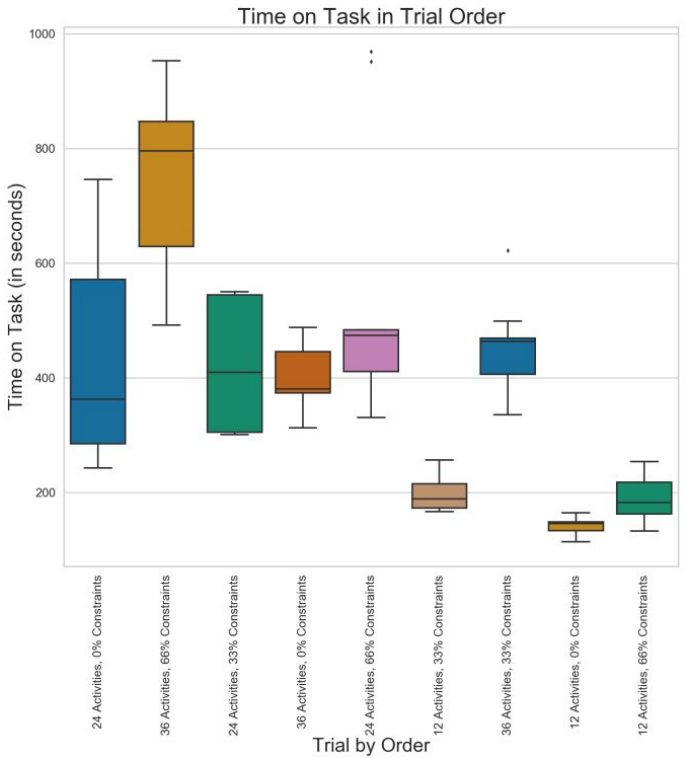
Workload

- Pairwise data was not collected
- An average workload score was calculated (Moroney, et al., 1992)
- Repeated measures ANOVA was conducted
    - Significant main effect of the number of activities was found ($F(2,16)=5.97$, $p<0.05$). Pairwise comparisons revealed that, on average, workload was significantly lower in conditions with 12 activities than 36 activities ($p<0.05$).
    - There was also a significant main effect of the number of tasks with constraints on average reported workload ($F(2,16)=17.36$, $p<.001$). Pairwise comparisons revealed that on average, workload was significantly lower in conditions with 0% activity constraints than 66% activity constraints ($p<0.005$)
- No significant interactions effects were identified



Discussion

- As percentage of constraints increased, time on task increased
- When considering both percentage of constraints and number of activities, there was an observed compounding effect on increasing time on task
    - Possible order effects
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Future Research

- In early 2020, the team conducted subject matter expert interviews with former spaceflight planners and controllers
- This has given us more validation in the next iteration of our experiment
- In 2020 we started running the next planning & scheduling experiment remotely
  - Aiming to collect 32 participant data
  - Different types of constraints
- Continue to explore how self-scheduling can be best provided to crew members
  - Considerations for the development of scheduling aids

References

- Barreiro, Javier & Jones, Grailing & Schaffer, Steve. (2009). Peer-to-peer planning for space mission control. IEEE Aerospace Conference Proceedings. 1 - 9. 10.1109/AERO.2009.4839709.
- Moroney, W., Biers, D., Eggemeier, F., & Mitchell, J. (1992). A comparison of two scoring procedures with the NASA task load index in a simulated flight task. *Proceedings of the IEEE 1992 National Aerospace and Electronics Conference@m_NAECON 1992*. doi:10.1109/naecon.1992.220513

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