

# Mixed Integer Linear Programming in Planning



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## Overview

Traditional planning methods often involve human interaction, but with increasing communication delays as humans venture further from Earth new methods of planning must be derived. Activity Planning with Resources for the Exploration of Space (APRES) is a next generation mission planning system for ground operations of spacecraft, rovers, and landers. It operates using a mixed-initiative mission plan editing system with automation support for resource modeling, constraint specification, violation detection, and violation explanation. Mixed-integer linear programming (MILP) is used to optimize a linear planning problem, or model, consisting of integers and non-discrete intervals. Using MILP in APRES allows for flexibility in resource and temporal intervals used in real-world planning applications.

## Objectives

There are two objectives associated with this work. The first is to verify that a plan is possible by inputting a model to a mixed-integer linear program solver. There, a constraint checker verifies the plan and suggests the best solution from a set of optimal solutions. The second objective is to output the solution with only the desired information in an easily readable format.

## Discussion

APRES receives the initial, human created plan and verifies if the plan does or does not meet the applicable constraints for actions included in that model. If the plan does not meet the necessary constraints, the program will generate a recommended plan with a modified timeline. Currently, the Java interface for Solving Constraint Integer Programs (SCIP) is being used to solve plans.

Input involves actions and their respective temporal constraints, causal links, threats, and mutexes. Output displays informative results to the user in the format object start/end, time in seconds, time in hours, minutes, seconds, and objective value.

```
SCIP> read D:\Demo2-pan2.zpl
original problem has 155 variables (121 bin, 0 int, 0 impl, 34 cont) and 195 constraints

SCIP> optimize
presolving (8 rounds: 8 fast, 4 medium, 4 exhaustive):
130 deleted vars, 157 deleted constraints, 0 added constraints, 81 tightened bounds,
0 added holes, 27 changed sides, 0 changed coefficients
117 implications, 16 cliques
presolved problem has 25 variables (13 bin, 0 int, 0 impl, 12 cont) and 38 constraints
32 constraints of type <linear>
6 constraints of type <nonlinear>
PresolvingTime: 0.00

SCIP Status : problem is solved [optimal solution found]
Solving Time (sec): 0.00
Solving Nodes : 1 (total of 2 nodes in 2 runs)
Primal Bound : +9.69149999999940e+04 (9 solutions)
Dual Bound : +9.69149999999940e+04
Gap : 0.00 %
```

```
SCIP> display solution
ESAuger1      48897      13:34:57 (obj:0)
ESAuger2      63599      17:39:59 (obj:0)
ESStow        64800      18:00:00 (obj:0)
ESPan1        42715      11:51:55 (obj:0)
ESPan2        56098      15:34:58 (obj:0)
ESEnd         84600      23:30:00 (obj:0)
SSStart       21600      06:00:00 (obj:0)
SSUnstow      42716      11:51:56 (obj:0)
SSAuger1      43917      12:11:57 (obj:0)
SSAuger2      56099      15:34:59 (obj:0)
SSStow        63600      17:40:00 (obj:0)
SSPan1        38515      10:41:55 (obj:0)
SSPan2        48898      13:34:58 (obj:0)
SSEnd         84600      23:30:00 (obj:0)
ESStart       21600      06:00:00 (obj:0)
ESUnstow      43916      12:11:56 (obj:0)
Perturb       96914.999999994 26:55:15 (obj:1)
```

## Future Work

Once the constraints for a model are identified, APRES will solve the problem and inform the user if any violations are being made and explain why a plan may need to be altered.

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## References

- Orzech, G., "Planning & Scheduling: Activity Planning with Resources for the Exploration of Space (APRES)," NASA Available: <https://www.nasa.gov/content/planning-scheduling>.
- Bestuzheva, K., et al., "SCIP Optimization Suite," SCIP Available: <https://www.scipopt.org/>.