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OPTIMISATION OF CATEGORICAL CHOICES IN EXPLORATION MISSION CONCEPTS OF OPERATIONS USING BRANCH-AND-PRICE METHOD

Abstract

Space missions, particularly complex, large-scale exploration campaigns, can often involve a large number of discrete decisions or events in their concepts of operations. Whilst a variety of methods exist for the optimisation of continuous variables in mission design, the inherent presence of discrete events in mission ConOps disrupts the possibility of using methods that are dependent on having well-defined, continuous mathematical expressions to define the systems and instead creates a categorical mixed-integer problem. Typically, mission architects will circumvent this problem by solving the system optimisation for every permutation of the categorical decisions if practical, or use metaheuristic solvers if not. However, this can be prohibitively expensive in terms of computation time. Alternatively, categorical decisions in optimisation problems can be expressed using binary variables that indicate if the decision was taken or not. If implemented naïvely, commercially available mixed integer linear optimisation solvers are still slow to solve such a problem, in some cases not performing much better than combinatorially testing every permutation of the ConOps.

Problems of this class can be solved more efficiently using “column generation” and “branch-and-price”, methods. Here, smaller, simpler subproblems are created by removing significant numbers of variables. The subproblem is solved, and the unused variables are priced by examining the dual linear program in order to test which, if any, could improve the objective of the subproblem if they were to be added. Branch-and-price methods are highly problem-specific, and so there is no readily-available solution to these categorical problems. As such, the following paper proposes a tailored process for defining subproblems representing space exploration mission concepts of operations featuring common categories of decisions. Then, the column generation step is described and applied to these problems to develop the optimal solution to the ConOps. The process is applied to two case studies. Firstly, it is applied to the NASA Marshall Advanced Concepts Office (ACO) ConOps for a crewed Mars mission, in which the staging of the trans-Martian spacecraft is modelled using discrete decisions. Secondly, the process is applied to the payload delivery scheduling of translunar logistics in the context of an extended Artemis surface exploration campaign model.