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Team 15

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Automated Task-Scheduling System Design

INTRODUCTION

Background

The Canadian Space Agency (CSA) is the pioneering organization responsible for the research and development of all space-related technologies in the country.

Scope

The goal of the project is to develop an automated task-scheduling system for a constellation of five satellites each in their sun-synchronous orbit.

The system is required to receive image order requests from various users and balance the request priorities against satellite maintenance requests derived from ground control. The system is to then generate a feasible task schedule for all satellites in the constellation.

DESIGN PROCESS

Problem Definition

- Gained clarification on system characteristics through research and Client Inquiry

Built Supporting Framework

- Developed data processing and retrieval workflows through code

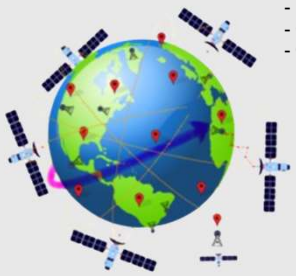
Developed Solution Approach

- Formulated a Mathematical Model to represent system objectives and parameters
- Created a Heuristic approach as an alternative solution

Prototyped and Tested Approaches

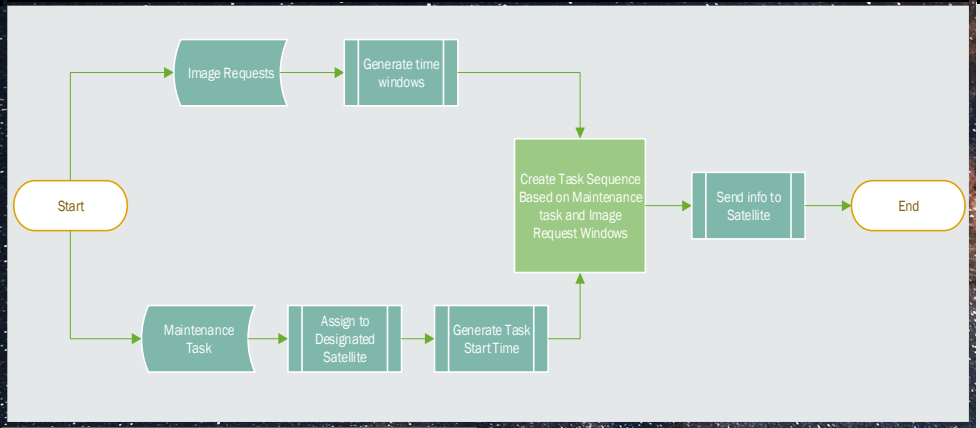
- Converted mathematical models to Excel and AMPL formats for logic testing
- Generated solution with heuristic to compare with model results

SATELLITE CONSTELLATION DIAGRAM



- Image request locations
- Ground station mast
- CSA satellites

SYSTEM PROCESS FLOW



ALGEBRAIC MODEL

Sets: K – Satellites, 1, 2, ... $|K|$

J – Jobs, 1, 2, ... $|J|$

$W = J \cup |J| + 1$ – jobs and one satellite node

$H_k - set\ of\ windows\ for\ jobs\ on\ satellite\ k$

Variables:

$x_{ijk} = \begin{cases} 1, & if\ job\ i\ and\ j\ are\ sequential\ on\ satellite\ k \\ 0, & otherwise \end{cases}$

$y_{ihk} = \begin{cases} 1, & if\ job\ i\ uses\ window\ h\ on\ satellite\ k \\ 0, & otherwise \end{cases}$

$s_{ik} = start\ time\ of\ job\ i\ on\ satellite\ k$

Parameters:

c_i = priority of task i (smaller is better, all priorities negative)

b_{ihk} = beginning of window h for job i on satellite k

e_{ihk} = end of window h for job i on satellite k

d_i = duration of job i

Objective:

Min $\sum_{i \in W} \sum_{j \in W} \sum_{k \in K} c_{ijk}\, x_{ijk}$

Minimize the sum of priorities of jobs chosen to be executed.

Constraints:

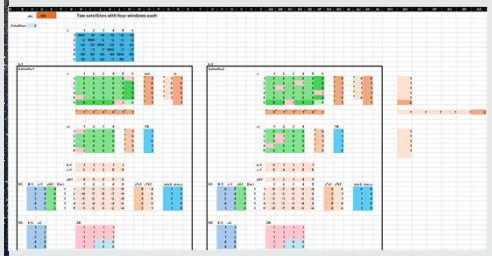
1. $\sum_{j \in W} x_{ijk} \leq 1\ \forall\, i \in W,\ k \in K$
2. $\sum_{i \in W} x_{ijk} \leq 1\ \forall\, j \in W,\ k \in K$
3. $\sum_{h \in H_k} y_{ihk} \leq 1\ \forall\, i \in J,\ k \in K$
4. $\sum_{j \in J} \sum_{k \in K} x_{ijk} \leq 1\ \forall\, i \in J$
5. $\sum_{i \in J} \sum_{k \in K} x_{ijk} \leq 1\ \forall\, j \in J$
6. $\sum_{k \in K} \sum_{h \in H_k} y_{ihk} = 1\ \forall\, i \in J$
7. $\sum_{j \in J} x_{ijk} \leq \sum_{h \in H_k} y_{ihk}\ \forall\, i \in J,\ k \in K$
8. $\sum_{j \in J} \sum_{k \in K} x_{ijk} \leq |K|\ \forall\, i = |J| + 1$
9. $\sum_{i \in J} \sum_{k \in K} x_{ijk} \leq |K|\ \forall\, j = |J| + 1$
10. $\sum_{j \in W} x_{ijk} = \sum_{j \in W} x_{jik}\ \forall\, i \in W,\ k \in K$
11. $s_{ik} - s_{jk} + d_i - M_{ijk} * (1 - x_{ijk}) \leq 0\ \forall\, i \in J,\ j \in J,\ k \in K$
12. Where $M_{ijk} = \max(e_{ihk} : h \in H_k) - \min(b_{jhk} : h \in H_k) + d_i$
13. $s_{ik} \leq \sum_{h \in H_k} e_{ihk} * y_{ihk}\ \forall\, i \in J,\ k \in K$
14. $s_{ik} \geq \sum_{h \in H_k} b_{ihk} * y_{ihk}\ \forall\, i \in J,\ k \in K$

$Let\ parameter\ z_{ihk} = \begin{cases} 1 & if\ window\ h\ is\ active\ for\ job\ i\ on\ satellite\ k \\ 0 & otherwise \end{cases}$

15. $y_{ihk} \leq z_{ihk}\ \forall\, i \in J, h \in H, k \in K$

MS EXCEL SOLUTION TESTING

The algebraic model developed was tested with a small problem set in Microsoft Excel. The problem consisted of 2 satellites, 5 tasks, and 4 time windows per satellite and was solved using Gurobi.



The model was able to successfully generate the optimal solution to the problem with jobs 1&5 being done on the 1st satellite and jobs 2,3 &4 being done on the 2nd. With the model proven to generate feasible solutions, the problem sets can be expanded to larger problems that more accurately represent the 5-satellite constellation.

HEURISTIC SOLUTION APPROACH

Pre-Processing

- Maintenance tasks are ordered and assigned first by the start times of their given window due to their top priority
- Data Cleaning removes non-viable windows from list of windows for each image request

Set-Up and Execution

- Starts with the list of maintenance start-times
- Take the first image request that has viable windows
- Cycle through list to find a window that fits within scheduled maintenance tasks

WEB INTERFACE DEVELOPMENT

Purpose

The website serves as a dynamic front-end platform designed to interface with a sophisticated back-end scheduling system for satellite imagery requests.

It streamlines the process for users to order images, which are then displayed after the system processes the requests.

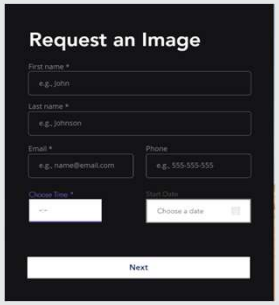


Image Request form

Website Features

- **Detailed Image Request Forms:** Users can input coordinates, desired timing, and image quality specifications.
- **Developer Mode Access:** Enables direct editing of JavaScript code for backend communication.

NEXT STEPS

Remaining work

The work to be completed over the remainder of the term is highlighted below:

Solution Improvement

The team aims to improve the solutions generated by the heuristic by comparing it against the solutions generated by the model solved by Gurobi and adding cuts to the heuristics to push its solutions closer to optimality

Front-End to Back-End Merging

- Linking the front-end code to the back-end using Django.
- Creating an account that lets admins/operators view the tasks on each satellite.