Metaheuristic Methods for Operating Theatre Scheduling

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Department of Industrial Systems Engineering and Management | IE3100R System Design Project

SingHealth
Defining Tomorrow's Medicine

Problem Overview

Company Background

SingHealth was formed in 2000 and is currently the largest cluster of healthcare institutions in Singapore. Providing services ranging from primary to acute care, the cluster consists of acute hospitals, community hospitals, national specialty centers, and polyclinics.

SingHealth's three missions are to 'Care to Heal', 'Educate to Empower', and 'Innovate to Advance'. These missions ensure SingHealth to excel in being a healthcare provider in Singapore.

Problem Description

In hospitals, **Operating Theatres (OT)** constitute 60% of the total revenue while costing up to about 40% of the hospital's expenses. An effective OT scheduling system will help in improving key performance indicators and bring value to both patients and other stakeholders of the hospital.

The purpose of the systems design project is the optimization of the surgery case scheduling problem (SSP) which comprises the optimal appointment of surgical cases to available operating theatre time slots.

Objectives

- **Metaheuristics to Optimize SSP**
  Using multi-objective metaheuristic algorithms to schedule surgeries. The three objectives considered are OT overtime, idle time and patient waiting time. The algorithms will assign each patient surgery a day, OT, and starting time.
- **Design of Prototype Frontend Interface**
  To implement the metaheuristic algorithms through a user-friendly interface that can be used by hospital managers and scheduling personnel on the ground.

Skill Sets

Research Skills
Programming
Teamwork & Communications
Multi-objective Optimization

Methodology

- **Multi-objective Optimization (MOO)**

Minimization of 3 criteria in SSP :

$$\text{Minimize } F(x) = [f_1(x), f_2(x), f_3(x)]$$

$f_1(x)$ = *OT overtime*, $f_2(x)$ = *OT idle time*, $f_3(x)$ = *Patient waiting time*

- **Proposed steps in solving SSP with Metaheuristics:**

Step 1: List of surgery requests → Step 2: Assign the n surgeries considering surgery duration, MAS and slot availability → ***Initial feasible solution*** → Step 3: Calculate objective values: **Overtime, Patient Waiting Time & OT Idle Time** → Step 4: Search objective space for near optimum solution with metaheuristics algorithms → Step 5: Report solutions in the pareto front and their corresponding schedule

Machine Learning model to predict expected number of surgery request of the same discipline and durations

- **4 Metaheuristic algorithms implemented**

Multi-objective Stochastic Hill Climbing with Restart (MOSHCR)

Ulungu's Multi-objective Simulated Annealing (UMOSA)

Tabu Search for Multi-objective Combinatorial Optimization (TAMOCO)

Elitist Non-Dominated Sorting Genetic Algorithm (NSGA-II)

Backend Design

- **Solution Representation**
  3 dimensional arrays are used to represent the surgical case schedule in Python. Each slot represents 15 minutes of time and is each filled with 7 digit integers, where each digit represents key information of the surgery such as fixed or swappable surgery, surgery type, surgery discipline and surgery code. Empty slots are stored as 0 in the array.

- **Neighbourhood Structure**
  The set of neighbours for a solution is defined as any solution that can be obtained by a swap between any two surgeries from the current solution. Master Allocation Schedule (MAS) constraints and slot availability are considered before allowing the swap.

- **Tabulation of Fitness**
  - All slots after 5pm is considered overtime
  - All empty slots before 5pm is considered as idle time
  - Waiting time is the day where the patient's surgery slot is allocated in

0	int	int	int	int
int	int	0	0	0

5pm

Overtime
Idle time

Results

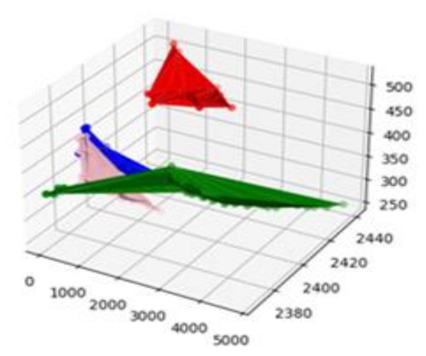
- **Computational Experiments**

To assess the performance of the metaheuristic algorithms, *81* scenarios were tested, each experiment considering **different schedule fullness**, **planning horizon**, **number of surgeries to be scheduled** and **maximum allowable runtime**.

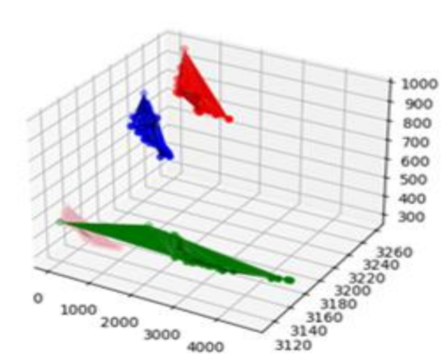
- **Results**

3 dimensional plots are used to visualize and compare the different estimated Pareto fronts generated by the 4 metaheuristics algorithms.

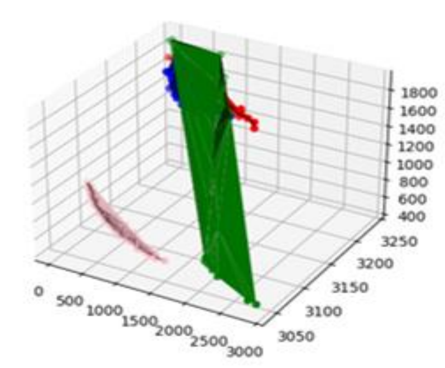
In general, the MOSHCR (red) tended to perform the worst, followed by UMOSA (blue), while the TAMOCO (green) and NSGA-II (pink) consistently performed better than the former two algorithms. When the objective space is large, **NSGA-II** tended to outperform all other heuristics.



Planning horizon: **2 Weeks**
Schedule fullness: 50%
Number of surgeries: 50
Maximum runtime: 10 minutes

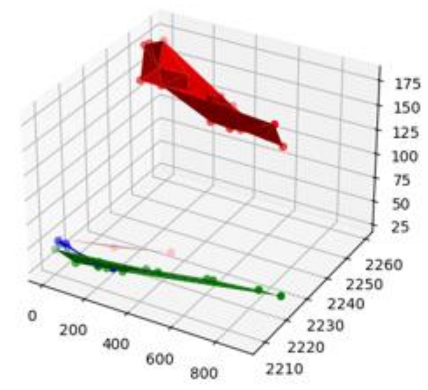


Planning horizon: **4 Weeks**
Schedule fullness: 50%
Number of surgeries: 50
Maximum runtime: 10 minutes

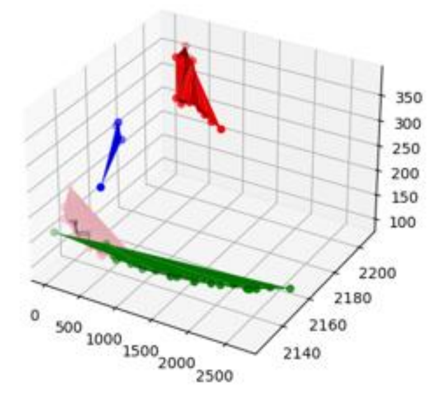


Planning horizon: **8 Weeks**
Schedule fullness: 50%
Number of surgeries: 50
Maximum runtime: 10 minutes

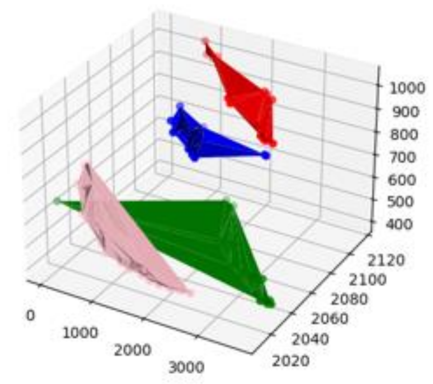
Pareto fronts with different planning horizon



Planning horizon: 4 Weeks
Schedule fullness: 75%
Number of surgeries: **12**
Maximum runtime: 5 minutes



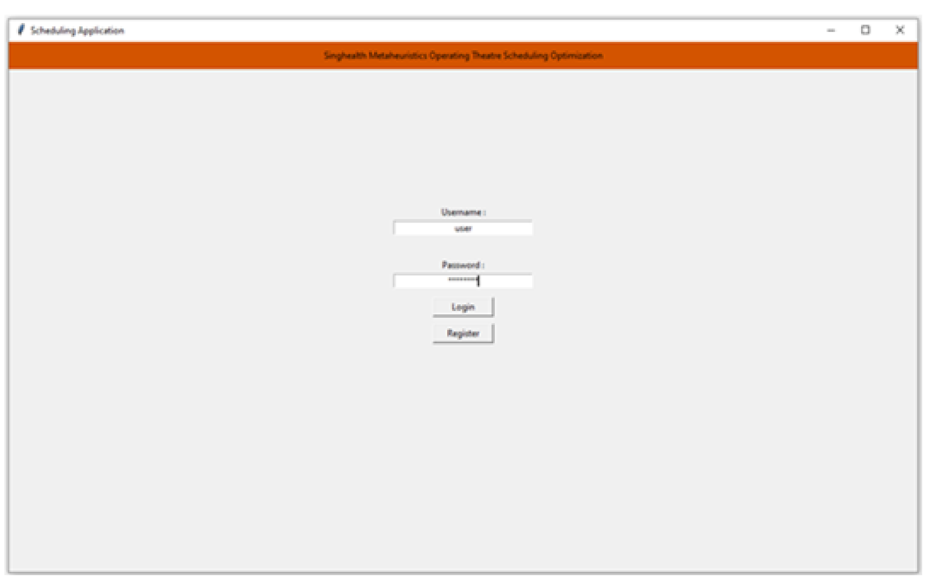
Planning horizon: 4 Weeks
Schedule fullness: 75%
Number of surgeries: **25**
Maximum runtime: 5 minutes



Planning horizon: 4 Weeks
Schedule fullness: 75%
Number of surgeries: **50**
Maximum runtime: 5 minutes

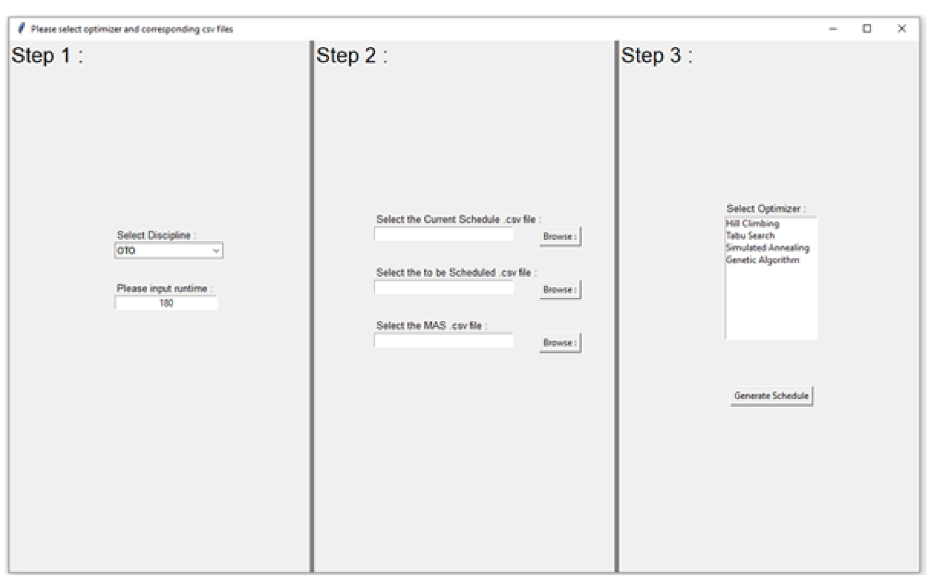
Pareto fronts with different number of surgeries to be scheduled

Graphical User Interface



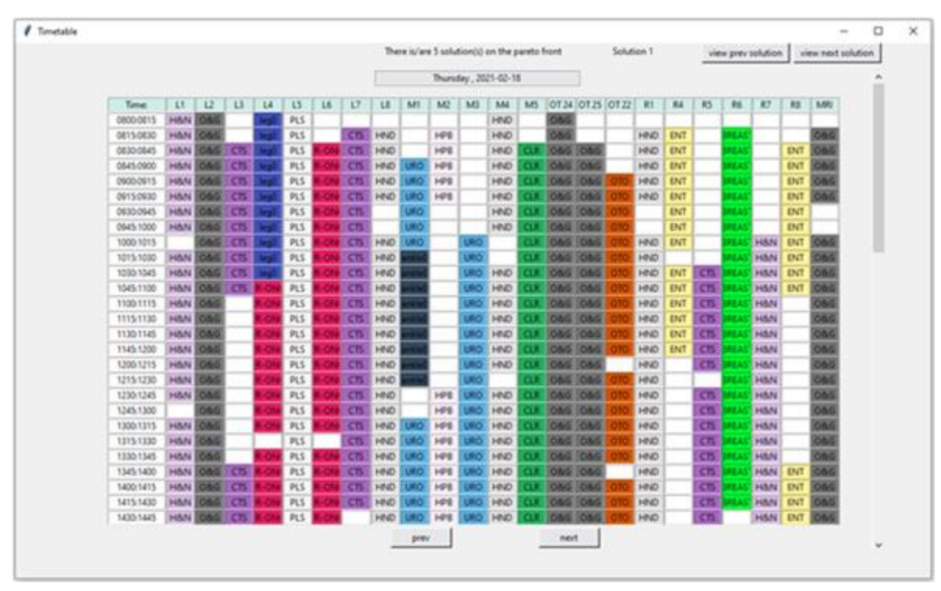
Login page

Users are required to either register or login to a pre-existing account to proceed to the step of the interface



Parameters and files selection page

In this page, the user will specify the necessary optimization parameters & select the appropriate input files



Schedule solutions page

In the final page of the interface, the solution is shown in the form of a time table with each column representing the respective operating theatres