Investigating Online Bin Packing Algorithms to Optimize Surgery Slot Allocation Performance

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Abstract

Operating Theatres (OTs) are one of the highest revenue earners but are costly to run. As such, hospitals would like to maximise OT usage. In this project, we analyse various algorithms (heuristics) that can be used to allocate surgeries and departments to OTs. We also develop an application that can simulate the processes of patient arrivals and surgeries scheduling. Lastly, we compare the performances of heuristics using multiple metrics, and provide some recommendations for optimising OT utilisation.

Problem Description

- Maximising the use of OTs stem from efficient allocation of surgeries, considering the three key stakeholders affected by surgery allocation:

Patients	Surgeries to be allocated **as early as possible**
Health Professionals	Surgeries to be allocated **within working hours**
Hospital Admins	Surgeries to be allocated to **maximise revenue-to-cost ratio**

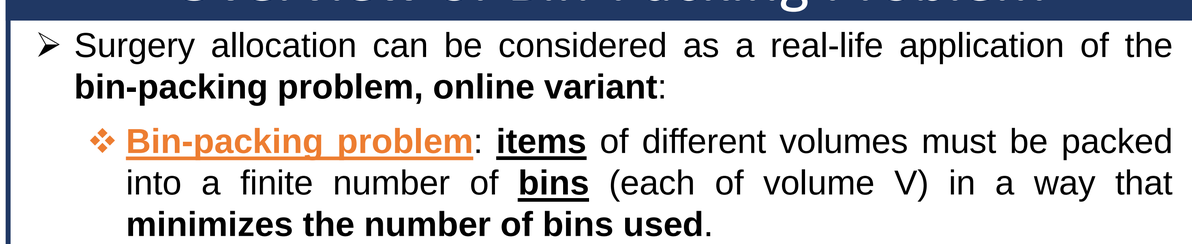
- As such, we use **3 metrics** to evaluate surgical allocation efficiency:
  - **Waiting Time to Surgery (WTS)**: Time difference between when the patient is first allocated a surgery, and when the surgery starts.
  - **Operating Theatre Utilisation Rate (OTUR)**: The percentage of time (out of a single working day) that an OT is used.
  - **Variance of OTUR (Staff Welfare)**: The consistency in workload allocated to staff, determined by variance of OTUR across time.

Overview of Bin-Packing Problem

- Surgery allocation can be considered as a real-life application of the **bin-packing problem, online variant**:
  - **Bin-packing problem**: **items** of different volumes must be packed into a finite number of **bins** (each of volume V) in a way that **minimizes the number of bins used**.
  - **Online variant**: items arrive **one at a time** (in an arbitrary order); each item must be allocated a bin, before considering the next one. (as opposed to the **offline variant** where all items are given upfront)
- In hospital context, each bin is a full working day of the given OT, while each item is a surgery whose duration reflects the item's size.

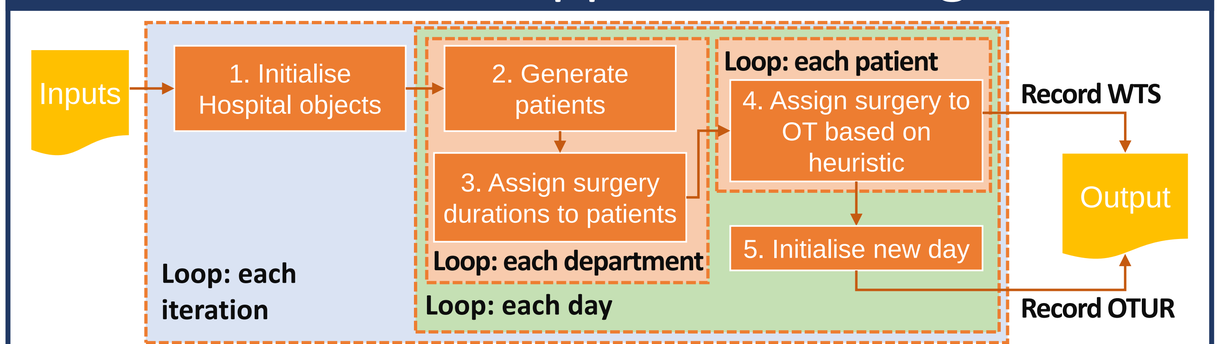
Heuristics Analysed

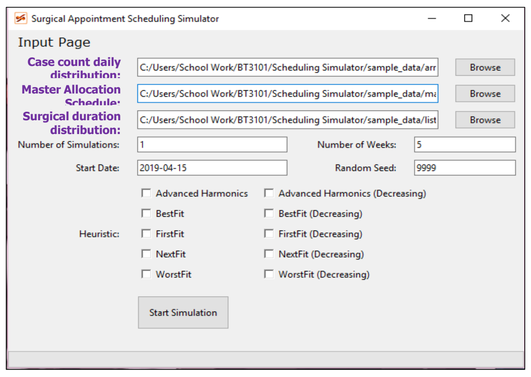
- **First Fit**: packs each item into ***the leftmost (first) bin*** where it fits. If no bin has enough space, open a new bin for the new item.
- **Best Fit**: packs each item into ***the most full bin*** where it fits, i.e. ***minimise bin remaining space***. If no bin has enough space, open a new bin for the new item.
- **Next Fit**: packs each item into ***the same bin as the last added item***, if that bin has enough space. If not, open a new bin for it.
- **Worst Fit**: packs each item into ***the least full bin*** where it fits, i.e. ***maximise bin remaining space***. If no bin has enough space, open a new bin for the new item.

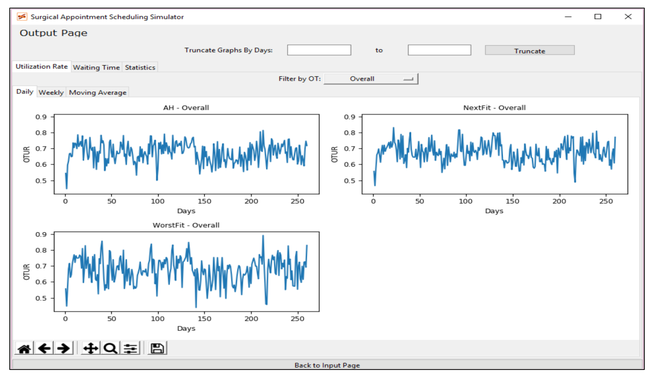


- **Advanced Harmonic**: Adapted from ***"A new and improved algorithm for online bin packing"*** by János Balogh et al., 2017.
  - Split each bin into two containers; each container is assigned three attributes: sign, type, and class, which dictate its maximum capacity, as well as the classification and number of items that it can hold.
  - Each item is tagged with a classification based on its size. This classification dictates how the algorithm packs the item.
- **Decreasing Variants**: all heuristics have a Decreasing variant, where instead of being packed one by one, items are ***packed in batch***. The item batch is ***sorted in descending order of size*** before packing.

Simulation Application Design



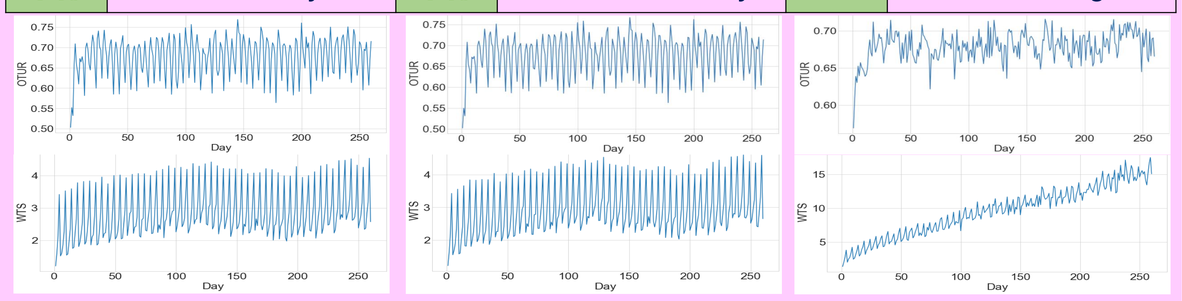




Results and Discussions

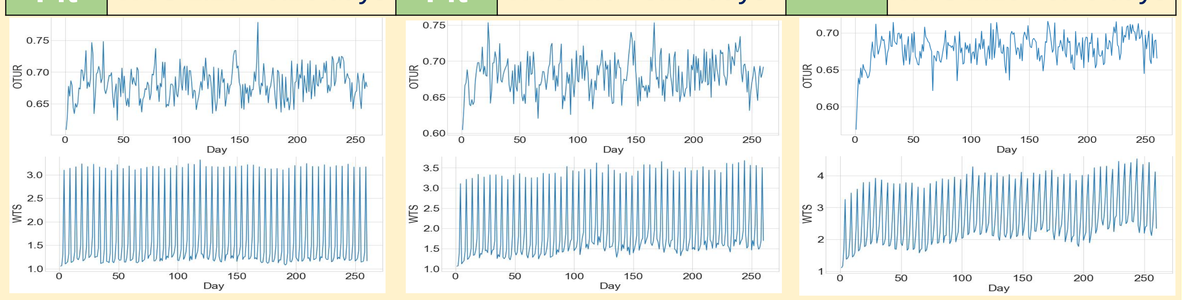
- **Base Case**: Best heuristics: **First Fit**, **Best Fit**, **Advanced Harmonic (AH)**.
  - WTS inconsistent across departments. For those with high demand, WTS doesn't converge to stable state ➔ **Uneven distribution of OTs**.
  - **Solution**: flexible OT-department master allocation schedule (MAS).

First Fit	**OTUR** 62.5% - 70% **WTS** 2.5 - 4 days	**Best Fit**	**OTUR** 65% - 70% **WTS** 2.5 - 3.75 days	**AH**	**OTUR** 62.5% - 67.5% **WTS** no convergence



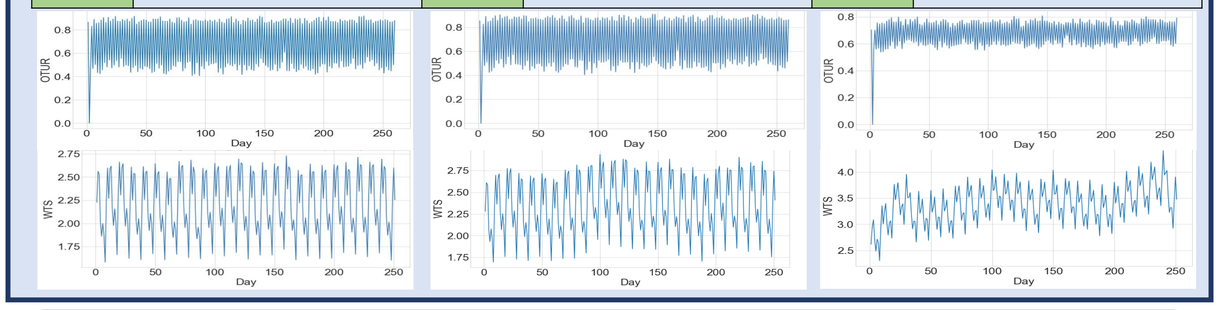
- **Flexible MAS**: Transfer load from overutilised OTs to underutilised OTs.
  - Both OTUR and WTS improve. **Best Fit** offers best performance, but suffers from high variance. **Advanced Harmonic** offers slightly worse performance, but has low variance.

First Fit	**OTUR** 66.25% - 70% **WTS** 1.25 - 3.25 days	**Best Fit**	**OTUR** 67% - 71% **WTS** 1.5 - 3.25 days	**AH**	**OTUR** 67% - 70% **WTS** 2.25 - 3.75 days



- **Decreasing Variant**: Delay scheduling by 2 days. Sort 2 days worth of surgeries in descending duration before allocating surgical slots.
  - OTUR further improves. **Best Fit** and **First Fit** perform better, but **Advanced Harmonic** is still the most stable.
  - **Moving average** WTS is analysed, instead of daily average WTS

First Fit	**OTUR** 55% - 85% **WTS** 1.9 - 2.4 days	**Best Fit**	**OTUR** 55% - 85% **WTS** 1.9 - 2.6 days	**AH**	**OTUR** 65% - 75% **WTS** 3 - 3.75 days



Recommendations

OTUR & WTS Focus ➔ Best Fit; Flexible Scheduling

VS

Staff Welfare Focus ➔ Advanced Harmonic; Decreasing Variant; Flexible Scheduling

- Efficiency-Stability trade-off
- Might consider a hybrid approach