Slot Allocation and Fairness

STOR-i Problem Solving Day, 19th November 2021

Jamie Fairbrother[1]

[1] Department of Management Science, Lancaster University

Introduction

Airport congestion

- In many airports around the world, demand to use the airport infrastructure exceeds available capacity
- This can lead to congestion-related delays
- The expansion of infrastructure is not possible in the short to medium term and so congestion must be mitigated through the management of demand.

Slot Allocation

- Outside of the US, demand is managed through the IATA Worldwide Slot Guidelines (WSG)
- Under WSG, airlines must request and obtain slots to use the airport
- A slot is a time interval during which an aircraft can use an airport infrastructure for the purposes of landing or take-off
- An independent *coordinator* proposes an initial allocation for slots to airlines based on airline requests

OR-MASTER Project

- OR-MASTER is a EPSRC funded project to develop more efficient and holistic approaches to slot scheduling

Jamie Fairbrother
Snr. Research Associate

Kevin Glazebrook
Co-Investigator

Rob Shone
Research Associate

Konstantinos Zografos
Principal Investigator

THEME 1
SINGLE AIRPORT AND NETWORK WIDE SLOT ALLOCATION MODELLING

THEME 2
DECLARED CAPACITY MODELLING WITH STOCHASTIC CONSIDERATIONS

THEME 3 (coordinated by Queen Mary Univ.)
DEVELOPMENT OF HEURISTIC AND HYPER-HEURISTIC ALGORITHMS → GENERALISATION OF ALGORITHMS → ALGORITHMIC TESTING

Fotios Katsigiannis
PhD student

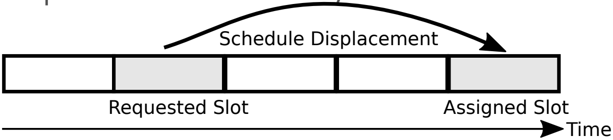
Simplified Optimization Model

Problem Statement

- We have:
  - $\mathcal{F}$ = set of flights requesting pairs of arrival and departure slots
  - $\mathcal{T} = \{1, \ldots, T\}$ = set of time intervals
- Each request $f \in \mathcal{F}$ has preferred time arrival and departure slot times t_f^A and $t_f^D \in \mathcal{T}$
- Each flight must be allocated slots such that:
  - No more than u slots can be allocated for each period t
  - Arrival-departure pairs must satisfy minimum turnaround time of l

Displacement

- Due to capacity constraints, some requests cannot be allocated their preferred slot
- The difference between a preferred and allocated time is called the *schedule displacement*
- Aim of slot allocation is typically to mininimize schedule displacement in some way



Decision Variables

$$x_f^t = \begin{cases} 1 & \text{if } f \text{ allocated arrival slot at time } t \\ 0 & \text{otherwise.} \end{cases}$$

$$y_f^t = \begin{cases} 1 & \text{if } f \text{ allocated departure slot at time } t \\ 0 & \text{otherwise.} \end{cases}$$

Optimization Model

$$\text{minimize} \sum_{f\in\mathcal{F}} \sum_{t\in\mathcal{T}} \left(|t - t_f^A| x_f^t + |t - t_f^D| y_f^t \right)$$ (minimize total schedule displacement)

$$\text{subject to} \sum_{t\in T} x_f^t = 1, \; f \in \mathcal{F}$$ (assign each flight an arrival slot)

$$\sum_{t\in T} y_f^t = 1, \; f \in \mathcal{F}$$ (assign each flight a departure slot)

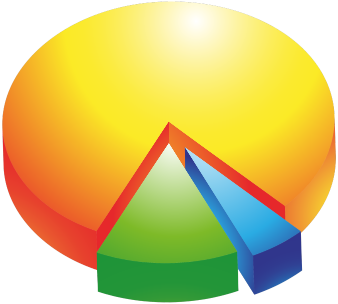
$$\sum_{f\in\mathcal{F}} \left(x_f^t + y_f^t \right) \leq u, \; t \in \mathcal{T}$$ (capacity constraints)

$$\sum_{t\in\mathcal{T}} t y_f^t - \sum_{t\in\mathcal{T}} t x_f^t \geq l, \; f \in \mathcal{F}$$ (turnaround constraints)

$$x_f^t, y_f^t \in \{0, 1\}, f \in \mathcal{F}, \; t \in \mathcal{T}.$$

Fairness

- Each request *m* is made by an airline $a \in \mathcal{A}$
- Each airline wants as little schedule displacement as possible
- The formulation above does not control how displacement is distributed amongst the airlines
- Some airlines may have disproportionately more displacement than others



Problem

Questions

1. How can the fairness of a schedule be quantified?
2. How can a fair schedule be constructed?
3. Is there a trade-off between schedule displacement and fairness? Can this be controlled?

Materials

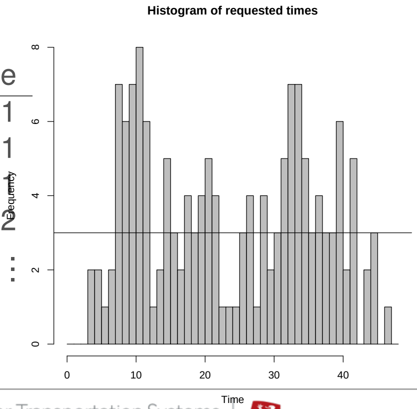
- *request_data.csv*: synthetic request data
- *Jupyter notebook*: *The Slot Allocation Problem.ipynb*
    - Solves slot allocation problem for given data set, writes results to CSV file, provides various plots
- R scripts:
    - *plot_results.R*: alternative script for plotting data and results (requires output CSV file from Jupyter notebook)

Data

- $|\mathcal{F}| = 75, \; |\mathcal{T}| = 48$
- Capacity $u = 4$
- Minimum turnaround time $l = 1$

request.arrs	request.deps	airline
2	3	A1
3	5	A1
3	4	A1
2	4	A2
⋮	⋮	⋮

Table: request_data.csv

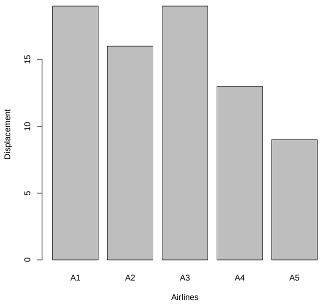


Results

- The function “solve_slot_allocation_problem” takes the request data frame, and other problem parameters and returns a data frame containing allocated slots:

alloc.arrs	alloc.deps
2	4
2	5
3	6
3	4
⋮	⋮

Table: Optimal schedule data frame



- A request pair and corresponding allocations have the same row index

Considerations

- A very large displacement is much worse than a few small displacements (due to demand, crew-scheduling, and constraints from origin/destination airports)
- A measure of fairness which leads to tractible (e.g. linear/convex quadratic) optimization is desirable
- The measure of fairness should be easily understood by non-expert stakeholders

Problem Solving Day: Logistics

- Split into teams to work on problem
- If you have questions about problem, send me a message on Teams (or to group)
- Prepare 5 minute presentation to present responses
- Reconvene on Teams at 16:45 to present work

Problem Solving Day: Tips

- Discuss problem carefully before proposing solutions
- Make good use of problem experts
- Code and data can be used to test and demonstrate your ideas, but don’t worry if there isn’t time
- If you would like to modify the optimization code, I can help

Questions?

Group 1

- George Aliatimis
- Danielle Notice
- Nikos Tsikouras

Group 2

- Ben Lowery
- Carla Pinkney
- Matthew Speers

Group 3

- Harini Jayaraman
- Thomas Newman
- Connie Trojan
- Luke Fairley