The University of Nottingham

asap automated scheduling optimisation & planning research

The trade-off between taxi time & fuel consumption in airport ground movement

Stefan Ravizza

Jun Chen, Jason Atkin, Edmund Burke, Paul Stewart

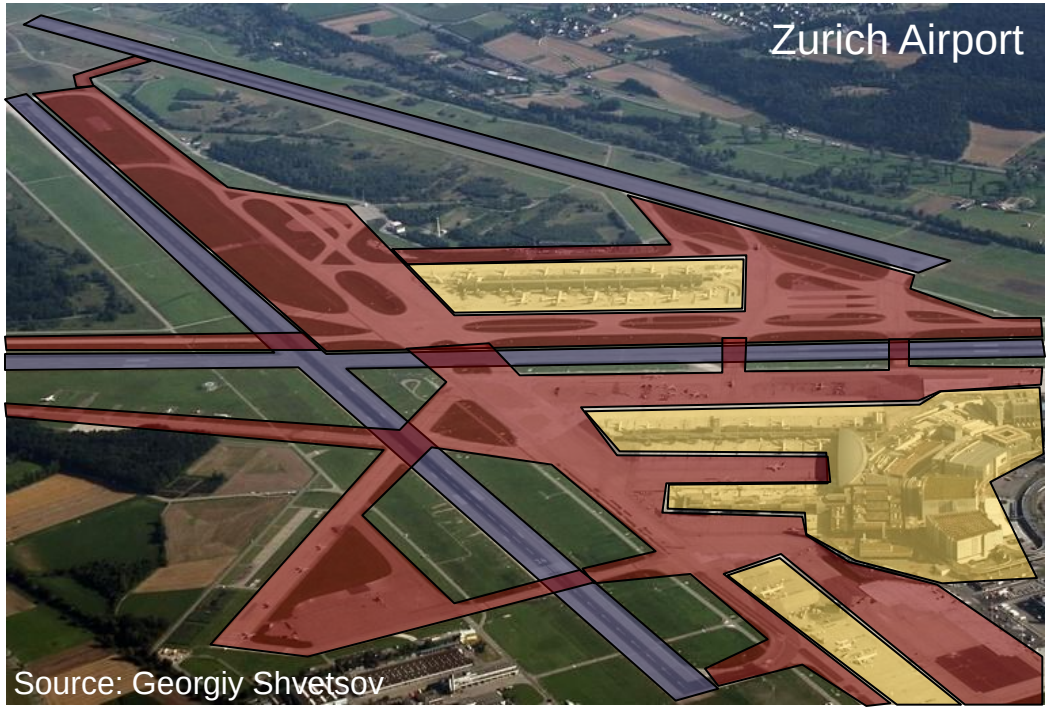
CASPT - S3.a: Fleet Logistics and Costs

Outline

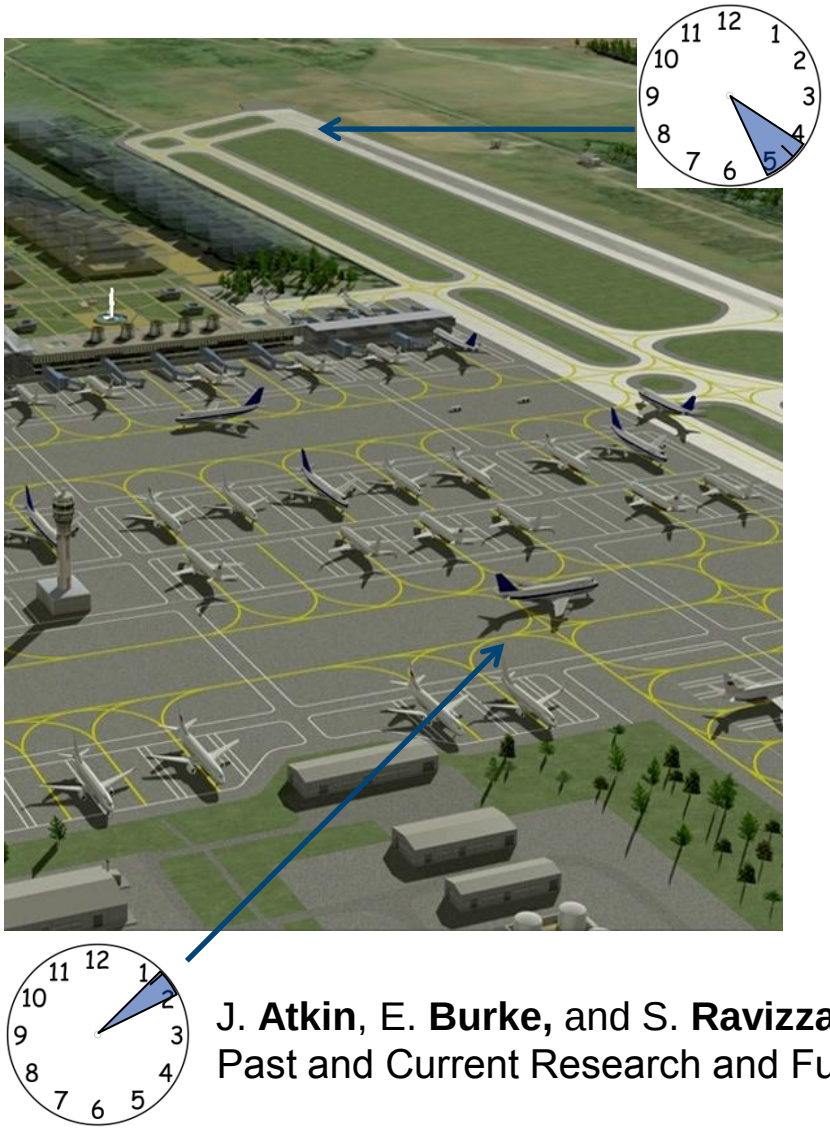
- Airside airport operations
- Ground movement problem
  - » Sequential routing algorithm
- Is there potential to reduce fuel consumption?
  - » Concept of the new approach
- Results
  - » Analysis based on Zurich Airport data

Linked Airport Operations

- With increasing complexity and load at airports, more **advanced decision support systems** are needed
- Airside airport operations are **highly connected**
  - » Runway sequencing
    - Departures
    - Arrivals
  - » Gate assignment
  - » Ground movement



Ground Movement Problem



- **Routing** and scheduling problem
- Restrictions:
  - » Set of possible routes
  - » Time windows for source and target
  - » Separations between aircraft
  - » Different movement speeds
- **Dynamic** nature

J. **Atkin**, E. **Burke,** and S. **Ravizza**, “The Airport Ground Movement Problem: Past and Current Research and Future Directions,” *ICRAT*, Hungary, 2010.

Routing Algorithm

- Sequential routing and scheduling approach
  - Minimises taxi time

- Quickest Path Problem with Time-Windows (QPPTW)
  - Dijkstra on the underlying graph with labelling for the time-windows, respecting the edge reservations for all of the aircraft previously routed

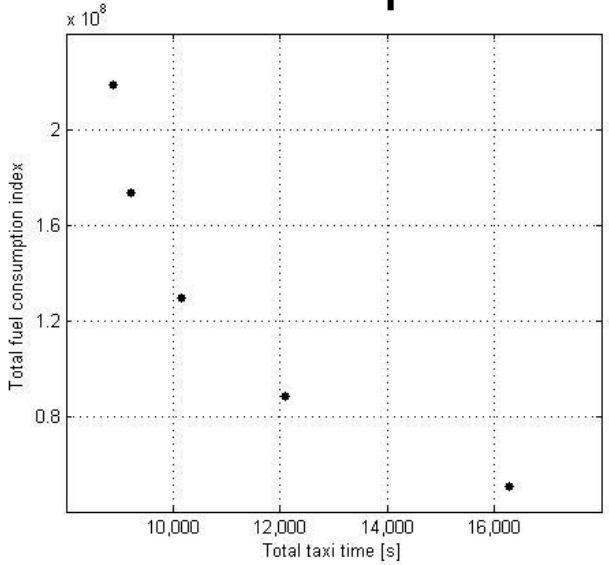
- Absorbing waiting times for departures at stands
  → **stand holding**

J. **Atkin**, E. **Burke**, and S. **Ravizza**, "A more realistic approach for airport ground movement optimisation with stand holding," *MISTA*, USA, 2011.

Can we do better?

Concept at a Glance

- **Output:** global discretised pareto-front



- Framework:
  1. Loop for each **objective function** discretisation
  2. Loop for each **aircraft**

k-QPPTW

- Finding the best *k* routes w.r.t. minimal taxi time using the k-QPPTW algorithm

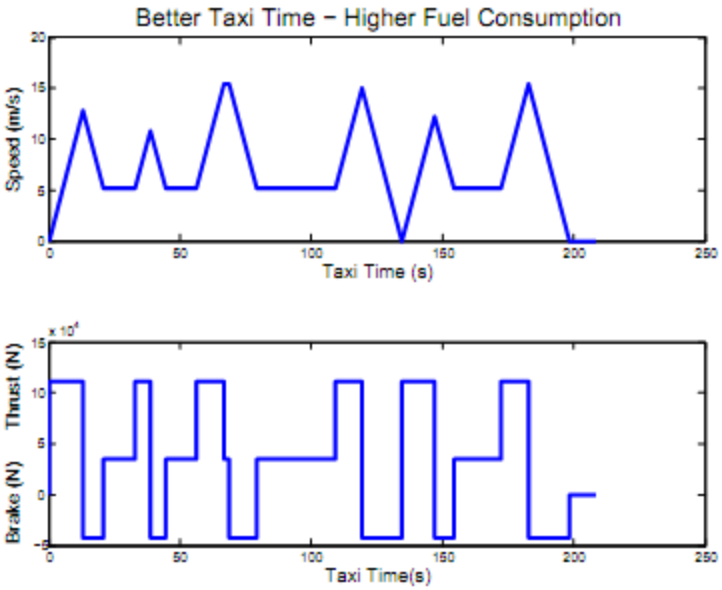
Population Adaptive Immune Algorithm

- Loop for each of the ***k* routes** of an aircraft
  - » Approximate the pareto-front of both objectives, using the population adaptive immune algorithm
- Considering "**time-efficiency**" & "**fuel-efficiency**"
- **Aircraft models** link acceleration, deceleration, and speed to taxi-time and fuel burn
- Taking reservations into account

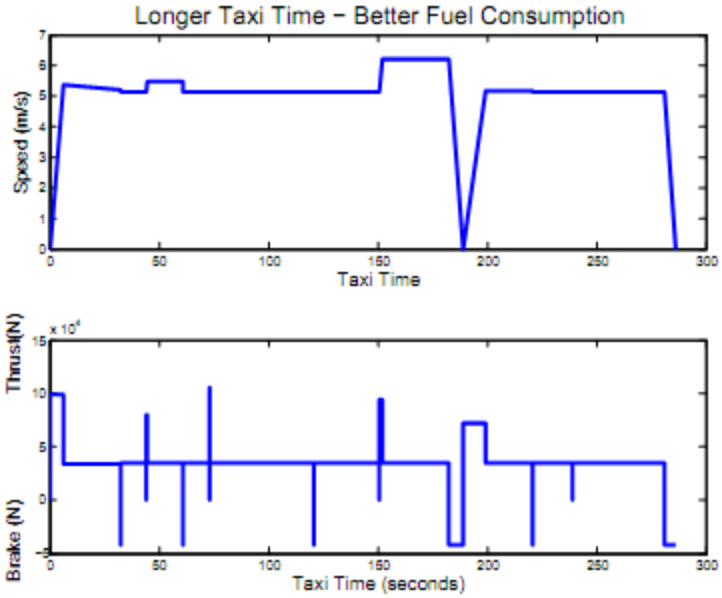
J. **Chen**, P. **Stewart**, "Planning aircraft taxiing trajectories via a multi-objective immune optimisation", *ICNC*, China, 2011.

Trajectories

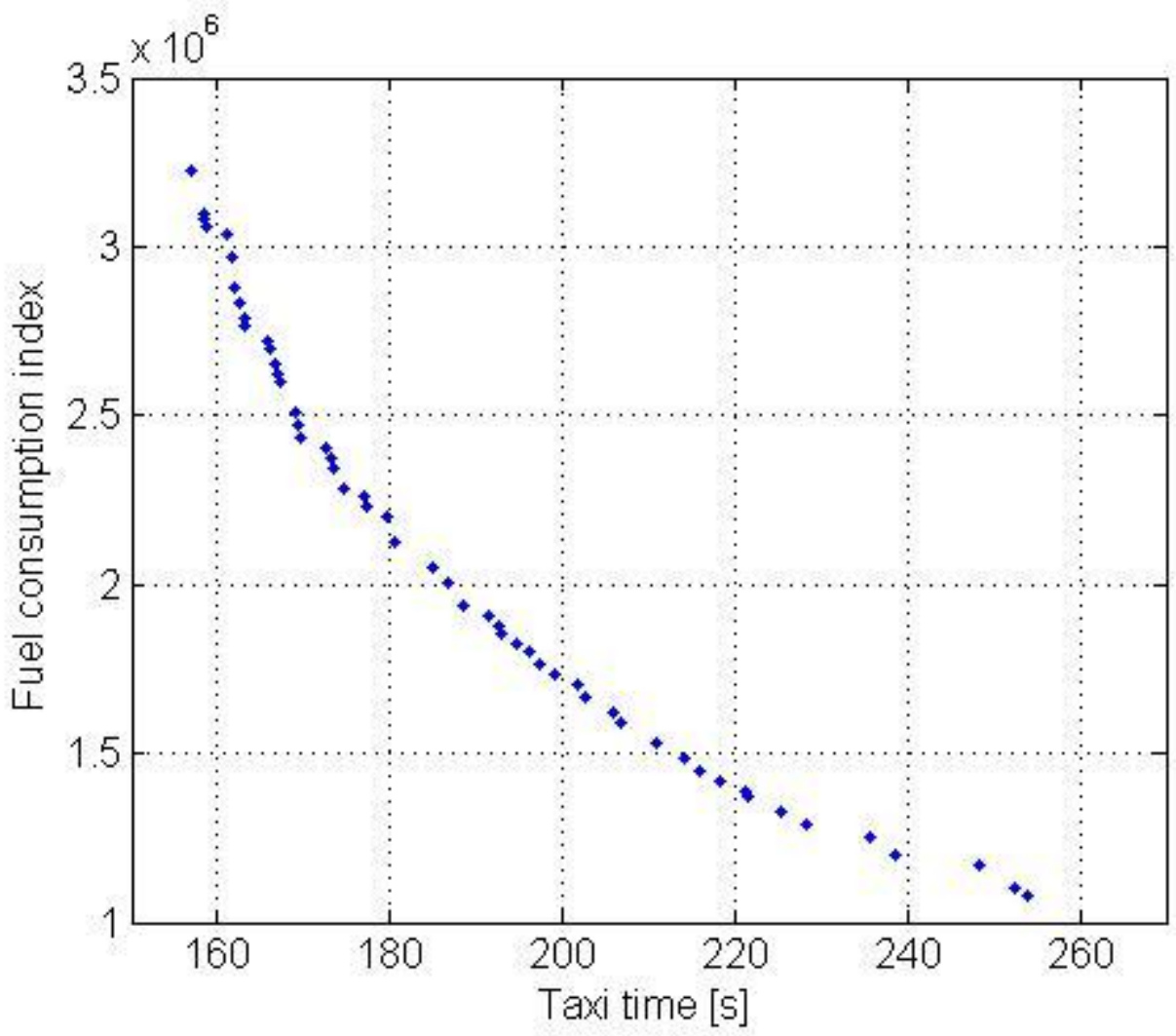
Time-efficient



Fuel-efficient

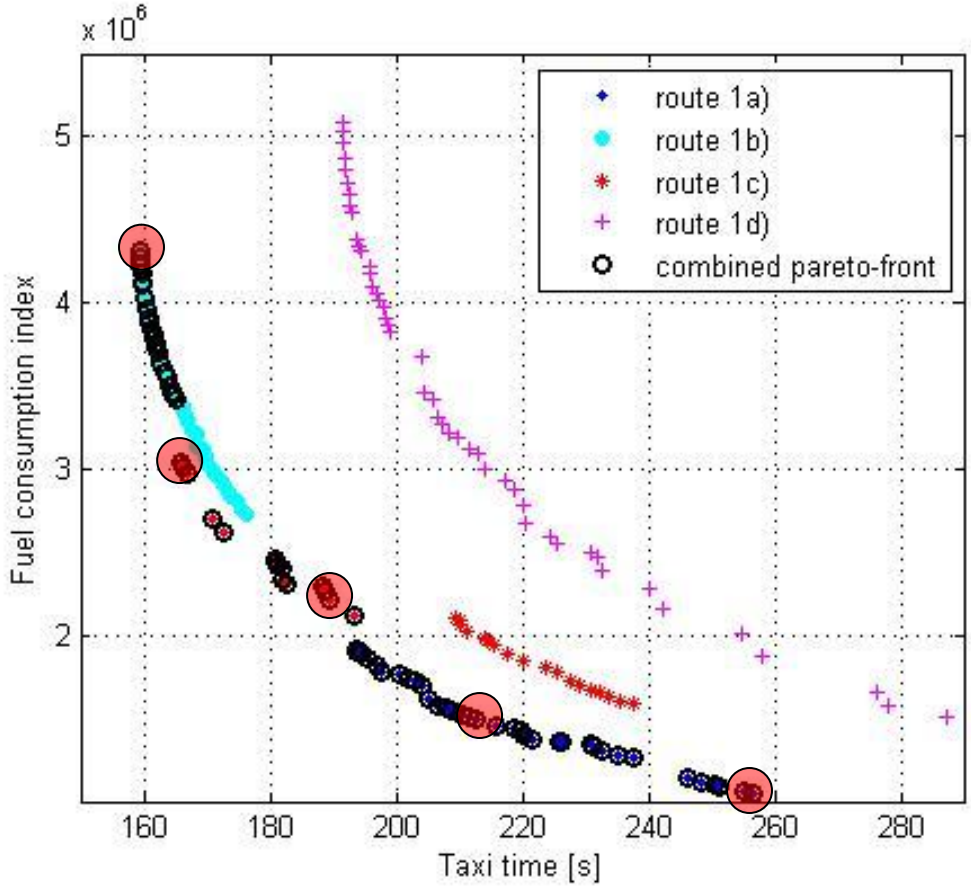


Pareto-front of a Route



Combined Pareto-front

- Plot of 4 different routes
- Combined pareto-front with discretisation



Pseudocode

```
1  Sort all flights by pushback/landing time
2  foreach objective function discretisation i ← 1 to l do
3      foreach aircraft a do
4          Find the best k routes w.r.t. minimal taxi times using the k-QPPTW
           algorithm
5          foreach route k of aircraft a do
6              Approximate the pareto-front of both objectives, using the population
               adaptive immune algorithm (PATT-PAIA)
7          Generate the combined pareto-front for the source-destination pair of
           aircraft a
8          Discretise this pareto-front into l roughly equally spaced points
9          Select the ith point and reserve the relevant route for aircraft a
10     Save the accumulated values for all aircraft for both objective functions for the
       global pareto-front
11 Output: Global discretised pareto-front
```

Results

- One week's operation at Zurich Airport
- 2. objective function: $F_{Total} = F_{Resistance} + F_{Acceleration}$

	Mon	Tue	Wed	Thu	Fri	Sat	Sun
⌀ Taxi time							
Time-efficient [s]	156	157	128	174	152	165	154
Fuel-efficient [s]	285	293	214	320	292	316	295
Growth	83%	87%	67%	84%	92%	91%	91%
⌀ Fuel cons. index							
Time-efficient [$\times 10^3$]	3832	3291	3492	4002	3173	3754	3718
Fuel-efficient [$\times 10^3$]	884	762	742	922	700	849	823
Growth	334%	332%	371%	334%	353%	342%	352%
Number of aircraft	57	58	46	58	56	63	52

Different Objective Function

- 2 different phases:
  - » Acceleration (10% of maximal fuel flow)
  - » Taxiing with constant speed, deceleration, holding (5.5%)

	Different objective function
∅ **Taxi time**	
Time-efficient [s]	155.5
Fuel-efficient [s]	156.7
Growth	0.8%
∅ **Fuel flow**	
Time-efficient [kg]	23.8
Fuel-efficient [kg]	23.5
Growth	1.2%

M.E.J. **Stettler**, S. **Eastham**, S.R.H. **Barrett**, "Air quality and public health impacts of UK airports. Part I: Emissions", *Atmospheric Environment* ,45(31), 2011.

Summary

- **Novel concept** using combined:
  - » k-QPPTW
    - Finds best possible routes for an aircraft
  - » Population adaptive immune algorithm
    - Finds approximation of the pareto-front for different speed profiles for each of these routes

- **Trade-off**
  - » Depends very much upon the actual modelling of the fuel-based obj. function (physics-based vs. fuel flow)
  - » These appears not to be well understood

My References

Published / accepted:

- "The airport ground movement problem: Past and current research and future directions",
  In Proceedings of the 4th International Conference on Research in Air Transportation (**ICRAT 2010**), Budapest, Hungary, pages 131–138, 2010.
- "A statistical approach for taxi time estimation at London Heathrow Airport",
  In Proceedings of the 10th Workshop on Models and Algorithms for Planning and Scheduling Problems (**MAPSP 2011**), Nymburk, Czech Republic, pages 61–63, 2011.
- "A more realistic approach for airport ground movement optimisation with stand holding",
  In Proceedings of the 5th Multidisciplinary International Scheduling Conference (**MISTA 2011**), Phoenix, Arizona, USA, pages 146-160, 2011.
- "On the utilization of fuzzy rule-based systems for taxi time estimations at airports",
  In Proceedings of the 11th Workshop on Algorithmic Approaches for Transportation Modelling, Optimization, and Systems (**ATMOS 2011**), Saarbrücken, Germany, pages 134-145, 2011.
- "Exploration of the ordering for a sequential airport ground movement algorithm",
  Technical Report, 1543, University of Nottingham, 2011.
- "Trade-off between taxi time and fuel consumption in airport ground movement",
  Accepted for the Conference on Advanced Systems for Public Transport (**CASPT 2012**)

Submitted:

- "A statistical approach for improving taxi time estimations at airports",
  Submitted to a journal.
- "A more realistic approach for airport ground movement optimisation with stand holding",
  Submitted to a journal.

Contact Details

Stefan Ravizza

PhD Student

smr@cs.nott.ac.uk

http://www.asap.cs.nott.ac.uk/atr/

The University of Nottingham

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