Models for Aircraft Landing Optimization

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* The research study is founded by European Organisation for the Safety of Air Navigation (EUROCONTROL).
Talk Outline

- Background and Motivations
- Problem Definition
- Brief Review of Previous studies
- Proposed Model
- Initial Experimental Results
- A Look to the Future
Increasing airport capacity has become a limiting factor in meeting the rising demand for more flights.

General Solutions:

- Europe: SESAR (2005-2020)
- USA: NextGen (2003-2025)

One of the main factors which determines the runway throughput is asymmetries in the minimum required separation between aircraft during landing and take-off.

⇒ It also makes the problem more complicated.

Although optimally sequencing and scheduling landing and take-off aircraft can increase the runway throughput, due to complexity of the problem

⇒ It is hard to find the optimal solution in most of the real cases.

Different scientific communities with numerous studies have tried to develop optimal/good algorithms to increase the capacity of the runway during the last decades.
The majority of the developed methods have/can not be implemented because the methods may

- relax / dismiss hard (critical) operational constraints
  - Dismissing the safety issues
  - More focus on decision problem rather than control problem
  - Assuming the symmetries in Separation matrix

- have unreasonable algorithm runtime
  - Looking for an optimal solution rather than a quick and good solution

- study a static rather than dynamic environment
  - Considering theoretical model rather than practical model
  - Considering availability of all the information in advance
  - Ignoring re-sequencing and rescheduling

- ignore the requirements of the various stakeholders
  - Dealing with single objective function

- Extend landing scheduling models for solving take-off problems or vice versa
Problem Definition

• Aircraft Landing Problem (ALP): Sequencing and scheduling of aircraft which are landing into the available runways at the airport by optimizing different objectives subject to variety of operational constraints.

• ALP consists of Sequencing, Scheduling, and Runway Assignment decision problems.

• Aircraft Landing Models can be studied in Static and Dynamic cases.
  - Static (Off-line) Environment
    The model is solved based on a given set of aircraft when the complete information of aircraft is available.
  - Dynamic (On-line or Real-time) Environment
    The solutions are revised over time as new information becomes available.

• In the real world the static environment does not exist!
Common Operational Constraints

- Minimum separation requirement
- Required time windows
- Limited deviation from a nominal or FCFS sequence
- Precedence constraints
Objective Functions

Common Objectives

- Runway throughput
- Approaching time of aircraft in the air
- Controllers’ workload
- Fairness among the aircraft
- Aircraft taxi-in/-out time
- Arrival/departure delays
- Balance between arrivals and departures
- Operating costs
- Engine runtimes before the take-off
- Airlines’ timetables
- Passenger delays
- Priorities among their flights
- Connectivity
- Punctuality of the operative schedule
- Changing the gate due to delay
- Environmental effects
Modelling Techniques:

- Machine Scheduling
- Cumulative Travelling Salesman Problem (CTSP)
- Queueing Theory
- Mixed Integer Programming (MIP)

Solution Methods:

- Dynamic Programming
- Branch-and-Bound
- Branch-and-Price
- Evolutionary Algorithms
- Tabu Search
- Genetic Algorithm
- Ant Colony
- ...
Previous Studies

First Publications on Runway Optimization:

- Blumstein’s (1959) publication on estimating the capacity of arrivals runway
- Dear’s (1976) report on scheduling aircraft in TMA.

- About 240 research studies have been carried out during the last three decades.
- More than 60 publications have been appeared in literature related to ALP.
- The majority of the proposed methods on ALP have never been implemented.
Dynamic Programming (DP) as an exact method:

- Psaraftis (1978) showed the simplified ALP is closely related to the classical TSP.
- Psaraftis (1980) proposed a DP recursion solution for sequencing the single machine jobshop.
- Bianco et al. (1999) suggested a DP formulation for the ALP as a CTSP-RT problem.
- Balakrishnan and Chandran (2006) proposed a DP-based approach for a fixed set of aircraft (Static case).
- Chandran and Balakrishnan (2007) introduced a DP algorithm to compute the tradeoff curve between the robustness and throughput.
- Lee and Balakrishnan (2008) extended the previous framework by presenting a DP algorithm for minimizing the total delay costs of the arrival schedule.
Previous Studies (Cont’d)

Genetic Algorithm (GA) as a heuristic method:

- Stevens (1995) investigated on the first application of GA in minimizing the earliness/lateness of the ALP.
- Ciesielski et al. (1997, 1998) presented two GA for the real time ALP.
- Cheng et al. (1999) designed four different genetic schemes for solving the multiple-runway ALP.
- Beasley et al. (2001) developed a population heuristic to improve the runway utilization.
- Hasen (2004) examined the efficiency and effectiveness of GA and GP methods in solving ALP.
- Capri et al. (2004) presented a GA algorithm.
- Hu et al. (2005) introduced the Receding Horizon Control -based GA to minimize the airborne delay.
- Hu et al. (2008) presented a new construction of chromosomes as a 0-1-value matrix based on the neighbouring relation between each pair of aircraft.
- Hu et al. (2009) designed a GA with uniform crossover for the multi-runway ALP.
The majority of research on the aircraft landing problem considers sequencing the aircraft in the Terminal Manoeuvering Area (TMA).

However, sequencing aircraft further away from the airport (such as Extended TMA) may produce better results. ⇒ Problem is divided into three stages.

- **Sequencing Stage (Stg 1):** It starts by entering the aircraft into the airport landing planner’s radar range about 40 minutes before touchdown.
- **Modifying Schedule Stage (Stg 2):** It starts 11 minutes before landing and takes 8 minutes and includes the final approach step.
- **Freezing Stage (Stg 3):** It consists of the runway controller’s range of operation which is 3 minutes long.
Multi-criteria Objective Function:

- **Minimizing the Delay** (Lateness and Earliness)
  Deviation of the scheduled Landing Time from the assigned Time Window

- **Maximizing the Runway Throughput** (Runway Utilization)
  Average Landing Time and/or Largest Landing Time (makespan)

- **Minimizing the Fuel Burn** (Carbon dioxide emission)
  Amount of extra fuel burn with respect to deviation of the Scheduled Landing Time from FCFS sequence

- Suggested objective function can potentially satisfy the interest of all parties.
Operational Constraints:

- **Runway usage:** Each runway can be used by at most one aircraft at a time.

- **Wake Vortex Separation:** Aircraft has to observe a separation distance to avoid turbulence caused by preceding aircraft.

- **Time Constraints:** Based on operational and technical considerations such as limited fuel, airspeed, etc., each aircraft has a maximum and a minimum allowable airborne time which have to be treated as hard constraints.

  A time slot (or *time window*) assigned to each landing aircraft (which typically starts 5 minutes before target landing time and ends 10 minutes after it) does not necessarily coincide with the time constraint.

- **Time Shifting:** There is limited flexibility in moving the aircraft’s landing time either forward or backward in time relative to its estimated landing time.

  *Time shifting* is considered rather than *position shifting* in re-sequencing the aircraft which it can be dependent on aircraft type.

- **Precedence Constraints:** Airline preferences may dictate that one aircraft should land before another one.
The Mixed Integer Programming Model is solved using Xpress IVE and Gurobi on Pentium Core Duo 3.0GHz with 4GB RAM.

The problem instances produced by Beasley et al. (2000) are modified and are used to test the MIP model.

Symmetric matrices for separation are considered!

### Initial Experimental Results

<table>
<thead>
<tr>
<th>Problem Size</th>
<th>Number of constraints</th>
<th>Number of Decision Variable</th>
<th>Xpress Runtime</th>
<th>Gurobi Runtime</th>
</tr>
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<tbody>
<tr>
<td>10</td>
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</tr>
</tbody>
</table>

Although the MIP model is not appropriate for on-line scheduling at busy airports, it may be suitable for the medium sized traffic.

The computational time of the MIP model highly depends on the dataset.
**A Look to the Future**

- Existing research generally considers some of the common and obvious constraints.
  - This research aims to capture vital operational constraints that have been observed from the daily work of controllers in our model building.

- Majority of designed algorithms take far too long to run by air traffic controllers in real time.
  - We have started to design algorithms by merging the DP approach with some heuristics to obtain quickly good solutions (near-optimal solutions) to be of use to air traffic controllers.

- The goal is to obtain some generic algorithms which can be simply modified for different airport!
References

References

- Hu XB, Chen WH (2005a) Genetic Algorithm Based on Receding Horizon Control for Arrival Sequencing and Scheduling. Engineering Applications of Artificial Intelligence 18(5):633642
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