The Multicriteria Aircraft Landing Problem

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Outline

‘Runway congestion is causing delays’

Soubhik Mitra, Hindustan Times
Mumbai, April 19, 2011

First Published: 01:21 IST(19/4/2011)
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The extra time taken by airplanes to vacate the runaway is one of the reasons behind the delays at Mumbai airport, stated a report by civil aviation ministry presented in a review meeting on delays held earlier this month. According to the minutes of the meeting (a copy of which is with *HT*), flights have

Jetstar to sue Sydney Airport for massive flight delays

April 20, 2011 6:06 PM EST

Airports and Delay

"The efficient operation of airports, and runways in particular, is critical to the throughput of the air transportation system" (Balakrishnan and Chandran, 2010)

Even if there is adequate capacity, peaked schedules and/or randomness in aircraft arrivals causes delay

Wake Vortex Constraints

Aircraft movement creates turbulence

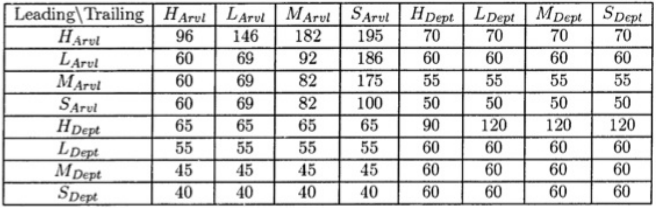
- especially during take-off and landing
- notably *wingtip vortices*

Turbulence is especially hazardous during take-off and landing

Wake Vortex Constraints

There are required temporal separations between operations on a common runway

These wake vortex separations depend upon
  lead and trail aircraft type
  operation type



Leading\Trailing	H_{Arvl}	L_{Arvl}	M_{Arvl}	S_{Arvl}	H_{Dept}	L_{Dept}	M_{Dept}	S_{Dept}
H_{Arvl}	96	146	182	195	70	70	70	70
L_{Arvl}	60	69	92	186	60	60	60	60
M_{Arvl}	60	69	82	175	55	55	55	55
S_{Arvl}	60	69	82	100	50	50	50	50
H_{Dept}	65	65	65	65	90	120	120	120
L_{Dept}	55	55	55	55	60	60	60	60
M_{Dept}	45	45	45	45	60	60	60	60
S_{Dept}	40	40	40	40	60	60	60	60

Table 2.1: The Minimum Separation Matrix

The Aircraft Landing Problem

The system is easily modeled via mathematical programming:

Sequence and schedule aircraft landings on a common runway to maximize capacity

Sequence-dependent job shop scheduling
(see also irrigation scheduling)

Aircraft Landing Problem: decision variables

$x_i \equiv$ the time operation i is performed

$$\delta_{i,j} \equiv \begin{cases} 1 & \text{if operation } i \text{ is performed before operation } j \\ 0 & \text{otherwise} \end{cases}$$

Aircraft Landing Problem: base formulation

$$
\begin{aligned}
\text{min} \quad & \sum_{i \in I} x_i & & (1)\\
\text{s.t.} \quad & E_i \leq x_i \leq L_i & \forall i \in I \quad & (2)\\
& \delta_{i,j} + \delta_{j,i} \leq 1 & \forall i,j \in I \quad & (3)\\
& x_i - x_j + \delta_{i,j}(S_{j,i} + L_j - E_i) \geq S_{j,i} & \forall i,j \in I \quad & (4)\\
& \delta_{i,j} \in \{0,1\} & \forall i,j \in I \quad & (5)
\end{aligned}
$$

Aircraft Landing Problem: early and late costs

$$\min \quad \sum_{i \in I} \alpha\, x_i + \beta\, y_i \tag{1}$$

$$\text{s.t.} \quad E_i \le (T_i + x_i - y_i) \le L_i \qquad \forall i \in I \tag{2}$$

$$\delta_{i,j} + \delta_{j,i} \le 1 \qquad \forall i,j \in I \tag{3}$$

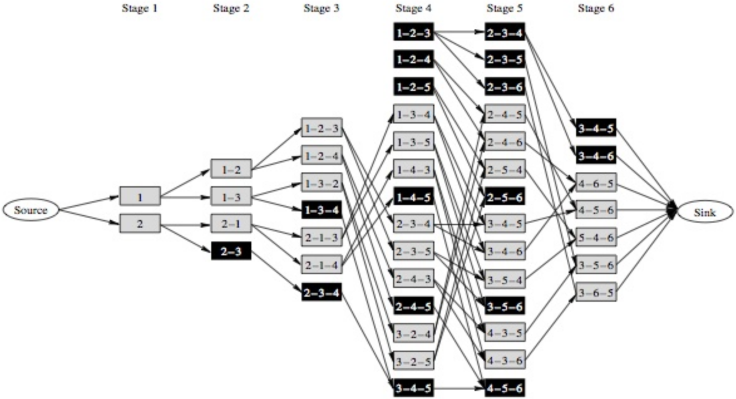
$$(T_i + x_i - y_i) - (T_j + x_j - y_j) + \delta_{i,j}(S_{j,i} + L_j - E_i) \le S_{j,i} \qquad \forall i,j \in I \tag{4}$$

$$\delta_{i,j} \in \{0,1\} \qquad \forall i,j \in I \tag{5}$$

$$x_i, y_i \ge 0 \qquad \forall i \in I \tag{6}$$

Aircraft Landing Problem: constrained position shifting

Position	1	2	3	4	5	6
Possible aircraft assignments	1 2	1 2 3	2 3 4	3 4 5	4 5 6	5 6

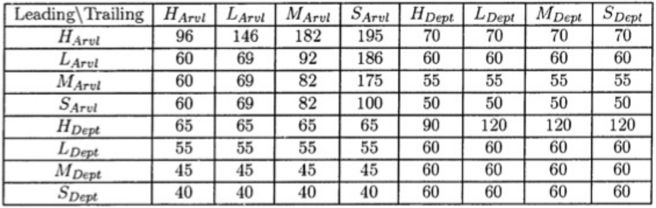


Note. Nodes shaded in black do not belong to any source-sink path and hence can be pruned from the network.

Aircraft Landing Problem: implications

Consider a toy problem: 1 S and 1 H plane waiting to land.

We have two possible sequences: SH and HS.



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S_{Dept}	40	40	40	40	60	60	60	60

Table 2.1: The Minimum Separation Matrix

Aircraft Landing Problem: implications

SH: Small plane lands at time 0, Heavy plane lands at time 60.
HS: Heavy plane lands at time 0, Small plane lands at time 195.

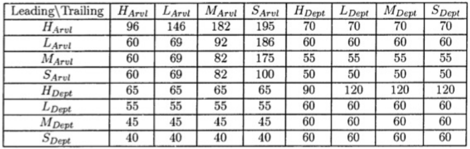

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Table 2.1: The Minimum Separation Matrix

Sequence optimization involves looking for opportunities to move smaller aircraft ahead of larger aircraft in the queue

Especially if minimizing makespan,
    if delay costs are equal for all aircraft,
    if considering long activity sequences

Aircraft Landing Problem: implications

Favor smaller aircraft ???

Can be bad for the traveling public

Can be bad for environmental impacts

Can be bad for long-term system performance

NB: Benefits of schedule optimization more important when sequencing large numbers of runway operations

Aircraft Landing Problem: alternative objectives

Minimize the costs of fuel burn, noise pollution, and emissions
[Solveling et al., 2011]

Minimize inequity
[Soomer and Koole, 2008]

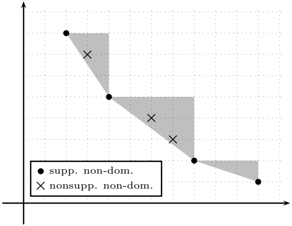
Aircraft Landing Problem: shortcomings

All previous approaches have been single-objective

Require translation to common units
(costs of emissions, inequity)

Results are sensitive to translation models

Only find supported efficient solutions



Outline

1. Introduction to the Aircraft Landing Problem (ALP)
2. The Multicriteria Problem
3. Sample Results
4. Conclusion

Minimizing Environmental Impacts

$$
\begin{aligned}
\min \quad & \sum_{i \in I} x_i && && (1)\\
\min \quad & \sum_{i \in I} P_i \; x_i && && (2)\\
\text{s.t.} \quad & E_i \leq x_i \leq L_i && \forall i \in I && (3)\\
& \delta_{i,j} + \delta_{j,i} \leq 1 && \forall i, j \in I && (4)\\
& x_i - x_j + \delta_{i,j}(S_{j,i} + L_j - E_i) \geq S_{j,i} && \forall i, j \in I && (5)\\
& \delta_{i,j} \in \{0, 1\} && \forall i, j \in I && (6)
\end{aligned}
$$

The ϵ-Constraint Method

$$\begin{aligned}
\min \quad & \sum_{i \in I} x_i && && (1)\\
\text{s.t.} \quad & \sum_{i \in I} P_i \, x_i \leq \epsilon && && (2)\\
& E_i \leq x_i \leq L_i && \forall i \in I && (3)\\
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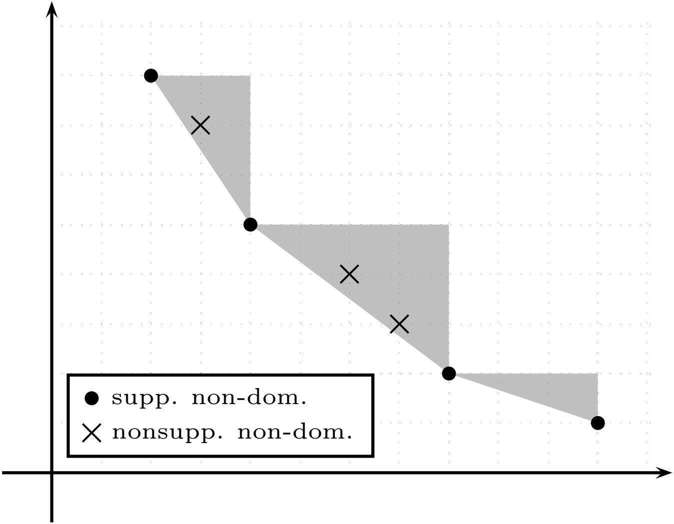

Minimizing Reversals

$$\begin{aligned}
\min \quad & \sum_{i \in I} x_i & & \quad (1)\\
\min \quad & \sum_{i,j \in Z} \delta_{i,j} & & \quad (2)\\
\text{s.t.} \quad & E_i \leq x_i \leq L_i & \forall i \in I & \quad (3)\\
& \delta_{i,j} + \delta_{j,i} \leq 1 & \forall i,j \in I & \quad (4)\\
& x_i - x_j + \delta_{i,j}(S_{j,i} + L_j - E_i) \geq S_{j,i} & \forall i,j \in I & \quad (5)\\
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\end{aligned}
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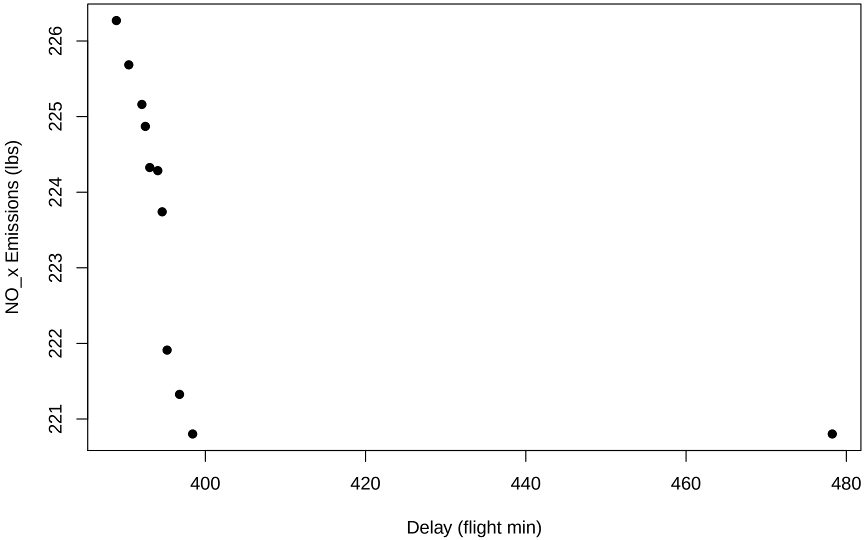
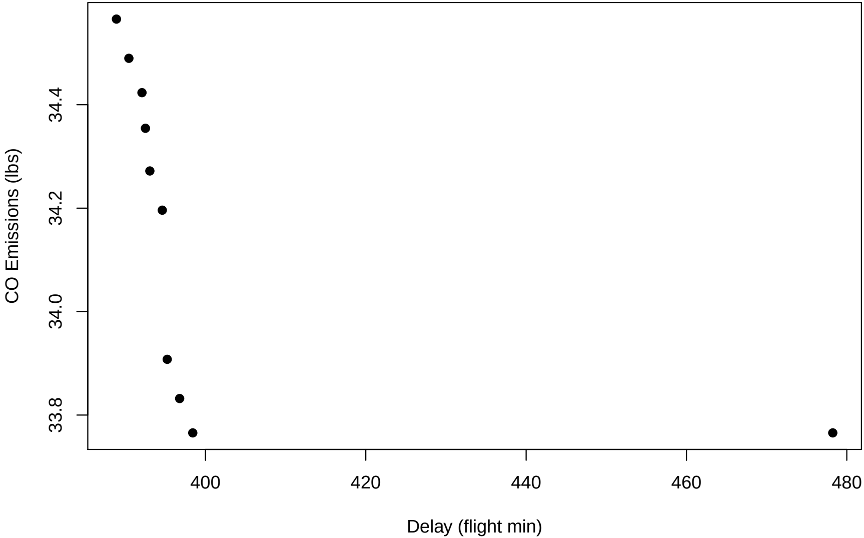
Sample Problem

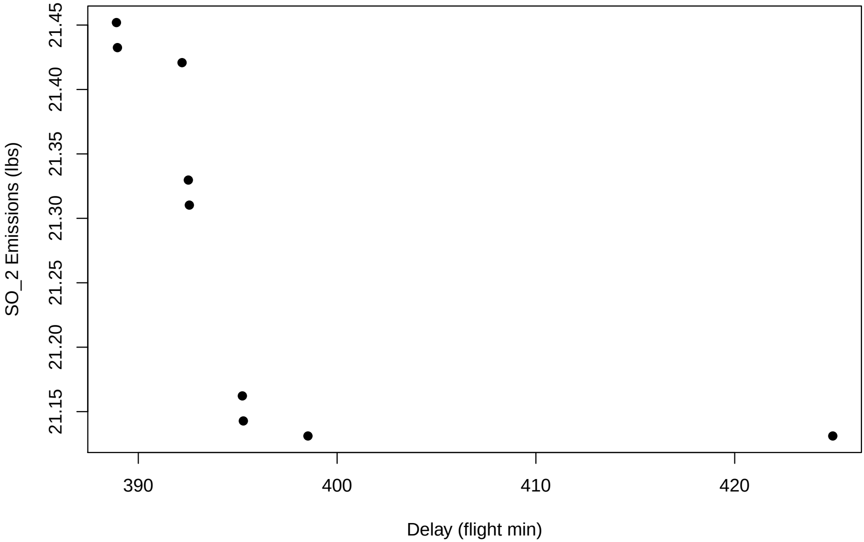
20 aircraft landing on a common runway

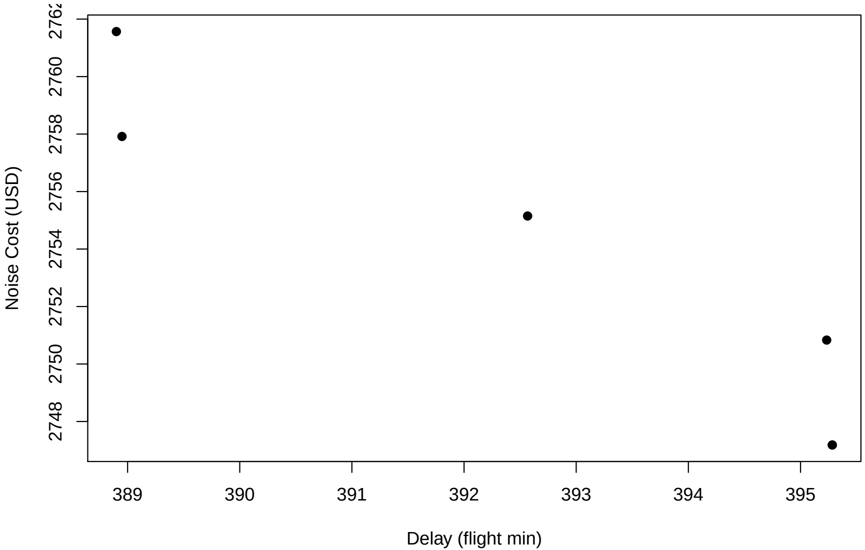
Earliest times of arrival are randomly generated (U[0,30])
Latest times of arrival are set to 50

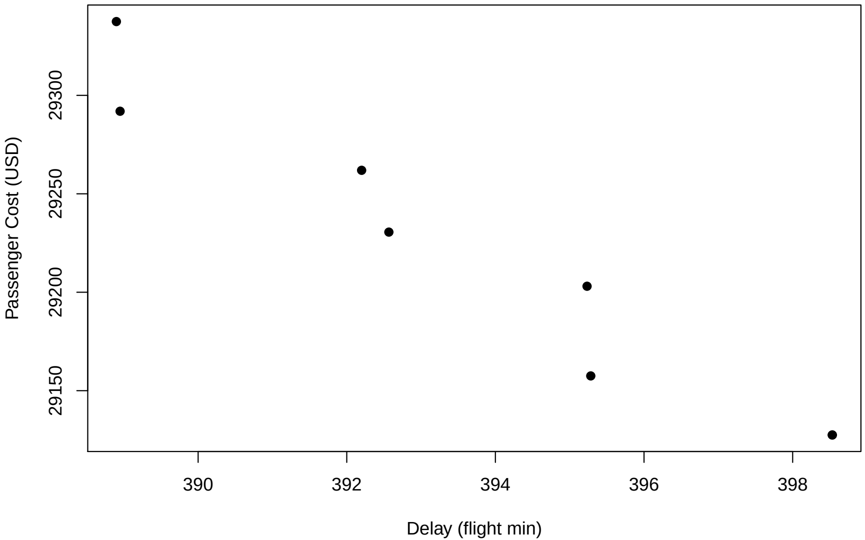
Environmental impact data from [Solveling et al., 2011]
Assume delay can be absorbed in cruise phase of flight


NO_x Emissions (lbs)
226
225
224
223
222
221
400
420
440
460
480
Delay (flight min)


CO Emissions (lbs)
34.4
34.2
34.0
33.8
400
420
440
460
480
Delay (flight min)


SO_2 Emissions (lbs)
21.45
21.40
21.35
21.30
21.25
21.20
21.15
390
400
410
420
Delay (flight min)


2762
2760
2758
2756
2754
2752
2750
2748
Noise Cost (USD)
389
390
391
392
393
394
395
Delay (flight min)


Passenger Cost (USD)
29150
29200
29250
29300
390
392
394
396
398
Delay (flight min)

Outline

Conclusions

We have formulated and solved Bicriteria Aircraft Landing Problems

There are trade-offs between environmental impacts and delay

There are trade-offs between different delay objectives

Future Work

We need to test the approach on larger-scale problems
  - Multicriteria problems
  - Multiple runway problems

Further research is needed to define appropriate objective functions
  - Equity particularly poorly understood