Fair Allocation Concepts in Air Traffic Management

Thomas Vossen, Michael Ball
R.H. Smith School of Business &
Institute for Systems Research
University of Maryland
Ground Delay Programs

- Delayed departures
- Delayed arrivals/no airborne holding
- Delayed departures
Collaborative Decision-Making

Traditional TFM:
- Flow managers alter routes/schedules of individual flights to achieve system wide performance objectives

Collaborative Decision-Making (CDM)
- Airlines and aircraft operators share information and collaborate in determining resource allocation

CDM in GDP context:
- CDM-net, communications network that allows real-time information exchange
- Allocation procedures that increase airline control and encourage airline provision of up-to-date information
GDPs under CDM

Resource Allocation Process:

• FAA: *initial “fair” slot allocation*  
  [Ration-by-schedule]

• Airlines: *flight-slot assignments/reassignments*  
  [Cancellations and substitutions]

• FAA: *periodic reallocation to maximize slot utilization*  
  [Compression]

Note:

- reduced capacity is partitioned into sequence of arrival slots
- ground delays are derived from delays in arrival time
Allocating Slots under CDM

*Ration-By-Schedule:*

Step 1: Order flights by their *original scheduled time of arrival*

Step 2: Select the first flight that has not been assigned an arrival slot.
   - assign the selected flight to the earliest unassigned slot
   - repeat step 2.

The resulting allocation is independent of current status of flights and is not affected by status information given by airlines!!
Slot Reallocation under CDM

Need for Inter-airline slot exchange:
slots made available through flight cancellations and delays

Compression Algorithm

<table>
<thead>
<tr>
<th>Initial</th>
<th>Final</th>
</tr>
</thead>
<tbody>
<tr>
<td>AAL1:1200</td>
<td>AAL1:1200</td>
</tr>
<tr>
<td>AAL2:1201</td>
<td>AAL2:1201</td>
</tr>
<tr>
<td>UAL1:1202</td>
<td>UAL1:1202</td>
</tr>
<tr>
<td>USA1:1203</td>
<td>USA1:1203</td>
</tr>
<tr>
<td>UAL2:1204</td>
<td>UAL2:1204</td>
</tr>
<tr>
<td>COA1:1210</td>
<td>COA1:1210</td>
</tr>
<tr>
<td>USA2:1212</td>
<td>USA2:1212</td>
</tr>
<tr>
<td>AAL3:1214</td>
<td>AAL3:1214</td>
</tr>
</tbody>
</table>

S1200
S1202 CNX
S1204
S1206
S1208
S1210
S1212
S1214
Motivation

Fairness Issues:

• Flight-based vs. airline-based,
  – e.g. RBS:flight-based, Compression: airline-based

• Possible “standards of comparison”

• Impact of program dynamics
  – flight cancellations/delays (compression)
  – flight exemptions
Related Allocation Problems

Apportionment problems:

• *How to assign house seats to states according to proportion of their populations*

Balanced just-in-time scheduling problems:

• *How to determine production schedules that minimize variation in the production rate of successive units of different product types.*
GDPs as apportionment

“Coarse-grained” one-period GDP:

Flights: \( F_a \)

Delay: \( D = n - C \)

Slot: capacity \( C \)

Interpretation as apportionment:

- capacity \( C \) = house seats
- airlines = states
- flights = populations
GDPs as balanced JIT problem

“Finer-grained” GDP:

- Airlines = products, flights = product quantities
- Minimize deviation between “ideal” rate and actual production

\[
\begin{align*}
\text{flts} & \quad \text{Possible deviation measures} \\
\text{time} & \\
\end{align*}
\]

- “ideal” production rate
- Cumulative production

\[
\begin{align*}
n_b & \\
X_b & \\
n_a & \\
\end{align*}
\]
GDP Situation

“Release times” defined by scheduled arrivals

Questions:
• What are appropriate “production rates”?
• How to minimize deviations?
• Managing program dynamics
Determining fair shares

Sketch:

• Assume slots are *divisible*
  – leads to probabilistic allocation schemes

• Approach: impose properties that schemes need to satisfy
  – fairness properties
  – structural properties (consistency, sequence-independence)
Determining fair shares

Two possibilities:

• earlier flights have priority over later flights
  – e.g. *Ration-by-schedule*

• all flights have equal priority
  – leads to “*proportional random assignment*”:
    – At each step, assign next slot to airline $a$ with probability proportional to airlines’ current flights.
Empirical Comparison

Deviation PRA vs. RBS (LaGuardia)

- On the aggregate, both methods give similar shares
- no systematic biases
Program Dynamics

Question:
• If RBS is fine, why bother with minimizing deviation, balancing the schedule?

Answer: GDP dynamics
• Flight cancellations, delays (e.g. compression)
• Exemption-handling
1. Flight Cancellations/Delays

- Infeasibility/suboptimality require rescheduling
- Use balanced jit paradigm to minimize airline deviations from RBS schedule
1. Flight Cancellations/Delays

**Approach:**
- Minimize deviation between ideal and actual position for \( k \)-th flight of airline \( a \), for all \( a,k \)

**Priority Method:**
- Input: ordered list of priorities for each airline
- Sequentially assign slots:
  - Assign current slot to airline with highest remaining priority that can use slot (given its earliest arrival times)

- *Results similar to compression algorithm*
2. Flight exemptions

Flight exemptions introduce systematic biases:
- USA (11m/flt), UCA (18m/flt) “lose” under exemptions
2. Flight Exemptions

Objective:

• Use deviation model to mitigate exemption bias
  – e.g. “inverse” compression

Possible approaches:

• Optimization model adjusted for constraints posed by exempted flights
• Adjustment of priority method
  – may not minimize overall deviation measure
2. Flight Exemptions

- Minimize deviations using optimization model that incorporates exemptions
- reduces systematic biases, e.g. USA from 11m/flt to 2m/flt, UCA from 18m/flt to 5m/flt
2. Flight Exemptions

- Minimize deviations using adjustment of priority scheme
- Lesser, but still significant bias reduction, e.g. USA from 11m/ftl to 5m/ftl, UCA from 18m/ftl to 7m/ftl
Discussion

Approach yields system where:

• airlines are assigned priority *lists*
  – based on sched. arr. times, constant during GDP
• dynamic changes (capacity, airline data) initiate (re)rationing
  – ration according to *airline* priorities
• priority scheme cannot (completely) be maintained with flight exemptions
  – deviation model shows potential to reduce exemption bias