Ground Delay Program Decision-making using Multiple Criteria: a Single Airport Case

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Outline

- Introduction
- Ground Delay Program Models
- Performance Metrics
- Case Study
- Summary
Ground Delay Programs (GDPs) are implemented to balance the arrival demand with the reduced capacity at the arrival airport. This is achieved by delaying takeoffs of the GDP affected flights at the departure airports, which allows us to transfer airborne delay to ground delay.
Current Practice on GDP Planning

Strategic planning telecons

GDP decisions

FEDERAL AVIATION ADMINISTRATION

DELTA

UNITED

SOUTHWEST

American Airlines
Operational Challenges

- Flight operators participate in the decision making process by verbal input
- Discussion focuses on specific GDP parameters rather than program goals
- Different traffic managers may create different plans for the same situation
- No systematic method exists for incorporating flight operator’s preferences into GDP decisions
To address these issues, researchers from Maryland, MIT and Berkeley are proposing a new mechanism for flight operator community to systematically set performance expectations in the design of Traffic Management Initiatives (GDPs, Airspace Flow Programs).

We are doing the pilot study with GDPs.
Proposed GDP Planning Process

Information to users:
feasible performance vectors

<table>
<thead>
<tr>
<th></th>
<th>Capacity</th>
<th>Efficiency</th>
<th>Predictability</th>
</tr>
</thead>
<tbody>
<tr>
<td>V1</td>
<td>0.9</td>
<td>0.8</td>
<td>0.5</td>
</tr>
<tr>
<td>V2</td>
<td>0.5</td>
<td>0.7</td>
<td>0.9</td>
</tr>
<tr>
<td>V3</td>
<td>0.7</td>
<td>0.6</td>
<td>0.6</td>
</tr>
</tbody>
</table>

Inputs from user 1:
Grades for vectors

<table>
<thead>
<tr>
<th>Grades</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent</td>
</tr>
<tr>
<td>Good</td>
</tr>
<tr>
<td>Passable</td>
</tr>
</tbody>
</table>

Performance criteria and metrics?
Performance tradeoffs?

GDP parameters

Consensus vector
Research Objectives

- Identify and define performance criteria for GDPs
- Specify performance metrics for use in COuNSEL
- Build performance tradeoff curves between the criteria and associated metrics
- Link the performance vectors to GDP parameters
Ground Delay Program (GDP) Models at a Single Airport
Arrival Queueing Diagram

Cumulative arrivals

Scheduled cumulative demand curve

GDP start time

Arrival 1

Arrival 2

t1 t2 t3

λ
Arrival Queueing Diagram

Cumulative arrivals

Scheduled cumulative demand curve

Planned cumulative arrival curve under GDP (Basis for Controlled Time of Arrival)

C<sub>H</sub>, planned high airport arrival rate

Planned delay

n

GDP start time

t<sub>S</sub>

C<sub>L</sub>, planned low airport arrival rate

t<sub>CTA</sub>

Decision:

T, planned clearance time in the GDP
Arrival Queueing Diagram

Cumulative arrivals

Scheduled cumulative demand curve

errors in prediction

Planned cumulative arrival curve under GDP
(Basis for Controlled Time of Arrival)

Decision:

\[ T, \text{ planned clearance time in the GDP} \]

\[ \tau, \text{ actual clearance time} \]

\[ C_L, \text{ GDP start time} \]

\[ C_H, \text{ actual clearance time} \]
Early Weather Clearance

- High capacity level, $C_H$, is available at $\tau$, earlier than planned

Option 1: No GDP revision

Option 2: GDP revision - Early cancellation

Unnecessary ground delay

Revised cumulative arrival curve

Delay saving
**Late Weather Clearance**

- **GDP extension**: give priority to en-route flights, and extend ground delay for flights that have not departed yet.
## Two Models

<table>
<thead>
<tr>
<th>Model</th>
<th>Early weather clearance</th>
<th>Late weather clearance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early cancellation model</td>
<td>Early GDP cancellation</td>
<td>GDP extension</td>
</tr>
<tr>
<td>No early cancellation model</td>
<td>No early GDP cancellation</td>
<td>GDP extension</td>
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</table>
Performance Metrics
(introduced with early cancellation model)
Principles for Defining Metrics

- All the performance metrics are defined to be:
  - dimensionless
  - between 0 and 1
  - with 1 as the best
Capacity Criteria

- In the current practice, capacity has been the main performance target.
- Capacity performance criteria is to maximize throughput:
  - Avoid underestimating arrival rates.
  - Encourage early GDP cancellation if weather clears early.
\[ \alpha_c = \frac{N_R}{N_I} \]

- **\( N_I \)** — Arrival under perfect information at the time when queue clears, \( \tau_2 \)
- **\( N_R \)** — Realized arrival at this time
\( \alpha_c = \frac{N_R}{N_I} = 1 \)

- \( N_I \)—Arrival under perfect information at the time when queue clears, \( \tau_2 \)
- \( N_R \)—Realized arrival at this time

\[ N_I = N_R \]

Scheduled cumulative demand curve
Predictability Criteria

- Day-of-operation predictability allows a multitude of benefits:
  - Better estimate of the amount of delay
  - Better mitigate the impact of delay

- Predictability is defined to equalize planned delay and realized delay
  - Avoid overestimating arrival rates and make programs extensions unlikely
  - Discourage early GDP cancellation if weather clears early
Predictability Metric

\[ \alpha_p = \frac{\min(D_P, D_R)}{\max(D_P, D_R)} \]

- **D_P**—Planned total flight delay at the beginning of the GDP
- **D_R**—Realized total flight delay

\[ \alpha_p = \frac{D_R}{D_P} \]

Cumulative arrivals

```
Early cancellation
```

```
GDP extension
```

\[ \alpha_p = \frac{D_P}{D_R} \]

Cumulative arrivals
Efficiency Criteria

- Unit airborne delay cost is larger than unit ground delay cost
- Efficiency criteria is to minimize delay cost
  - Avoid underestimating arrival rates to reduce the delay cost
  - Encourage transferring airborne delay to ground delay
Efficiency Metric, Early Cancellation

\[ \alpha_e = \frac{C_P}{C_R} \]

- \( C_P \) — Minimum cost that would be incurred if perfect information were available about when the capacity will go up
- \( C_R \) — Realized cost

With perfect information \( C_P \) (ground delay cost)

Realized \( C_R \) (ground delay cost)

Revised cumulative arrival curve
Efficiency Metric, GDP Extension

\[ \alpha_e = \frac{C_P}{C_R} \]

- **C_P** — Minimum cost that would be incurred if perfect information were available about when the capacity will go up
- **C_R** — Realized cost

Cumulative arrivals

With perfect information $C_P$ (ground delay cost)

Cumulative arrivals

Realized $C_R$ (ground delay cost + airborne delay cost)
Use of Performance Metrics in GDP Decision Making

Information to users:
feasible performance vectors

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<td>0.6</td>
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</tbody>
</table>

$$\alpha_c = g(\lambda, C_L, C_H, F_{\min}, F_{\max}, T, \tau)$$

$$E[\alpha_c] = \int_{\tau_{\min}}^{\tau_{\max}} g(\lambda, C_L, C_H, F_{\min}, F_{\max}, T, \tau) f(\tau) d\tau$$

$$E[\alpha_c] = G(\lambda, C_L, C_H, F_{\min}, F_{\max}, T, f(\tau), \tau_{\min}, \tau_{\max})$$
Case Study
Set-up

1-minute airborne delay is twice expensive as 1-minute ground delay

\[ \lambda = 60 \text{ per hour} \]

\[ C_H = 80 \text{ per hour} \]

Real clearance time, \( \tau \): uniformly distributed between 2 hours and 6 hours

Flight time, \( F \): uniformly distributed between 0.5 hours and 7 hours
With increasing T, it means we designed the GDP assuming a longer period of low airport arrival rate and therefore it is more likely that we would have underestimated capacity under uncertainty.
Performance Metrics

- As T increases, efficiency first increases because of reduced chance of expensive airborne delay.
- After a certain point, efficiency will decrease with T because it is very likely that realized ground delay is much larger than it could be if we had perfect information.
Different from the other two metrics, predictability degrades when the GDP is revised.

The impact of GDP revision is more obvious with a larger $T$. 
User Preferences

- Different flight operators have different preferences on performance goals
- Each flight operator may prefer a point on the tradeoff curves that maximizes their utility, $U$
Constrained Optimization

Choose: \([\alpha_c, \alpha_p, \alpha_e]\) (performance metrics)
Maximize: \(U(\alpha_c, \alpha_p, \alpha_e)\) (utility)
Subject to:

\[G_{\text{without_revision}}(\alpha_c, \alpha_p, \alpha_e) = 0\]
Or
\[G_{\text{with_revision}}(\alpha_c, \alpha_p, \alpha_e) = 0\]
(feasible trade-off curves)
Assume a linear utility function:

\[ U(\alpha_c, \alpha_p, \alpha_e) = c_c \times \alpha_c + c_p \times \alpha_p + c_e \times \alpha_e \]
## Weights

<table>
<thead>
<tr>
<th>User</th>
<th>$C_c$</th>
<th>$C_p$</th>
<th>$C_e$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.5</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>2</td>
<td>0.25</td>
<td>0.5</td>
<td>0.25</td>
</tr>
</tbody>
</table>

**Efficiency**

**Capacity**

### Predictability

- User 2’s optimal vector: [0.885, 0.948, 0.644]
  - Implied ideal plan: $T=4.88$ hr, NO early cancellation

- User 1’s optimal vector: [0.955, 0.766, 0.769]
  - Implied ideal plan: $T=3.8$ hr, early cancellation

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**No GDP Revision**

- $\alpha_{C}=0.873$
- $\alpha_{e}=0.644$
- $\alpha_{C}=0.955$

**GDP Revision**

- $\alpha_{p}=0.766$
- $\alpha_{p}=0.948$
- $\alpha_{C}=0.955$
GDP Scope
GDP Scope

- So far, we assume all the flights heading to the airport will be affected when there is a GDP.

- In practice, only flights within a certain scope will be subject to GDP. Flights that are geographically farther than the scope, will be exempted from the program.
Delay is absorbed by the flights within the scope only

**Advantage:**
Fewer flights will be involved

**Disadvantage:**
There is more delay for flights that are affected
Impact of Scope, No Early Cancellation

- Scope has no impact on capacity and predictability
- Smaller GDP scope reduces the amount of airborne delay in the case of GDP extension
Impact of Scope, Yes Early Cancellation

Smaller scope benefits capacity and efficiency, but reduces predictability.
### Update on GDP Decisions

<table>
<thead>
<tr>
<th>User</th>
<th>Weights of performance goals</th>
<th>Full scope</th>
<th></th>
<th>Half scope</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$C_c$</td>
<td>$C_p$</td>
<td>$C_e$</td>
<td>Early cancellation?</td>
</tr>
<tr>
<td>1</td>
<td>0.5</td>
<td>0.25</td>
<td>0.25</td>
<td>YES</td>
</tr>
<tr>
<td>2</td>
<td>0.25</td>
<td>0.5</td>
<td>0.25</td>
<td>NO</td>
</tr>
<tr>
<td>3</td>
<td>0.25</td>
<td>0.25</td>
<td>0.5</td>
<td>YES</td>
</tr>
</tbody>
</table>

- When capacity or efficiency is the focused performance goal, GDP should be cancelled earlier if weather clears earlier. GDP scope has little impact on $T$.
- When predictability is the main goal, GDP should not be cancelled earlier if possible. GDP scope has little impact on $T$.
Summary
We have developed day-of-operation performance metrics for **capacity, predictability, and efficiency** in the design of GDPs
Using the GDP models, we are able to represent tradeoffs between performance goals and relate these to the GDP decisions on:

- clearance time
- scope
- and early cancellation
This capability will lead to improved GDP decision-making, in which traffic managers and flight operators can make informed tradeoffs based on their assessment of the value of different performance goals.
Thank you for listening!
Questions?