Combining Control by CTA and Dynamic En Route Speed Adjustment to Improve Ground Delay Program Performance

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Overview

• Motivation and Background
• Proposed changes to GDP planning architecture
• New GDP planning integer programming models
• Results
• Summary
Motivating Ideas

• Control by CTA
  – Klooster et al [2009], McDonald and Bronsvoort [2012], Nieuwenhuisen, and Gelder [2012], Delta (Atilla), United Airlines (Heathrow)

• Speed Control
  – GDP planning: Delgado and Prats [2011], [2013], [2014], Prats and Hansen [2011], Jones [2014]
  – Tactical planning: Neuman and Erzberger [1991], Knorr et al [2011], Swenson et al [2011], Jones et al [2013], ATD-1, Extended Metering

• Collaborative Decision Making
  – Wambsganns [1993], Ball et al [2001], Vossen and Ball [2006], [2006], Fearing et al [2011]

• Hedging Under Uncertainty
  – Capacity Uncertainty: Richetta and Odoni, [1993], Ball et al [2003], Mukherjee and Hansen [2007], Ball et al [2010]
  – Demand Uncertainty: Ball et al [2001]
GDP Background

• When faced with inclement weather the capacity of airports is often insufficient to meet demand
• To deal with these imbalances FAA managers impose a Ground Delay Program (GDP)
• Since inclement weather will often clear prior to the end of the GDP an exemption radius is set
  – Removes delays to long haul flights
  – Can reduce overall delay if the weather clears earlier than expected
Speed Control in Ground Delay Programs

• During GDPs, flight managers assign a controlled time of departure (CTD) to flights
• Assigning Controlled Times of Arrival (CTAs) in lieu of CTDs may offer a more attractive means of transferring delay
  – Provides carriers more flexibility and control
  – Allows for system-wide trade-offs

Delay allocation under conventional GDP Planning
Speed Control in Ground Delay Programs

• During GDPs, flight managers assign a controlled time of departure (CTD) to flights

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---

Delay allocation under CTA based GDP Planning

\[ \text{STD} \quad \text{CTD}_{\text{min}} \quad \text{CTD}_{\text{max}} \quad \text{STA} \quad \text{CTA} \]
Speed Control in Ground Delay Programs

- During GDPs, flight managers assign a controlled time of departure (CTD) to flights
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**Delay allocation under CTA based GDP Planning**

- FAA
- Airlines
- GD<sub>min</sub>
- Variable Delay
- Travel Time
- STD
- CTD<sub>min</sub>  CTD<sub>max</sub>
- STA
- CTA
Speed Control in Ground Delay Programs

- During GDPs, flight managers assign a controlled time of departure (CTD) to flights
- Assigning Controlled Times of Arrival (CTAs) in lieu of CTDs may offer a more attractive means of transferring delay
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GDP Planning Process

- Ration-by-Schedule
- Cancellation and Substitution
- Compression

**FAA:** Assign Slots
**Airlines:** Adjust Schedule
**FAA:** Inter-Airline Slot Exchange
Current Practice: RBS with Exemptions

- Flights are assigned to available slots based on the order they appear in the schedule
- Exempt flights receive priority
Shortcomings of Exemptions

- DAL490 and UA12 cannot make substitutions since exempt flights are airborne.
- Can add additional delay to flights or cause additional cancellations.

Cancellation and Substitution process in current CDM framework.
Advantage of Adding Speed Control

- With speed control Delta and United can reassign airborne flights and achieve better metrics.

Cancellation and Substitution process without exemptions. Delta and United can substitute and improve their on-time performance.
• Fuel efficiency is a concave function of speed

• General Characteristics:
  – Cost curves are relatively flat
  – Cruise speeds can often exceed the maximum range
  – Slowing down during cruise can increase specific range

• Airlines could adjust speeds of flights to reduce ground delays during GDPs at a relatively small fuel penalty
New GDP Architecture

- **FAA procedural modifications**
  - Replace the use of CTDs with CTAs in GDP planning
  - Remove the exemption radius
  - Allow en route speed changes by carriers

- **Airline decision making modifications**
  - Incorporate speed changes into substitution and cancellation process
  - Introduce a new stochastic optimization model to support airline decision-making with substitutions and cancellations
    - Model matches flights to assigned capacity
    - Allows airlines to hedge for early weather clearance
Conventional GDP Planning

Airborne Flights: Flight Positions and ETAs, AC speeds

Flight on Ground: Flight Schedule

Data

Algorithms

Allocations

Airline Decisions

FCFS

DB-RBS

Assign CTDs to Airlines

Substitute and Cancel Flights

Compression

FAA

Airlines

FAA
Conventional GDP Planning

Airborne Flights: Flight Positions and ETAs, AC speeds
  ➔ FCFS
  ➔ DB-RBS

Flight on Ground: Flight Schedule

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Mechanisms
Conventional GDP Planning

- **Airborne Flights:** Flight Positions and ETAs, AC speeds
- **Flight on Ground:** Flight Schedule

**FAA**
- FCFS
- Assign CTDs to Airlines

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- Substitute and Cancel Flights

**FAA**
- Compression

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Airline Decisions

Mechanisms
Conventional GDP Planning

- **System has limited measures for recourse in the presence of unplanned conditions**
- **Slow to react in the presence of early clearance of weather**
- **Cannot take full advantage of opportunities for potential trades**
CTA Based GDP Planning

Airborne Flights: Flight Positions and ETAs, AC speeds

Flight on Ground: Flight Schedule

FAA

FCFS

RBS

Assign CTAs to Airlines

Airlines

Substitute and Cancel Flights

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CTA Based GDP Planning

- Airborne Flights: Flight Positions and ETAs, AC speeds
- Flight on Ground: Flight Schedule

FAA
- FCFS
- Assign CTAs to Airlines

Airlines
- Substitute and Cancel Flights

FAA
- Compression

Data
- Algorithms
- Allocations
- Airline Decisions
CTA Based GDP Planning

Airborne Flights: Flight Positions and ETAs, AC speeds
Flight on Ground: Flight Schedule

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- Assign CTAs to Airlines

Airlines
- Substitute and Cancel Flights

FAA
- Compression

Data
- Algorithms
- Allocations
- Airline Decisions
- Mechanisms

Hedging
- Departure Time Changes
- Flight Cancellations
- Speed Control
CTA Based GDP Planning

Airborne Flights: Flight Positions and ETAs, AC speeds

Flight on Ground: Flight Schedule

FCFS

RBS

Assign CTAs to Airlines

Substitute and Cancel Flights

FAA

Airlines

FAA

Compress

Speed Control

Departure Time Changes

Data

Algorithms

Allocations

Airline Decisions

Mechanisms
CTA Based GDP Planning

- System is more flexible in accommodating unplanned conditions
- More effective delay in the presence of early clearance of weather
- Allows additional substitution opportunities
- Adjustments can be performed to react to both major and minor perturbations
CTA Based GDP Planning

Model 1: Airline Substitution and Cancellation Model
- Hedging
- Incorporates Speed Control into Decisions

Model 2: FAA Compression Model
- Adds speed control to current compression framework
Goal: We want to account for the possibility of early clearance when assigning flights.
Evolution of a GDP

Scenario Tree

GDP Activity

$t_{start}$ $t_{c1}$ $t_{c2}$ $t_{c3}$ $t_{c4}$ $t_{end}$

Yes Yes Yes Yes Yes
Model 1: Airline Substitution and Cancellation

Stage 1: Initial Assignment

<table>
<thead>
<tr>
<th>Flight</th>
<th>Arrival Time</th>
</tr>
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<tbody>
<tr>
<td>DAL53:5:03</td>
<td>S1-5:10</td>
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<tr>
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<td>S2-5:12</td>
</tr>
<tr>
<td>DAL142:5:10</td>
<td>S3-5:14</td>
</tr>
<tr>
<td></td>
<td>S4-5:16</td>
</tr>
<tr>
<td></td>
<td>S5-5:18</td>
</tr>
<tr>
<td></td>
<td>S6-5:20</td>
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Slots Allocated with RBS

DAL

Other Airlines
Model 1: Airline Substitution and Cancellation

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DAL

Other Airlines
Stage 1: Initial Assignment

Flight
DAL53:5:03
DAL201:5:06
DAL142:5:10

Arrival Time
S1-5:10
S2-5:12
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Cancelled Flights

DAL

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Cancelled Flights

DAL

Other Airlines
Model 1: Airline Substitution and Cancellation

Stage 1: Initial Assignment
- Flight: DAL53:5:03
- Flight: DAL201:5:06
- Flight: DAL142:5:10

Arrival Time:
- S1-5:10
- S2-5:12
- S3-5:14
- S4-5:16
- S5-5:18
- S6-5:20

Stage 2: Revised Assignment

Arrival Time:
- S1-5:08
- S2-5:10
- S3-5:12
- S4-5:14
- S5-5:18
- S22-5:42

Feasible Range without Holding
Feasible Range with Holding

Cancelled Flights

DAL
- Green

Other Airlines
- Blue

Cancelled Flights

DAL201:5:06
DAL142:5:10
Model 1: Airline Substitution and Cancellation

Stage 1: Initial Assignment

- Flight: DAL53:5:03
- Arrival Time: S1-5:10, S2-5:12, S3-5:14, S4-5:16, S5-5:18, S6-5:20

Stage 2: Revised Assignment

- Arrival Time: S1-5:08, S2-5:10, S3-5:12, S4-5:14, S5-5:18, S22-5:42

Cancelled Flights: DAL201:5:06, DAL142:5:10

Incorporates Planning over Multiple Scenarios

DAL

Other Airlines
Model 1: Airline Substitution and Cancellation

Stage 1: Initial Assignment

Flight
DAL53:5:03
DAL201:5:06
DAL142:5:10

Arrival Time
S1-5:10
S2-5:12
S3-5:14
S4-5:16
S5-5:18
S6-5:20

Cancelled Flights

Stage 2: Revised Assignment

Arrival Time
S1-5:08
S2-5:10
S3-5:12
S4-5:14
S5-5:18
S22-5:42

Airlines can choose to remain in original slot if they expect no early weather clearance in scenario.
Model 1: Airline Substitution and Cancellation

Stage 1: Initial Assignment
- Flight: DAL53:5:03
  - Arrival Time: S1-5:10, S2-5:12, S3-5:14, S4-5:16, S5-5:18, S6-5:20
- Flight: DAL201:5:06
- Flight: DAL142:5:10

Stage 2: Revised Assignment
- Arrival Time: S1-5:08, S2-5:10, S3-5:12, S4-5:14, S5-5:18, S22-5:42

Cancelled Flights
- DAL
- Other Airlines

Airlines can also fly faster if they expect the weather to clear early in the scenario.
Model 1: Airline Substitution and Cancellation

Stage 1: Initial Assignment
- Flight: DAL53:5:03
- Arrival Time:
  - S1: 5:10
  - S2: 5:12
  - S3: 5:14
  - S4: 5:16
  - S5: 5:18
  - S6: 5:20

Stage 2: Revised Assignment
- Arrivals:
  - S1: 5:08
  - S2: 5:10
  - S3: 5:12
  - S4: 5:14
  - S5: 5:18
  - S6: 5:20
  - S22: 5:42

Cancelled Flights
- DAL
- Other Airlines

Objective: Each airline minimizes the total expected cost of assignments and cancellations over all scenarios.
Model 2: Compression

RBS++: Vossen and Ball [2006] with speed control
Impact of Changes on Airline Costs

• The proposed changes have potential to reduce airline costs
  – Airlines can choose whether to prioritize cancellations or delay
  – End result is fewer missed connections and/or better customer service

• Computational experiment was conducted to evaluate potential cost savings
  – GDP cancellation probabilities and amount of ground delay recovered was taken from Inniss and Ball\(^1\)
  – Examined GDP cost savings under various early weather clearance scenarios

Airline Cost Model

• Adopted cost model used by Vakili and Ball (ATM seminar 2009)
• Approach assumes block time is free during first 15 min, then $32 per min on the ground and $64 in the air
• We assume equal cost of ground and air delay of $40 after first 15 min
• Model also assumes airlines take delay cost of $0.1 per min
• Updating to 2013 airline costs reach $0.125 per min
• Parameters
  – P: Number of passengers of aircraft
  – x: Minutes of flight delay
  – M_p: The delay threshold beyond which it becomes cost effective to cancel the flight

\[
C(x, P) = \begin{cases} 
0 & x < 15 \\
(40 + 0.125P)(x - 15) & 15 \geq x \geq M_p \\
(40 + 0.125P)(M_p - 15) & x > M_p 
\end{cases}
\]
Experimental Test Conditions

- Data Source: TFMS and ASDX files
- Airport: ATL
- Date of Flights: May 1, 2011
- 5-hour GDP
- Aircraft speeds ranged from Mach 0.72-0.85
- Capacity reduced to 40 flights per hour
- Load Factor of 0.8
- Flight cancellation costs equal delay costs at 120 min
- Exemption Radius of 1000 nm for Conventional GDPs
Cost Savings under Early Cancellation

- CTA assignment leads to significant cost savings when the weather clears sufficiently early
- Earlier departure times allow for greater delay recovery
Cost Savings under Early Cancellation

- CTA assignment leads to significant cost savings when the weather clears sufficiently early
- Earlier departure times allow for greater delay recovery

### Percentage Cost Savings

<table>
<thead>
<tr>
<th>Cancellation Hour</th>
<th>Winter</th>
<th>Spring</th>
<th>Summer</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>19.56</td>
<td>22.32</td>
<td>22.32</td>
</tr>
<tr>
<td>1</td>
<td>19.46</td>
<td>22.21</td>
<td>22.21</td>
</tr>
<tr>
<td>2</td>
<td>17.47</td>
<td>19.87</td>
<td>19.09</td>
</tr>
<tr>
<td>3</td>
<td>5.51</td>
<td>6.25</td>
<td>5.72</td>
</tr>
<tr>
<td>4</td>
<td>1.75</td>
<td>1.72</td>
<td>1.23</td>
</tr>
<tr>
<td>&gt;=5</td>
<td>1.57</td>
<td>1.54</td>
<td>1.06</td>
</tr>
</tbody>
</table>
Experimental Test Conditions

- Data Source: TFMS and ASDX files
- Airport: ATL
- Date of Flights: May 1, 2011
- 5-hour GDP
- Aircraft speeds ranged from Mach 0.72-0.85
- Capacity reduced to 40 flights per hour
- Load Factor of 0.8
- Flight cancellation costs equal delay costs at 90 min
- Exemption Radius of 1000 nm for Conventional GDPs
- Uniform Probabilities for scenarios
Cancellations and Substitutions

- Assumed up to 60 minutes of early GDP clearance
- Proposed changes lead to fewer cancellations and more delay

<table>
<thead>
<tr>
<th>Airline</th>
<th>Percentage of Flights Cancelled</th>
<th>Passenger Delay</th>
<th>Number of Flights</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Conventional GDP</td>
<td>CTA Based GDP</td>
<td>Conventional GDP</td>
</tr>
<tr>
<td>Delta (DAL)</td>
<td>27.78</td>
<td>24.07</td>
<td>11.14</td>
</tr>
<tr>
<td>Air Tran (TRS)</td>
<td>32.14</td>
<td>28.57</td>
<td>12.37</td>
</tr>
<tr>
<td>American Southeast (ASQ)</td>
<td>27.59</td>
<td>17.24</td>
<td>18.29</td>
</tr>
<tr>
<td>American (AAL)</td>
<td>33.33</td>
<td>33.33</td>
<td>46.5</td>
</tr>
<tr>
<td>Pinnacle (FLG)</td>
<td>25</td>
<td>0</td>
<td>29.25</td>
</tr>
</tbody>
</table>
Cancellations and Substitutions

- Assumed up to 30 minutes of early GDP clearance
- Proposed changes lead to fewer cancellations and more delay

### Percentage of Cancellations

<table>
<thead>
<tr>
<th>Flight</th>
<th>Conventional</th>
<th>CTA Based</th>
</tr>
</thead>
<tbody>
<tr>
<td>DAL</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>TRS</td>
<td>20</td>
<td>15</td>
</tr>
<tr>
<td>ASQ</td>
<td>15</td>
<td>10</td>
</tr>
<tr>
<td>AAL</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>FLG</td>
<td>5</td>
<td>0</td>
</tr>
</tbody>
</table>

### Minutes of Delay per Flight

<table>
<thead>
<tr>
<th>Flight</th>
<th>Conventional</th>
<th>CTA Based</th>
</tr>
</thead>
<tbody>
<tr>
<td>DAL</td>
<td>30</td>
<td>25</td>
</tr>
<tr>
<td>TRS</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>ASQ</td>
<td>20</td>
<td>15</td>
</tr>
<tr>
<td>AAL</td>
<td>15</td>
<td>10</td>
</tr>
<tr>
<td>FLG</td>
<td>10</td>
<td>5</td>
</tr>
</tbody>
</table>
Effect of Exemption Radius

- Used integer programming models seeded from DB-RBS instead of RBS
- The addition of the exemption radius transfers delay from DAL and TRS to regional Airlines ASQ

### Percentage of Cancellations

<table>
<thead>
<tr>
<th>airline</th>
<th>DAL</th>
<th>TRS</th>
<th>ASQ</th>
<th>AAL</th>
<th>FLG</th>
</tr>
</thead>
<tbody>
<tr>
<td>With Radius</td>
<td>30%</td>
<td>25%</td>
<td>32%</td>
<td>27%</td>
<td>35%</td>
</tr>
<tr>
<td>Without Radius</td>
<td>25%</td>
<td>20%</td>
<td>28%</td>
<td>23%</td>
<td>30%</td>
</tr>
</tbody>
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### Minutes of Delay per Flight

<table>
<thead>
<tr>
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<th>TRS</th>
<th>ASQ</th>
<th>AAL</th>
<th>FLG</th>
</tr>
</thead>
<tbody>
<tr>
<td>With Radius</td>
<td>45 minutes</td>
<td>40 minutes</td>
<td>50 minutes</td>
<td>45 minutes</td>
<td>60 minutes</td>
</tr>
<tr>
<td>Without Radius</td>
<td>40 minutes</td>
<td>35 minutes</td>
<td>45 minutes</td>
<td>40 minutes</td>
<td>55 minutes</td>
</tr>
</tbody>
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Impact of Early Cancellation

- Early cancellation is more helpful to dominant carriers with more long haul flights

Minutes of Delay Recovered

![Graph showing minutes of delay recovered for different carriers (DAL, TRS, ASQ, AAL, FLG) for different delay times (0, 15, 30, 45, 60 minutes).]
Impact of Early Cancellation

- Early cancellation is more helpful to dominant carriers with more long haul flights.
Summary and Future Work

• Proposed a new strategy for managing GDPs
  – Control by CTA
  – En Route Speed Control
  – Eliminated Exemption Radius

• Strategy provides opportunities for significant cost savings

• Strategy may lead to airline behavioral changes
  – Fewer cancellations
  – More delay

• Near Term Challenges
  – Compliance
  – Modifying current procedures

• Long Term Challenges
  – Need to reconcile flexibility with Trajectory Based Operations
  – Managing flights with dynamic adjustment