Airline Crew Augmentation: Decades Of Improvements From Sabre

10 November 2014 • Xiaodong Luo, Yogesh Dashora and Tina Shaw
The Airline Crew Scheduling Process: Managing The Complexity

- Flights
- Duty/Pairing
- Roster Generation
- Rosters
- Pairing Generation
- Report/Alert/Monitor
- Recovery
- Actualized Rosters

Pairing Optimization
- Cockpit Crew Pairings
- Cabin Crew Pairings

Roster Optimization

Recovery Optimization
Cockpit crew costs can be **8%** of overall airline costs (billions USD annually)

Crew pairing optimization is a dominant factor in controlling this cost.
The Anatomy Of A Crew Pairing

Breaking down the pairing cost:
- Crew days
- Hotels
- Deadheads
Crew Augmentation Defined

What is Crew Augmentation?

Adding crew members for flight safety

Dynamic Crew Requirements
Crew Teaming/Crew Splitting
Downranking
Aspects Of Crew Augmentation In Detail

Quantifying the crew augmentation requirements

- Ranks: captain first officer
- Crew types: Basic Crew, Augmented Crew and Double Crew

<table>
<thead>
<tr>
<th>Crew Type</th>
<th>Captain</th>
<th>First Officer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Augmented</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Double</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

Crew splitting/crew teaming

- Crew splitting is the opposite of crew flying together (a.k.a. crew teaming)
- There is trade-off involving crew splitting:
  - crew cost
  - operational friendliness
  - stable groups

Downranking

<table>
<thead>
<tr>
<th>Crew Type</th>
<th>Captain</th>
<th>First Officer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Augmented (downranking)</td>
<td>3</td>
<td>0</td>
</tr>
</tbody>
</table>
Example 1: Saving Crew Days Utilizing Extended Duty Limits

<table>
<thead>
<tr>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
<th>Day 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>0600</td>
<td>1200</td>
<td>1800</td>
<td>0600</td>
</tr>
<tr>
<td>A → C</td>
<td>C → A</td>
<td>A → C</td>
<td>C → A</td>
</tr>
<tr>
<td>0600</td>
<td>1200</td>
<td>1800</td>
<td>0600</td>
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</tr>
<tr>
<td>A → C</td>
<td>C → A</td>
<td>A → C</td>
<td>C → A</td>
</tr>
</tbody>
</table>

KPI

<table>
<thead>
<tr>
<th>KPI</th>
<th>Before</th>
<th>After</th>
<th>Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crew Days</td>
<td>3 Captains 3 First Officers</td>
<td>2 Captains 1 First Officer</td>
<td>1 Captain 2 First Officers</td>
</tr>
<tr>
<td>Hotel Nights</td>
<td>2 Captains 2 First Officers</td>
<td>0</td>
<td>2 Captains 2 First Officers</td>
</tr>
<tr>
<td>Deadheads</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Caption: Captain ➔ First Officer
Example 1 (Cont.): Saving Crew Days Utilizing Extended Duty Limits

<table>
<thead>
<tr>
<th>Day</th>
<th>Crew Days</th>
<th>Hotel Nights</th>
<th>Deadheads</th>
<th>KPI</th>
<th>Before</th>
<th>After</th>
<th>Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day 1</td>
<td>3 Captains</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day 2</td>
<td>2 Captains</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day 3</td>
<td>1 Captain</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**KPI**
- Crew Days
- Hotel Nights
- Deadheads

**Before**
- 3 Captains
- 2 First Officers
- 0

**After**
- 2 Captains
- 2 First Officers
- 0

**Savings**
- 1 Captain
- 0
- 0
Example 2: Saving Crew Days Via Shortened Rest And Crew Splitting

<table>
<thead>
<tr>
<th>KPI</th>
<th>Before</th>
<th>After</th>
<th>Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crew Days</td>
<td>10 Captains</td>
<td>8 Captains</td>
<td>2 Captains – 2 First Officers</td>
</tr>
<tr>
<td></td>
<td>5 First Officers</td>
<td>7 First Officers</td>
<td></td>
</tr>
<tr>
<td>Hotel Nights</td>
<td>6 Captains</td>
<td>4 Captains</td>
<td>2 Captains</td>
</tr>
<tr>
<td></td>
<td>3 First Officers</td>
<td>3 First Officers</td>
<td></td>
</tr>
<tr>
<td>Deadheads</td>
<td>0</td>
<td>1 First Officer</td>
<td>- 1 First Officer</td>
</tr>
</tbody>
</table>

**Diagram:**

- **Day 1:**
  - A → B
  - B → A

- **Day 2:**
  - A → B
  - B → A

- **Day 3:**
  - A → B
  - B → A

- **Day 4:**
  - A → B
  - B → A

Legend:
- Captain
- First Officer
Example 3: Saving Crew Days Utilizing Crew Splitting And Downranking

<table>
<thead>
<tr>
<th>KPI</th>
<th>Before</th>
<th>After</th>
<th>Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crew Days</td>
<td>10 Captains, 8 First Officers</td>
<td>12 Captains, 5 First Officers</td>
<td>- 2 Captains, 3 First Officers</td>
</tr>
<tr>
<td>Hotel Nights</td>
<td>6 Captains, 5 First Officers</td>
<td>8 Captains, 3 First Officers</td>
<td>- 2 Captains, 2 First Officers</td>
</tr>
<tr>
<td>Deadheads</td>
<td>1 Captain, 2 First Officers</td>
<td>1 Captain</td>
<td>2 First Officers</td>
</tr>
</tbody>
</table>
Adding Augmentation

Objectives/Constraints

- Minimize crew pairing costs
- Cover the flight schedule
- Manpower limits
- Augmentation Modeling

Rules

- Government union rules
- Quality measures
- Augmentation rules
The Crew Pairing Problem With Augmentation

Sabre OR Differentiators
More Complex Models Should Consider

- Dynamic Augmentation
- Crew Teaming And Splitting
- Downranking
Traditional Crew Pairing Models

The set-covering set-partitioning model (Anbil92, Barnhart94)

\[
\begin{align*}
\text{(CPP)} \quad & \text{minimize} \quad \sum_{p \in P} c_p x_p \\
\text{such that} \quad & \sum_{p \in P} a_{ip} x_p = e_i, \quad \forall i \in F \\
& \sum_{p \in P} b_{jp} x_p \leq m_j, \quad \forall j \in J \\
& x_p \in \{0,1\}, \quad \forall p \in P
\end{align*}
\]

- For even **2000 legs**, the possible pairings could run into **Quadrillions** \(10^{15}\)
- Column generation is the method to solve the problem
Alternative Crew Pairing Models

The duty partition model (Vance 97)

\[(DP)\] minimize \( \sum_{p \in P} c_p x_p \)

such that \( \sum_{d \in D} g_{id} y_d = e_i, \quad \forall i \in F \)

\( \sum_{p \in P} h_{drp} x_p = l_{rd} y_d, \quad \forall d \in D, \forall r \in R \)

\( \sum_{p \in P} b_{jp} x_p \leq m_j, \quad \forall j \in J \)

\( x_{p}, y_{d} \in Z^{+}, \quad \forall p \in P \)

The set-covering set-partitioning model (Yan and Chang 2002)

\[(CPP_A)\] minimize \( \sum_{p \in \bar{P}} c_p x_p \)

such that \( \sum_{p \in P} a_{ip} x_p = e_i, \quad \forall i \in F \)

\( \sum_{p \in P} b_{jp} x_p \leq m_j, \quad \forall j \in J \)

\( x_{p} \in \{0,1\}, \quad \forall p \in \bar{P} \)
A Comprehensive Crew Augmentation Model From Sabre

\[(AUG)\] minimize \( \sum_{p \in P} c_p x_p \)

such that \( \sum_{p \in P_B} a_{ip} x_p + \sum_{d \in D} g_{id} y_d = e_i, \quad \forall i \in F \)

\( \sum_{p \in P} h_{drp} x_p + \sum_{u \in R} z_{dur} - \sum_{v \in R} z_{drv} = l_{rd} \left( \sum_{p \in P_B} f_{dp} x_p + y_d \right), \quad \forall d \in D, \forall r \in R \)

\( \sum_{p \in P} b_{jp} x_p \leq m_j, \quad \forall j \in J \)

\( x_p, y_d, z_{dur} \in Z^+, \quad \forall p \in P, \forall d \in D, \forall u, r \in R \)
The Progression Of Our Methodology

- **1995**: MIP Model
- **2005**: Global Approach (Fixed Pool)
- **2005**: Primal-Dual Over Fixed Pool
- **2014**: Delayed Column Generation Using Network Optimization
- **2014**: Dual Stabilization, Branch And Price
- **2014+**: One Pairing Optimizer

Key Metrics:
- Problem size
- Quality
- Speed
The Sabre Solution Components

- Delayed column generation
- Primal-dual subproblem simplex method
- Network subproblems
- Dual stabilization
- Branch and price
- Heuristics
- Post optimization (also meta heuristics)

Advanced OR Techniques From Multiple Areas

- Non-Linear programming
- Network optimization
- Integer programming
- Meta-heuristics
System Architecture

- Object Manager GUI
- Rules Manager GUI
- Scenario Manager GUI
- Pairing Editor GUI

Data Objects (Schedule/Deadhead/Rule/Cost/Param)

Solution Mapper

Short Haul Pairing Optimizer

Long Haul Pairing Optimizer

Reports

LP/MIP Solver

Rules Engine

Cost Engine

Scenarios
Demonstrating Real Savings

Select Real Customer Datasets
- Long-haul
- Short-haul
- Combination

Benchmark Against Conventional Approaches
- S1: A two step approach
- S2: Manual augmentation
- S3: Cost Adjustment Approach
- S4: Pairing level augmentation optimization approach (Yan and Chang (2002))

Evaluate Results
- Measurable cost savings against all conventional approaches
- Identify additional benefits
Conventional Approaches Explained

Benchmark Against Conventional Approaches

S1: A two step approach
S2: Manual augmentation based on flights
S3: Cost Adjustment Approach
S4: Pairing level augmentation optimization approach (Yan and Chang (2002))
### Three Real Airline Datasets

<table>
<thead>
<tr>
<th>Airline</th>
<th>Years In Production</th>
<th>Aircraft Type</th>
<th>Scenario Duration</th>
<th>Flights Per Week</th>
<th>Average Flight Duration</th>
<th>Maximum Pairing Length</th>
<th>Maximum Duties In Pairing</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Long-haul</td>
<td>20</td>
<td>777</td>
<td>Week</td>
<td>156</td>
<td>6.4 hours</td>
<td>15 days</td>
<td>9</td>
</tr>
<tr>
<td>B Short-haul</td>
<td>10</td>
<td>738</td>
<td>Week</td>
<td>1500</td>
<td>2.5 hours</td>
<td>6 days</td>
<td>6</td>
</tr>
<tr>
<td>C Combination</td>
<td>1</td>
<td>MD11</td>
<td>Month</td>
<td>165</td>
<td>3.5 hours</td>
<td>10 days</td>
<td>6</td>
</tr>
</tbody>
</table>

We use: real data, real rules and real costing
Projected Annual Savings Over Conventional Approaches

<table>
<thead>
<tr>
<th>Airline</th>
<th>LHPO Savings* Over S1</th>
<th>LHPO Savings* Over S2</th>
<th>LHPO Savings* Over S3</th>
<th>LHPO Savings* Over S4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A</strong> Long-Haul</td>
<td>23,056,280</td>
<td>32,427,668</td>
<td>13,250,756</td>
<td>12,034,620</td>
</tr>
<tr>
<td><strong>B</strong> Short-Haul</td>
<td>479,700</td>
<td>1,757,288</td>
<td>171,132</td>
<td>0</td>
</tr>
<tr>
<td><strong>C</strong> Combination</td>
<td>872,460</td>
<td>523,872</td>
<td>353,196</td>
<td>327,300</td>
</tr>
</tbody>
</table>

*Savings include Salary, Hotel, Deadheading and other airline specific costs.
Benefits In Addition To Cost Savings

- Quality Improvements
  - Improved reliability of operations
  - Improved safety
  - Enhanced crew quality of life
  - Increased crew satisfaction

Measurable Outcomes
- Better crew utilization (up to five percent)
- More days off
- Reduction in hotel and travel costs (up to five percent)

Tangible Results

Intangible Results
In Summary

Sabre Long-Haul Pairing Optimizer

Innovative OR Modeling

- Advanced OR techniques from multiple areas
- Solid software engineering
- In production for decades → has saved airlines millions in crew costs
- Large (AUG) models can be solved by using our system
- Poised for future work
Meeting The Challenges Of The Future

- Growing demand of long range air travel
- Regulatory changes
- More fuel efficient aircraft
- More low cost/regional carriers are offering long haul flights
- More airlines are flying mixed range flights