Optimization in Airline Planning and Marketing

Institute for Mathematics and Its Applications

November 2002
Barry C. Smith
Overview

- Airline Planning and Marketing Landscape
- Applications of Optimization Modeling
- Planning and Marketing Integration
- Unsolved and Under-solved Problems
- Future Outlook
Airlines Make Money Only When They Match Supply and Demand
The Problem is Large and Dynamic

- Major US domestic carriers:
  - Operate 5000 flights per day
  - Serve over 10,000 markets
  - Offer over 4,000,000 fares
- Schedules change twice each week
- On a typical day, a major carrier will change 100,000 fares
- Airlines offer their products for sale more than one year in advance
- The total number of products requiring definition and control is approximately 500,000,000
- This number is increasing due to the proliferation of distribution channels and customer-specific controls
Effective Planning and Marketing is a Continuous Process

Enterprise Planning

Product Planning

Tactics and Operations
There Should be Continuity

<table>
<thead>
<tr>
<th>Time Horizon</th>
<th>Objective</th>
<th>Constraints</th>
</tr>
</thead>
<tbody>
<tr>
<td>• 18 Months +</td>
<td>• Maximize NPV of Future Profits</td>
<td>• Financial Resources • Regulation</td>
</tr>
<tr>
<td>• 18 Months – 1 Months</td>
<td>• Maximize NPV of Future Profits</td>
<td>• Route Structure • Fleet • Maintenance Bases • Crew Bases • Facilities</td>
</tr>
<tr>
<td>• 3 months – Departure</td>
<td>• Maximize NPV of Future Profits</td>
<td>• Schedule • Pricing Policies • Price • Restrictions • Availability</td>
</tr>
</tbody>
</table>

**Decisions**

- Route Structure
- Fleet
- Maintenance Bases
- Crew Bases
- Facilities

**Constraints**

- Financial Resources
- Regulation

**Schedule**

- Fleet Assignment
- Pricing Policies

**Pricing Policies**
Significant Optimization Applications

- Tactics and Operations
  - Yield Management
- Product Planning
  - Fleet Assignment
Yield Management Objectives

Sell the right seat
To the right passenger
At the right price
YM is Essential to Airline Profitability

- Annual benefit of Yield Management to a major airlines is 3% – 6% of total revenue
- A major airlines’ revenue benefits from yield management exceed $500,000,000 per year
- Applying this rate to the industry ($300 billion/year) yields potential benefits of $15 billion per year
- The possibilities for even the most sophisticated carriers go well beyond what is achieved today
YM Controls

- Overbooking
- Revenue Mix
  - Discount allocation
  - Traffic flow
- Groups
## Yield Management Evolution

### 1970’s:
- **Class Code**
  - Rev +4%
  - 3 MM

### 1960’s:
- **Overbooking**
  - Revenue +2%, 300k

### Value of Last Seat

<table>
<thead>
<tr>
<th>Full Fare</th>
<th>Origin-Destination Market</th>
<th>Low Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Value</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Class Code</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deep Discount</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

1970’s: Class Code
Rev +4%
3 MM

1960’s: Overbooking
Revenue +2%, 300k
Stop selling Current (low-value) products when:
Profit (Current) < Profit (high-value) * P (Sell out)

- Sell to Current Customer
  - Current Profit
  - Hold for Higher-Value Customer
  - Sell out
  - High-Value Profit
  - Unsold Product
  - $0

Revenue Mix Problem – Flight Leg
# Yield Management Evolution

<table>
<thead>
<tr>
<th></th>
<th>Value of Last Seat</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>High Value</strong></td>
<td></td>
</tr>
<tr>
<td>Full Fare</td>
<td></td>
</tr>
<tr>
<td>Deep Discount</td>
<td></td>
</tr>
<tr>
<td><strong>Origin-Destination Market</strong></td>
<td></td>
</tr>
<tr>
<td>Full Fare</td>
<td></td>
</tr>
<tr>
<td>Deep Discount</td>
<td></td>
</tr>
<tr>
<td><strong>Low Value</strong></td>
<td></td>
</tr>
</tbody>
</table>

1960’s: Overbooking Revenue +2%, 300k

1970’s: Class Code
Rev +4%
3 MM

1980’s: OD
Rev +5%
30 MM

1990’s: Bid Price
Rev +6%
1 MM

1970’s: OD
Rev +5%
30 MM

1980’s: OD
Rev +5%
30 MM

1990’s: Bid Price
Rev +6%
1 MM
Max $\sum_{ODF} Pax_{ODF} \times Rev_{ODF}$

Subject to:

$Pax_{ODF} = f(Allocation_{ODF}, Demand_{ODF})$

$\sum_{ODF} Pax_{ODF} \leq Capacity_{Flight}$

Allocations $\geq 0$
Passengers = f (Allocation, Demand)
Revenue Mix Approaches

- Deterministic Leg ➔ Allocations (wrong)
- Stochastic Leg ➔ Allocations (BA, MIT)
- Deterministic Network ➔ Allocations (wrong)
- Stochastic Network ➔ Bid Price (AA)
- Deterministic Network ➔ EMSR ➔ VN Allocations (MIT)
- Stochastic Network ➔ ADP on Leg ➔ Bid price (Columbia)
- ADP on Network ➔ Real-time evaluation (GIT)
Yield Management Evolution

1960’s:
- Overbooking Revenue
  - +2%, 300k

1970’s:
- Class Code
  - Rev +4%
  - 3 MM

1980’s:
- OD
  - Rev +5%
  - 30 MM

1990’s:
- Bid Price
  - Rev +6%
  - 1 MM

2000’s:
- Mult. Channels
- CRM

Value of Last Seat

High Value | Origin-Destination Market | Low Value
---|---|---
Full Fare
Class Code
Deep Discount
Fleet Assignment Models (FAM) assign aircraft types to an airline timetable in order to maximize profit. FAM is widely used in the airline industry, with AA and DL reporting 1% profit margin improvements from FAM.

Given a flight schedule and available fleet of aircraft, FAM maximizes operating profit subject to the following physical and operational constraints:

- **Cover**: Each flight in the schedule must be assigned exactly one aircraft type.
- **Plane Count**: The total number of aircraft assigned cannot exceed the number available in the fleet.
- **Balance**: Aircraft cannot appear or disappear from the network.
Basic FAM Formulation

Max $\sum_{a \in Aircraft} \sum_{f \in Flights} x_{f,a} (R_{f,a} - C_{f,a})$

Subject to

$\sum_{a \in Aircraft} x_{f,a} = 1 \ \forall f \in Flights$

$\sum_{s \in Stations} y_{a,0,s} \leq PC_a \ \forall a \in Aircraft$

$y_{a,t-1,s} + \sum_{f \in Arrival_{s,t}} x_{f,a} - \sum_{f \in Departure_{s,t}} x_{f,a} - y_{a,t,s} = 0$

$\forall a \in Aircraft, s \in Stations, t \in Times_s (circular)$

$x_{f,a} \in \{0,1\} \ \forall a \in Aircraft, s \in Stations, t \in Times_s \geq 0$
FAM Extensions

- Time windows (US, MIT)
- Integration
  - Routing (UPF, MIT, GIT)
  - Crew (Gerad)
  - Yield Management (MIT, LIS, Sabre, GIT)
Leg Revenue Modeling Approaches

- Average passenger fare: Inconsistent with yield management practices. As capacity is added, incremental passengers have lower average revenue.

- Leg revenue: Modeling passenger revenue on a flight as a function only of capacity on this flight assumes that there is no upline or downline spill.

- These assumptions create inconsistencies with subsequent airline marketing processes, in particular O&D yield management, and tend to bias FAM solutions to over-use of large aircraft.
Improving Revenue Modeling in FAM

- **Allocations**
  - For each flight leg allocate space to each passenger path
  - Piecewise linear approximation for traffic/revenue on each path
  - Solve the OD YM model inside of FAM
  - Model size explodes -- There are 150,000-500,000 passenger paths in a typical problem for a major carrier

- **Decomposition**
  - Solve yield management model outside of FAM
  - Incorporate model results into FAM
Integration of FAM and YM

FAM

\[ \Pi_{\text{Capacity}} \]

YM

\[ \Pi_{\text{Capacity}} \]

Bid Price
Revenue Function Approximation: One Leg, One Cut

\[ R_{0f} + \lambda_f \times CAP_f \geq R(CAP_f) \]

- Revenue ($ US)
- Bidprice, \( \lambda \) ($/seat)
- Leg Capacity (No. of Seats)
- \( R_0 \)
- \( CAP_j \)
OD FAM Master

\[
\text{Max } R_{\text{Total}} - \sum_{a \in \text{Aircraft}} \sum_{f \in \text{Flights}} x_{f,a} \cdot C_{f,a}
\]

\text{Subject to } \text{Cover, Plane Count, Balance, and:}

\[
R^i_0 + \sum_{f \in \text{Flights}} \lambda^i_f \sum_{a \in \text{Aircraft}} Cap_a \cdot x_{f,a} \geq R_{\text{Total}} \quad \forall i \in \text{OD Cuts}
\]
Revenue Function Approximation: One Leg, Multiple Cuts

\[ R^i_{0f} + \lambda^i_f \cdot CAP_f \geq R(CAP_f) \]
Planning and Marketing Integration
Ideal Planning

Enterprise Planning

Product Planning

Tactics and Operations
Planning Reality

- Planning & Scheduling
- Sales
- Pricing
- Yield Management
- Distribution
- Customers
Airline Pricing

Simple Concepts
- Relatively fixed seat capacity
- High fixed costs
- Combination of elastic and inelastic market segments

Complex Reality
- Oligopoly market behavior
- Multi-period repeated trial
- Strategy is generally dominated by mechanics (tactics)
- The pricing process is often unclear to airline executives
Sales and Distribution: Multi-channel

Airline Capacity

- Forecast of Demand and Free Market Value
- On Tariff -- GDS
- AL.com
- Distressed Inventory
- TA.com
- FFP Burn/Earn
- Corporate
- Tour/Cruise/Cons
- Partners

Customers
Bid Prices Support Integration

Planning & Scheduling

Sales

Pricing

Yield Management

Distribution

Customers
Unsolved and Under-solved Problems

Opportunities
- Enterprise Planning
  - Facilities
  - Manpower
  - Fleet
- Longitudinal Planning
- Alliance Optimization
- Customer Relationship Management
- Robust Planning
  - Demand
  - Operations
  - Competition
- Support for Labor Negotiations

Supporting Models
- Customer Behavior Modeling
- Simulation
  - Airline
  - Alliance
  - Industry
- Scenario Analysis
The Evolving Environment

- **Distant Past:** Airlines initiated development of optimization-based systems
- **Recent Past:** Following deregulation of the US domestic industry, airlines supported technology development
  - Technical leadership shifted from airlines to academics, consultants and software providers
- **Current:** The current market conditions have reduced the ability of major US carriers to support significant new development
- **Future:** The marketplace for new optimization applications will be dominated by the requirements of the emerging carriers – low-cost, alternative business models
  - Simple
  - Flexible
  - Developed outside of the carrier
  - Operated outside of the carrier
Optimization in Airline Planning and Marketing

Institute for Mathematics and Its Applications

November 2002
Barry C. Smith