

Integrating O&D Revenue Management and Airline Scheduling Processes

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American Airlines

Presentation Overview

Overview of the Airline Business Process

- Scheduling
- Pricing
- Revenue Management

Integration of Scheduling and Revenue Management

- Consistent Scheduling and Revenue Management (O&D FAM)
- Results from Benchmark Studies and Practice

Another Opportunity: Near-term Re-fleeting

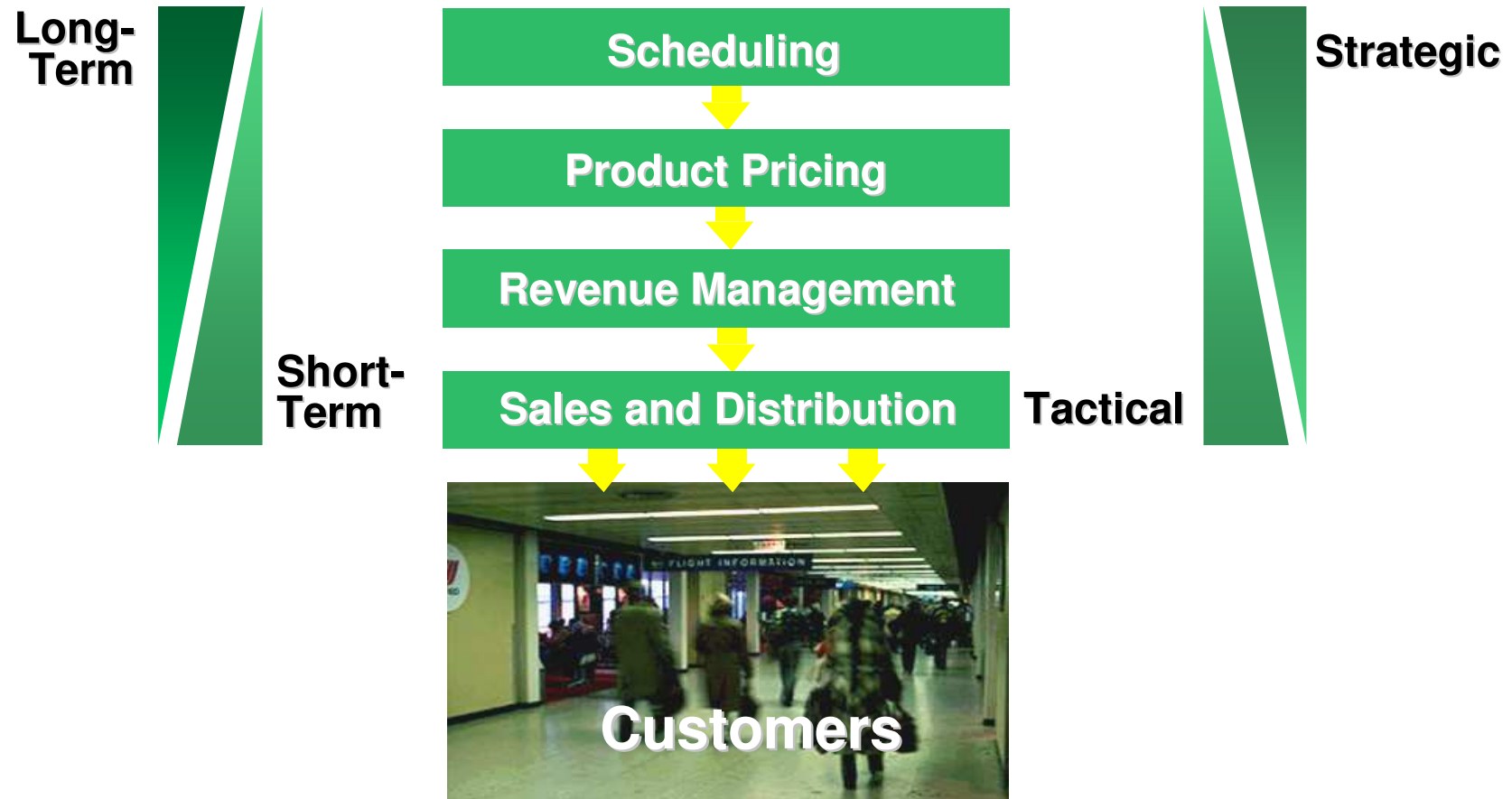
- O&D-based Demand Driven Dispatch (D³) methodology
- Benchmark Results
- Pilot Study
- Production Implementation

Recap: Benefits and Hurdles



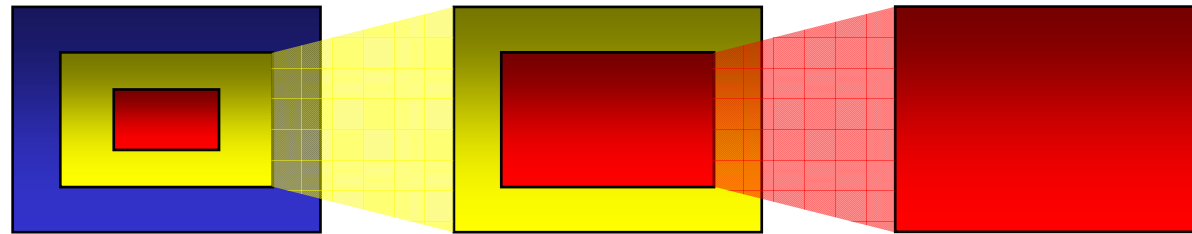
Airline Business Overview

A Typical View



Airline Business Overview

Objectives, Decisions and Constraints

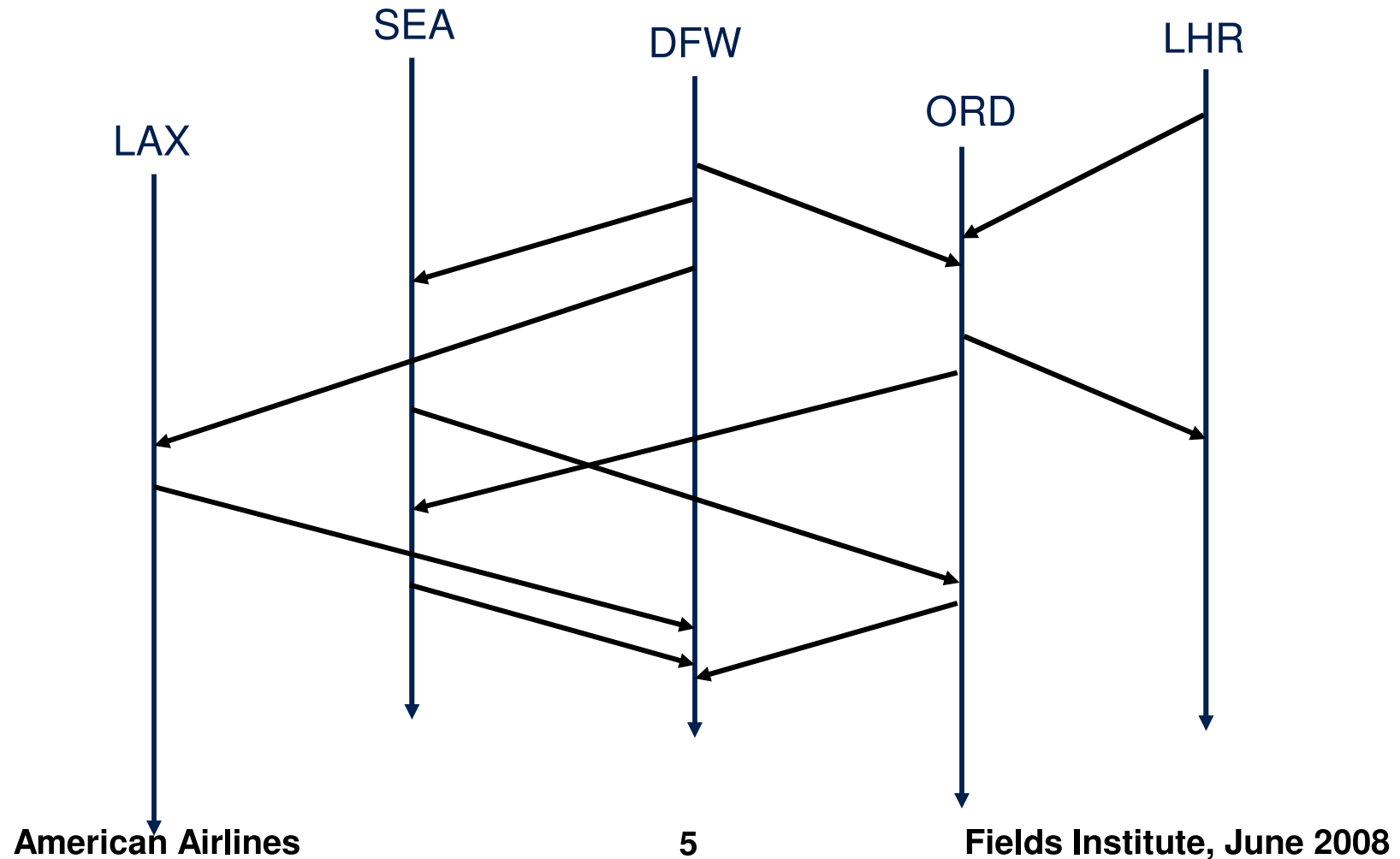


Time Horizon	• 18 Months +	• 18 Months – 1 Months	• 3 months – Departure
Objective	• Maximize NPV of Future Profits	• Maximize NPV of Future Profits	• Maximize NPV of Future Profits
Decisions	<ul style="list-style-type: none"> • Route Structure • Fleet • Maintenance Bases • Crew Bases • Facilities 	<ul style="list-style-type: none"> • Schedule • Pricing Policies 	<ul style="list-style-type: none"> • Price • Restrictions • Availability
Constraints	<ul style="list-style-type: none"> • Financial Resources • Regulation 	<ul style="list-style-type: none"> • Route Structure • Fleet • Maintenance • Crew Bases • Facilities 	<ul style="list-style-type: none"> • Schedule • Pricing Policies



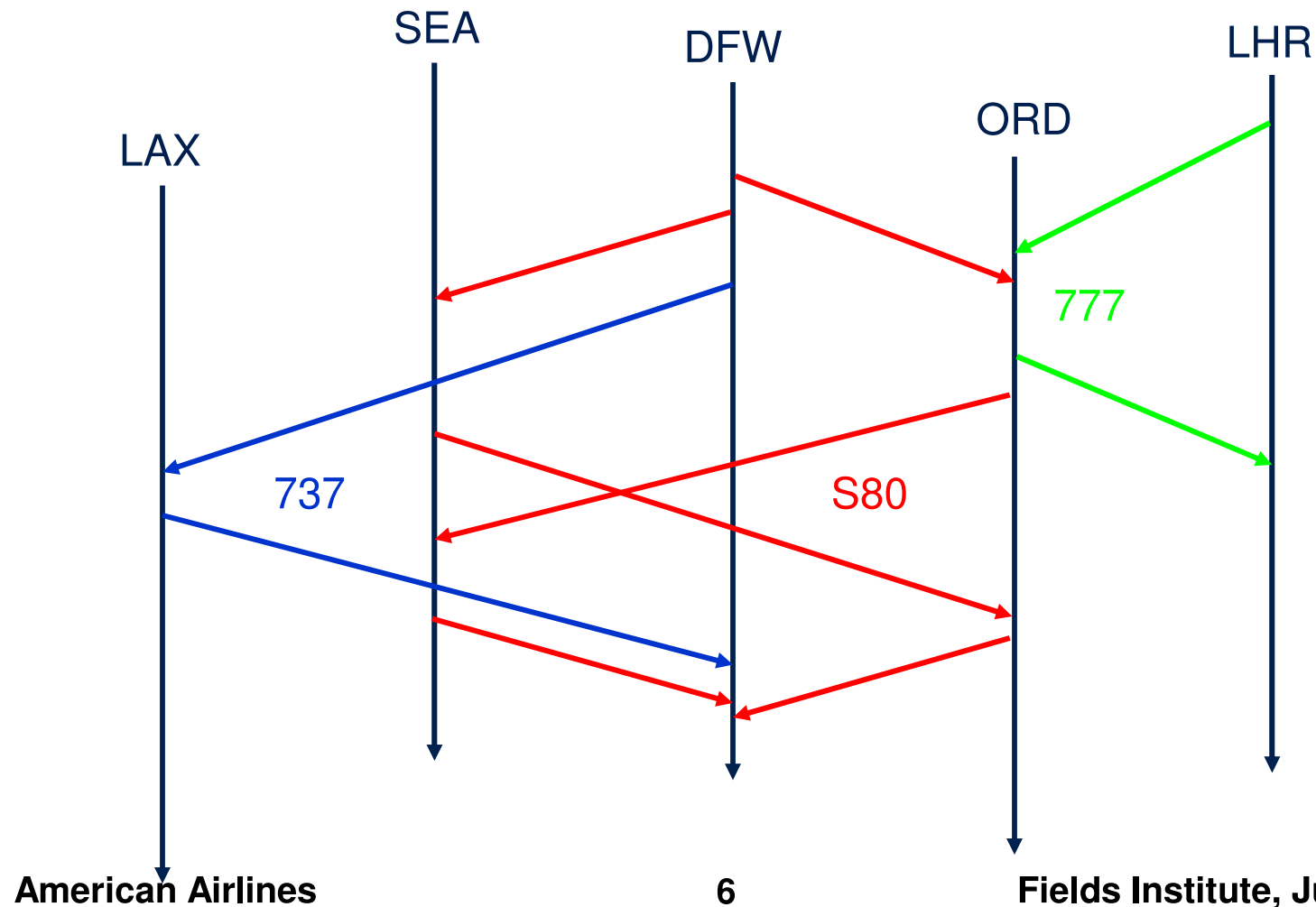
Scheduling: Defining the Product

Frequency and Timing



Scheduling: Allocating Capacity

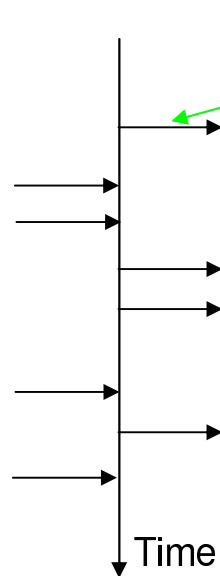
Fleet Assignment



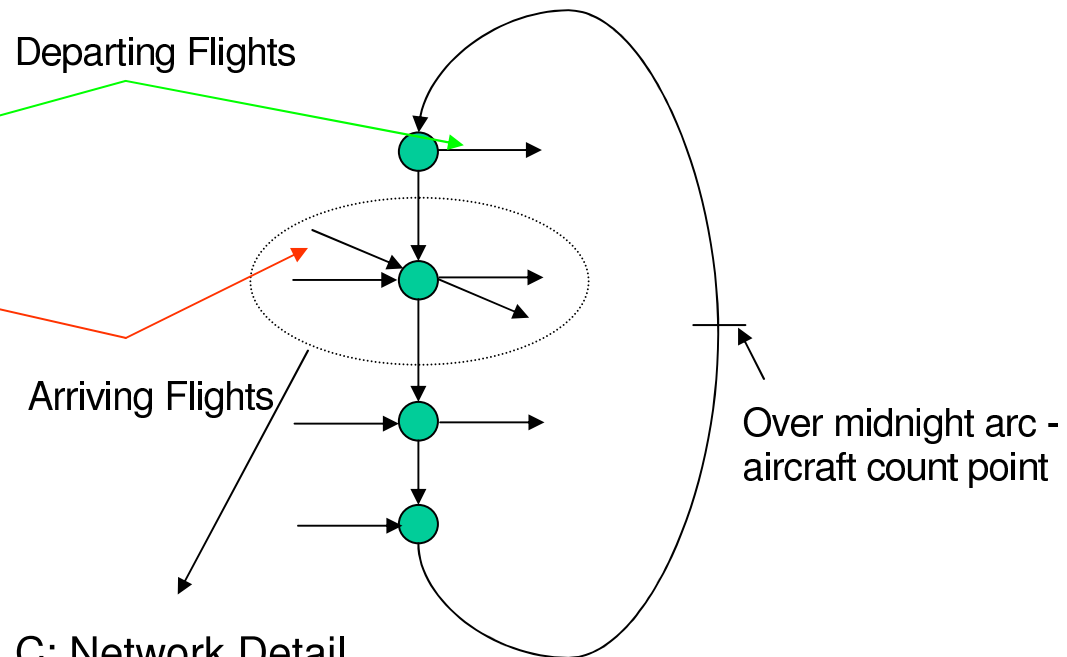
Scheduling: Allocating Capacity

Fleet Assignment Modeling Network

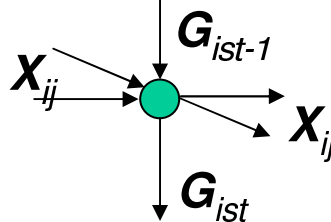
A: Station Timeline



B: Network Representation



C: Network Detail



Scheduling

Typical Leg-based Fleeting Approach

**Maximize
Schedule
Profitability**

$$\max P = \sum_{j=1}^m \sum_{i=1}^n (R_{ij} - C_{ij}) x_{ij} \quad (\text{Objective: Maximize Profit}) \quad (1)$$

subject to:

$$\sum_{j \in \text{Re}(i,j)} x_{ij} + \sum_{s \in \text{St}(s,i)} G_{ist} \leq NP_i \quad \forall i \quad (\text{Plane Count}) \quad (2)$$

**Aircraft
conservation
of flow**

$$G_{ist-1} - G_{ist} + \sum_{j \in \text{IN}(j,s,t)} x_{ij} - \sum_{j \in \text{OUT}(j,s,t)} x_{ij} = 0 \quad \forall i, s, t \quad (\text{Balance}) \quad (3)$$

$$\sum_{i=1}^n x_{ij} = 1 \quad \forall j \quad (\text{Cover}) \quad (4)$$

**Don't use
more
aircraft
than
available**

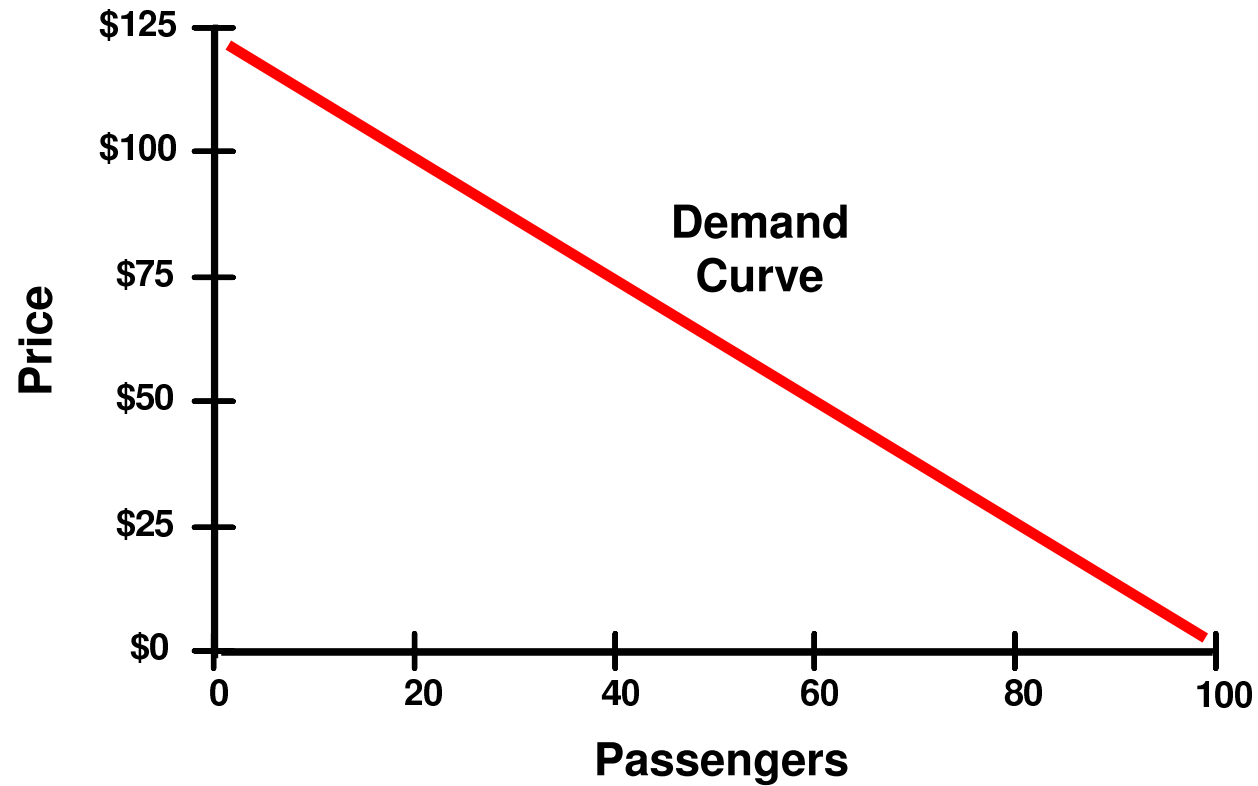
**Assign a
fleet type
to every
flight in the
schedule**

$$x_{ij} \in \begin{cases} 1 & \text{if aircraft type } i \text{ is assigned to schedule leg } j \\ 0 & \text{otherwise} \end{cases} \quad \forall i, j \quad (5)$$



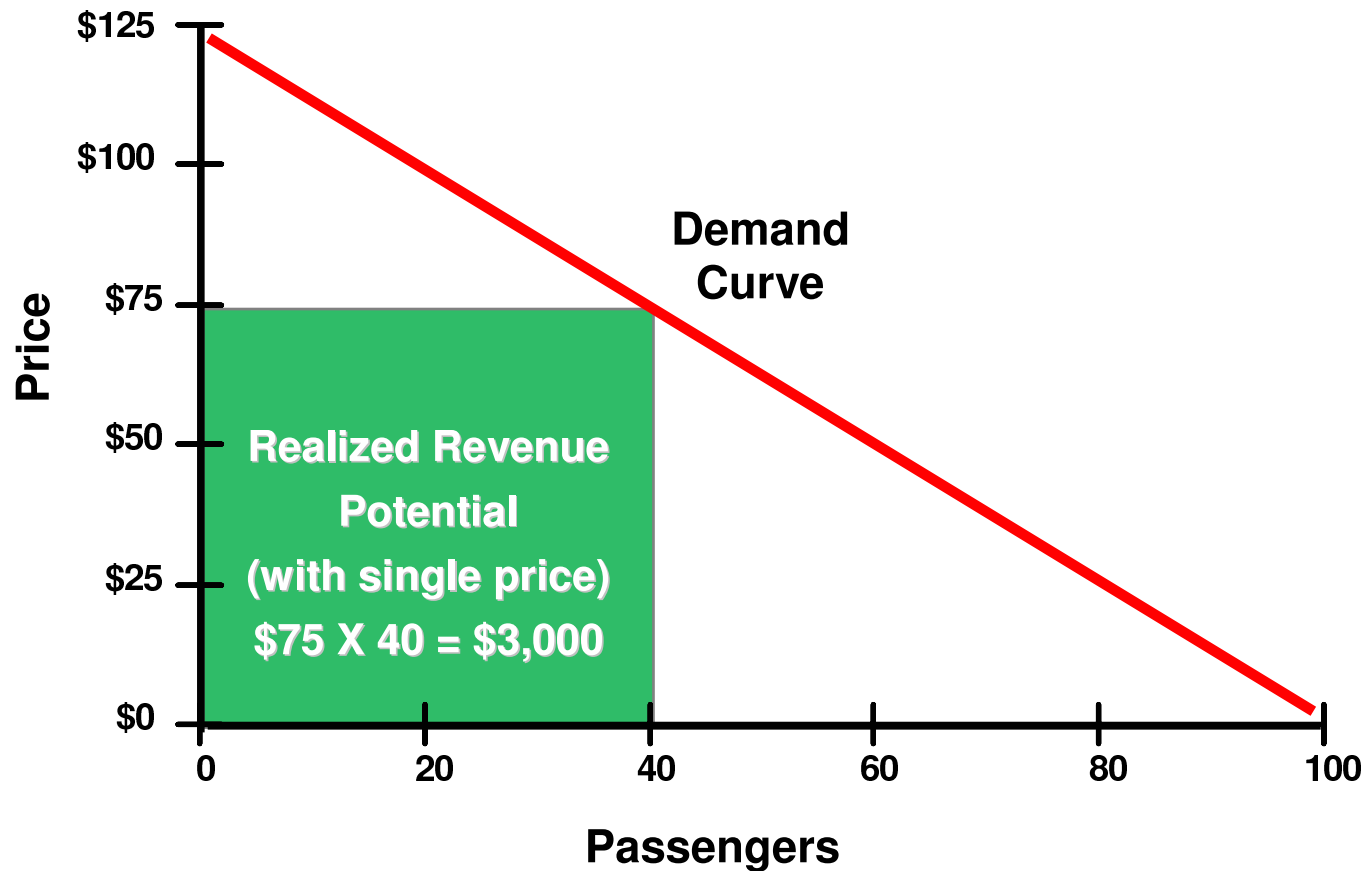
Pricing

Relationship Between Price and Demand



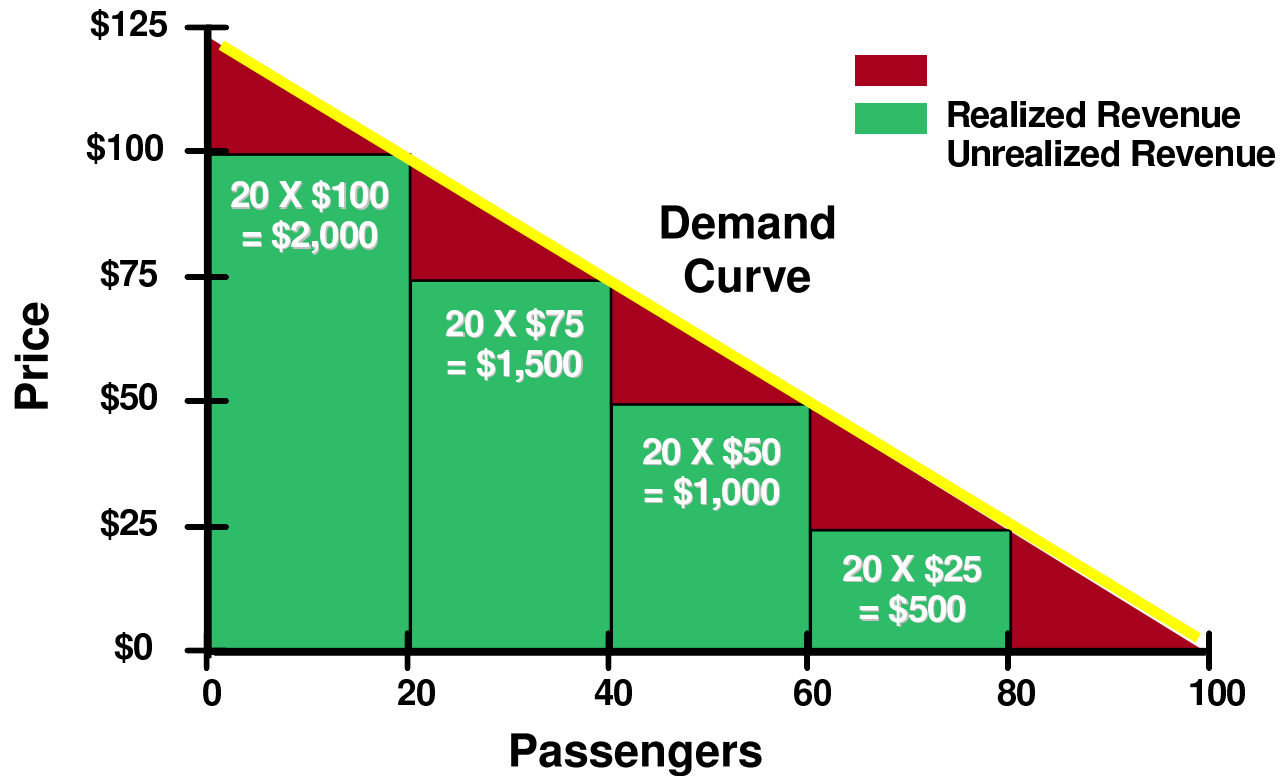
Pricing

One Price - Limited Revenue Potential



Pricing

Differential Pricing - Revenue Generation

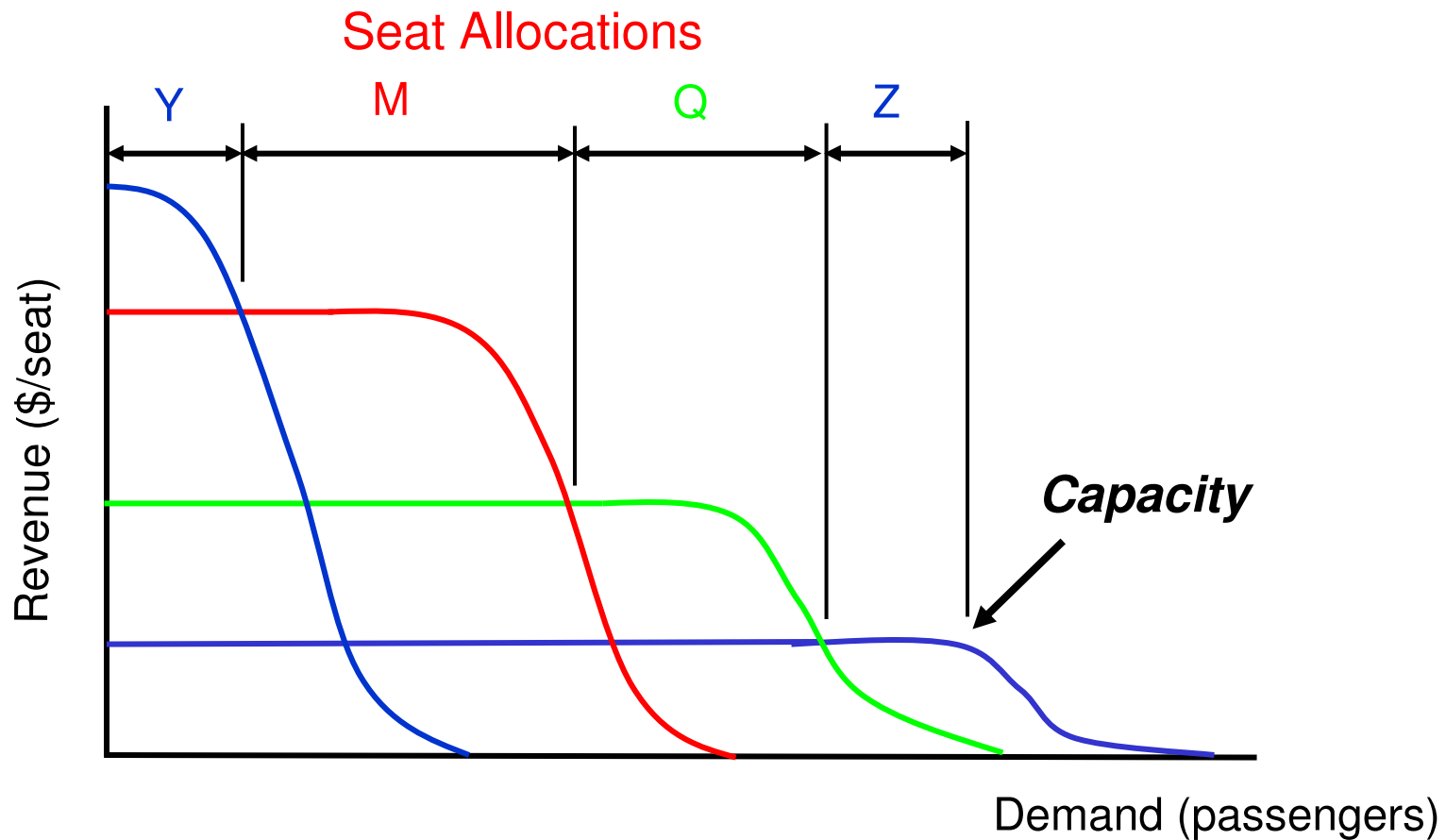


Total Realized Revenue = \$5,000



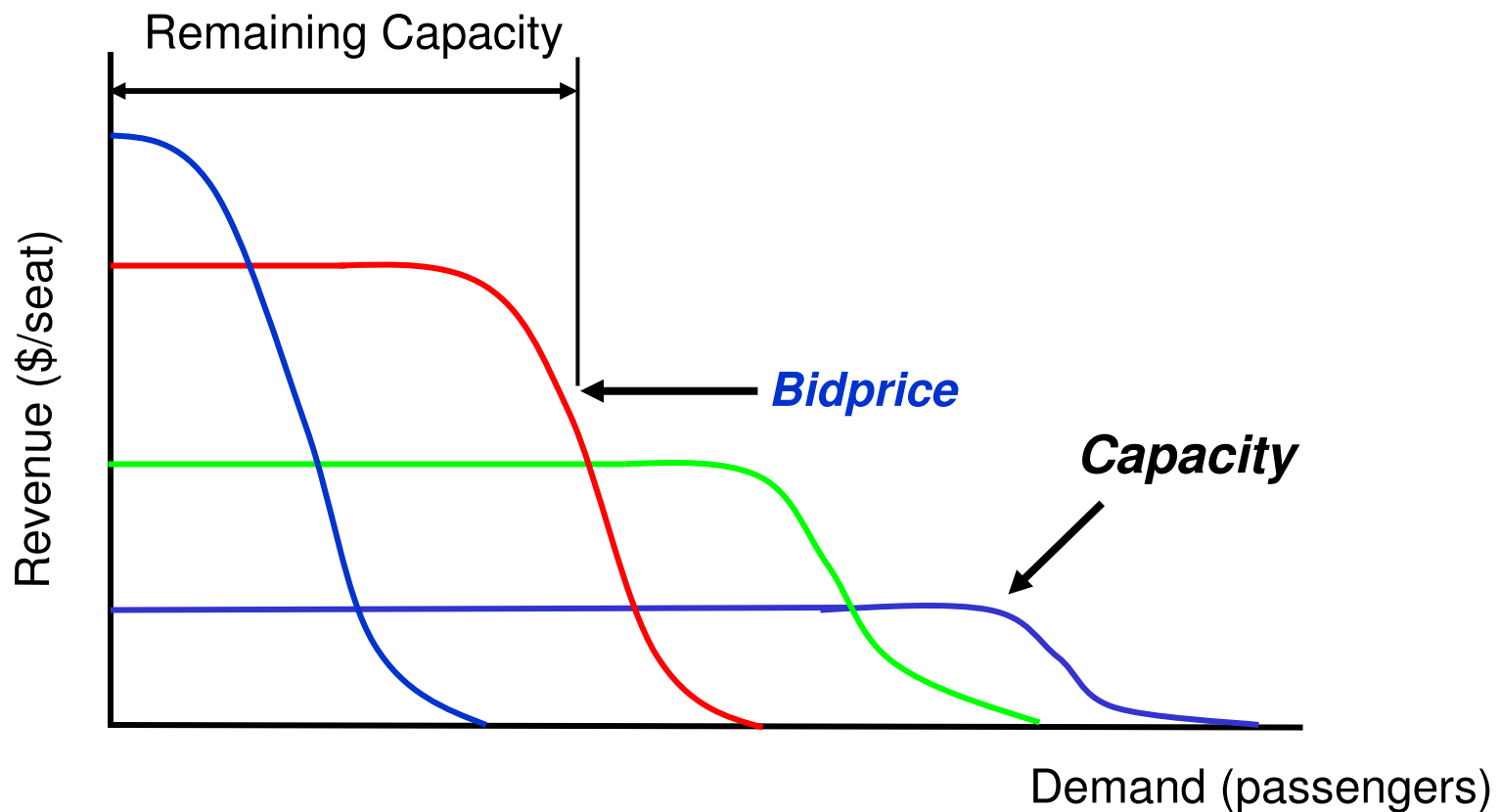
Revenue Management

Inventory Control



Revenue Management

Inventory Control with Remaining Capacity



Shortcomings and Issues

Problems with a Sequential Planning Process



American Airlines

- **Loss of network effects:** Current sequential approach cannot accurately capture network effects. Leg-level revenue estimates do not reflect changes in traffic due to upline and downline capacity changes
- **Inconsistent planning and management paradigms:** Uses leg-based approach to solve an O&D network problem when assigning capacity. This leads to an inefficient assignment of valuable resources (aircraft capacity) to cover the underlying passenger demand and results in lost profit
- **Overemphasis on Flow Traffic:** Biases schedule development and fleet mix solution toward larger aircraft (local vs. through traffic)
- **Limited Degrees of Freedom in the Planning and Operational Cycles:** A sequential approach gives the airline relatively few degrees of freedom at any point in the planning and operational cycle. An integrated process can exploit added degrees of freedom to produce a better solution



Integrating Fleet and RM

O&D-Based Inventory Control

Maximize total system revenue

$$\max R = \sum_{j \in OD} r_j (a_j) \quad (6)$$

Subject to:

$$\sum_{j=1}^m a_j \leq C_i \quad \forall i \in F \quad (7)$$

$$a_j \geq 0 \quad \forall j \in OD \quad (8)$$

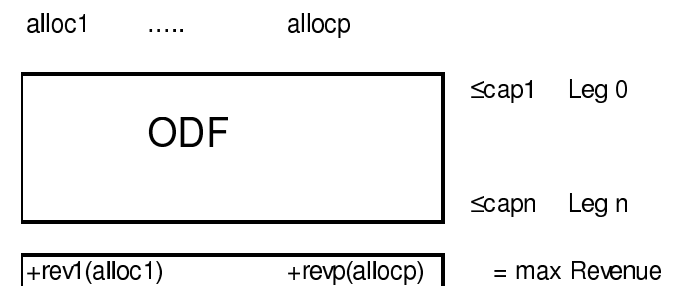
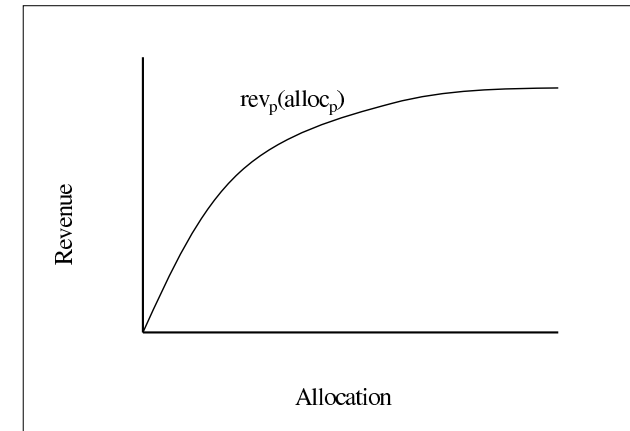
Don't sell more seats than available



Integrating Fleet and RM

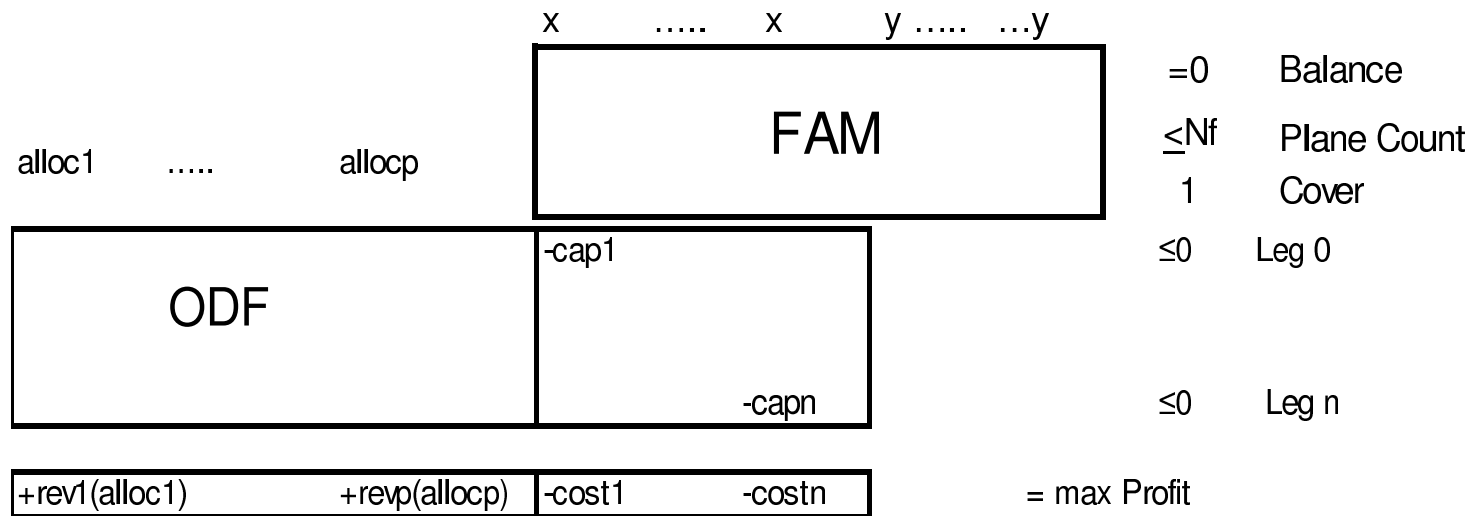
O&D-Based Inventory Control

- Airlines with hub and spoke networks serve many origin/destination (O&D) markets on every flight
- Airlines use revenue management to maximize revenue by controlling the sale of seats to high vs. low value fares in each O&D (ODF)
- RM sets an allocation for each ODF; bookings and revenue are non-linear functions of the allocation
- The RM problem (ODYM), maximizes total network revenue while ensuring that total allocations on each flight leg do not exceed capacity



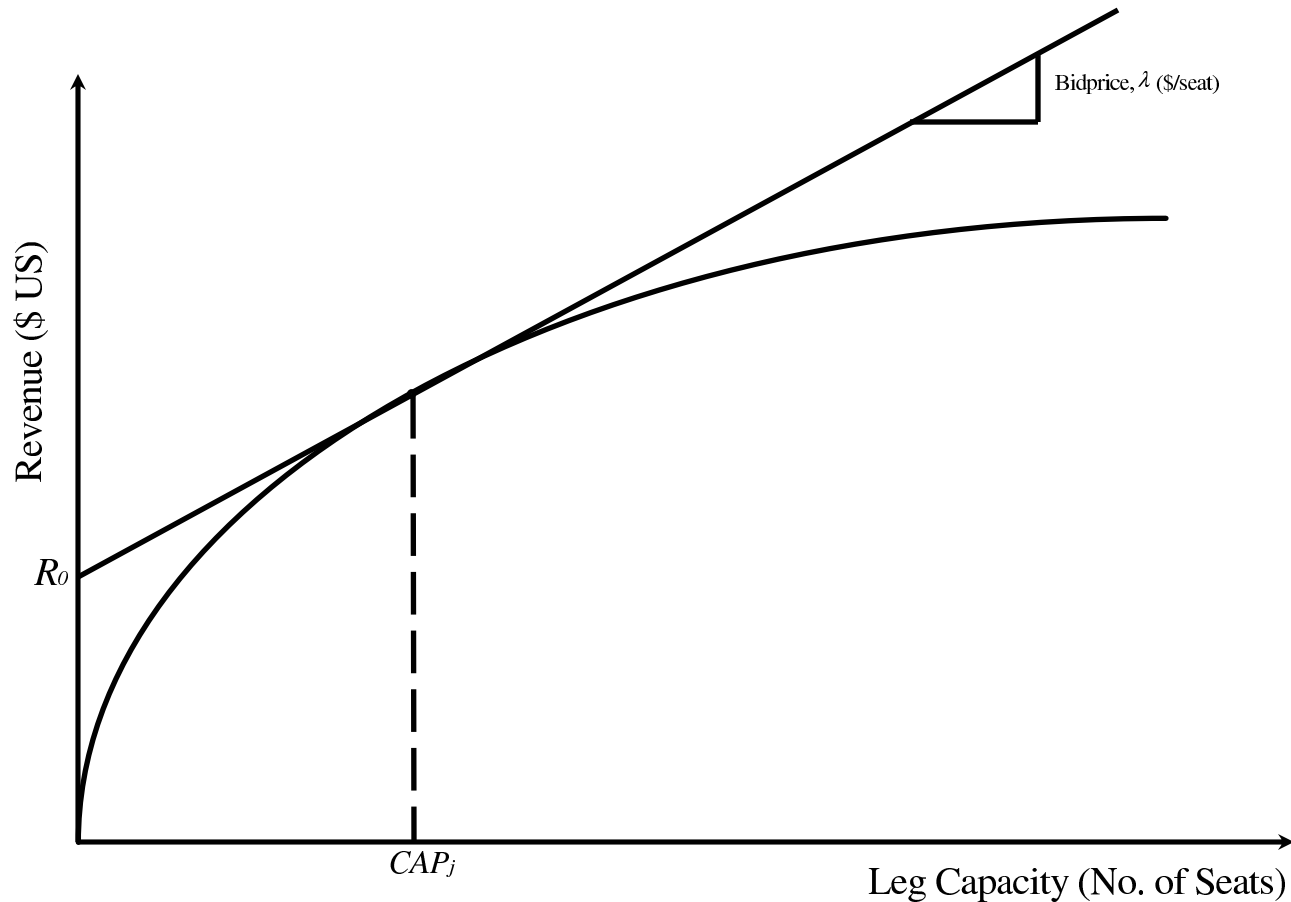
Integrating Fleeting and RM

O&D-Based Fleeting and Scheduling



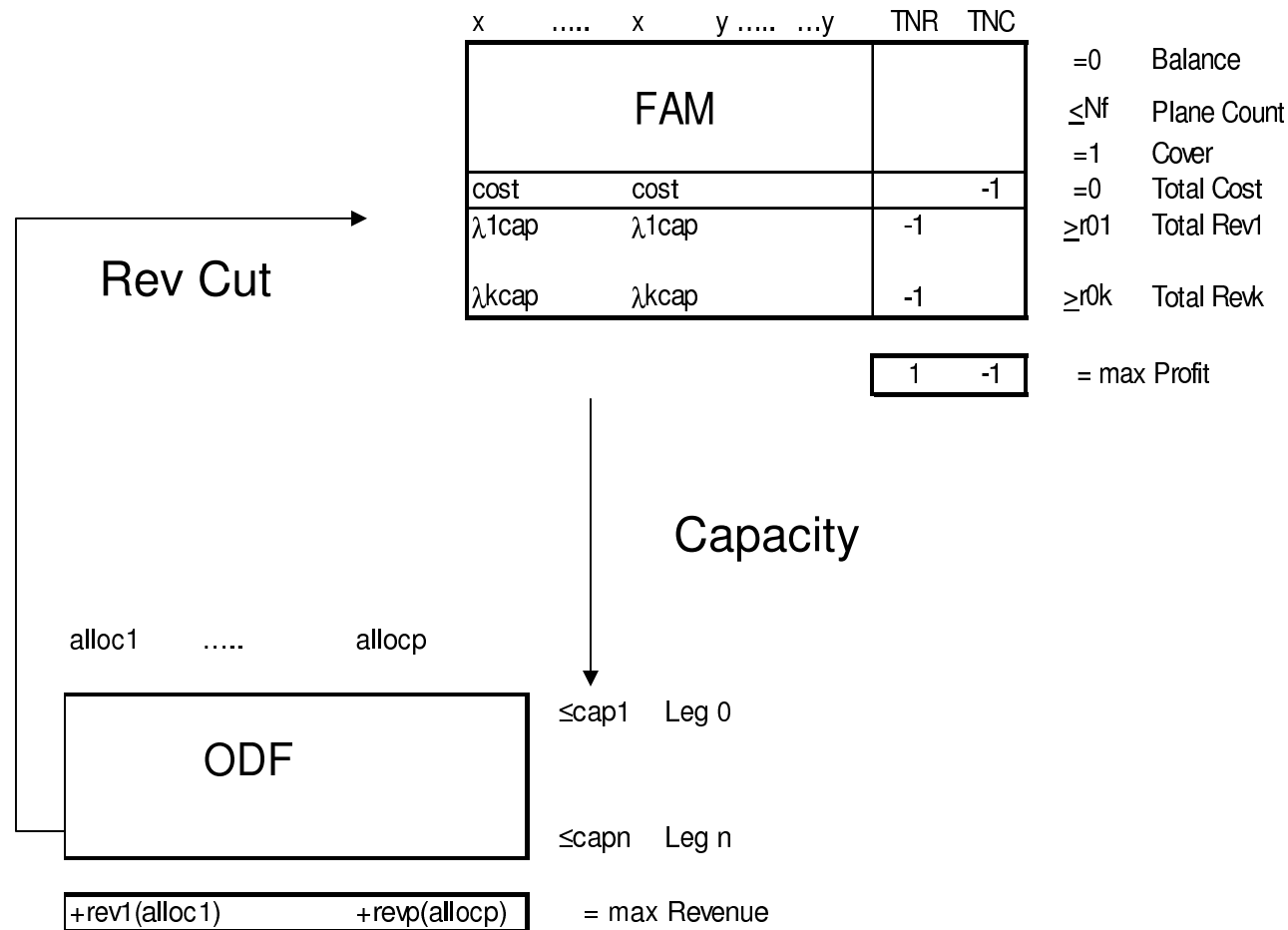
Integrating Fleet and RM

O&D-Based Revenue Function



Integrating Fleeting and RM

Decomposition Approach



Integrating Fleeting and RM

O&D-based Fleet Assignment

$$\max P = R_{Total} - C_{Total} \quad (\text{Objective: Maximize Profit}) \quad (9)$$

subject to:

$$\sum_{j \in \text{Re}(i,j)} x_{ij} + \sum_{s \in \text{St}(s,i)} G_{isT} \leq NP_i \quad \forall i \quad (\text{Plane Count}) \quad (2)$$

$$G_{ist-1} - G_{ist} + \sum_{j \in \text{IN}(j,s,t)} x_{ij} - \sum_{j \in \text{OUT}(j,s,t)} x_{ij} = 0 \quad \forall i, s, t \quad (\text{Balance}) \quad (3)$$

$$\sum_{i=1}^n x_{ij} = 1 \quad \forall j \quad (\text{Cover}) \quad (4)$$

$$\sum_{j=1}^m R_{0_{jv}} + \sum_{j=1}^m \lambda_{jv} \left(\sum_{i=1}^n CAP_{ij} x_{ij} \right) - R_{Total} \geq 0 \quad \forall v \quad (\text{Revenue}) \quad (10)$$

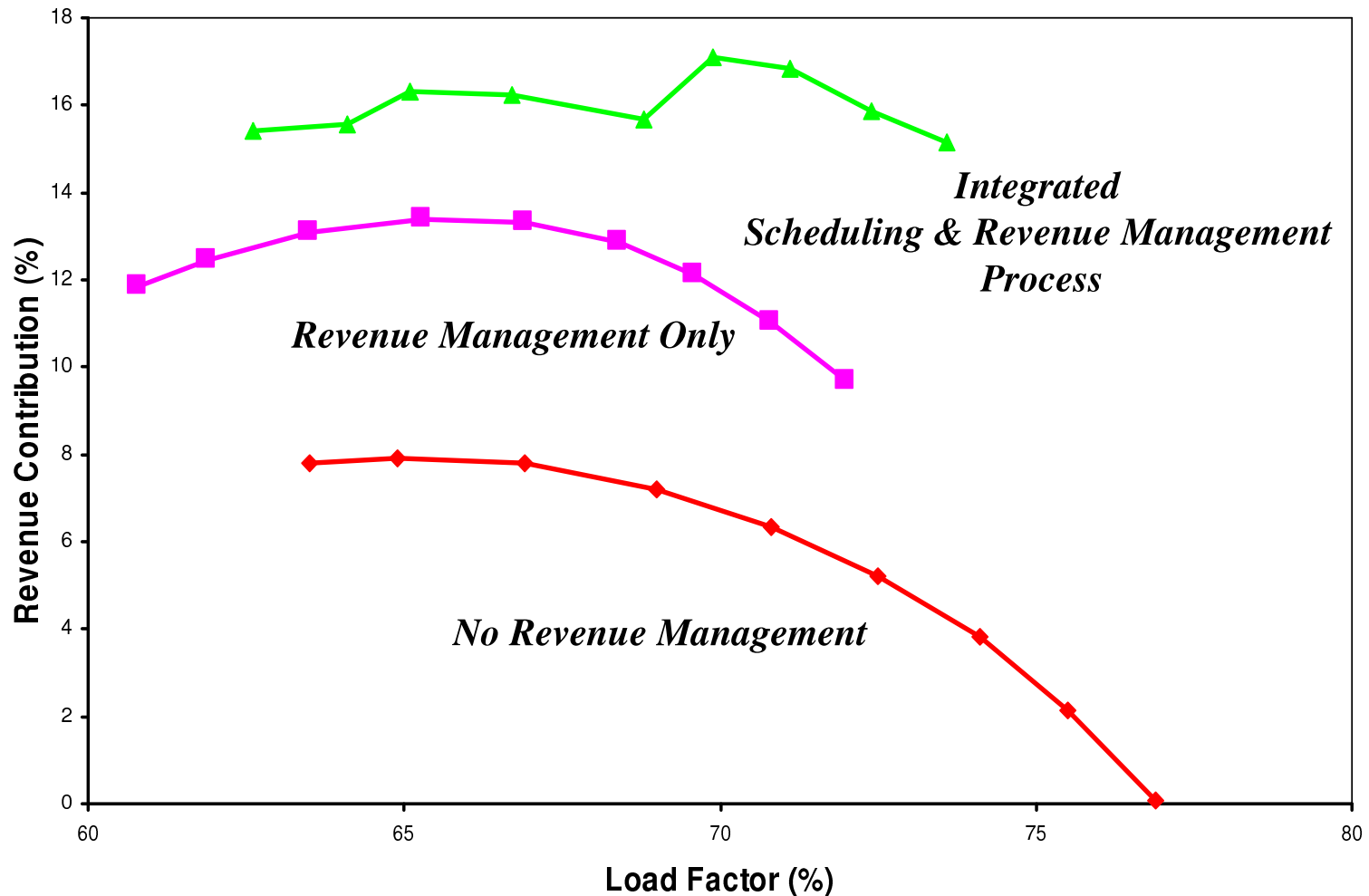
$$C_{Total} - \sum_{j=1}^m \sum_{i=1}^n C_{ij} x_{ij} = 0 \quad (\text{Cost}) \quad (11)$$

$$x_{ij} \in \begin{cases} 1 & \text{if aircraft type } i \text{ is assigned to schedule leg } j \\ 0 & \text{otherwise} \end{cases} \quad \forall i, j \quad (5)$$



Integrating Fleeting and RM

Consistent Scheduling and RM Benefits



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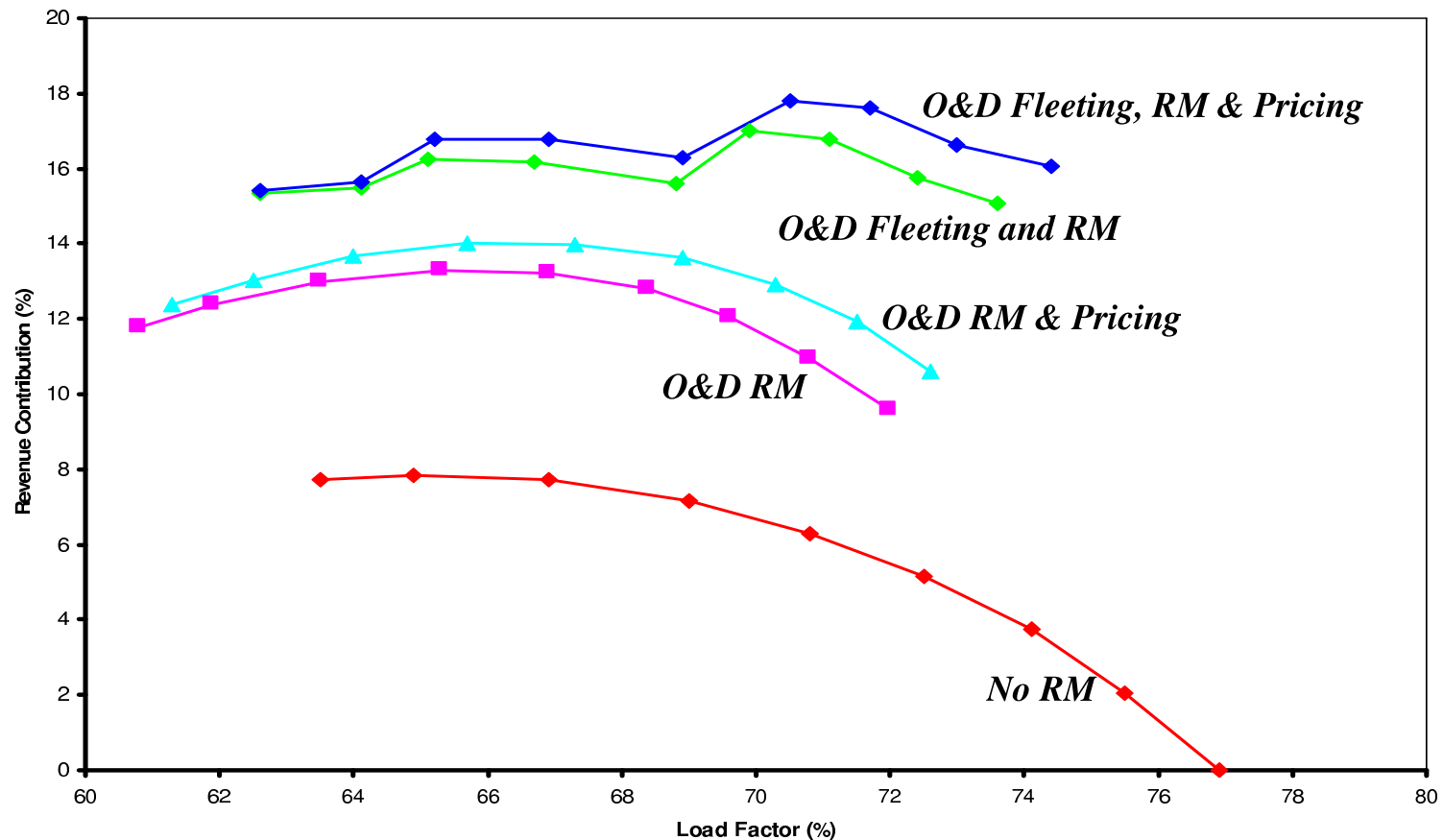
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Fields Institute, June 2008



Integrating Fleeting and RM

Extension to Consider Pricing Effects



Integrating Fleeting and RM

Extension to Large Scale Airline Network

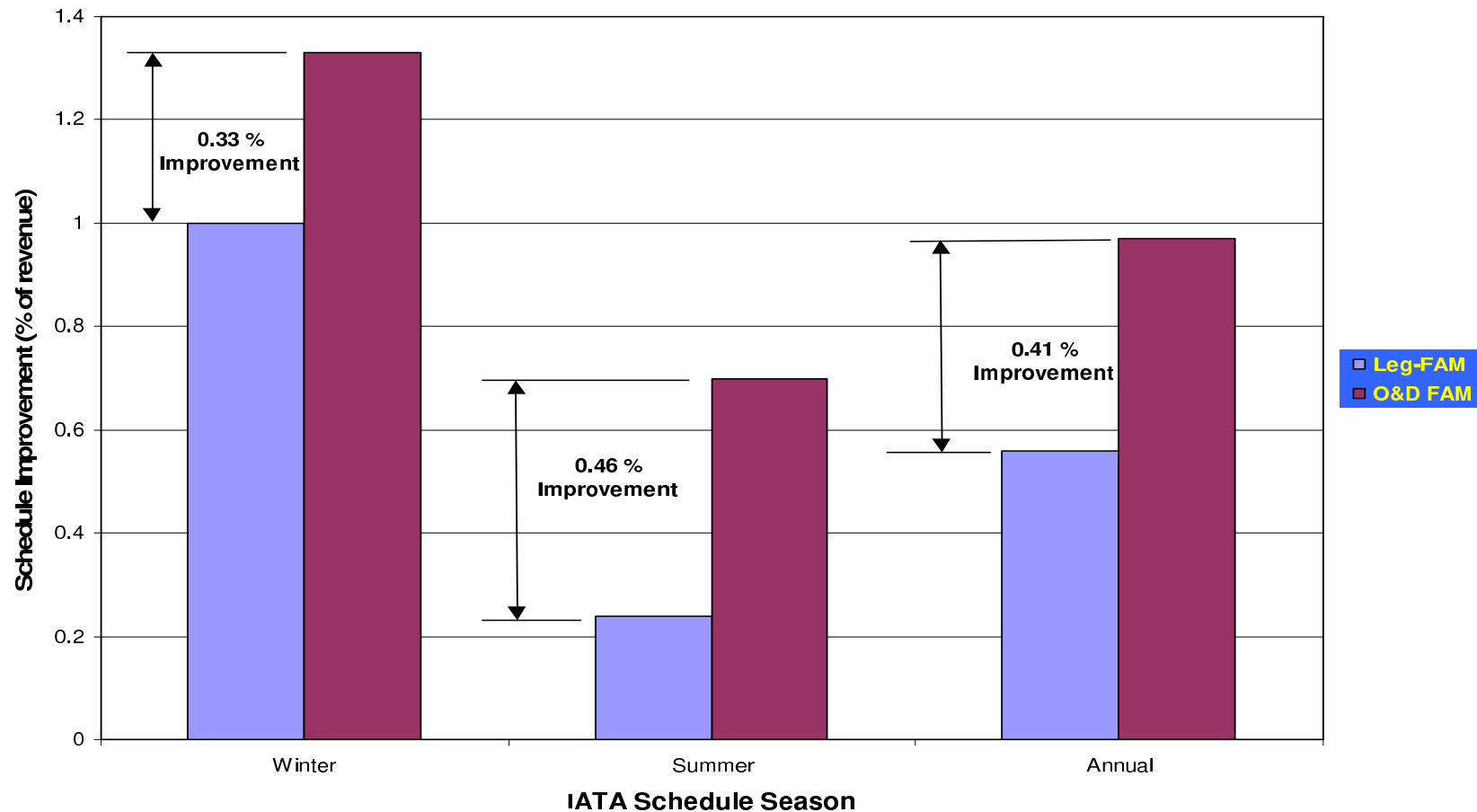
Benchmark Details

- 4,500 flight legs
- 26 sub-fleets
- 800 aircraft
- 150,000 total O&D markets (Including International Markets).
- One fare-class per O&D service
- No Jet-Prop Swaps
- International Fleeting Maintained
- Switching Mode (no flights can be dropped)



Integrating Fleeting and RM

Benchmark Results on Large Scale Network



Integrating Fleeting and RM

Production Results on Large Scale Network

Capacity Switching Run – Allocating capacity to a fixed schedule

Fleeting Scenario	Daily Operations	Change in Passenger Traffic (%)	Change in Revenue (%)	Change in Cost (%)	Change in Profit (%)
Fall	4,034	(3.65)	(1.80)	(2.40)	1.21
Spring	4,434	0.10	0.71	(1.20)	7.20

Schedule Reduction Run – Simultaneous allocation of capacity and reduction of schedule

Fleeting Scenario	Daily Operations	Change in Passenger Traffic (%)	Change in Revenue (%)	Change in Cost (%)	Change in Profit (%)
Base	4,930	-	-	-	-
Leg-FAM	4,569	(1.9)	(2.5)	(5.2)	11.6
O&D FAM	4,281	(13.1)	(9.5)	(14.9)	18.1



Integrating Fleeting and RM

Observations and Conclusions from Practice

- Results using existing forecasting methods and a consistent O&D Fleeting and RM approach illustrate significant potential benefits over segment-based FAM.
- Benchmark results show potential annual profit improvements ranging from 0.54% to 0.77% of revenue.
- Capacity Switching and Schedule Reduction results show similar improvements in the overall profitability of the schedule
- O&D Fleeting and RM process provides a better balance between available resources (capacity/supply) and the O&D-based demands.
- O&D Fleeting produces a schedule fleeting consistent with the RM process used to manage the seat inventory. This provides better opportunities to increase the overall schedule yield.
- Potential benefits from a consistent O&D Fleeting and RM process will increase as forecasting capabilities improve.



Airline Business Overview

D³ using O&D FAM => Revenue Opportunity



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Revenue Opportunity



Near-term Re-fleeting

O&D-Based Demand Driven Dispatch (D^3)

Objective and Methodology

- Objective: Increase overall profitability by making strategic near-term aircraft swaps between crew compatible equipment (first proposed by Berge and Hopperstad, 1993)
- Use the same O&D-based technique used to fleet the schedule
 - Use O&D revenue management demand forecasts instead of average market forecasts
 - Apply close to the day of departure
- Driving Forces:
 - Paradigm shift: Many airlines fleet the schedule using leg-based methods while managing the seat inventory using O&D-based methods. This leads to an inconsistent matching of supply and demand.
 - Daily forecast variability: D^3 exploits opportunities created by the systemic daily variation of ODF demand flowing through the network. These effects are not captured when schedules are built using typical day forecasts.
 - Forecast Error: D^3 improves schedule profitability by using improved forecast data nearer the day of departure.



Demand Driven Dispatch (D³)

Benchmark, Pilot and Implementation

Benchmark Guidelines

- Reading Day 13
- Potential swaps: 566 candidate flight legs
- 4800 total flight legs in schedule
- 115,000 total O&D fare classes (Including International Markets) considered in analysis
- All other fleets held constant

Pilot Study Guidelines

- Reading Day 13
- Pilot ran for 5 days
- Maximum number of swaps = 12 round trips (24 legs)
- O&Ts Held Constant
- Approximately 4800 flight legs and 115,000 O&D fare classes (Including International Markets) considered per day

Production Implementation

- Reading Day 13-14
- Process runs three times per week
- Uses automated data feeds from RM system
- Similar guidelines to Benchmark and Pilot



D³ Benefits and Timing

What the Theory Tells Us – Benchmark Results

Measure	Input Schedule	D ³ Solution
Incremental Profit Gain (% of Total Revenue)		0.64
Switched Flights		114
Segments Flown		
RJ3	230	198
RJ4	336	368
Utilization		
RJ3	10:31	9:37
RJ4	10:02	10:14

Maximum
benchmark
results – no
switching limits



Establishing
some practical
limits – Switching
limit vs. benefit

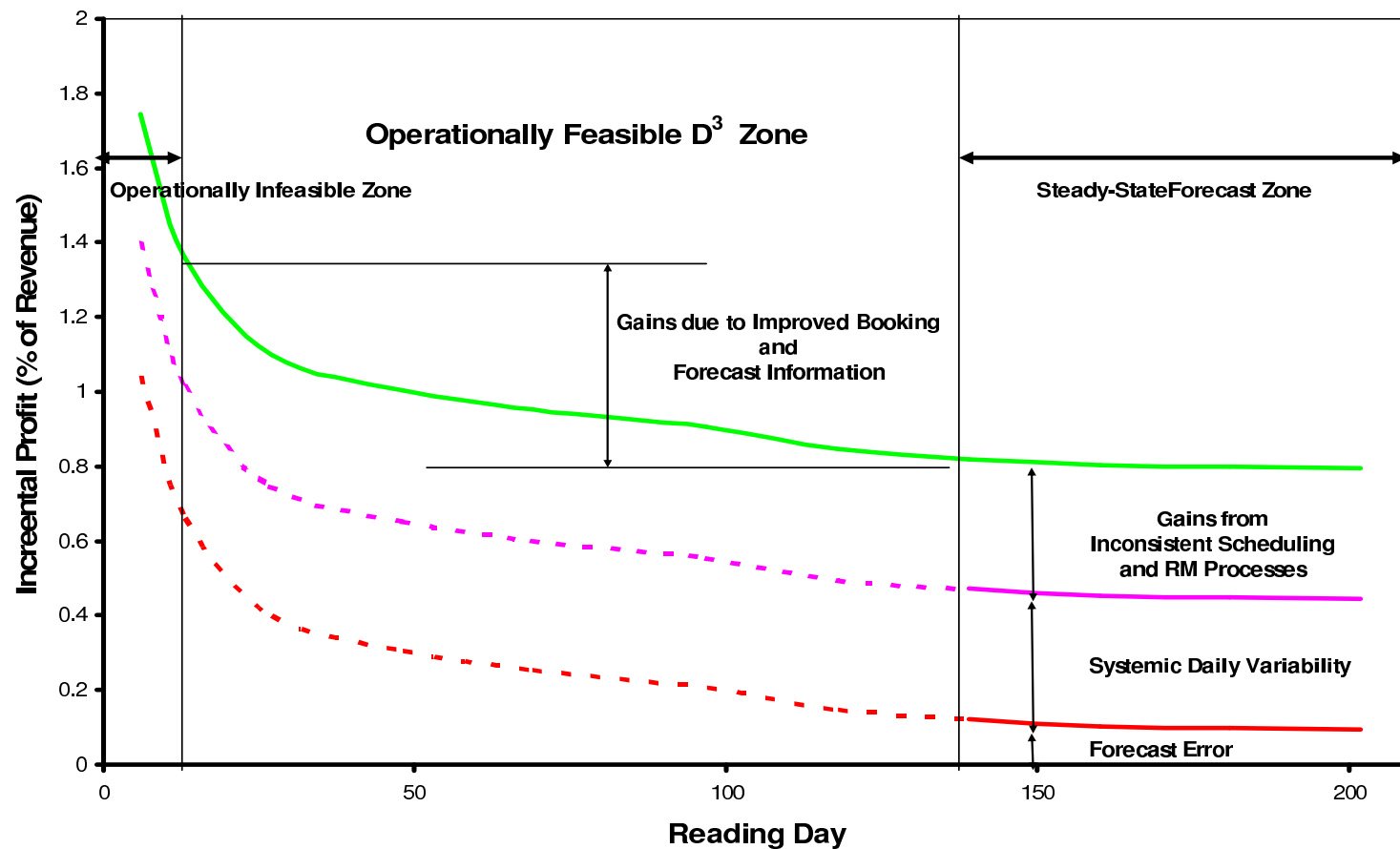


Swap Limit	Daily Profit Increase (% of Revenue)	Cumulative Percent of Total
25	0.25	39%
50	0.35	56%
75	0.50	78%
100	0.60	94%
114	0.64	100%



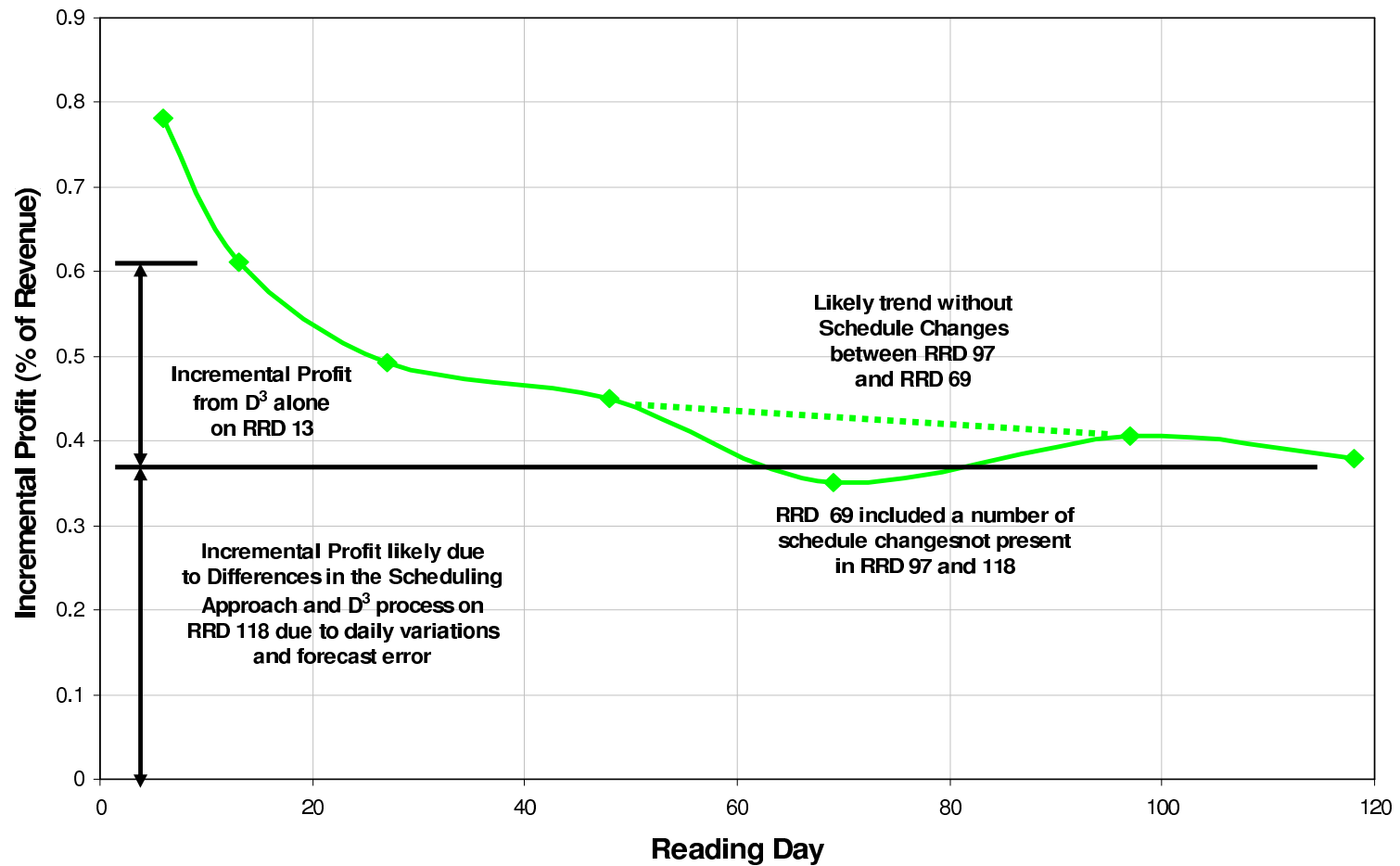
D³ Benefits and Timing

What the theory tells us



D³ Benefits and Timing

What Happens in Practice



D³ Benefits and Timing

What Happens in Practice – Pilot Study Results

Metric	D ³ Results
Average Daily Incremental Passengers	33
Estimated Annual Traffic Increase	12,045
Daily Incremental Profit (% of Revenue)	0.27%



D³ Summary

What Happens in Practice – Pilot Study Results

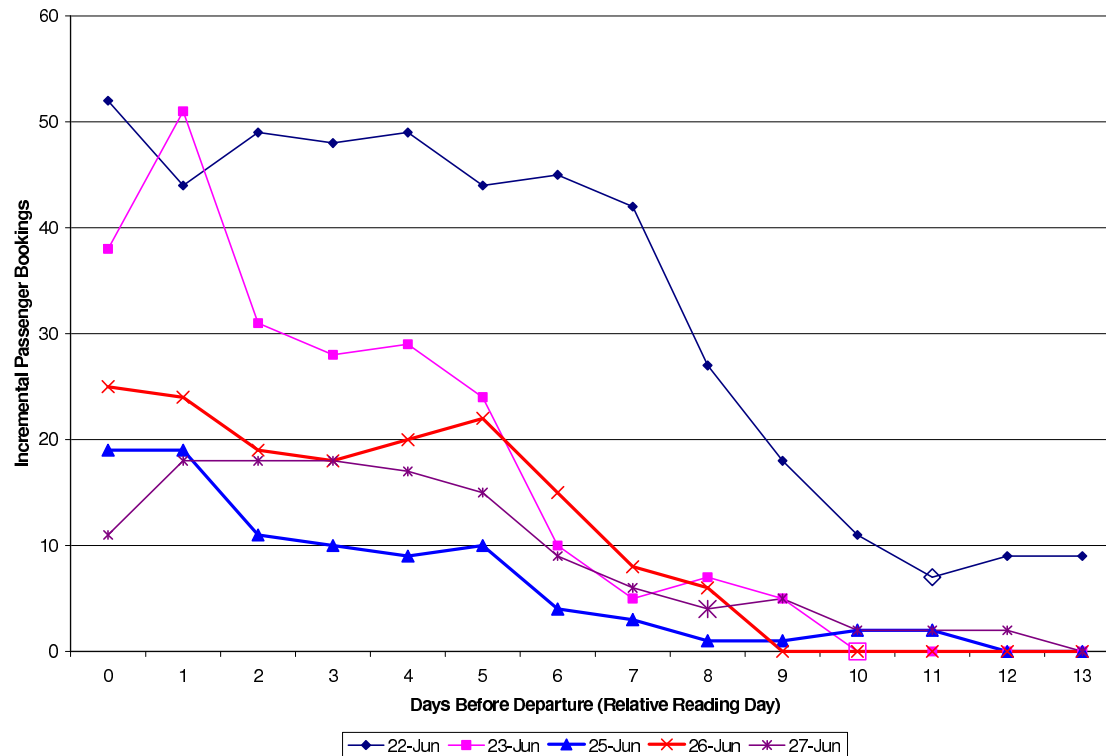
- Results clearly illustrate the potential benefit associated with D³ swaps of crew compatible aircraft near the day of departure.
- D³ effectively exploits the daily variations in ODF demand forecasts to identify revenue opportunities not realized during the schedule planning process.
- D³ provides an added degree of freedom to the RM process. This added flexibility allows an airline to adapt to better forecasts near the day of departure.
- A portion of these benefits are likely due to inconsistencies between the scheduling and RM processes (Leg-based planning vs. O&D-based control).
- Timing of D³ highly dependent on ability to market added capacity.
- Must account for M&E, crew and operational issues.



D³ Benefits and Timing

What Happens in Practice – Pilot Study Results

Incremental Passenger Bookings for Pilot Study



D³ Benefits and Timing

What Happens in Practice – Production Results

Incremental Passenger Bookings at ORD for First Year in Production

	Pax over 44	Days Swapped	Avg Pax/Day
January	56	13	4.31
February	61	22	2.77
March	276	28	9.86
April	124	29	4.28
May	239	31	7.71
June	263	28	9.39
July	189	22	8.59
August	315	31	10.16
September	138	20	6.90
October	427	31	13.77
November	327	30	10.90
December	394	20	19.70
Yearly Total	2809	305	9.21



Recap of the Integration Paradigm

Benefits and Hurdles

Benefits:

- Integrated scheduling and RM processes can uncover significant revenue opportunities near the day of departure not realized in a typical sequential process.
- Implementation facilitates a natural and systematic feedback mechanism between scheduling and RM processes. As a result, capacity better matches the underlying demand.
- Provides opportunities for further process improvements to improve revenue and/or cut costs (pricing, M&E, Crew).

Hurdles:

- Paradigm shift requires analysts in RM and Scheduling to think about the scheduling and seat allocation problem much differently.
- Implementation requires a higher level coordination between different airline functions (Scheduling, RM and SOC).
- Integration puts added emphasis on the importance of forecasting at the Leg and O&D level.

