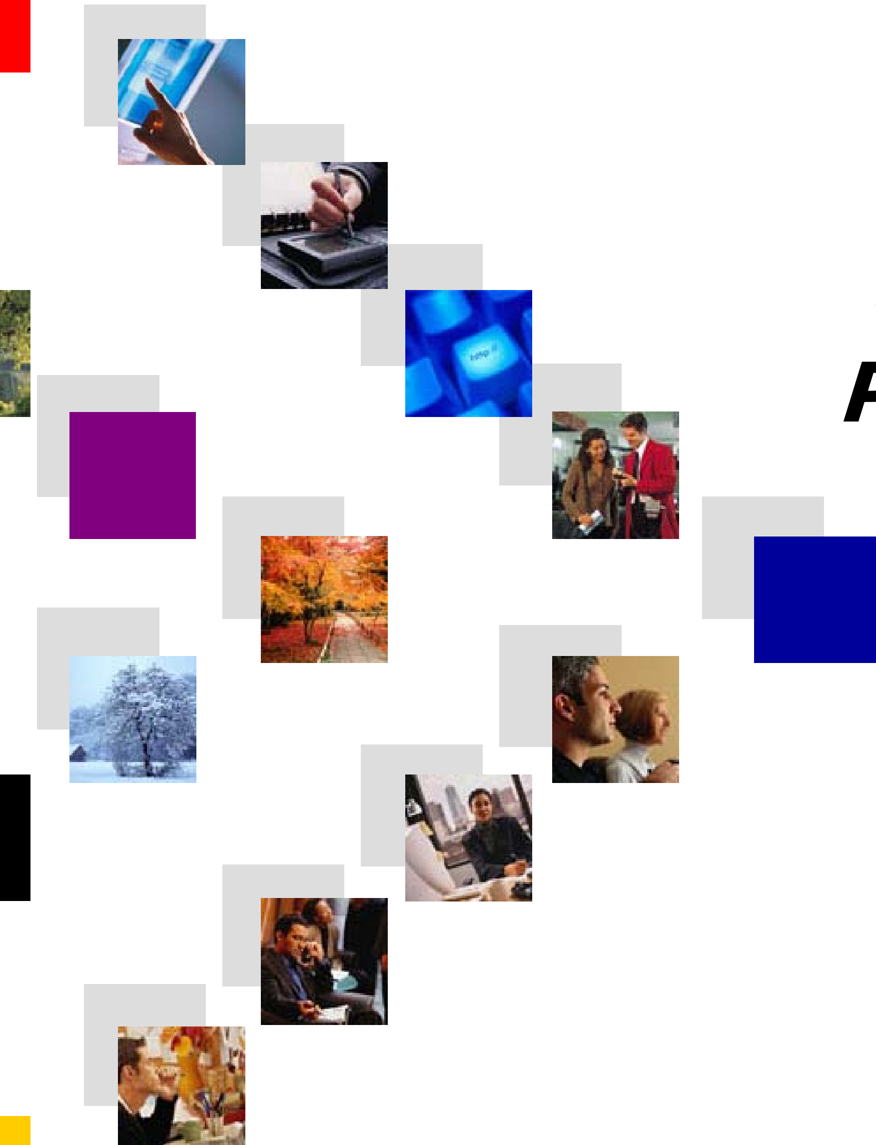


Optimization in Airline Planning and Marketing

Institute for Mathematics and Its Applications

November 2002
Barry C. Smith

Sabre

Overview

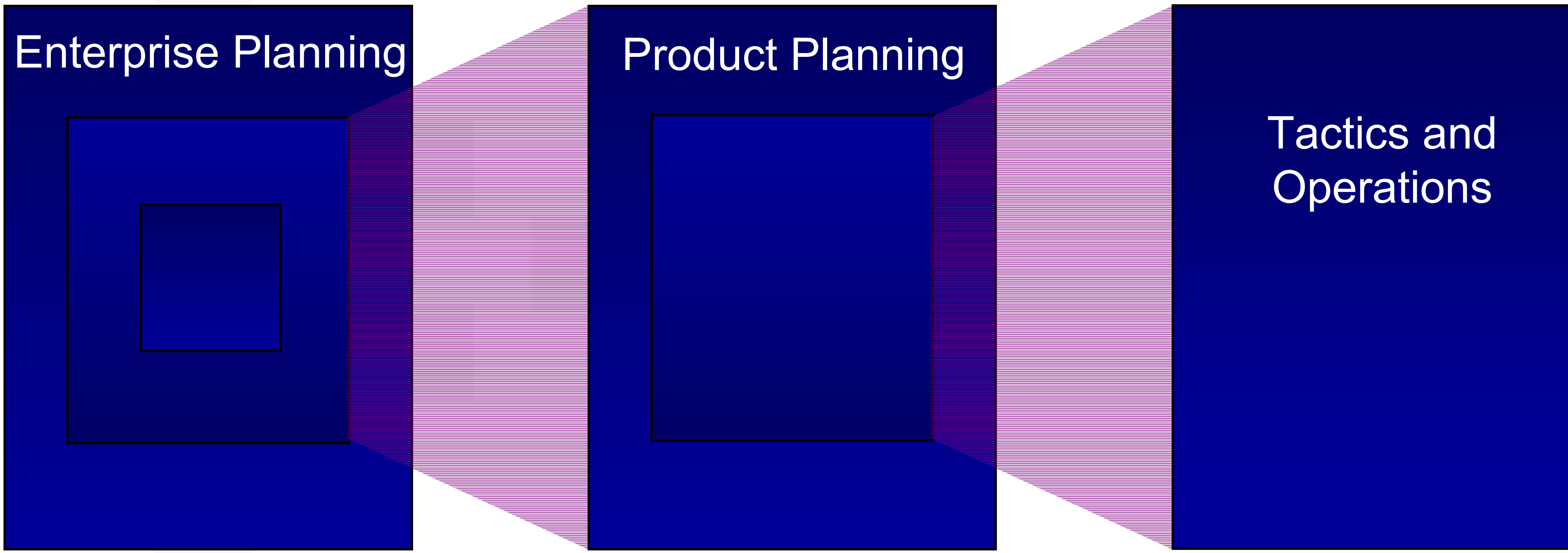
- Airline Planning and Marketing Landscape
- Applications of Optimization Modeling
- Planning and Marketing Integration
- Unsolved and Under-solved Problems
- Future Outlook

Airlines Make Money Only When They Match Supply and Demand

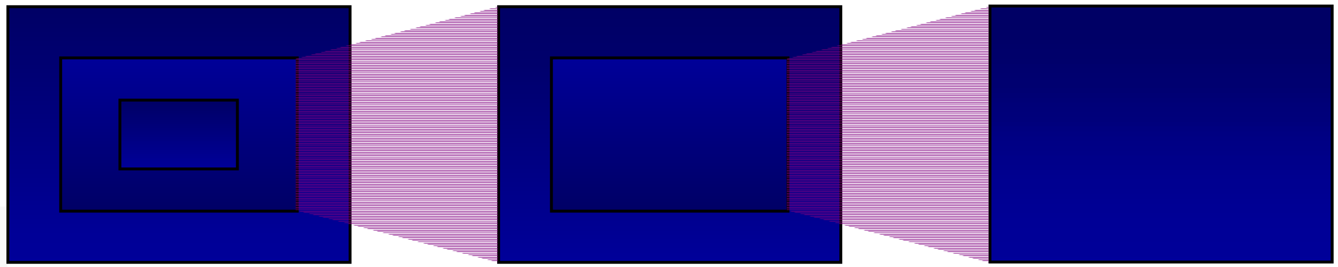
The Problem is Large and Dynamic

- 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



There Should be Continuity



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	• Route Structure • Fleet • Maintenance Bases • Crew Bases • Facilities	• Schedule • Fleet Assignment • Pricing Policies	• Price • Restrictions • Availability
Constraints	• Financial Resources • Regulation	• Route Structure • Fleet • Maintenance • Crew Bases • Facilities	• Schedule • 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 pric

YM is Essential to Airline Profitability

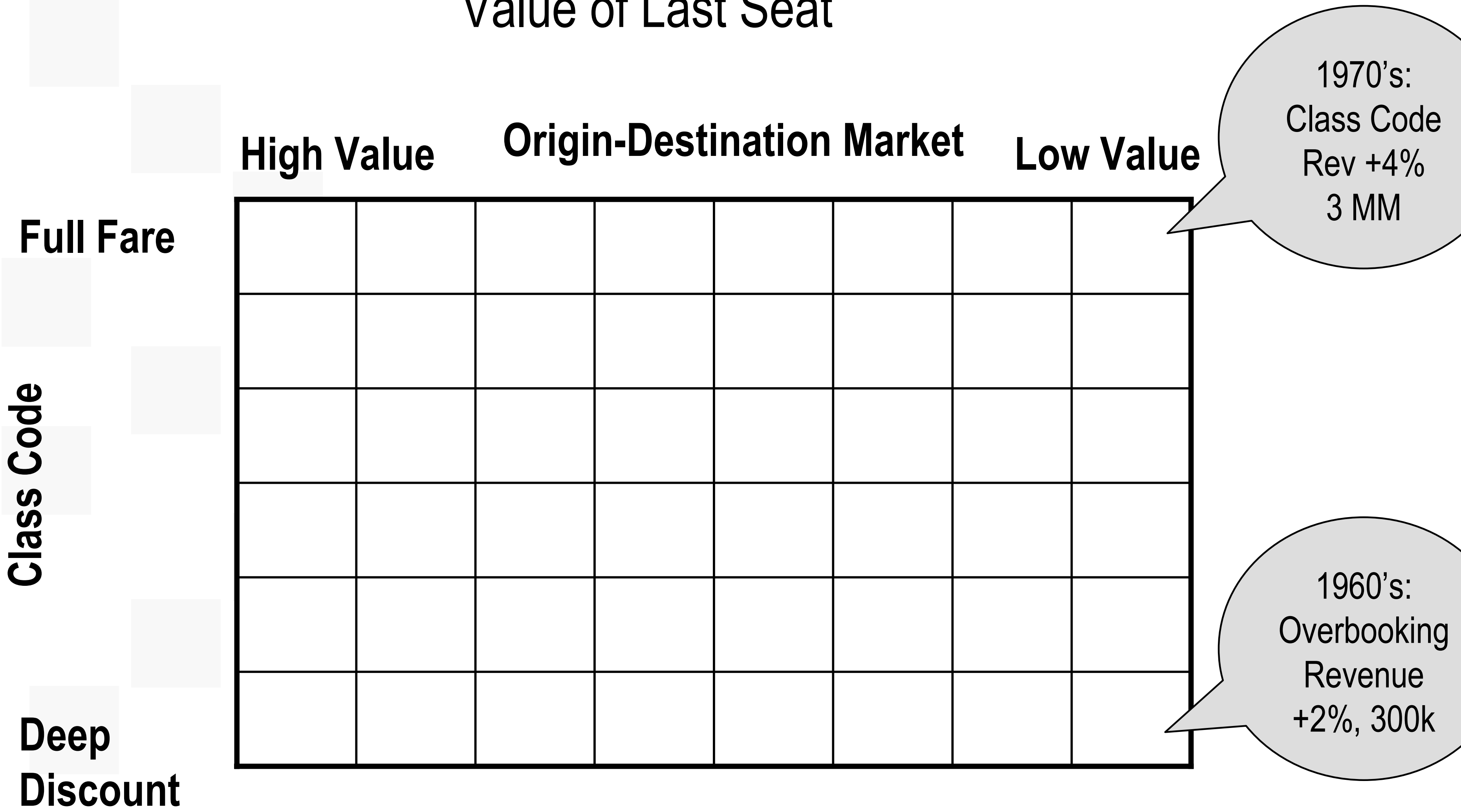
- Annual benefit of Yield Management to a major airlines is 3% – 6% of total revenue
- A major airlines' revenue benefits from yield management exceed $500,000,000 per year
- Applying this rate to the industry ($300 billion/year) yields potential benefits of $15 billion per year
- The possibilities for 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

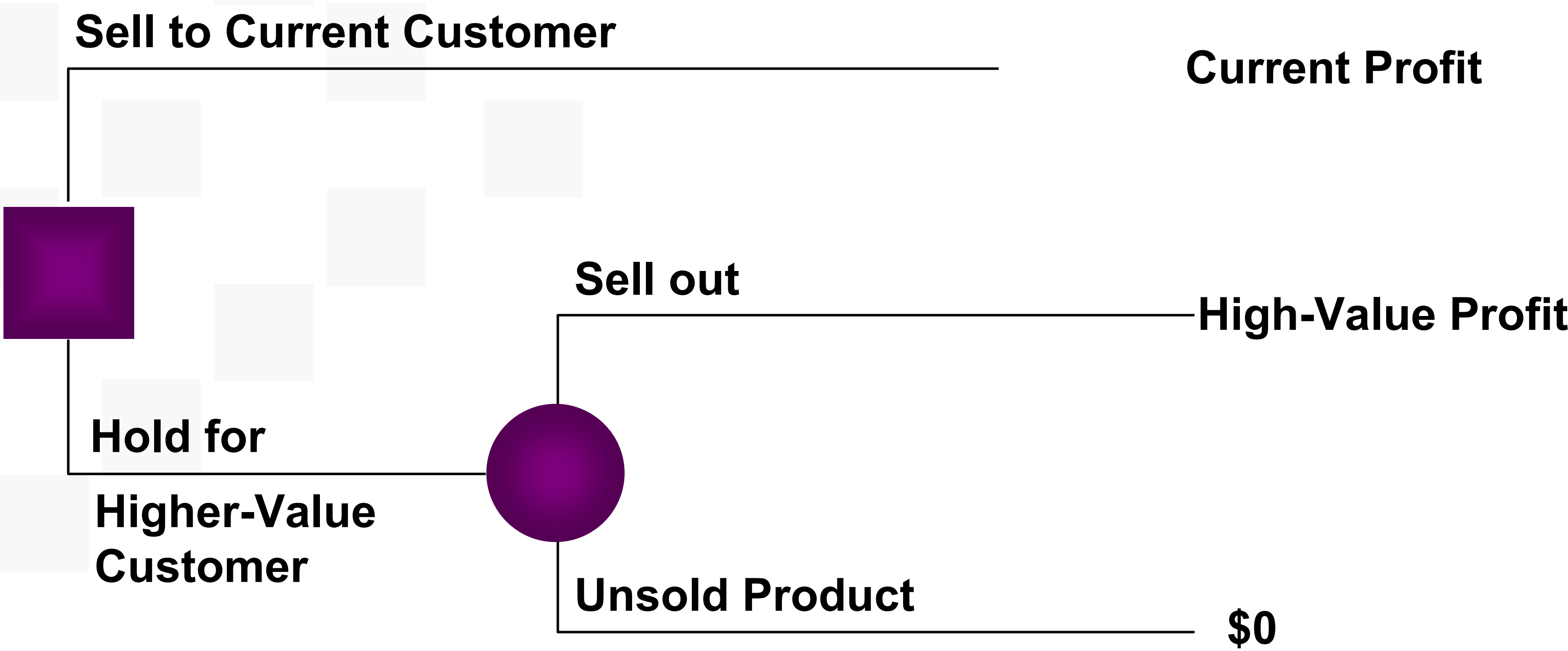
Value of Last Seat



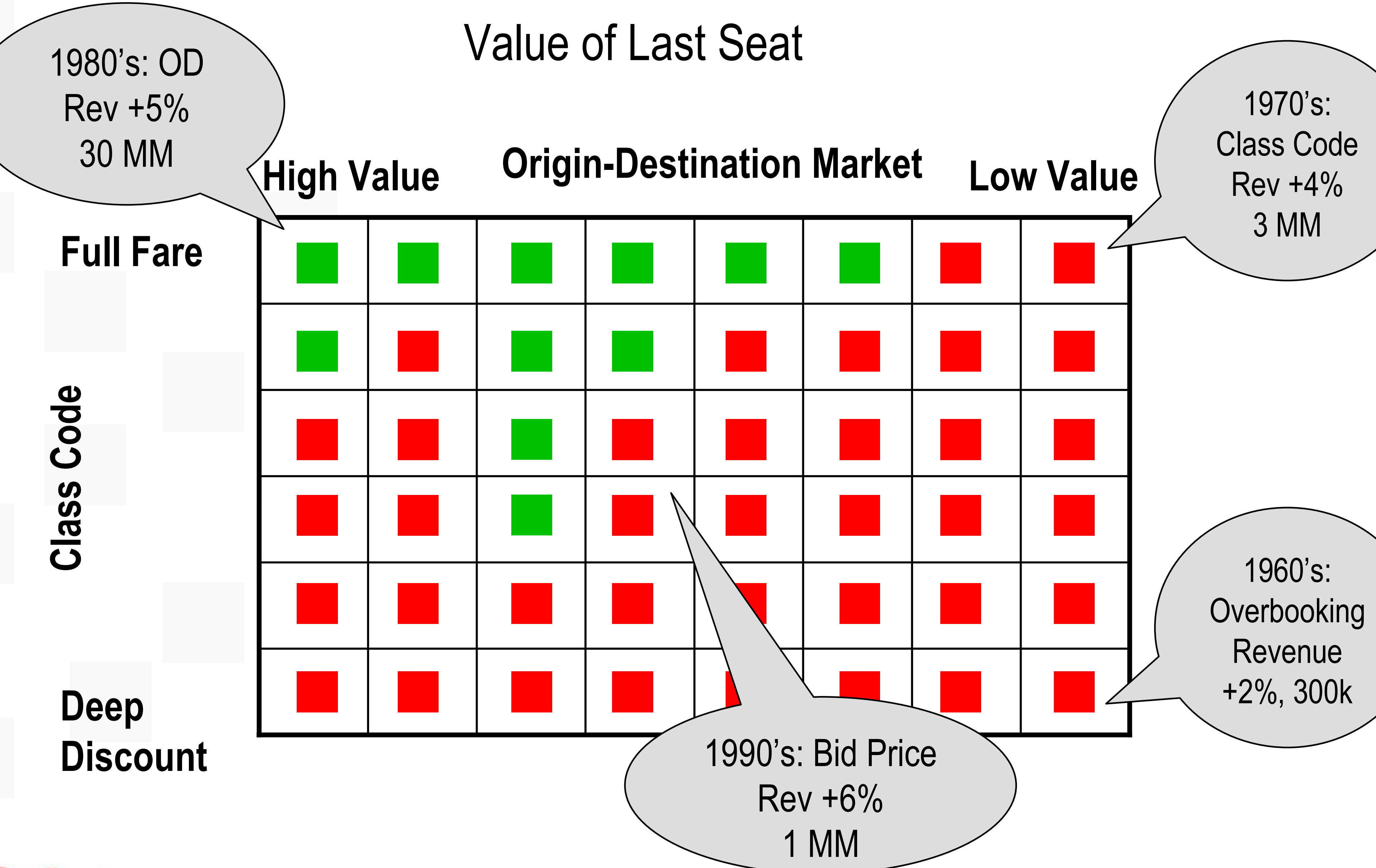
Revenue Mix Problem – Flight Leg

Stop selling Current (low-value) products when:

Profit (Current) < Profit (high-value) * P (Sell out)



Yield Management Evolution



Revenue Mix Problem – Network

$$\text{Max} \sum_{ODF} Pax_{ODF} * \text{Re}\, v_{ODF}$$

Subject to :

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

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

$$Allocations \geq 0$$

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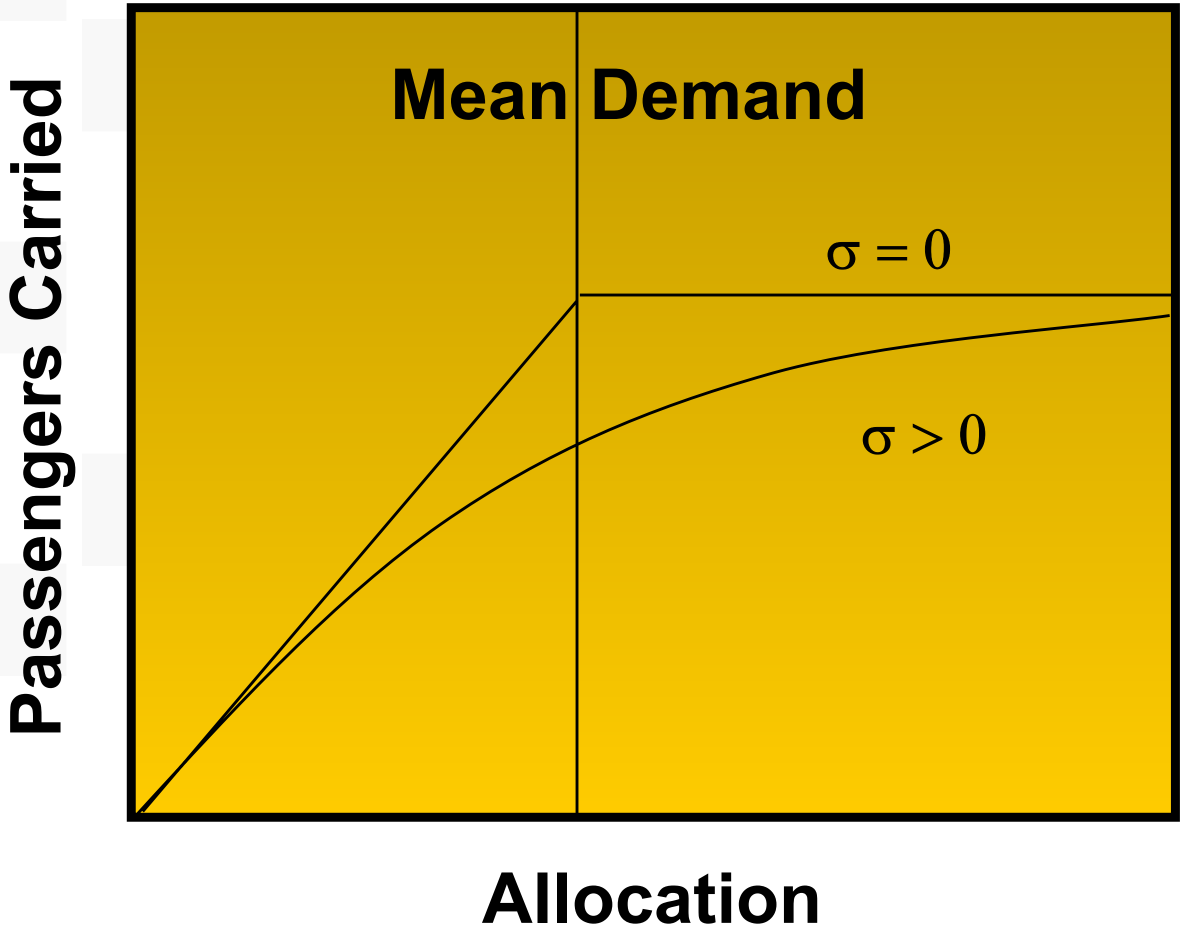
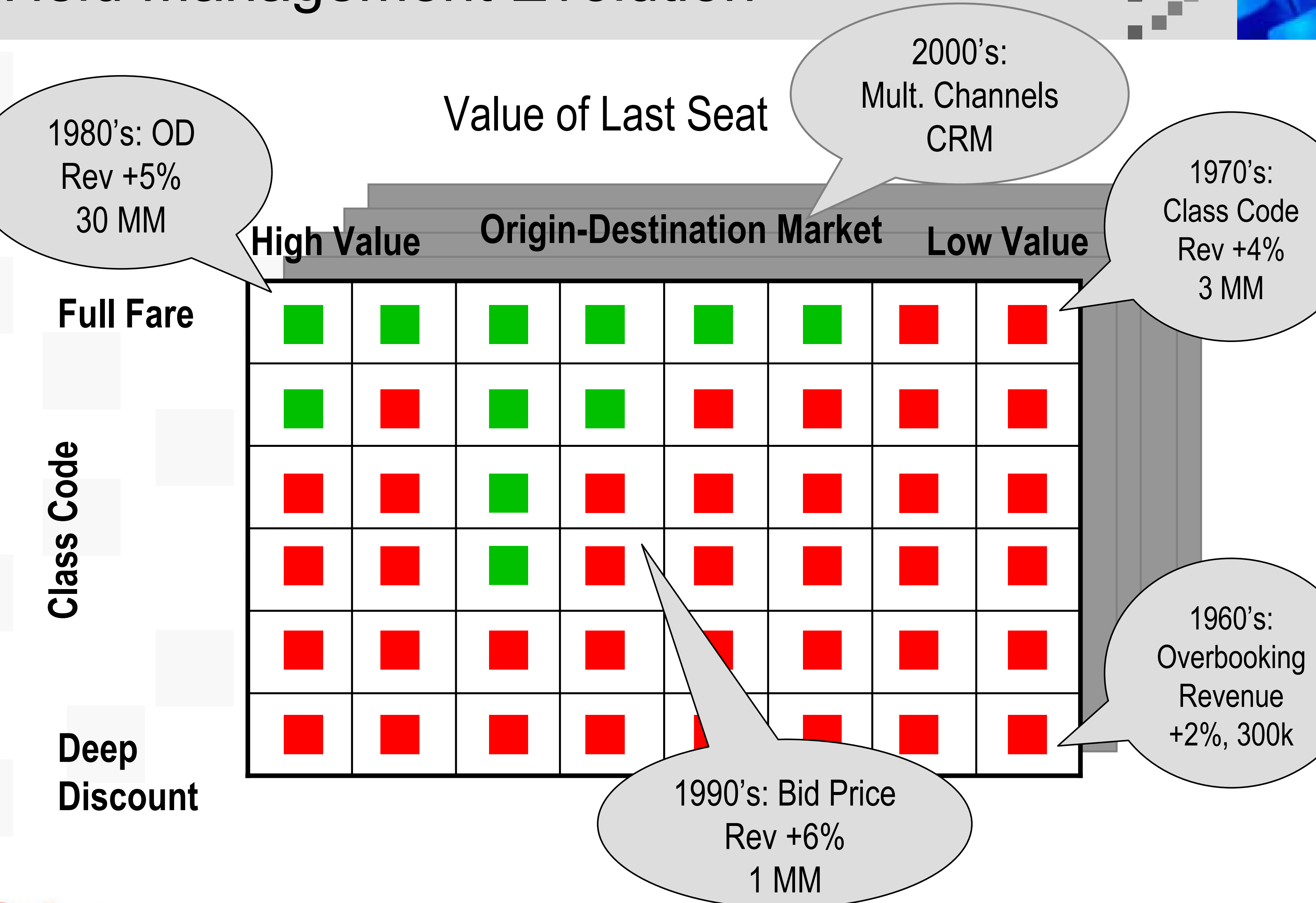
Passengers = f (Allocation, Demand)



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



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Fleet Assignment – FAM

- Fleet Assignment Models (FAM) assign aircraft types to an airline timetable in order to maximize profit
- FAM is widely used in the airline industry
  - AA and DL have reported 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

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

$$Subject\ \ to$$

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

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

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

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

$$x_{f,a} \in \{0,1\} \ \ y_{a,t,s} \ge 0$$

FAM Extensions

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

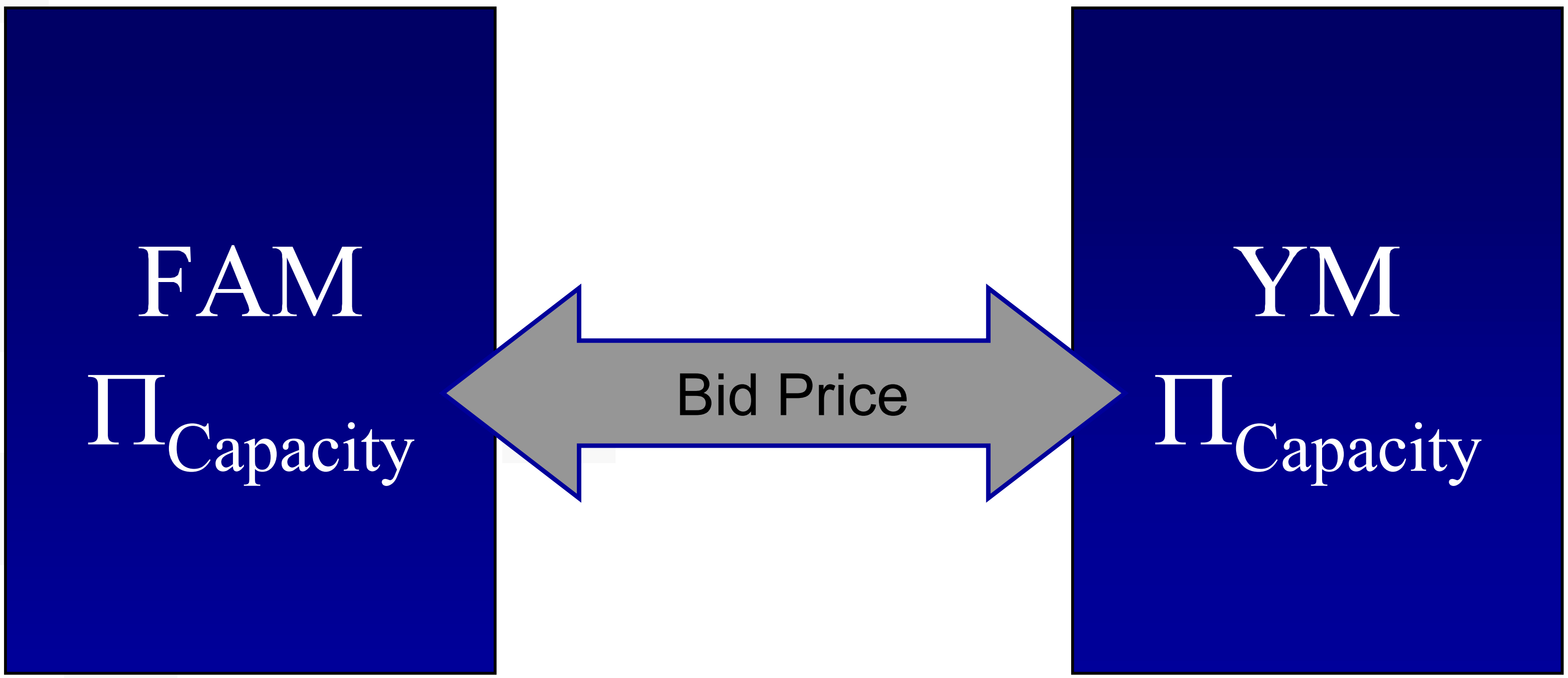
Leg Revenue Modeling Approaches

- 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

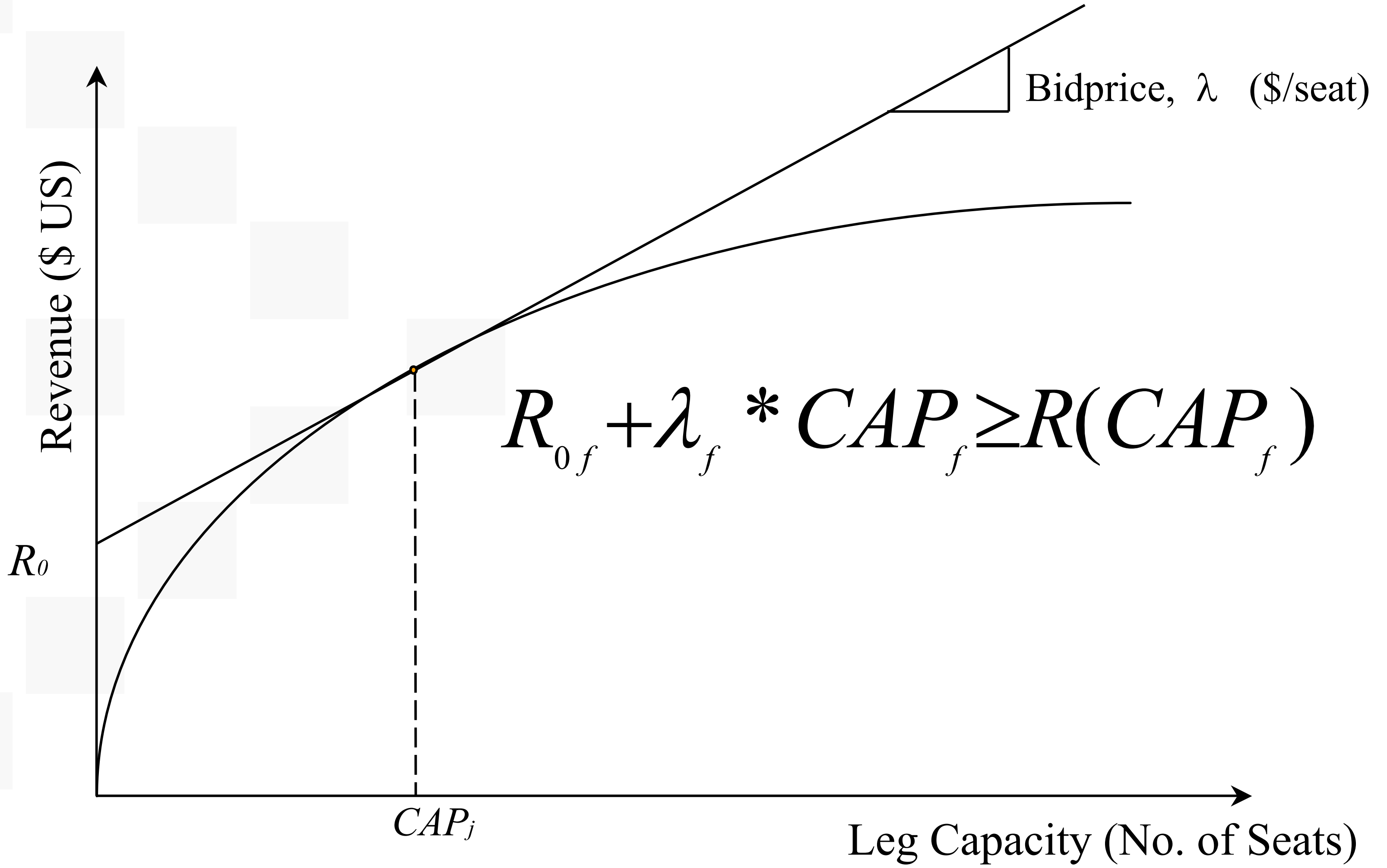
Improving Revenue Modeling in FAM

- 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



Revenue Function Approximation: One Leg, One Cut



$$R_{0f} + \lambda_f * CAP_f \geq R(CAP_f)$$

OD FAM Master

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

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

$$R_0^i + \sum_{f \in Flights} \lambda_f^i \sum_{a \in Aircraft} Cap_a x_{f,a} \geq R_{Total} \qquad \forall \, \text{i} \in \text{OD Cuts}$$

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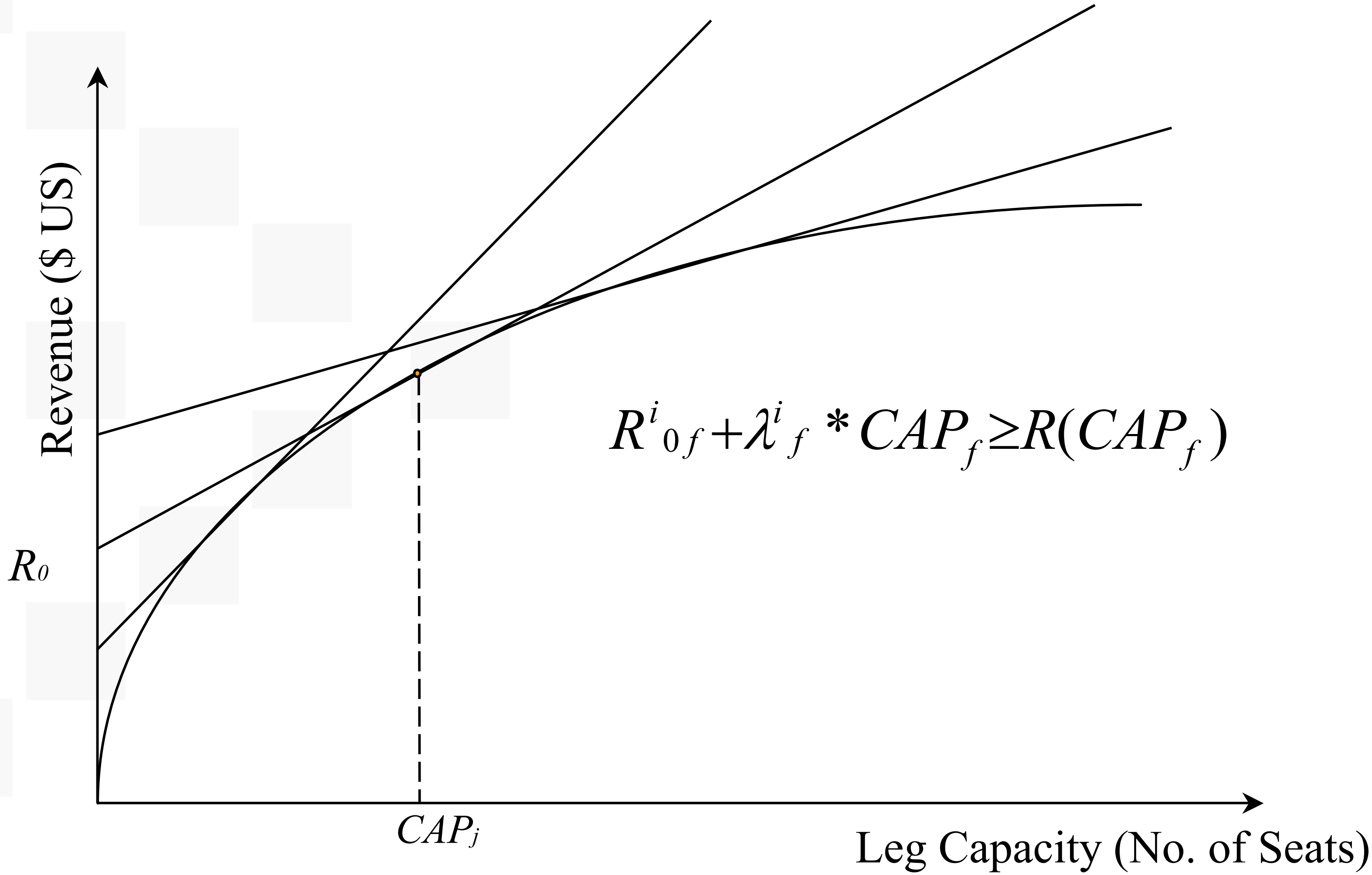
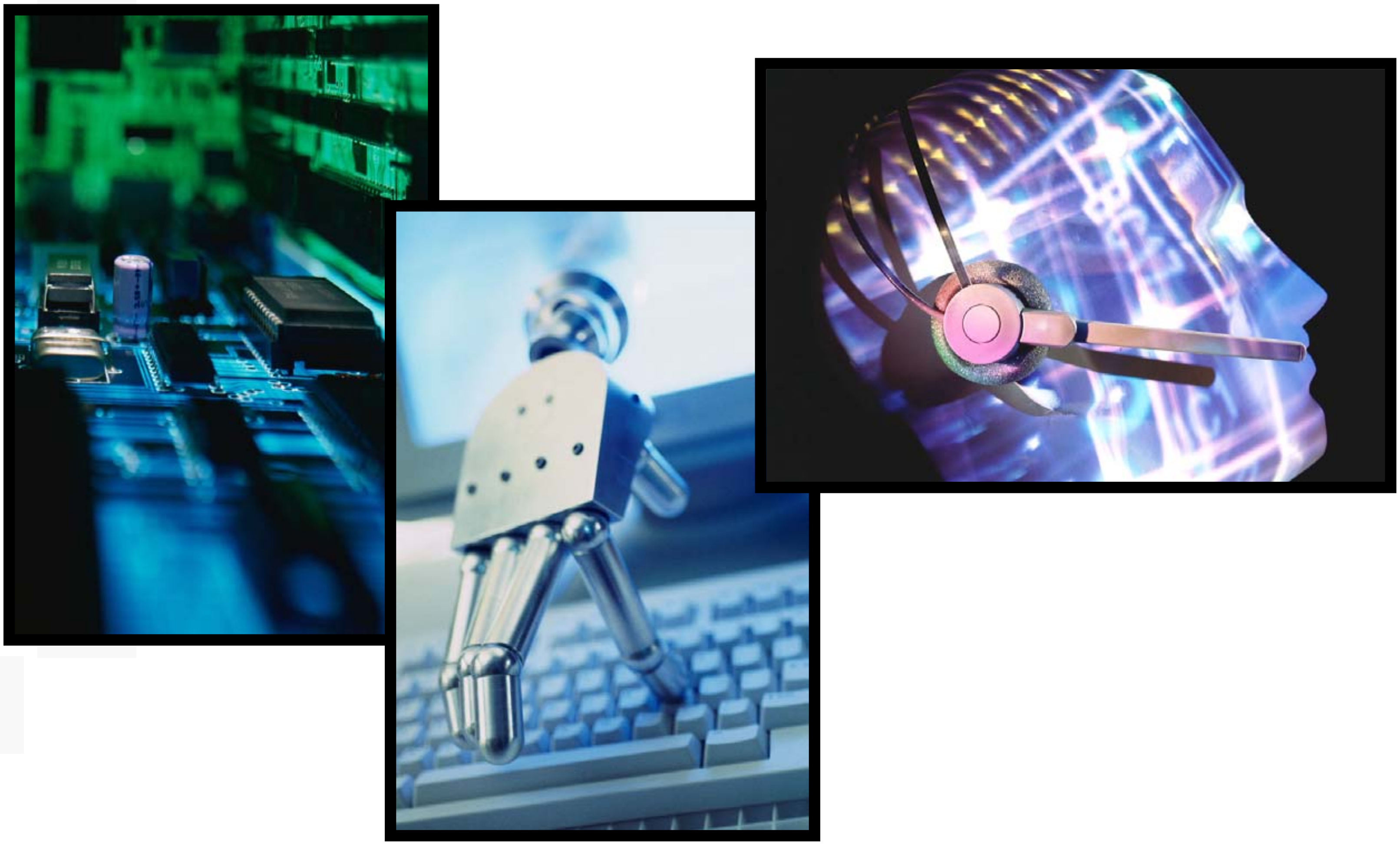
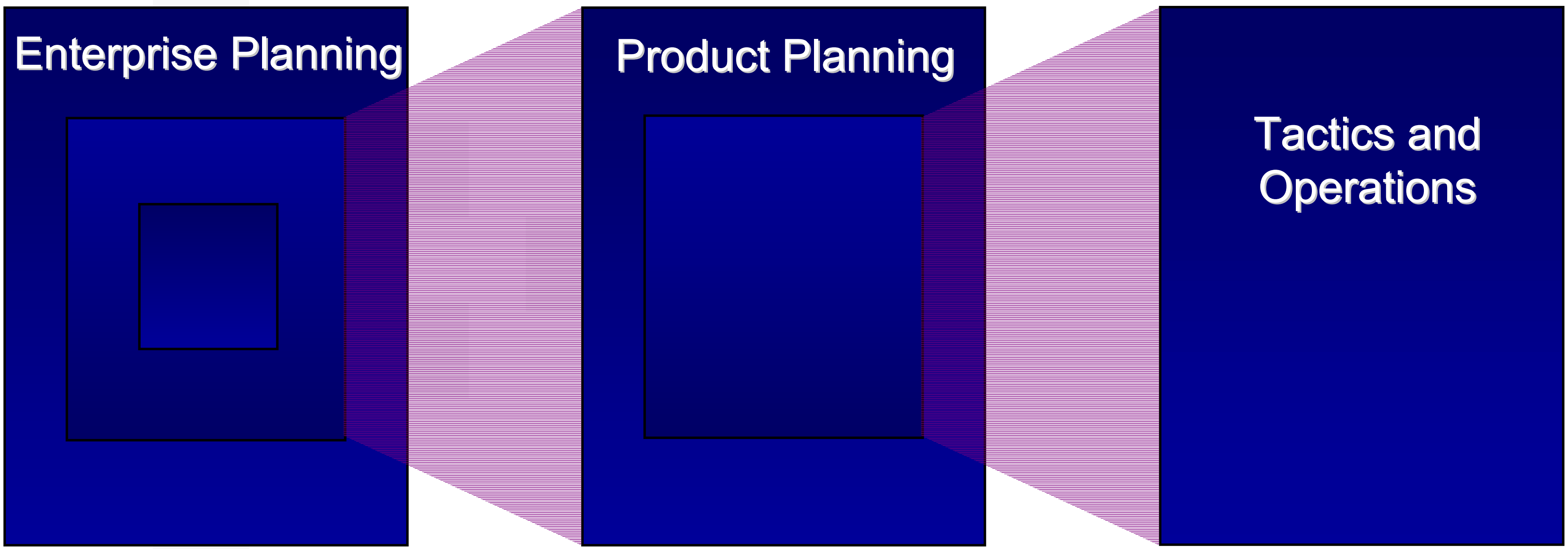
Revenue Function Approximation: One Leg, Multiple Cuts



Planning and Marketing Integration



Ideal Planning



Planning Reality

Airline Pricing

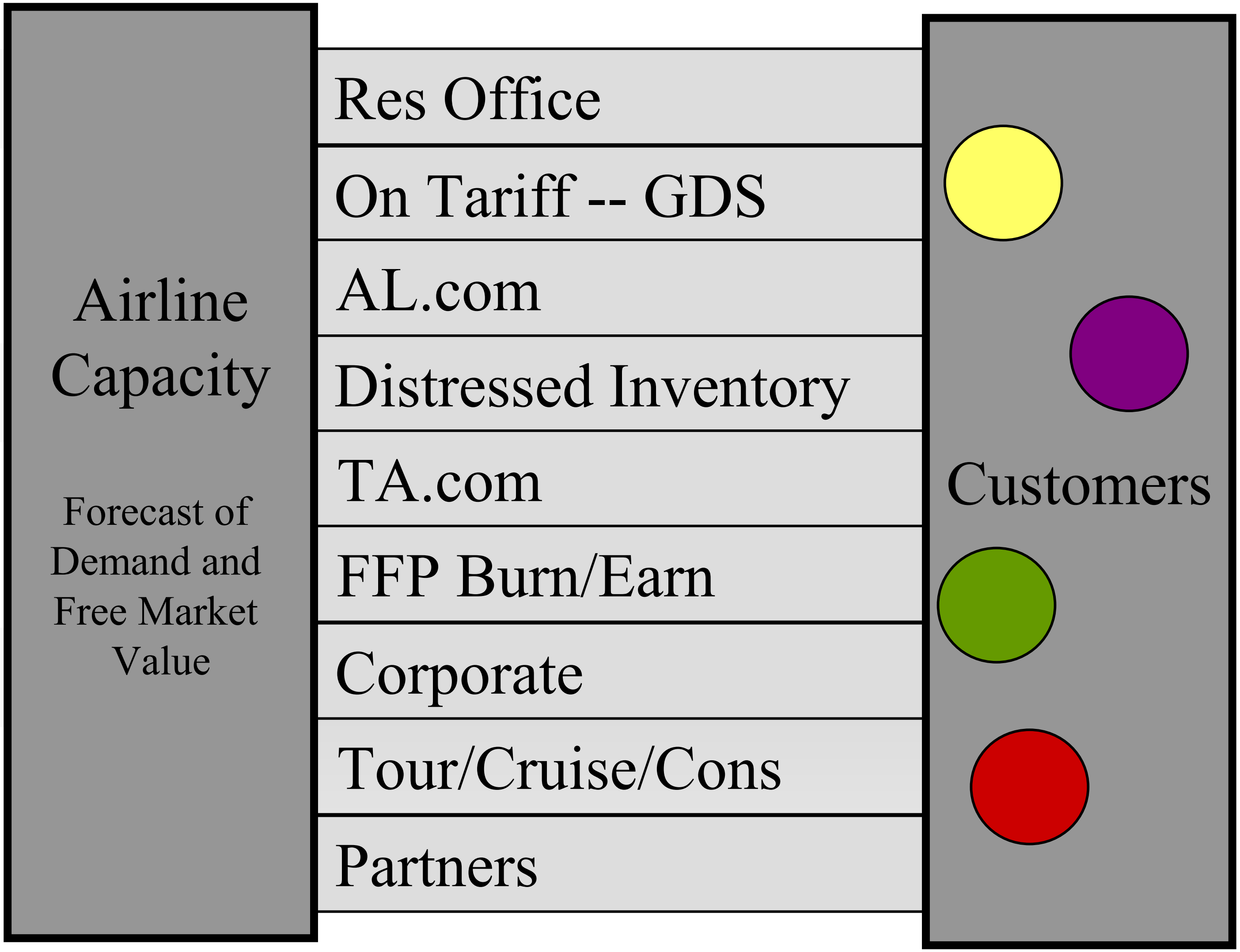
Simple Concepts

- 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



Bid Prices Support Integration

Unsolved and Under-solved Problems

Opportunities

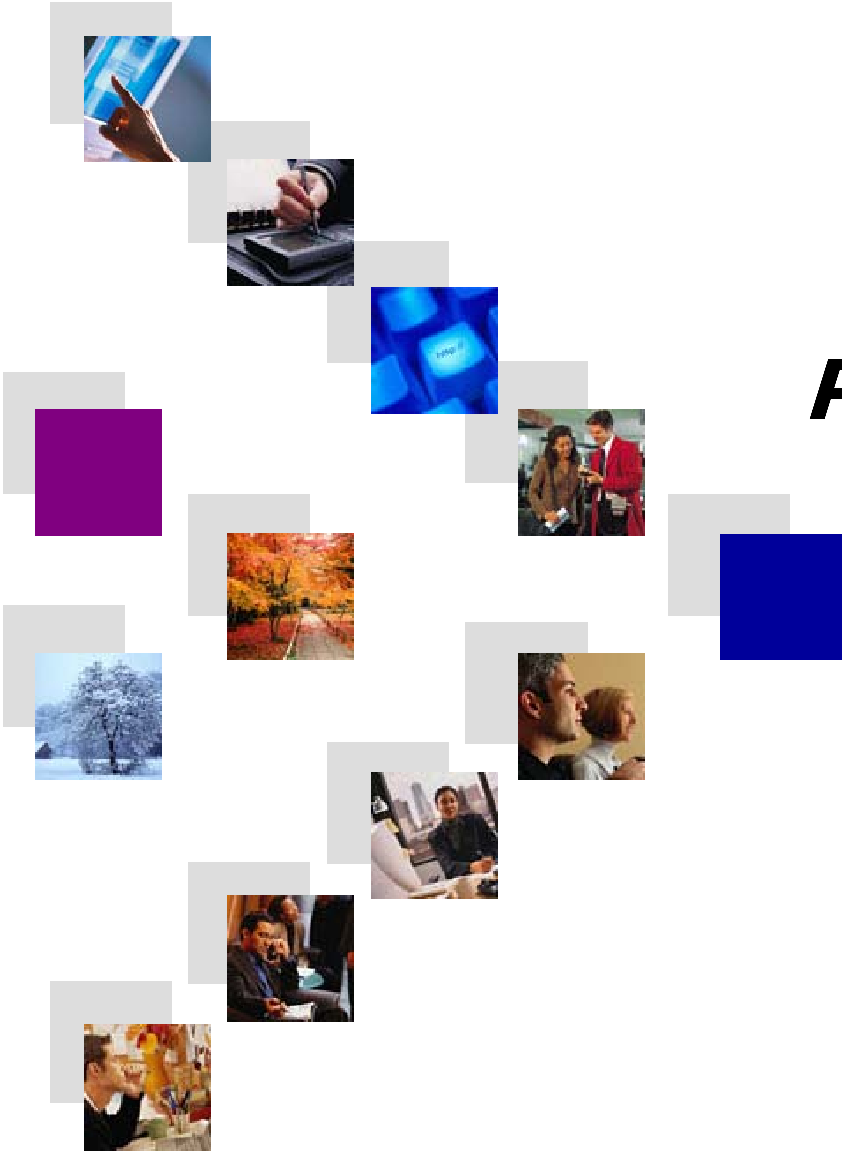
- Enterprise Planning
  - Facilities
  - Manpower
  - Fleet
- Longitudinal Planning
- Alliance Optimization
- Customer Relationship Management
- Robust Planning
  - Demand
  - Operations
  - Competition
- Support for Labor Negotiations

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



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