Flight Transportation Laboratory
R 93-1

PRESENTATIONS FROM THE ANNUAL MEETING OF THE

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Optimization vs. Control in Airline Revenue Enhancement
Professor Peter P. Belobaba

Airline Price Elasticity Estimation
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Assessment of the Potential Diversion of Air Passengers to
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OPTIMIZATION VS. CONTROL IN

AIRLINE REVENUE ENHANCEMENT

Professor Peter P. Belobaba

MIT Flight Transportation Laboratory

May 1993

OVERVIEW

- Optimal solutions to airline "seat allocation" problems do not ensure revenue enhancement from seat inventory control.

- Objective of this presentation is to illustrate how revenue gains are affected by:

    - optimization algorithm

    - control mechanism

    - revision capabilities

- We will consider single-leg and multi-leg flight examples.

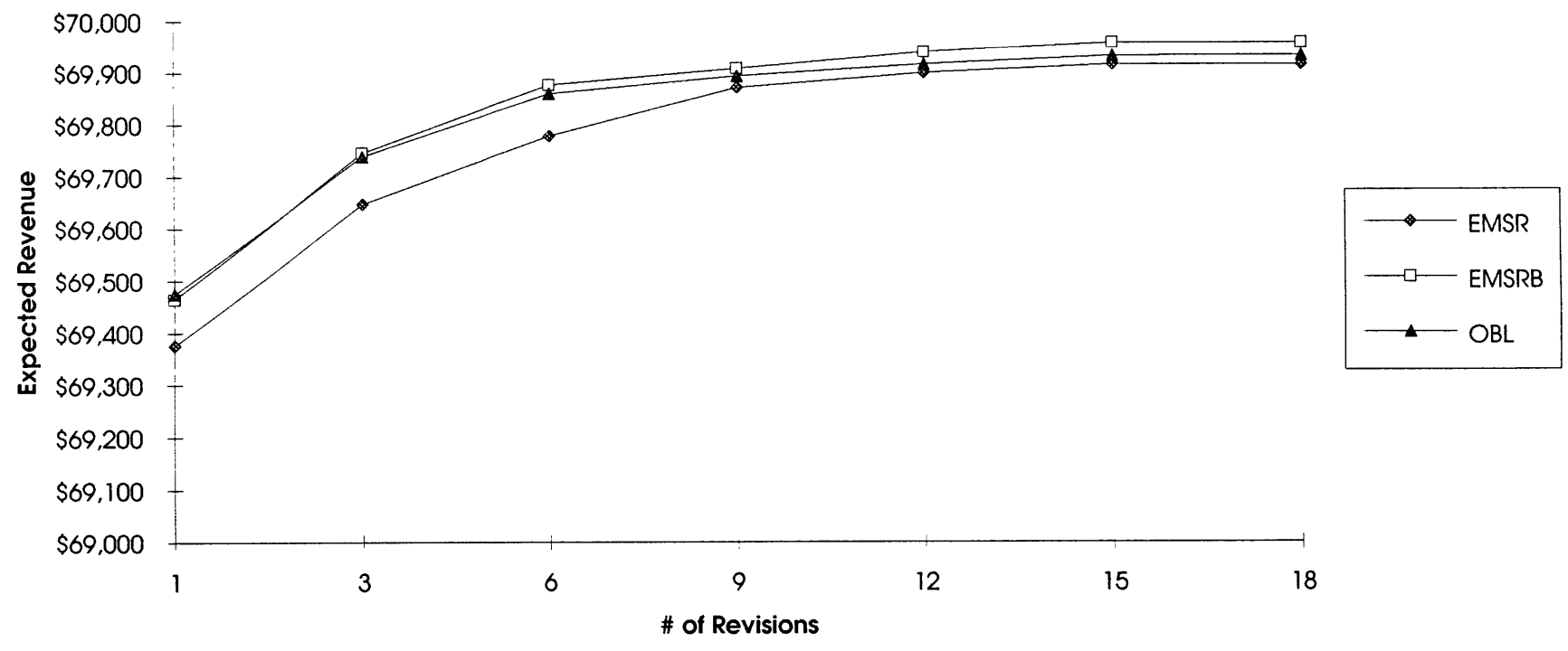# SINGLE FLIGHT LEG - Nested Booking Classes

- Recognized that optimal allocations based on traditional optimization not appropriate:

  - Optimum Booking Limits (OBL) - Curry 1990

  - EMSR and EMSRB Heuristics - Belobaba 1987, 1992

- These nested algorithms assume:

  - all demand arrives in single period

  - lowest class requests are made first, highest class last.

- Both assumptions are violated in real world.

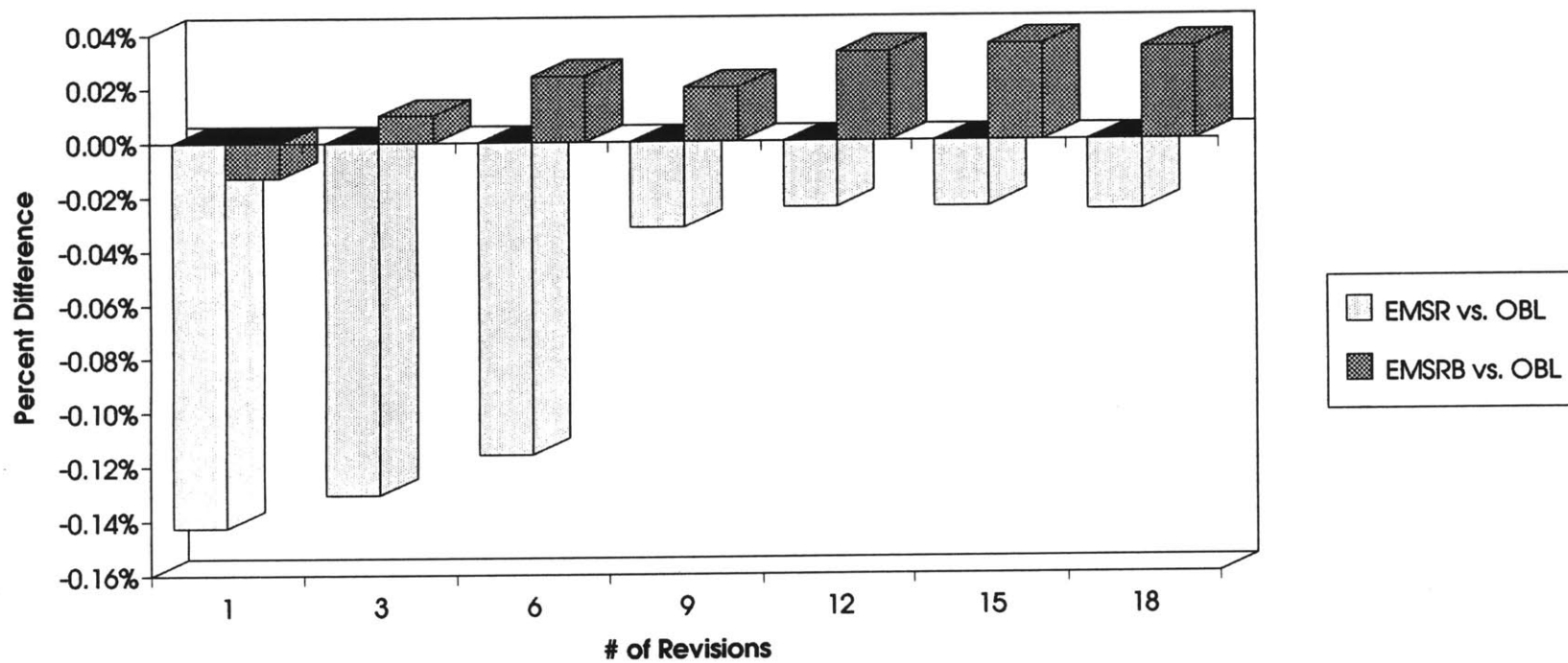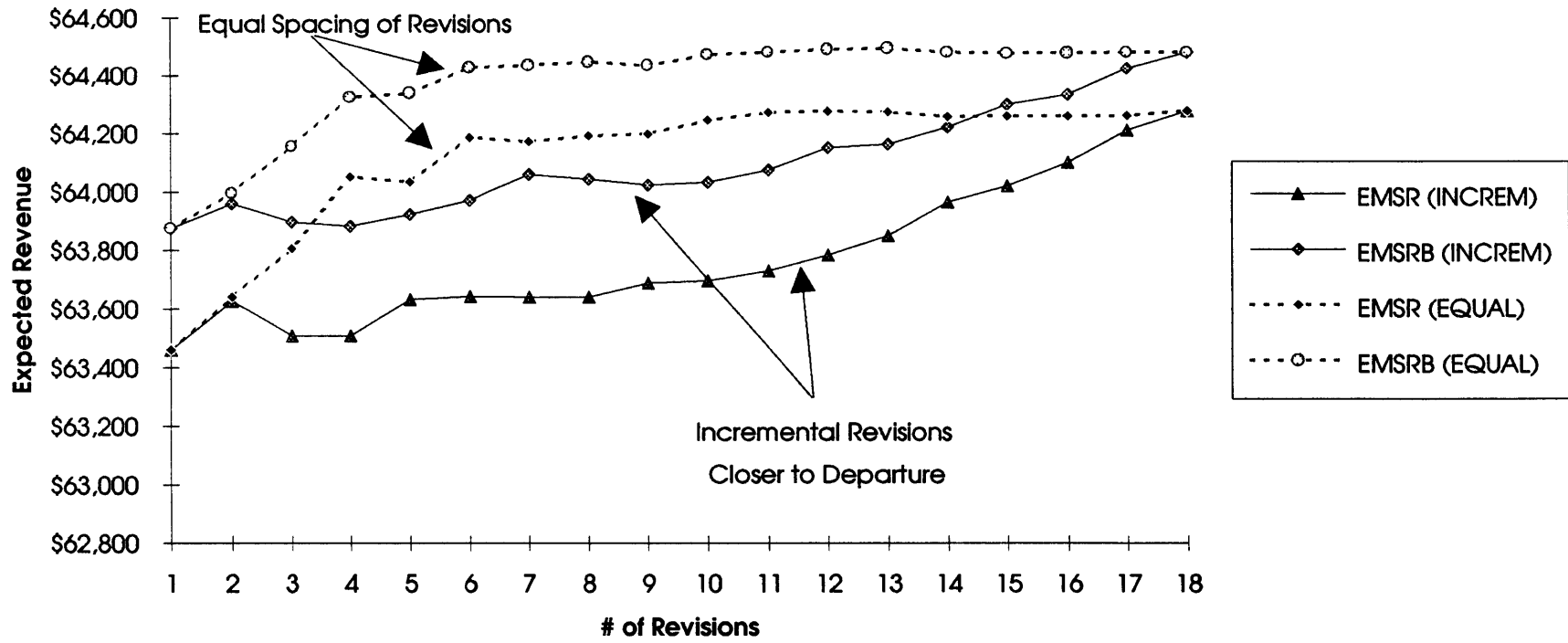# SINGLE FLIGHT LEG: Cumulative Bookings for 18 Periods
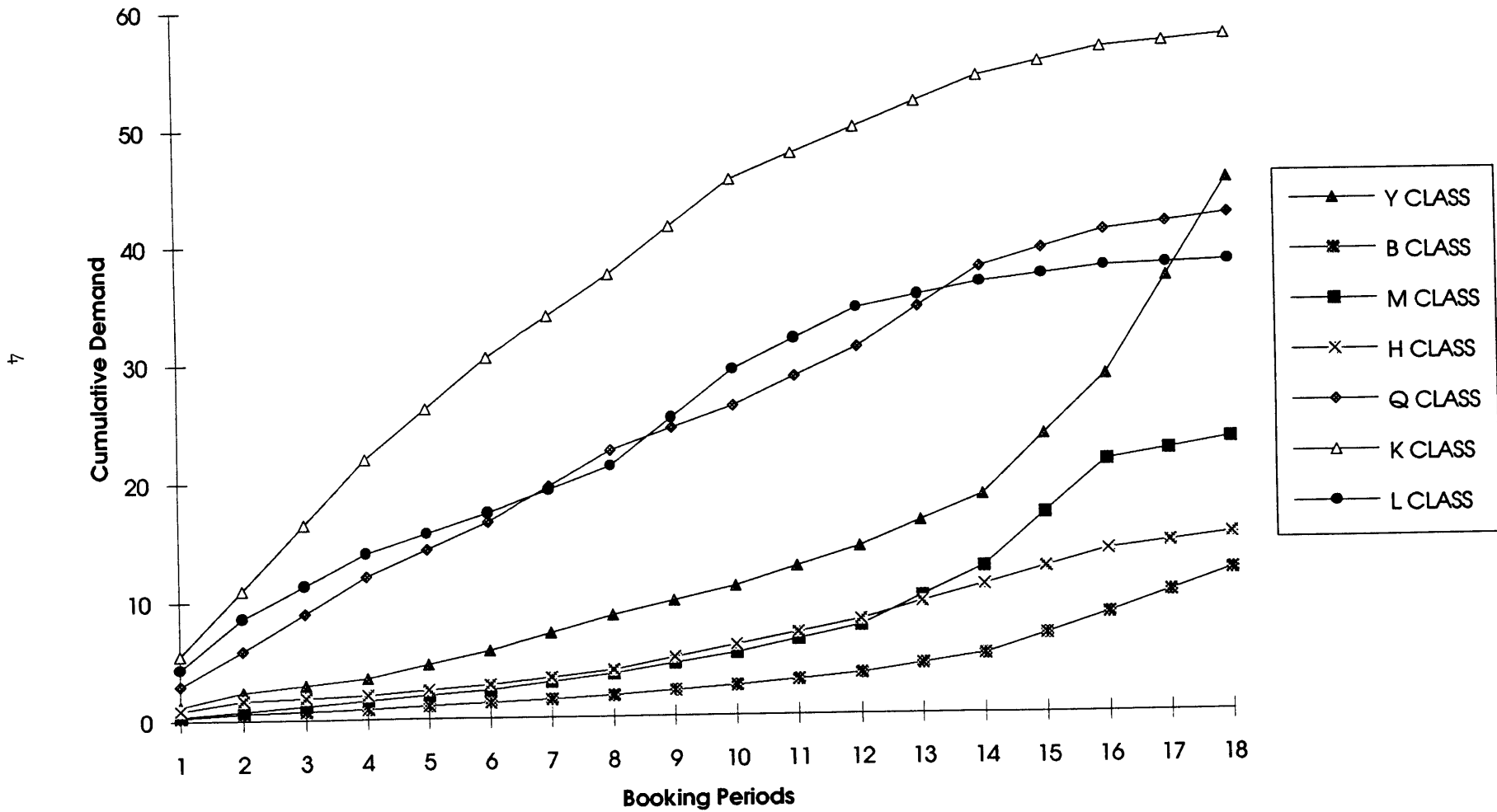
EMSR, EMSRB and OBL

% Difference in Expected Revenue from OBL

Comparison of Revision Patterns

LESSONS FROM SINGLE LEG PROBLEM

- Nested booking classes shown to generate higher expected revenues than partitioned classes.

- Use of nested booking classes led to development of better optimal and heuristic solutions.

- Optimal solution to static nested class problem not guaranteed to outperform heuristics when bookings dynamic & interspersed.

- Number and pattern of revisions has substantial impact on relative revenue enhancement.

MULTIPLE FLIGHT LEGS: "Segment Control"

- Additional revenue potential from controlling by O-D itinerary as well as by booking class over multiple flight legs.

- Most obvious approach is network optimization to determine seat allocations to each itinerary / booking class combination.

- "Optimal" network solutions can lead to negative revenue impacts compared to EMSR nested leg booking class control.

TWO-LEG EXAMPLE: Capacity = 150

CLASS	Segment A-B			Segment A-C			Segment B-C		
	MEAN	STD DEV	FARE	MEAN	STD DEV	FARE	MEAN	STD DEV	FARE
Y	15	8	200	10	6	500	10	6	350
B	10	6	160	15	8	390	20	9	260
H	5	4	125	5	4	305	15	8	200
V	25	10	105	20	9	245	30	11	170
Q	30	11	85	15	8	210	10	6	140
TOTAL	85			65			85		

<u>COMPARISON OF CONTROL METHODOLOGIES</u>

We calculated the relevant booking limits for the following
control methods:

1.   **EMSR Nested Leg-Based Control**

2.   **"Optimal" Probabilistic Segment Allocations**

3.   **Nested Allocations by Segment**

For each methodology, we then simulated a booking
process to estimate loads and revenues.

1. EMSR NESTED LEG-BASED CONTROL

Demands and fares aggregated by leg booking class; limits set by booking class only.

Leg A-B		Leg B-C	
CLASS	LIMIT	CLASS	LIMIT
Y	150	Y	150
B	139	B	135
H	109	H	101
V	95	V	88
Q	50	Q	50

2. OPTIMAL PROBABILISTIC SEGMENT ALLOCATIONS

Probabilistic "network LP" used to find optimal
seat allocation to each segment / fare.

CLASS	SEGMENT A-B LIMITS	SEGMENT A-C LIMITS	SEGMENT B-C LIMITS
Y	21	12	12
B	14	16	23
H	7	4	18
V	27	14	33
Q	29	6	12

3. NESTED ALLOCATIONS BY SEGMENT

Optimal probabilistic seat allocations are nested
within each segment for control purposes.

CLASS	SEGMENT A-B LIMITS	SEGMENT A-C LIMITS	SEGMENT B-C LIMITS
Y	98	52	98
B	77	40	86
H	63	24	63
V	56	20	45
Q	29	6	12

REVENUE IMPACTS: Static Simulation

METHOD	REVENUE	LOAD LEG A - B	LOAD LEG B - C
1. LEG EMSR	$45,447	140.6	140.4
2. SEG. ALLOC.	$40,854	120.3	120.6
3. NESTED / SEG.	$43,294	125.1	127.3

- Leg EMSR outperforms "optimal" segment allocations by 11%.

- Nesting allocations within each segment improves performance, but revenues still 5% below Leg EMSR.

REVENUE IMPACTS: Dynamic Revision

- 16-period simulation shows revenue shortfalls reduced with more frequent re-optimization:

    Segment Allocations : -1.8%

    Nested Seg. Alloc. :   +0.4%

- Even with frequent revisions, however, <u>partitioned</u> allocations in both cases limit revenue enhancement, compared to Leg EMSR.

- <u>Nesting</u> of segment (itinerary) limits is essential to improve revenue impacts.

LEG-BASED SEGMENT CONTROL HEURISTICS

- Use existing booking class demand data by flight leg (no itinerary/class forecasts).

- Derive expected marginal seat revenue (EMSR) curve for each flight leg based on booking class demand and revenues.
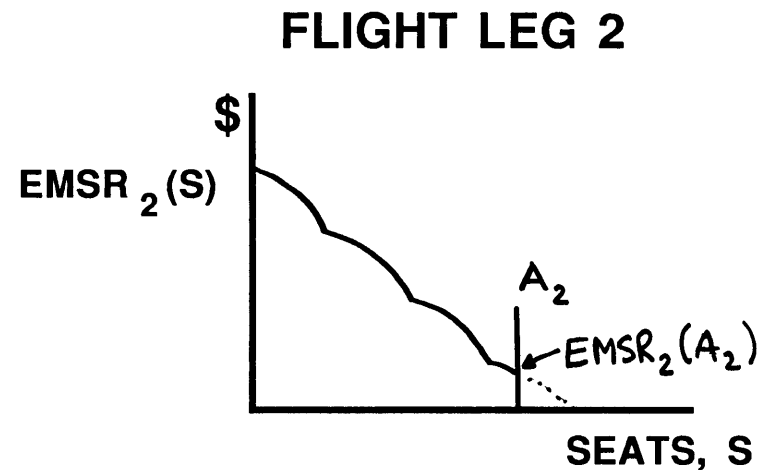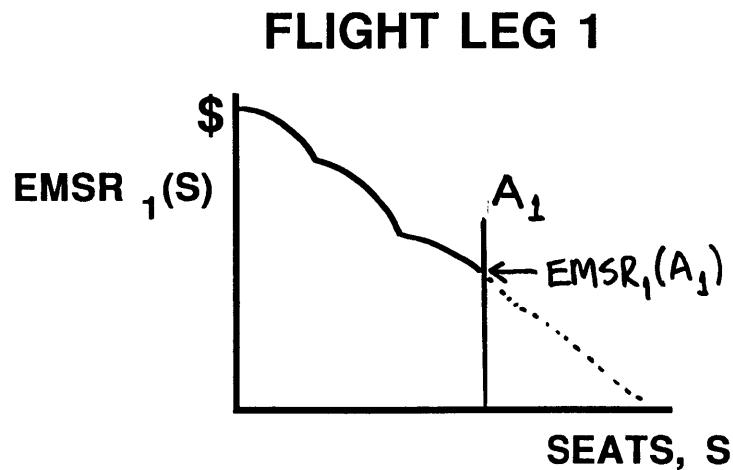
SINGLE FLIGHT LEG DEPARTURE

1. EMSR Segment Bidprice Heuristic

- Accept request for itinerary i, class k if:

$$F_{ik} \geq \sum_{\ell \in i} EMSR_{\ell}(A_{\ell})$$

where F_{ik} =   Total fare, itinerary i, class k

A_{ℓ} =   Seats available on leg l.
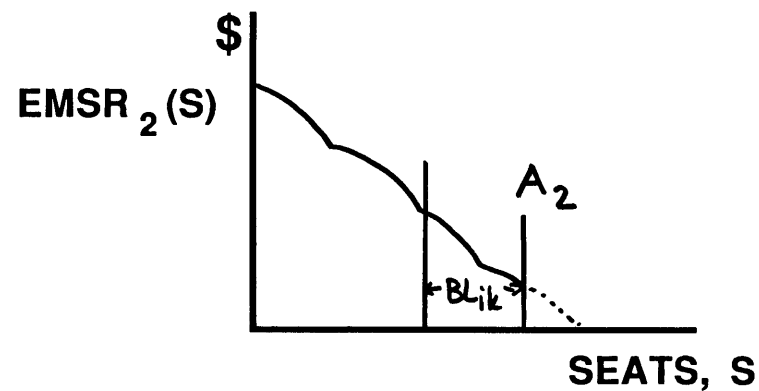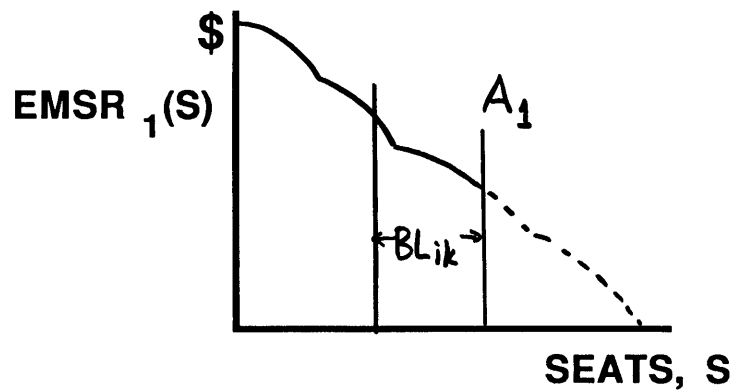

FLIGHT LEG 1

FLIGHT LEG 2

2.   EMSR Segment Limit Heuristic

- Determine nested booking limits for each (i, k):

$$BL_{ik} = \left[\text{Max } S \mid F_{ik} \geq \sum_{\ell \in i} EMSR_\ell (A_\ell - S) \right]$$
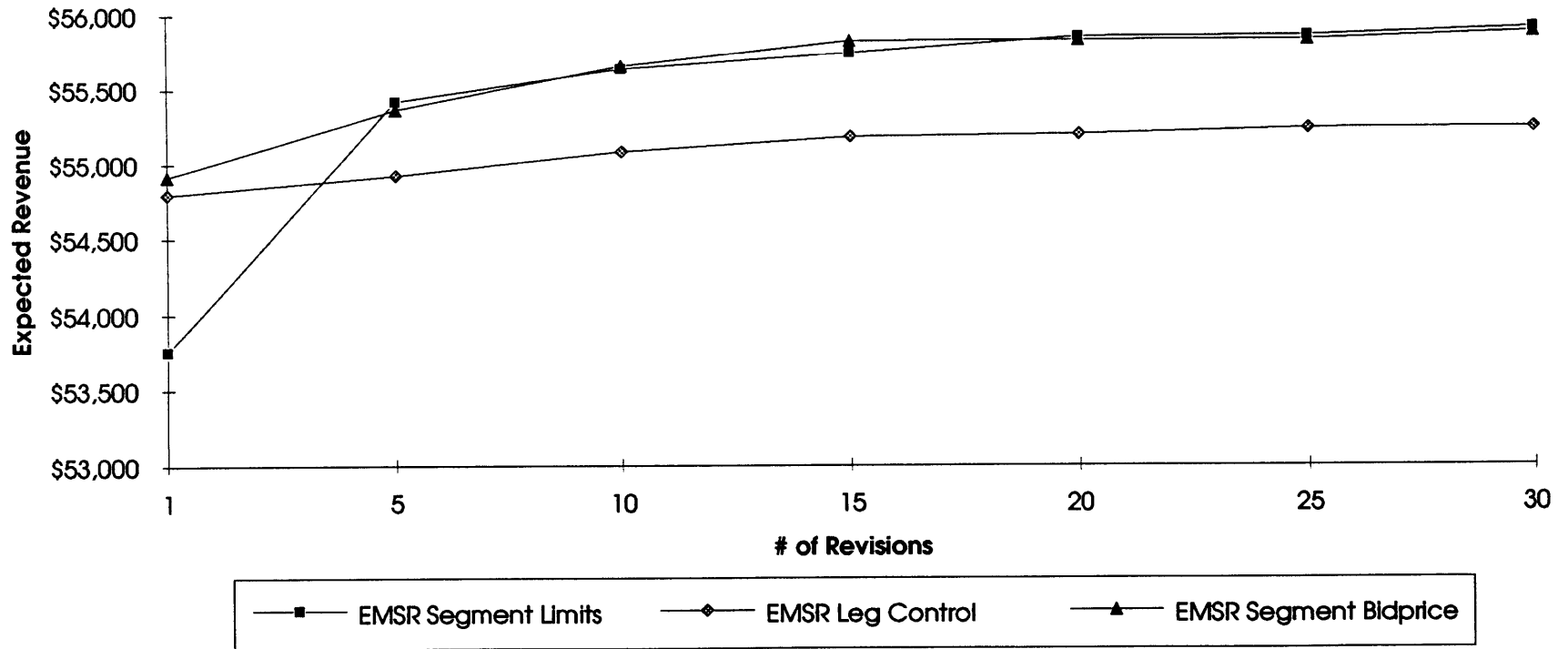
SIMULATION: Leg-Based Segment Control Heuristics

* 4 multi-leg flights; 30 booking periods

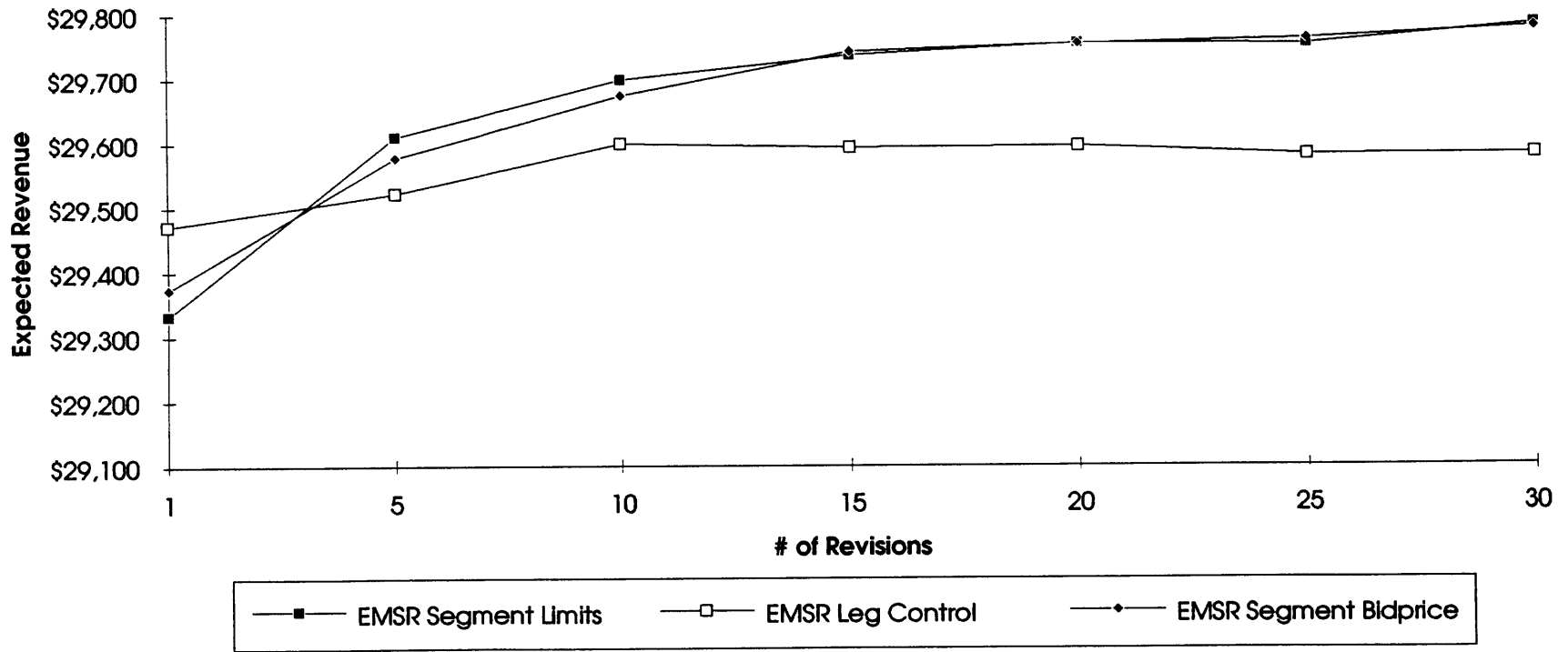|	# Legs	# Classes	# ODs	ALF(s)
Flight #1	3	4	6	0.94
Flight #2	2	4	3	0.76
Flight #3	4	4	10	0.84
Flight #4	3	4	6	0.88

* Compared revenue impacts of
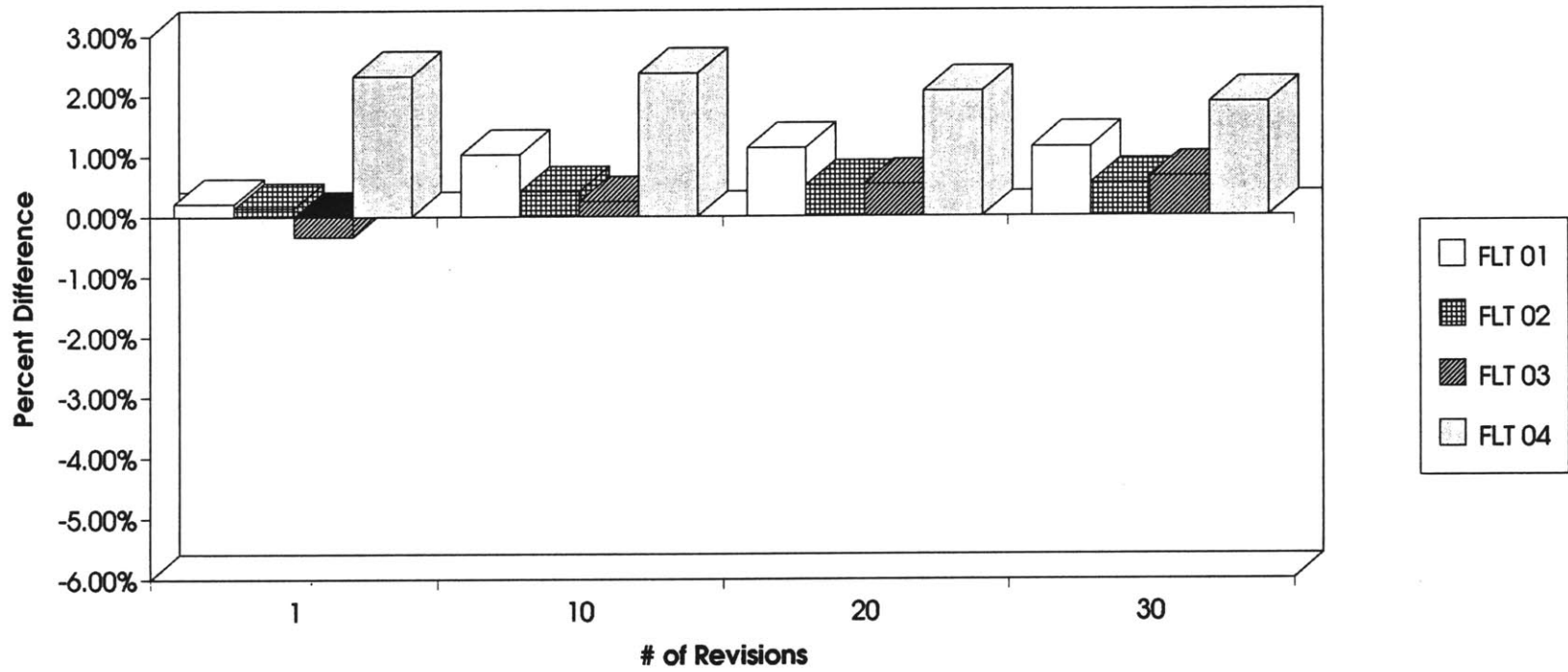- EMSR Leg Control
- EMSR Segment Bidprice
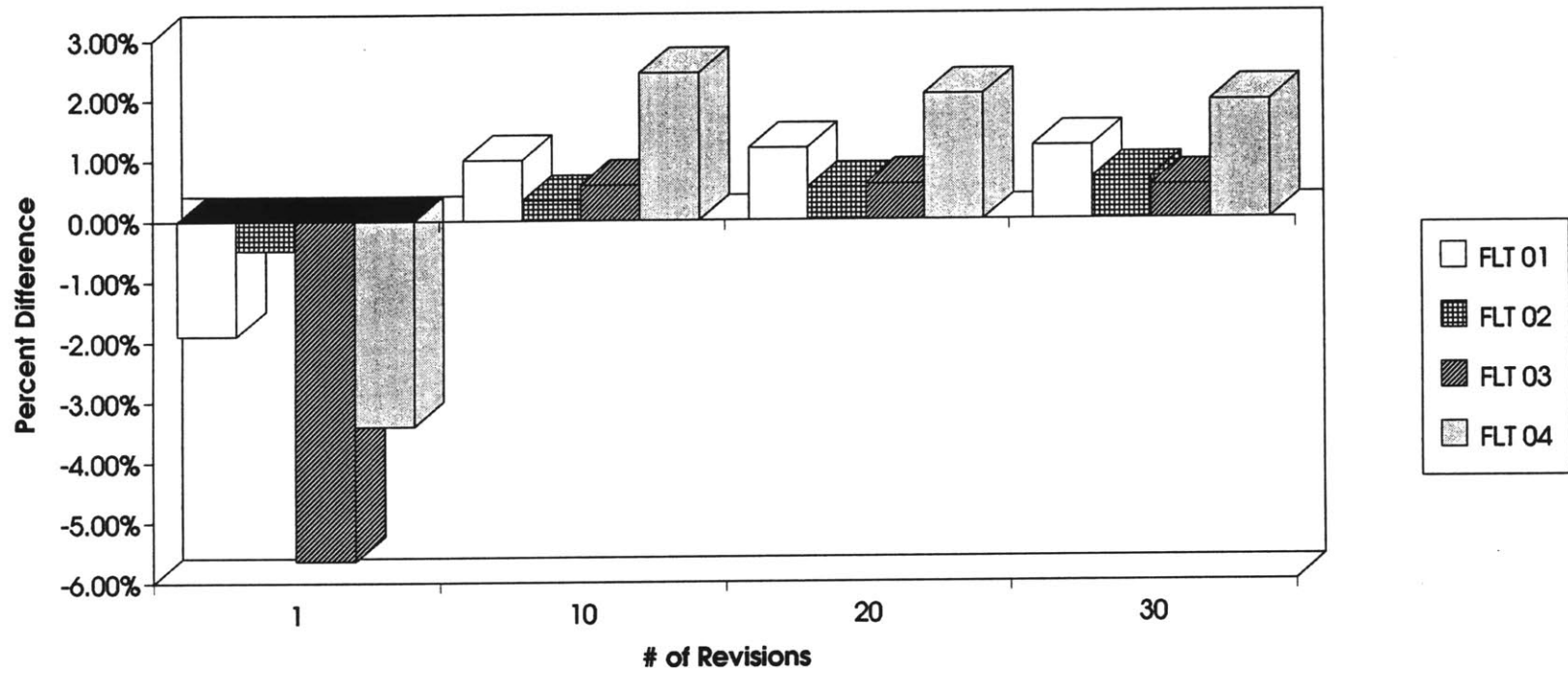- EMSR Segment Limits

FLIGHT #01

FLIGHT #02

EMSR SEGMENT BIDPRICE VS. EMSR LEG CONTROL

EMSR SEGMENT LIMTS VS. EMSR LEG CONTROL

LESSONS FROM MULTI-LEG PROBLEM

- Simple leg-based heuristics can outperform network optimization approaches:

  - Match control capabilities better
  - don't need itinerary/class data
  - can be implemented easily

- Segment control lessons provide insight and direction for larger-scale O-D control of connecting hub network.

- To be continued: ORSA Phoenix, Oct. 1993.

SUMMARY

- Optimization model is only 1 component of revenue enhancement through seat inventory control:

    - data availability/forecasting issues
    - control capabilities of CRS
    - number and pattern of updates

- Use of many "optimal" solutions either impractical or undesirable.

- Relevant performance measure is revenue impact compared to current leg booking class control.

Airline Price Elasticity Estimation

Presentation to MIT/Industry
Cooperative Research Program
Prepared by Theodore C. Botimer
MIT Flight Transportation Laboratory
May 20, 1993

Price Elasticity Analysis

Objective

- Develop a method to measure the sensitivity of travelers to changes in fare level

Definitions

- Price elasticity of demand
  The % change in demand induced by a 1% increase in price level

- Own price elasticity of demand
  The % change in demand induced in a product by a 1% increase in its own price

- Cross price elasticity of demand
  The % change in demand induced in a product by a 1% increase in the price of another product

Calculation of price elasticity

$$\text{Price Elasticity} = \frac{\% \, \Delta \, \text{Demand}}{\% \, \Delta \, \text{Price Level}}$$

Properties of Price Elasticity (PE) Measures

- Air transportation is a "normal good"

- Minimum absolute value of 0

- Inelastic range of PE [0 , 1)

- Unit elastic product has PE value of 1

- Elastic range of PE (1 , ∞]

- For a price increase :

     * Revenue decreases in elastic range
     * Revenue does not change for unit elastic
     * Revenue increases in inelastic range

Level of Detail of Analysis

- Fare product/ fare class level desired

- Carrier level desired

- Data constraints prevent this

- Look at overall OD market elasticity

- Look at single price level for OD market

- Treat models as unimodal

Methods Available for Analysis

- **Direct calculation of price elasticity**

  - **Point Price Elasticity**

  - **Arc Price Elasticity**

- **Indirect calculation of price elasticity**
  - using an aggregate demand model

$$T_{ij} = \alpha \prod_{k=1}^{K} S_{ijk}^{\beta_k} \prod_{n=1}^{N} L_{ij}^{\gamma_n} P_{ij}^{\delta}$$

where
  i and j are the origin and destination city, respectively
  T is the traffic level in the OD Market
  P is the average air travel price level in the OD market
  L are each of the N OD market level of service measures
  S are each of K socioeconomic trait measures in i and j
  α, β, γ, δ are OD market specific parameters

Available Variables for the Analysis

- Demand Measures
    - -- Revenue passenger miles (RPMs)
    - -- Passengers

- Difficulties
    - - Traffic growth trend
    - - Variability of demand
    - - Seasonal differences in demand
    - - Structural changes in demand

- Price Level Measures
    - -- Average fare (AF)
    - -- Weighted average of "selling fares"

- Difficulties
    - - Inflation
    - - Growth in wages
    - - Volatility of fare levels

Point Price Elasticity Measurements

For any demand function $Q = Q(P)$:

$$E_{p,q} = \frac{dQ}{dP} * \frac{P}{Q}$$

Actual calculation :

$$\text{Point Price Elasticity} = \frac{\% \, \Delta \, \text{Pax}}{\% \, \Delta \, \text{Rev/Pax}} = \frac{\left(\dfrac{\text{Pax}_{1992:1} - \text{Pax}_{1991:1}}{\text{Pax}_{1991:1}} \right)}{\left(\dfrac{\text{Rev/Pax}_{1992:1} - \text{Rev/Pax}_{1991:1}}{\text{Rev/Pax}_{1991:1}} \right)}$$

Valid for infinitessimally small intervals of ΔP :

$$\frac{dQ}{dP} = \lim \frac{Q(P + \Delta P) - Q(P)}{\Delta P} \quad \text{as} \quad \Delta P \to 0$$

Problems :

High variability in P makes :
- small ΔP unlikely
- information from small ΔP values questionable

Arc Price Elasticity Measurements

Three references commonly used :

1) Midpoints method (avg price, avg quantity)

2) Final quantity, initial price

3) Final quantity, final price

Arc elasticity measures the secant between the two points on a demand function

Small values of ΔP are preferable but not strictly required as with the point elasticity estimates

Arc Price Elasticity Measurements

Midpoints method :

$$\text{Arc Price Elasticity} = \left(\frac{\Delta \text{Pax}}{\Delta \text{Rev}/\text{Pax}}\right)\left(\frac{\frac{1}{2}(\text{Rev}/\text{Pax}_{1992:1} + \text{Rev}/\text{Pax}_{1991:1})}{\frac{1}{2}(\text{Pax}_{1992:1} + \text{Pax}_{1991:1})}\right)$$

or

$$\text{Arc Price Elasticity} = \left(\frac{\Delta \text{Pax}}{\Delta \text{Rev}/\text{Pax}}\right)\left(\frac{\text{Rev}/\text{Pax}_{1992:1} + \text{Rev}/\text{Pax}_{1991:1}}{\text{Pax}_{1992:1} + \text{Pax}_{1991:1}}\right)$$

Arc elasticity with initial price and final quantity :

$$E_{q,p} = \frac{\Delta Q * P_1}{\Delta P * Q_2} = \frac{R_{\Delta q}}{R_{\Delta p}}$$

Arc elasticity with final price and final quantity :

- Same as point elasticity calculation
- Systematically over or underpredicts value

Indirect Price Elasticity Measurements

$$T_{ij} = \alpha \prod_{k=1}^{K} S_{ijk}^{\beta_k} \prod_{n=1}^{N} L_{ij}^{\gamma_n} P_{ij}^{\delta}$$

where
    i and j are the origin and destination city, respectively
    T is the traffic level in the OD Market
    P is the average air travel price level in the OD market
    L are each of the N OD market level of service measures
    S are each of K socioeconomic trait measures in i and j
    $\alpha, \beta, \gamma, \delta$ are OD market specific parameters

Logrithmic transformation :

$$\ln T_{ij} = \ln \alpha + \sum_{k=1}^{K} \beta_k \ln S_{ijk} + \sum_{n=1}^{N} \gamma_n \ln L_{ij} + \delta \ln P_{ij}$$

Simple model :

$$\ln T_{ij} = \ln \alpha + \gamma \ln L_{ij} + \delta \ln P_{ij}$$

where
    i and j are the origin and destination city, respectively
    T is the traffic level in the OD Market
    P is the average air travel price level in the OD Market
    L is a measure of frequency in the OD Market
    α, γ, δ are OD market specific parameters

Empirical Direct Price Elasticity Measurements

The OD markets analyzed were:

1) ATL-BOS
2) ATL-SEA
3) ATL-STL
4) BOS-PHX
5) CLT-MSY
6) DFW-PHL
7) JAN-SDF
8) MSP-SAN
9) SAV-SAN

The data used were collected from the DOT 10% coupon sample data over the period 1985:1-1990:4

Data were taken quarterly (most disaggregate level)

Price level was measured in average revenue per passenger (Rev/Pax)

Demand measured in coupon mileage (CPM $\approx$ RPM)

Percentage changes calculated at yearly intervals to overcome systematic seasonal variations

Direct Price Elasticity Measurements (con't)

Rev/Pax were adjusted for inflation using the consumer price index (CPI) with 1985 as a reference :

$$(Rev/Pax)_{adj} = (Rev/Pax)_{raw}/CPI$$

CPM Growth Trend Correction Procedure :

1) Calculate seasonal indices for CPM for Q1, Q2, Q3, and Q4

2) Deseasonalize CPM

3) Calculate a linear growth trend for deseasonalized CPM

4) Detrend CPM using calculated growth trend:

$$CPM_{detrend} = CPM_{raw}/(growth\ trend)$$

ATL-BOS
Quarterly PE
Midpoints Method

Year: Quarter	Percent Price Change Adjusted	Percent CPM Change Detrended	OD Market Price Elasticity	Corrected Market Price Elasticity
86:1	−30.30	12.23	−0.40	−0.40
86:2	−17.03	3.87	−0.23	−0.23
86:3	−7.96	−9.62	1.21	−3.00
86:4	−1.51	−1.09	0.72	−3.00
87:1	1.03	−10.46	−10.13	−3.00
87:2	−8.16	−2.74	0.34	−3.00
87:3	−6.43	21.03	−3.27	−3.00
87:4	0.85	−0.60	−0.71	−0.71
88:1	11.43	4.59	0.40	0.00
88:2	15.50	16.71	1.08	0.00
88:3	9.82	15.55	1.58	0.00
88:4	8.68	−5.39	−0.62	−0.62
89:1	4.60	−13.47	−2.93	−2.93
89:2	1.51	−21.70	−14.41	−3.00
89:3	−5.08	−27.42	5.40	−3.00
89:4	−9.62	6.50	−0.68	−0.68
90:1	−12.18	15.86	−1.30	−1.30
90:2	−8.96	8.03	−0.90	−0.90
90:3	−2.39	2.05	−0.86	−0.86
90:4	−4.36	−7.04	1.62	−3.00

ATL-SEA
Quarterly PE
Midpoints Method

Year: Quarter	Percent Price Change Adjusted	Percent CPM Change Detrended	OD Market Price Elasticity	Corrected Market Price Elasticity
86:1	-40.94	11.03	-0.27	-0.27
86:2	-11.30	3.06	-0.27	-0.27
86:3	-11.41	0.53	-0.05	-0.05
86:4	-8.88	-8.77	0.99	-3.00
87:1	1.46	-9.53	-6.52	-3.00
87:2	-9.93	7.05	-0.71	-0.71
87:3	0.21	-1.21	-5.68	-3.00
87:4	-0.71	-14.02	19.79	-3.00
88:1	1.43	-7.48	-5.24	-3.00
88:2	3.62	-4.72	-1.30	-1.30
88:3	7.31	-0.70	-0.10	-0.10
88:4	10.08	-4.65	-0.46	-0.46
89:1	15.13	-20.83	-1.38	-1.38
89:2	8.38	-7.70	-0.92	-0.92
89:3	-15.98	12.47	-0.78	-0.78
89:4	-18.23	42.23	-2.32	-2.32
90:1	-11.24	38.53	-3.43	-3.00
90:2	-1.94	5.07	-2.62	-2.62
90:3	7.52	-5.21	-0.69	-0.69
90:4	9.78	-37.60	-3.85	-3.00

ATL-STL
Quarterly PE
Midpoints Method

Year: Quarter	Percent Price Change Adjusted	Percent CPM Change Detrended	OD Market Price Elasticity	Corrected Market Price Elasticity
86:1	-16.12	2.05	-0.13	-0.13
86:2	3.77	0.31	0.08	0.00
86:3	-3.61	-6.12	1.70	-3.00
86:4	3.31	4.22	1.28	0.00
87:1	10.72	8.11	0.76	0.00
87:2	-1.26	6.39	-5.07	-3.00
87:3	3.59	18.25	5.08	0.00
87:4	2.05	8.69	4.23	0.00
88:1	6.06	-1.17	-0.19	-0.19
88:2	13.20	-7.06	-0.53	-0.53
88:3	7.09	2.62	0.37	0.00
88:4	0.39	-15.03	-38.85	-3.00
89:1	9.87	-14.14	-1.43	-1.43
89:2	8.04	-20.71	-2.58	-2.58
89:3	-4.34	-19.07	4.39	-3.00
89:4	-3.95	12.15	-3.07	-3.00
90:1	-21.31	20.56	-0.96	-0.96
90:2	-25.65	26.88	-1.05	-1.05
90:3	-4.11	5.24	-1.28	-1.28
90:4	6.20	-14.41	-2.32	-2.32

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BOS-PHX
Quarterly PE
Midpoints Method

Year: Quarter	Percent Price Change Adjusted	Percent CPM Change Detrended	OD Market Price Elasticity	Corrected Market Price Elasticity
86:1	-16.88	-13.29	0.79	-3.00
86:2	-6.08	-22.57	3.71	-3.00
86:3	-13.75	-10.62	0.77	-3.00
86:4	-17.14	11.40	-0.66	-0.66
87:1	-8.17	0.94	-0.11	-0.11
87:2	-13.17	9.31	-0.71	-0.71
87:3	-11.30	19.04	-1.68	-1.68
87:4	-8.36	9.62	-1.15	-1.15
88:1	-7.30	9.85	-1.35	-1.35
88:2	-0.20	3.82	-18.89	-3.00
88:3	2.51	3.09	1.23	0.00
88:4	6.06	-0.38	-0.06	-0.06
89:1	8.19	-8.74	-1.07	-1.07
89:2	-7.14	12.65	-1.77	-1.77
89:3	-14.35	-14.08	0.98	-3.00
89:4	-4.07	-13.86	3.40	-3.00
90:1	0.88	13.16	14.96	0.00
90:2	14.99	-15.28	-1.02	-1.02
90:3	20.73	-4.47	-0.22	-0.22
90:4	16.88	-2.68	-0.16	-0.16

CLT-MSY
Quarterly PE
Midpoints Method

Year: Quarter	Percent Price Change Adjusted	Percent CPM Change Detrended	OD Market Price Elasticity	Corrected Market Price Elasticity
86:1	-19.08	-0.12	0.01	-3.00
86:2	-7.35	-15.44	2.10	-3.00
86:3	-6.17	-10.33	1.67	-3.00
86:4	-4.80	-15.15	3.15	-3.00
87:1	-11.23	14.52	-1.29	-1.29
87:2	-8.43	27.80	-3.30	-3.00
87:3	-13.30	32.54	-2.45	-2.45
87:4	-13.56	14.11	-1.04	-1.04
88:1	11.20	-13.33	-1.19	-1.19
88:2	18.39	-14.06	-0.76	-0.76
88:3	17.52	-12.54	-0.72	-0.72
88:4	14.67	-14.31	-0.98	-0.98
89:1	9.72	-16.30	-1.68	-1.68
89:2	-3.26	3.96	-1.21	-1.21
89:3	-15.77	13.02	-0.83	-0.83
89:4	-7.48	23.43	-3.13	-3.00
90:1	-4.93	3.87	-0.78	-0.78
90:2	-4.09	5.80	-1.42	-1.42
90:3	-1.56	-18.89	12.08	-3.00
90:4	-5.04	-31.43	6.23	-3.00

DFW-PHL
Quarterly PE
Midpoints Method

Year: Quarter	Percent Price Change Adjusted	Percent CPM Change Detrended	OD Market Price Elasticity	Corrected Market Price Elasticity
86:1	-5.14	-26.46	5.15	-3.00
86:2	-5.65	-6.65	1.18	-3.00
86:3	-15.19	-8.28	0.54	-3.00
86:4	1.18	7.34	6.24	0.00
87:1	0.85	9.26	10.90	0.00
87:2	4.79	-6.73	-1.41	-1.41
87:3	15.54	2.98	0.19	0.00
87:4	6.75	11.39	1.69	0.00
88:1	7.02	-2.13	-0.30	-0.30
88:2	10.38	-3.22	-0.31	-0.31
88:3	7.60	-19.76	-2.60	-2.60
88:4	8.32	-1.60	-0.19	-0.19
89:1	6.28	-13.05	-2.08	-2.08
89:2	-1.85	-1.27	0.69	-3.00
89:3	-13.28	26.05	-1.96	-1.96
89:4	-7.08	4.14	-0.58	-0.58
90:1	3.34	25.93	7.76	0.00
90:2	0.64	14.66	22.94	0.00
90:3	1.45	2.81	1.94	0.00
90:4	-5.84	-9.30	1.59	-3.00

JAN-SDF
Quarterly PE
Midpoints Method

Year: Quarter	Percent Price Change Adjusted	Percent CPM Change Detrended	OD Market Price Elasticity	Corrected Market Price Elasticity
86:1	-24.75	2.10	-0.08	-0.08
86:2	-17.24	26.47	-1.53	-1.53
86:3	-10.26	20.54	-2.00	-2.00
86:4	-6.80	-1.02	0.15	-3.00
87:1	-16.84	26.33	-1.56	-1.56
87:2	-18.78	13.80	-0.73	-0.73
87:3	-22.76	15.66	-0.69	-0.69
87:4	-17.18	20.73	-1.21	-1.21
88:1	15.90	-12.13	-0.76	-0.76
88:2	13.39	-16.96	-1.27	-1.27
88:3	12.96	-20.90	-1.61	-1.61
88:4	16.46	16.93	1.03	0.00
89:1	12.16	-23.29	-1.92	-1.92
89:2	6.73	-55.29	-8.21	-3.00
89:3	7.55	11.72	1.55	0.00
89:4	11.49	-31.31	-2.73	-2.73
90:1	-10.78	28.79	-2.67	-2.67
90:2	-3.83	49.61	-12.95	-3.00
90:3	-10.34	-31.64	3.06	-3.00
90:4	-9.44	-3.62	0.38	-3.00

MSP–SAN
Quarterly PE
Midpoints Method

Year: Quarter	Percent Price Change Adjusted	Percent CPM Change Detrended	OD Market Price Elasticity	Corrected Market Price Elasticity
86:1	-34.57	16.83	-0.49	-0.49
86:2	-31.88	26.32	-0.83	-0.83
86:3	-26.40	33.19	-1.26	-1.26
86:4	-4.11	13.68	-3.33	-3.00
87:1	25.00	-28.91	-1.16	-1.16
87:2	26.88	-33.05	-1.23	-1.23
87:3	9.58	-27.38	-2.86	-2.86
87:4	6.43	-20.07	-3.12	-3.00
88:1	-6.36	0.45	-0.07	-0.07
88:2	-5.68	11.94	-2.10	-2.10
88:3	7.82	8.00	1.02	0.00
88:4	-8.09	25.61	-3.17	-3.00
89:1	11.53	10.18	0.88	0.00
89:2	10.58	0.89	0.08	0.00
89:3	-1.44	10.00	-6.95	-3.00
89:4	-1.30	3.81	-2.92	-2.92
90:1	-4.49	-10.72	2.39	-3.00
90:2	0.83	-8.63	-10.35	-3.00
90:3	0.11	-6.04	-57.25	-3.00
90:4	-19.16	-2.25	0.12	-3.00

SAV-SAN
Quarterly PE
Midpoints Method

Year: Quarter	Percent Price Change Adjusted	Percent CPM Change Detrended	OD Market Price Elasticity	Corrected Market Price Elasticity
86:1	-43.71	-21.08	0.48	-3.00
86:2	3.70	7.87	2.13	0.00
86:3	2.35	0.56	0.24	0.00
86:4	-5.96	27.20	-4.56	-3.00
87:1	-0.99	6.45	-6.51	-3.00
87:2	-25.63	-7.01	0.27	-3.00
87:3	-6.71	61.16	-9.12	-3.00
87:4	-11.37	1.45	-0.13	-0.13
88:1	11.65	-30.31	-2.60	-2.60
88:2	8.94	40.09	4.49	0.00
88:3	0.50	-36.96	-73.77	-3.00
88:4	25.44	-14.61	-0.57	-0.57
89:1	10.10	-20.82	-2.06	-2.06
89:2	13.29	-9.47	-0.71	-0.71
89:3	-16.12	-17.11	1.06	-3.00
89:4	-18.53	15.95	-0.86	-0.86
90:1	4.96	62.56	12.60	0.00
90:2	-14.98	-9.95	0.66	-3.00
90:3	0.22	9.11	40.90	0.00
90:4	-0.14	-71.04	498.18	-3.00

Assessment of the Potential Diversion of Air Passengers to High-Speed Rail in the NE Corridor

A Survey of Boston/New York Air Shuttle Passengers

Michael Clarke

MIT Flight Transportation Laboratory
Annual Meeting
Marlor Lounge 37-252
May 20, 1993

Introduction

- Current ATC problems

- Heavy air traffic demand in the Northeast Corridor

- Current Rail Service between Boston and New York
  - Duration (approximately four hours)
  - Distance 231 miles

- Technical Limitations
  - Curvature of tracks
  - Electrification
  - Utilization of High Speed Rail

Motivation

- In 1990, the Northeast corridor accounted for 50% of Amtrak's total passenger traffic and one third of its operating revenue

- High Speed Rail service between NY and DC has demonstrated that it can compete effectively with air service

- Amtrak is currently studying the Swedish built X-2000 tilt train, capable of speeds in excess of 150 mph for Bos-NY

- Introduction of High Speed "Tilt" Rail in the Boston-New York market could help alleviate ATC and other related problems

Motivation

- Proven technology exists for the such a project

- Use of high speed tilt trains would reduce travel time between city centers to less than three hours

- High Speed Project would require intensive capital investment for land acquisition and right of way construction

- Project focuses primarily of anticipated ridership, generated primarily from diversion of air shuttle passengers

Market Study of Modal Split
(Business trips)

% of trips

Air distance (km)
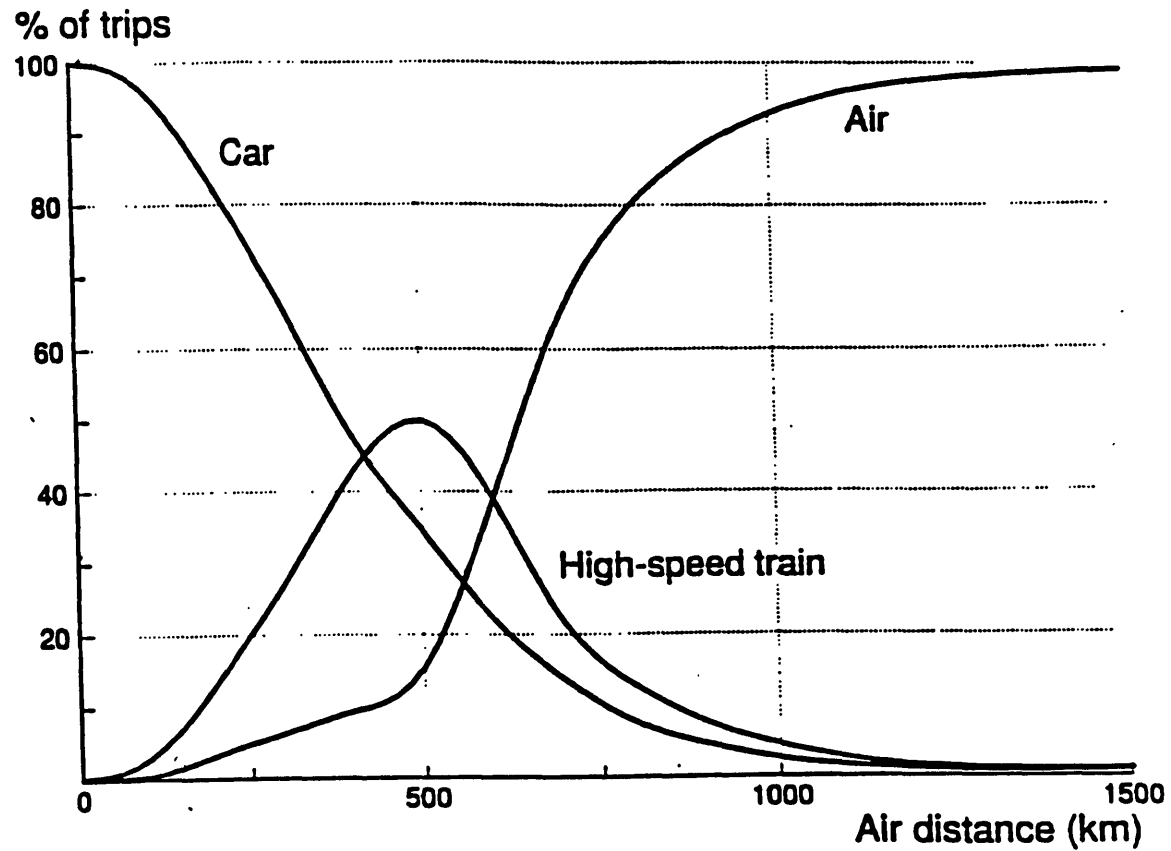
Survey Method

Design of Survey

- Air shuttle survey is based on the 1987 Washington-Baltimore regional air passenger survey conducted by the Maryland Department of Transportation

- Survey was designed to provide current user characteristics for air shuttle passengers departing from Boston Logan

Data Collection/Survey

- Survey will be conducted on a MacIntosh Powerbook 145

- Data entry automatically from survey responses

- Survey will be conducted May through September 1993

Survey Questions

- Place of residence
  - zip code/location

- Local access trip
  - point of origin (zip code)
  - time of departure from point of origin
  - time of arrival at Boston Logan

- Purpose of travel

- Planned egress trip
  - final destination (zip code)
  - location of final destination (borough in NY city)
  - estimated travel time between airport and final destination

Survey Questions

- Return trip (Boston resident)
  - point of origin (zip code)
  - estimated travel time between origin and airport
  - cost of travel including ground access

- Initial trip (New York resident)
  - point of origin (zip code)
  - actual travel time between origin and La Guardia airport
  - cost of travel including ground access

- Existing rail service
  - attractiveness
  - characteristics

Survey Questions

- High speed rail option
  - frequency of service
  - cost of service
  - on-board amenities

- Passenger Demographics
  - number of annual air shuttle trips
  - type of traveler (business vs. leisure)
  - gender
  - age group
  - household income

Important Issues

- Effects of **Revealed Preferences** on survey responses
    - determine factors affecting current travel decisions

- **Stated Preferences**
    - determine factors affecting future travel decisions (including high speed rail service)

- **Diversion** from existing air shuttles to high speed rail
    - frequency of service
    - relative fares
    - time of travel
    - amenities on new rail service

- Value of access/egress time

Summary

- Prospective deployment of tilt train technology in the US presents a number of technical challenges that must be met as a condition for success

- In addition, the profitability of the new service will depend on the costs of implementation, and the level of operating revenue attainable by the train service

- The introduction of high speed rail in the Boston - New York market could present a viable alternative to the current air shuttle services.

- The share shift that air shuttle traffic will experience will depend on the attractiveness of the rail service, and its overall feasibility

MIT/INDUSTRY COOPERATIVE RESEARCH PROGRAM IN AIR TRANSPORTATION

Annual Meeting

AIRPORT MARKET SHARE MODELING FOR MULTI-AIRPORT SYSTEMS

by François Cohas

PLAN OF THE PRESENTATION

I. MULTI-AIRPORT SYSTEMS (MAS)
1 Definition
2 Why studying MASs ?
3 What is our objective ?

II. BACKGROUND
1 Two characteristics
   A worldwide phenomenon
   Existence of an air traffic threshold
2 Choice of an airport
   By an airline
   By an air traveler

III. MOTIVATION FOR THE RESEARCH
1 Do MASs function well ?
2 An example
3 Volatility of traffic

IV. THE AIRPORT MARKET SHARE MODEL
1 Explanatory variables
2 Prevailing methodologies
3 Non linear relationships
4 The airport market share model
5 Equivalent frequency of service

V. CASE STUDIES

VI. ANALYSIS
1 Analysis of the results
2 Limitations of the model
3 Implications

A Multi-Airport System is a group of two or more major commercial airports in the same metropolitan region

Examples:

In the U.S.
- NEW YORK (KENNEDY, LAGUARDIA, NEWARK)
- CHICAGO (O'HARE, MIDWAY)
- SAN FRANCISCO (SAN FRANCISCO, OAKLAND, SAN JOSE)
- WASHINGTON (DULLES, NATIONAL, BALTIMORE)

In EUROPE
- LONDON (HEATHROW, GATWICK, STANSTED, LUTON)
- PARIS (CHARLES DE GAULLE, ORLY)

In ASIA
- TOKYO (HANEDA, NARITA)

I.2 WHY STUDYING MASs ?

Many reasons :

- To keep up with the growth in air traffic, MASs have been adopted all over the world.

- Understanding how they function is important since :

  Most airports with severe congestion are in large metropolitan areas which constitute major economic centers

  Airlines tend to favor hubs in these large cities because they constitute the origins and destinations of most air travelers.

- There is extensive historical evidence suggesting that MASs have been poorly understood, resulting in bad investments such as the construction of new airports that remained underused for very long periods of time.

Having a better understanding of how MASs function

- Some qualitative characteristics

- Development of a model capturing important attributes explaining airport market shares of air passengers.

CITY A

MS1 = ?
MS2 = ?
MS3 = ?

Airport 1

Airport 2

Airport 3

● CITY B
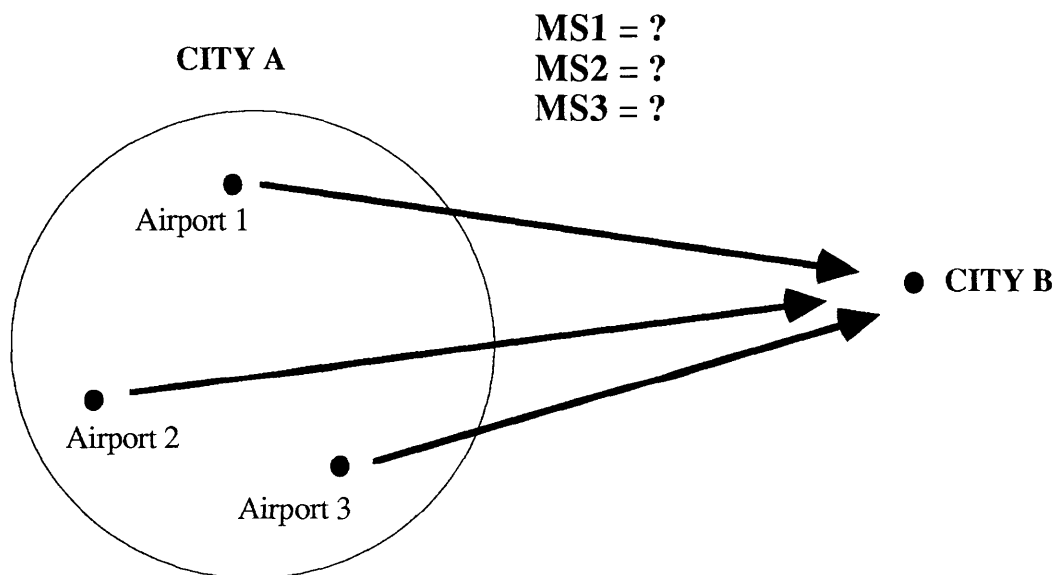
II.1 TWO CHARACTERISTICS

MASs have been adopted all over the world.

Existence of an Air Traffic Threshold

Metropolitan regions ranked by number of originating passengers (1988)

	City	Traffic	
		Originating	Total
1	New York	31	78
	London	25	62
	Los Angeles	23	57
	Tokyo	22	47
5	San Francisco	16	41
	Paris	16	40
	Chicago	15	65
	Dallas - Fort Worth	12	49
	Washington - Baltimore	12	34
10	Miami - Ft. Lauderdale	12	33
	Atlanta	11	46
	Boston	10	24
	Frankfurt	9	24
	Houston	8	23
15	Denver	8	32
	Osaka	8	17
	Honolulu	7	20
	Minneapolis - St Paul	7	19
	Las Vegas	7	16
20	Rome	7	16
	St Louis	6	20
	Toronto	6	19
	Orlando	6	16
	Phoenix	6	16
25	Hong Kong	6	15

Source: British Airport Services Ltd and BAA Ltd.

II.2 CHOICE OF AN AIRPORT

Airlines :

- Complex process
- Maximize long term profitability
- Importance of Frequency Share in a deregulated market

Passengers :

- Proximity to home (or office)
- Ease of access/egress
- Quality of airline service (frequency, non-stop flights, cheap fares,...)
- Parking (convenient, cheap,...)

Importance of market forces

"Natural tendency" for air traffic to concentrate at one airport.

So far as marginal cost due to increased congestion does not exceed marginal benefit, it is in the interest of the airline to provide service at the dominant airport. Air travelers will also choose the airport which offers the greatest variety of service.

Percentage of terminal passengers at first and second airport
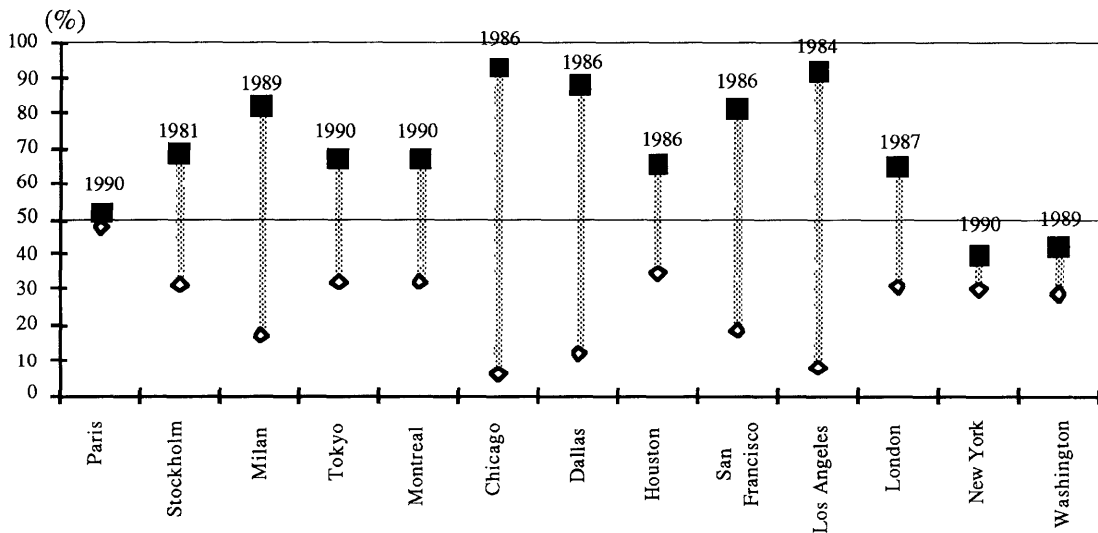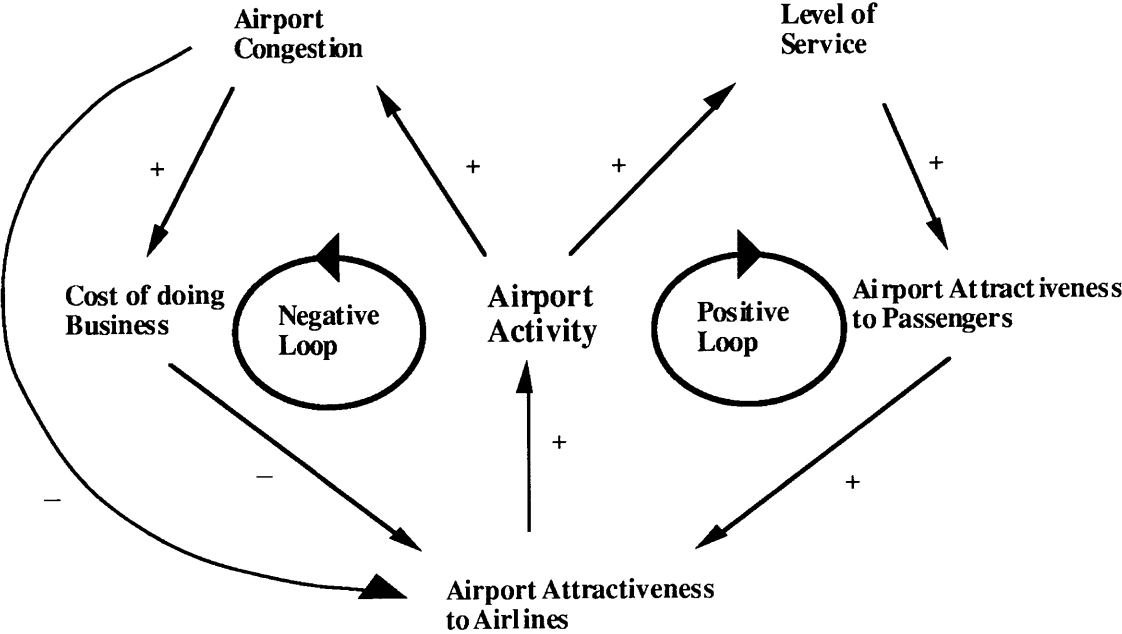
III.2 AN EXAMPLE

San Francisco Bay Area (SFO, OAK, SJC) - San Diego (SAN)

- **SFO-SAN: Southwest, USAir, United**
- **OAK-SAN: Southwest, USAir**
- **SJC-SAN: American, USAir**

SAN - SFO
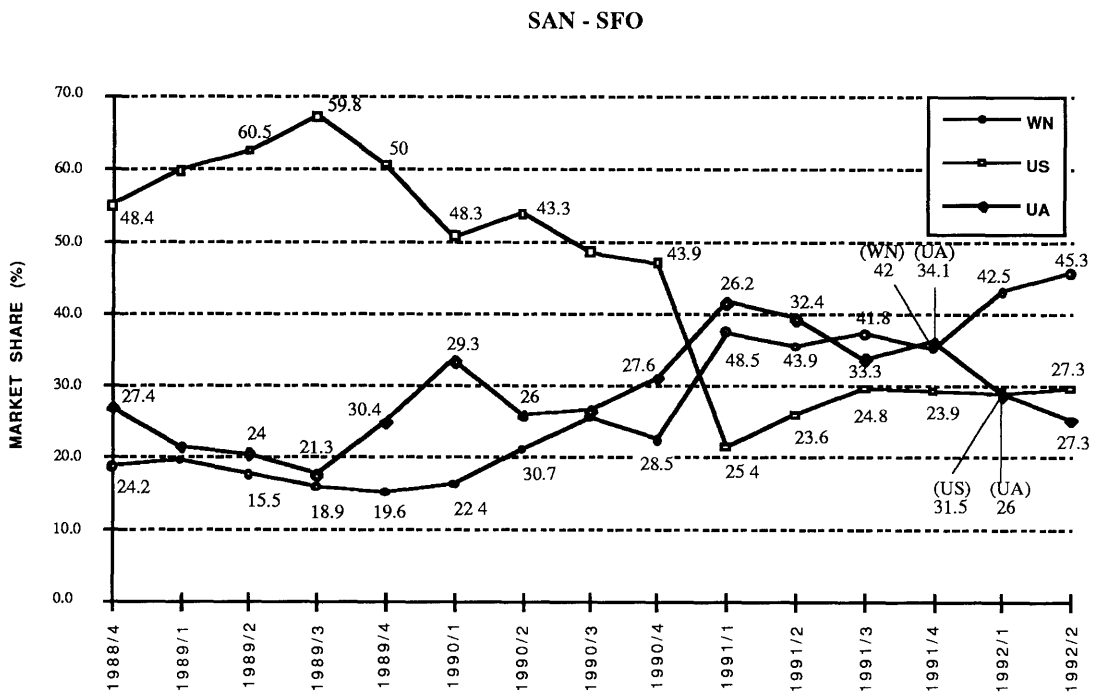
III.2 AN EXAMPLE

SAN - OAK
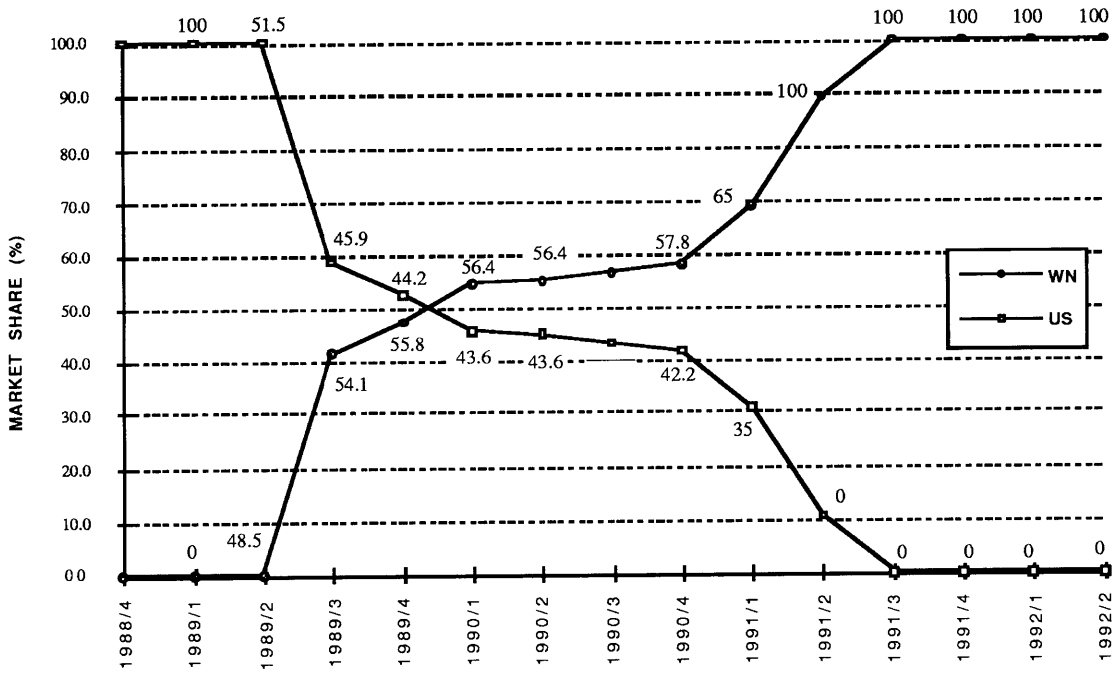
SAN - SJC
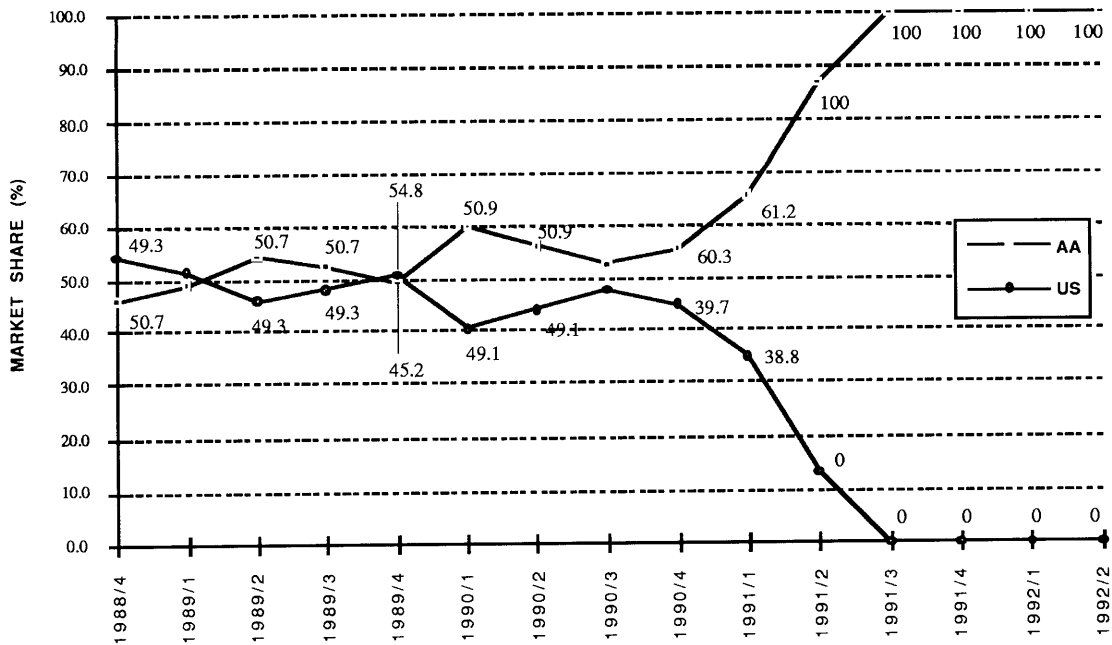
AIRPORT MARKET SHARES
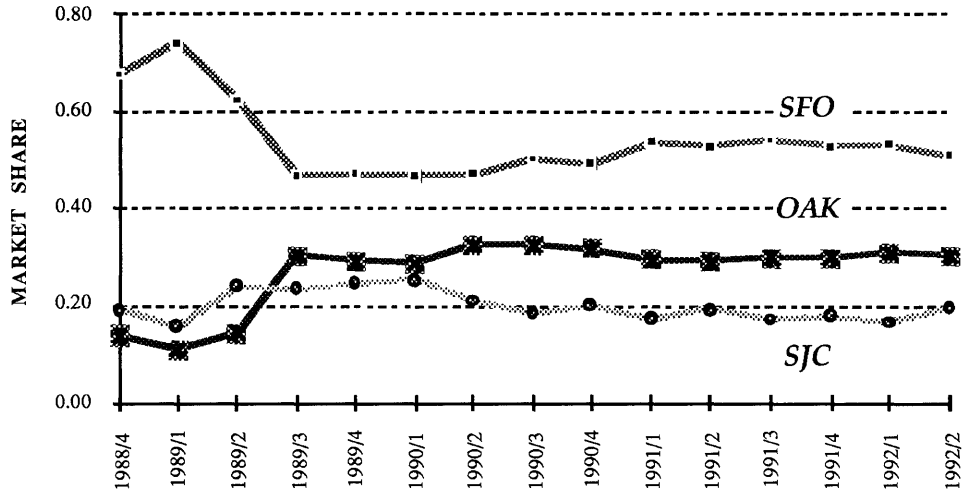
IV.1 EXPLANATORY VARIABLES

A broad range of potential explanatory variables :

- Fare
- Frequency of service
- Trip time (access time)
- Less crowded airport
- Directness of flight
- Schedule
- Equipment
- Airport recommended by travel agents or chosen by office
- etc.

IV.2 PREVAILING METHODOLOGIES

Previous studies have used choice models such as the multinomial logit model. Most often, they focus primarily on the choice made by the passenger.

Problem : Availability of data.

Need to carry out specific surveys to obtain the data that are necessary to calibrate the model.

IV.3 NON-LINEAR RELATIONSHIPS

- MS vs FS: S-shaped curve (competiton between airlines)

MARKET SHARE vs. FREQUENCY SHARE
(2 carriers)
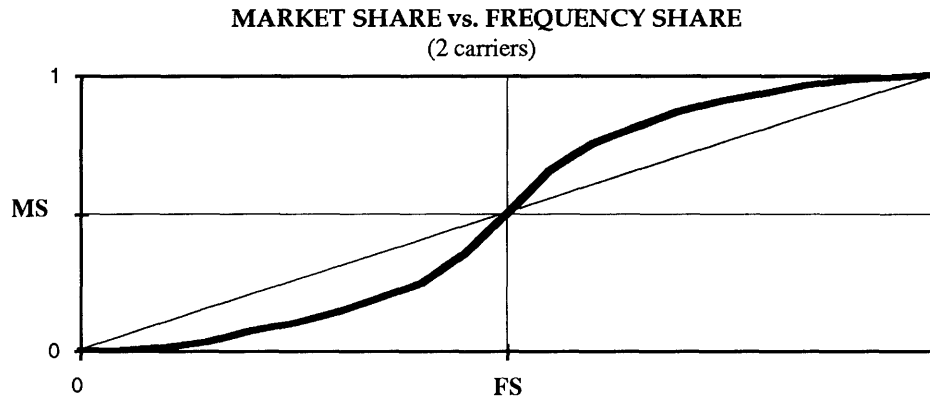
- Competition between airports

MS v. FS : S-CURVE (NEW YORK /NEW JERSEY AIRPORTS)
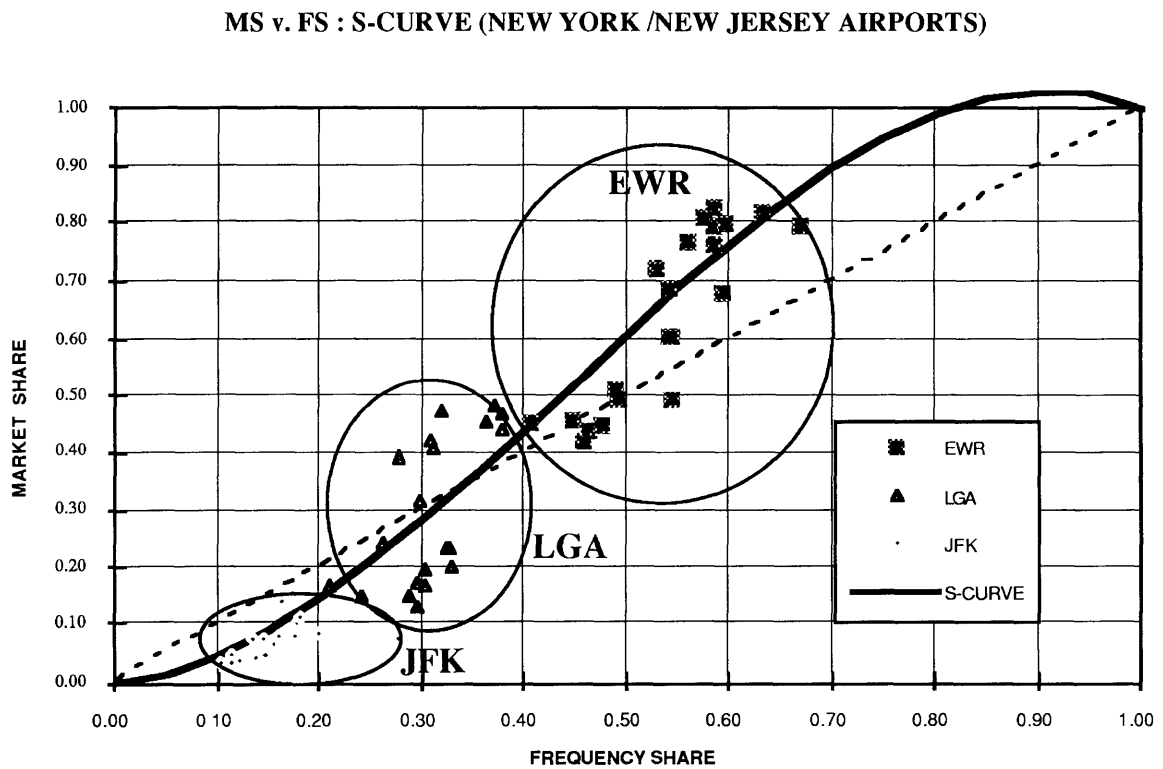
IV.4 THE MODEL

$$MS_i = K_i \times FS_i^\alpha \times Fare_i^\beta \times Other\ Fare_i^\gamma$$

- MS_i is airport i's market share.

- K_i is a parameter (different for each airport). This is airport i's market share everything else being equal.

- FS_i is airport i's (equivalent) frequency share.

- $Fare_i$ is the average fare (in constant dollars), weighted by traffic, at airport i.

- Other $Fare_i$ is the average fare at the competing airports.

- α, β, γ : Elasticities of MS with respect to Frequency and Fares

Problem: For a given airport, we know the average traffic and the average fare. What is the average frequency of service ?

Equivalent frequency of service :
Frequency aggregated across airlines, as perceived by air travelers.

Example : 2 airlines, each offering n=10 flights a day.

Equivalent
Frequency = ?

Airline #1   Airline #2   Airport
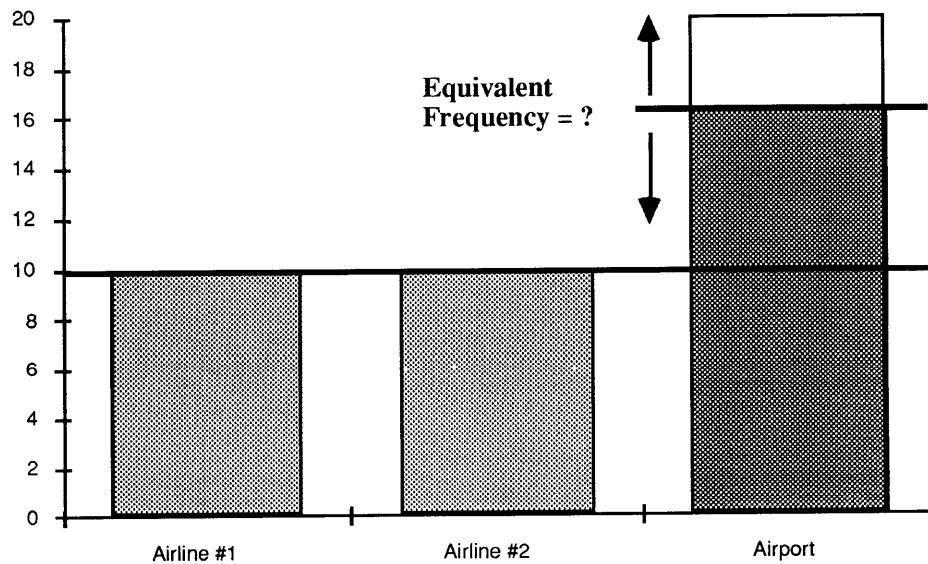
$$\text{Equivalent Frequency} = 10 \times (2)^{\alpha}$$

V. CASE STUDIES - RESULTS

MAS : NEW YORK / NEW JERSEY AIRPORTS

- **Minneapolis - St Paul** $(R^2 = 0.97)$

$$MS = K \times \left(\frac{FS^{0.75}}{F^{0.89}} \right) \times \overline{F}^{1.26}$$

- **Pittsburgh** $(R^2 = 0.96)$

$$MS = K \times \left(\frac{FS^{0.65}}{F^{0.69}} \right) \times \overline{F}^{0.87}$$

- **Raleigh Durham** $(R^2 = 0.98)$

$$MS = K \times \left(\frac{FS^{0.30}}{F^{0.92}} \right) \times \overline{F}^{0.91}$$

MAS : SAN FRANCISCO BAY AREA

- **Las Vegas** $(R^2 = 0.85)$

$$MS = K \times \left(\frac{FS^{0.52}}{F^{0.29}} \right) \times \overline{F}^{0.63}$$

- **Phoenix** $(R^2 = 0.95)$

$$MS = K \times \left(\frac{FS^{0.58}}{F^{0.98}} \right) \times \overline{F}^{0.87}$$

- **San Diego** $(R^2 = 0.94)$

$$MS = K \times \left(\frac{FS^{0.67}}{F^{0.81}} \right) \times \overline{F}^{0.42}$$

MAS : WASHINGTON / BALTIMORE

- **Atlanta** (R^2 = 0.96)

$$MS = K \times \left(\frac{FS^{0.52}}{F^{1.20}}\right) \times \overline{F}^{1.40}$$

- **O'Hare** (R^2 = 0.92)

$$MS = K \times \left(\frac{FS^{0.44}}{F^{0.98}}\right) \times \overline{F}^{1.08}$$

- **Raleigh-Durham** (R^2 = 0.89)

$$MS = K \times FS^{1.85} \times \overline{F}^{1.14}$$

AIRPORT MARKET SHARES : NYC (EWR, LGA, JFK) - MSP
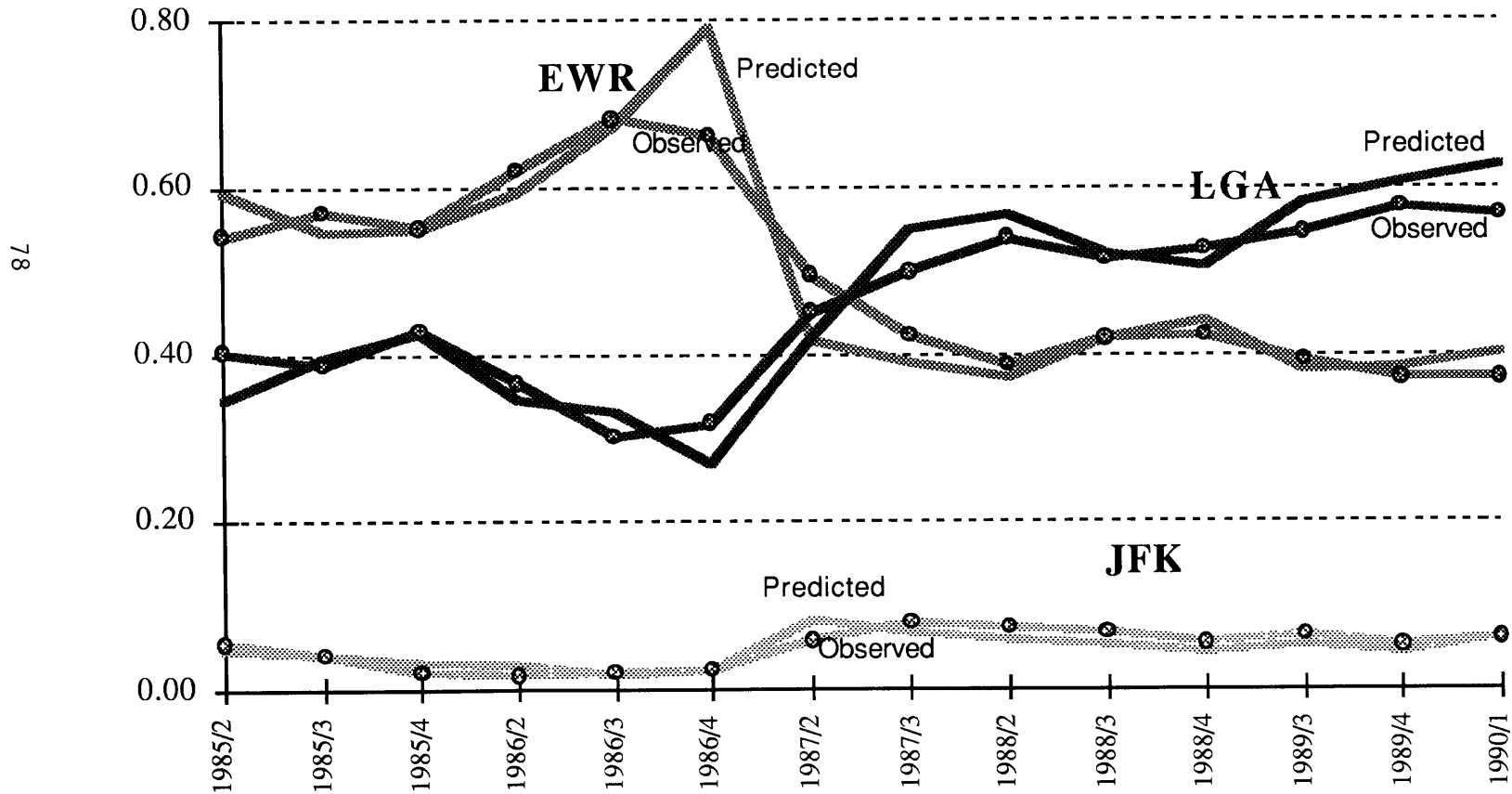
V. CASE STUDIES - RESULTS (cont'd)

AIRPORT MARKET SHARES : SAN FRANCISCO (SFO, OAK, SJC) - PHX
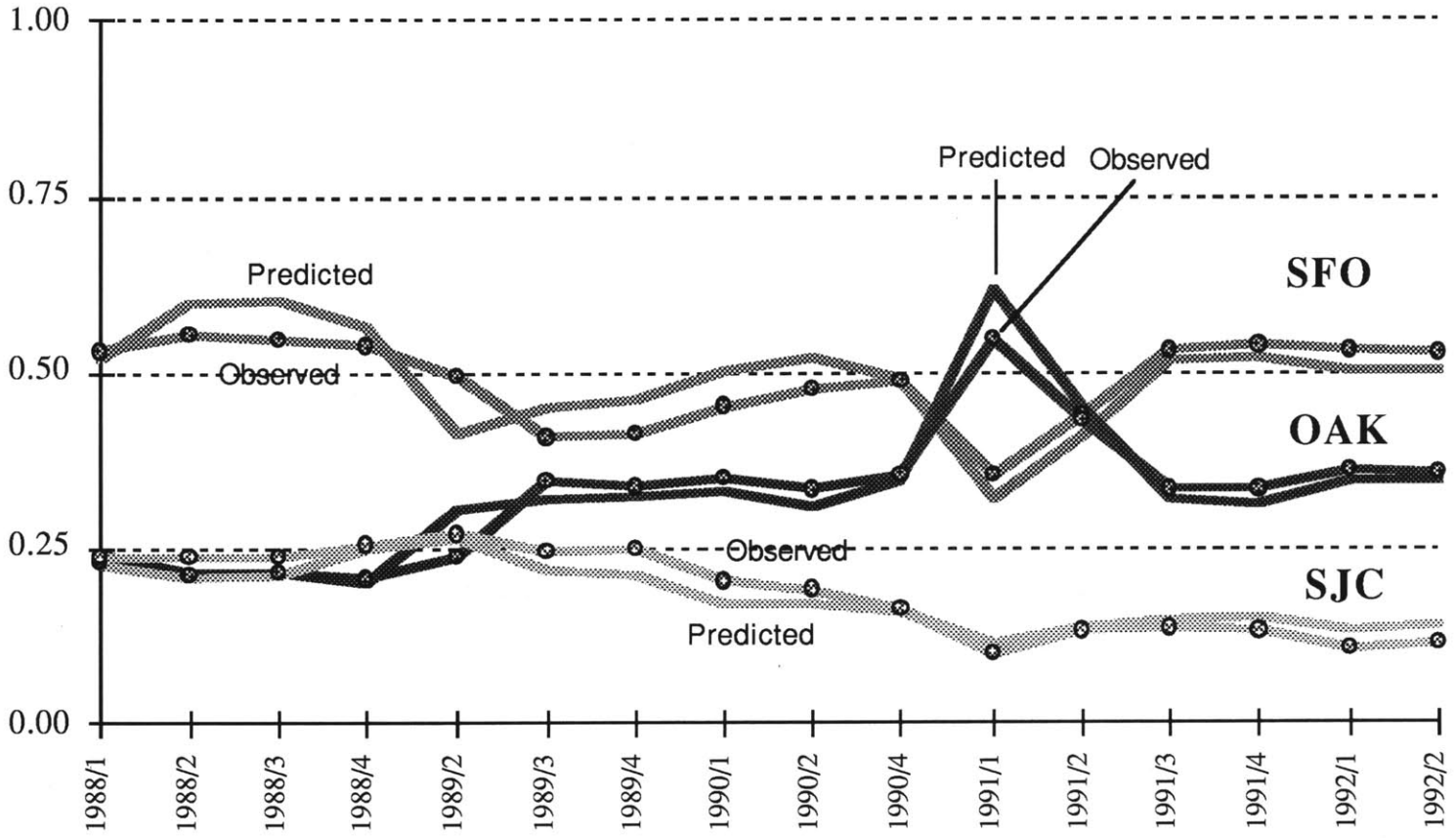
VI.1 ANALYSIS OF THE RESULTS

- Cross effects have to be taken into accounts

  The variables FS and Other fares are statistically significant

- Qualitative relationships are consistent with intuition

Frequency Share ↑	→	MS ↑
Fare ↑	→	MS ↓
Fare at competing airports ↑	→	MS ↑

- Numerical values of price and time elasticities make sense

(FS)	$0.3 \leq \alpha \leq 0.75$
(Fare)	$-0.98 \leq \beta \leq -0.29$
(Other Fare)	$0.42 \leq \gamma \leq 1.40$

- A reasonable statistical fit between the model and observed data

  $$0.85 \leq \text{Adjusted } R^2 \leq 0.98$$

VI.2 LIMITATIONS OF THE MODEL

- The data that we used were not very disaggregated (business vs leisure, ...)

- The model depends directly on fares and frequencies only.

- The model seems to give better results when the number of competitors is small.

- Equivalent frequency (not endogenous)

- The predictive value of the model diminishes as we aggregate origin-destination markets

VI.3 IMPLICATIONS

- General implication → Airport specialization

EXAMPLES OF AIRPORT DIFFERENTIATION

Metropolitan Region	Airports	Ratio (terminal passengers)(*)	Specialization
New York	Kennedy	100	Transcontinental; bulk cargo
	La Guardia	77	Medium-short haul
	Newark	75	cheap fares; express cargo
Los Angeles	International	100	Domestic, international business
	Ontario	12	California; express cargo
	Burbank	n.a.	California
London	Heathrow	100	Domestic, international business
	Gatwick	49	Charters
	Luton	6	Charters
Tokyo	Haneda	100	Domestic
	Narita	48	International
Paris	Orly	100	Southern; cheap fares
	Charles de Gaulle	93	Northern; East-West
Miami	International	100	Business; International; cargo
	Fort Lauderdale	n.a.	Holiday
San Francisco	International	100	Business; international
	San Jose	22	California; commuter
	Oakland	n.a.	Cheap fares
Washington	National	100	Short-haul, cheap fares
	Baltimore	65	Long-haul, cheap fares
	Dulles	65	Long-haul
Dallas	Dallas-Ft Worth	100	Hub operations (American)
	Love Field	12	Short-haul
Houston	Intercontinental	100	Hub operations (American)
	Hobby	46	Short-haul

(*). 1990 data, except San Francisco (1989)

n.a. : not available

Source: Aéroports de Paris (traffic); de Neufville, 1986 (Specialization).

- Implications for regional airports

Need to gain the support of several constituencies:

Air travelers (low fares, low congestion, cheap parking,...)

Airlines (should be persuaded that increasing service makes sense)

Local community (economic impact, more jobs, etc.)

DYNAMIC FLOW

CONTROL

Seth C. Grandeau

THE PROBLEM

- Inefficient Delay Strategies Used By CFCF

- Wasted Capacity

- Geographically Tiered Delay Programs

- Fractured Complex Structures

WORK WITH TSC

- Aircraft Situational Display (ASD)
  'Real Time' Radar
  ETAs For Every Flight

- Allow Us To Analyze Failures In Current
  System

- Aid in Building Probabilistic Models
  Determine Accuracy Of ETAs
  Updated ETAs Used For Dynamic Control

SOC VISITS

- System Operations Control Centers

- Day To Day Running Of The Airline

- Five Groups

- Centralized Control

- Visits To American And United

CREW SCHEDULING

- Track Flight And Cabin Crews

- Monitor Crew Status Within Faa And Company
  Guidelines

- Track Available Crews

- Organize And Rebuild Crew Rotations

FLIGHT DISPATCH

- Determine Fuel And Load Restrictions

- Monitor Arrival Of Resources
  Flight Crew
  Cabin Crew
  Aircraft

- Generating Flight Plans

- Flight Tracking

LOAD CONTROL

- Cargo Tracking

- Load Balancing

- Monitor Passengers On Board

- Monitor Fuel On Board

METEOROLOGY

- **Forecasting**

- Predictions Of Facility Closure

- Predictions Of Runway Switches

- Assist In The Generation Of Flight Plans

OPERATIONS ANALYSIS

- Monitoring Airlines Performance

- On-Time Performance

- Maintenance Failures

- Yield Management

SLOT SWAPPING

- Every Scheduled Arrival At A Facility Under A Delay Program Is Awarded A Slot

- Airlines Can Substitute Flights For Open Slots

- Airlines Cannot Trade Slots With Other Airlines

- Swaps Are Allowed Between Airline And It's Affiliated Regional Carrier

AMERICAN'S PHILOSOPHY

- **Maintaining Complexes**

- Performs Its Own Flow Control Procedures

- *Hub Slasher*

- Return To Normal Schedule For The Following Day's Operation

- Solves Slot Swapping Problem As A Joint Problem For Itself And It's Regional Carriers

UNITED'S PHILOSOPHY

- **Maintaining Schedule**

- Attempt To Get Every Flight Flown

- Can Impact Operations On Subsequent Day

- Solves Slot Swapping Problem For Itself At
  Expense Of It's Regional Carriers

AIRLINES' PROBLEMS WITH CFCF

- Not Enough Anticipation Of Problems

- Geographic Tier Structure For Delays

- No Priority Given To Diverted Aircraft

- Delay Programs Not Updated As Weather Changes Occur

95

DYNAMIC FLIGHT CONTROL

96

- Deterministic Vs. Probabilistic

- Delay's Quantized

- Frequent Updates As Better Information Is
  Available

- Airborne Holds For Hedging And To Prevent
  Starving Facility

- Garenteed Queue Position To Allow Slow-Ups
  And Speed-Ups

TOKEN SYSTEM

- Allow For Swapping Between Airlines

- Allow Airlines To Maximize Over All Airlines Not Individually

- Quantize Total Delay For Each Airline

- Point System With CFCF Acting As A Clearing House

- Grant Arrival Slots To Each Airline

DESIGN AND DEVELOPMENT

OF A

MULTI-MODAL TRAFFIC CONTROL SIMULATOR (MMTCS)

ROBERT W. SIMPSON

FLIGHT TRANSPORTATION LABORATORY, MIT
(617) 253-3756

MAY, 1993

GOAL

The purpose of this work is:

- to develop an initial implementation of a multi-modal general-purpose, real-time, interactive simulator of novel forms of automated control for vehicular traffic called

MMTCS, (Multi-Modal Traffic Control Simulator)

- aircraft - airborne, and on the airport surface
- ships in a harbour
- high speed trains
- expressway traffic flows

- it will be needed for:

1) concept development,
2) operational evaluation,
3) human factors acceptability

of automated decision support modules for advanced, computerized traffic control systems

SIMULATION TECHNOLOGY FOR MMTCS

Modern computer hardware and software now allows the design of a generalized, modular architecture for traffic simulation which can easily be adapted to a variety of scenarios

- saves time and money in creating a wide variety of experimental environments for Human Factors research on traffic controllers

- allows traffic controllers to work with a wide variety of new types of displays and novel automated decision support systems

- distributed processing using common workstations on a high speed local area network, and an object-oriented, modular approach to configuring the software allows rapid re-configuration of the controller's traffic console, its display formats, and its automation

- software modules for common functionalities such as vehicle motion, navigation, guidance, surveillance, and communications become a "simulation toolkit" from which to construct each new experimental environment

- it is easy to run two or more related simulations at the same time and transfer vehicles from one to the other

MMTCS ARCHITECTURE
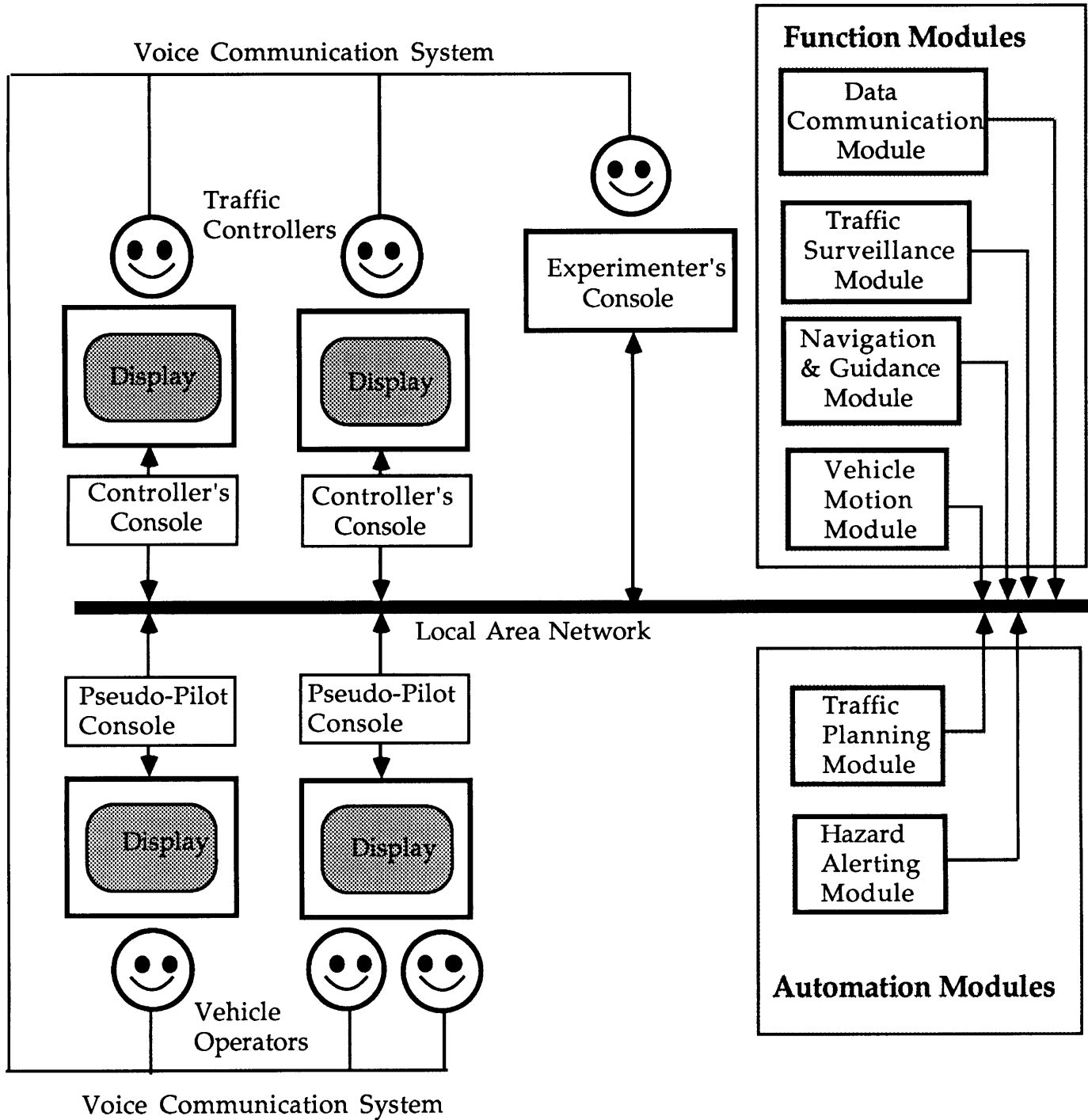
IMPLEMENTATION OF MMTCS

- Standard ANSI C as basic language for simulation environment (using structured, object oriented programming)

- X-WINDOWS for the Graphic environment

- Ethernet with TCP/IP protocol

- UNIX operating environment (AT&T System 5.3)

The first simulation environment describes the traffic environment on the surface of a busy (100 vehicles) airport (Frankfurt). It is being extended to describe Boston Logan airport and the surrounding airspace.

It is currently implemented on two Sun Sparc stations which have a 19 inch color displays for the experimenter's, controller's, and pseudo-pilot's console. All displays use a "mouse" to zoom, re-center, and call multiple windows.

There can be several simultaneous controllers (and their vehicle operators).

OPERATIONAL MODES of MMTCS

1. REAL-TIME

The simulation is designed to provide a real time, interactive
environment for human traffic controllers who can communicate
to the vehicle operators by radio voice communications, or by
data-link to the displays of the vehicle operator. There are various
controllable time intervals for simulation activities; eg. a 30 hz output
for visual out-the-window displays, a 1 second output for vehicle
motion, and a 4.8 second output for surveillance displays.

2. RE-PLAY

After any simulation run, it is possible to replay the results in fast time
(eg. perhaps 10 times real time), or to FAST-FORWARD to any desired
point where the simulation events can be studied in slow-time, or
where the simulation can be stopped to serve as an initial point to
re-iterate another real time simulation.

3. FAST-TIME

If fully automated traffic control can be created for some scenario, it
is then possible to add automated Traffic Generators to represent a
specific stochastic description of traffic flows (eg. random arrivals of
a specific mix of vehicle types at an average of 60 vehicles per hour).
Then simulation runs provide statistical evidence of the performance
of the Traffic Control system under these traffic conditions.

CURRENT APPLICATIONS - AIRPORT SURFACE

One of the current applications is the movement of aircraft on the runways and taxiways of a major airport. Aircraft arrive for landing, decelerate to an exit speed on the runway (depending on their type and surface conditions), and are assigned to a taxipath from that runway exit to their parking gate. After some hours, they are ready to "push-back" and are cleared by the Ground Controller to taxi via some assigned taxipath to a runway where they await clearance for takeoff. A Plan-view display of the airport is provided.

GROUND CONTROLLER COMMANDS

There is a complete set of commands normally used by ground controllers:

PROCEED (along a path specified by taxiway segments and intersections)

STOP (at an intersection or immediately)

TURN (left or right at next intersection)

FOLLOW, and YIELD (another specified aircraft)

CLEAR ACROSS (any active runway, prespecified)

CLEAR FOR TAKEOFF (enter from hold point or taxiway)

CLEAR TO CENTERLINE & HOLD

CLEARED FOR PUSHBACK

CURRENT APPLICATIONS - AIRPORT SURFACE

To reduce the workload of Pseudo-pilots, and ensure the realism of the simulation, there are ground motion dynamics automatically built into the simulation which are characteristic of the actual ground taxi behaviour of aircraft and pilots:

AIRCRAFT GROUND MOTION, NAVIGATION, AND GUIDANCE

1) taxispeed varies depending on aircraft type, the area of the airport (eg. ramp area, long straight taxiways to the runway), or surface conditions, low visibility, turning radius of exits and taxiways, etc

2) traffic will "Platoon" whenever a faster aircraft encounters a group of slower aircraft it will slow down and follow the platoon; consequently, there is an automatic shuffling forward in the takeoff queue whenever the leader is cleared onto the runway.

3) traffic will automatically slow and yield to aircraft which are arriving first at an intersection (unless otherwise commanded by the controller)

4) landing aircraft have a characteristic approach airspeed and will have different landing speeds in different winds. There is also a characteristic but random deceleration on the runway surface (which is reduced by runway surface conditions or low visibility) and aircraft then seek the first feasible exit (ie. they can reach a suitable exit speed at that point).

5) aircraft have a default taxipath from any runway exit to any assigned gate and will proceed on this path unless otherwise instructed. There is also a default path from any gate to any runway.

6) traffic will automatically stop at an active runway (unless otherwise cleared across by the ground controller). There is a lag in acceleration from a full stop to match the time required to "spool-up" jet engines.

7) aircraft will automatically pushback from a gate and turn into the taxi direction. There is a random time to start engines before slow taxi-out.

ATCSIM FUNCTIONALITIES

Voice Communication System

Traffic Controllers

Air Sector-1
Display

Ground Sector-1
Display

Display

Controller's Console

Controller's Console

Experimenter's Console

Local Area Network

Pseudo-Pilot Console

Pseudo-Pilot Console

Air Sector-1
Display

Ground Sector-1
Display

Vehicle Operators

Voice Communication System

Function Modules
(Airborne Simulation)

Data Communication Module

Traffic Surveillance Module

Navigation & Guidance Module

Vehicle Motion Module

Function Modules
(Ground Simulation)

Data Communication Module

Traffic Surveillance Module

Navigation & Guidance Module

Vehicle Motion Module

Traffic Planning Module

Hazard Alerting Module

Automation Modules
(Airborne Simulation)

Traffic Planning Module

Hazard Alerting Module

Automation Modules
(Ground Simulation)

Policy Level Decision Support

For Airport Passenger Terminal Design

Presented by :

Tom Svrcek
MIT Flight Transportation Laboratory
Cooperative Research Meeting, May 20, 1993

Outline Of Presentation

Research Objective

Traditional Approaches

New Methodology

Standard Configurations

Performance Characteristics

Configuration Robustness

"Best" Configurations

Further Research

Conclusions

Setting : Cocktail Party

Woman   :   So what do you do ?

Tom   :   I'm a Ph.D. student at the MIT Flight
                Transportation Laboratory.

Woman   :   What are you studying ?

Tom   :   Airport passenger terminal design.

Woman   :   So tell me, what's the best airport ?

Tom   :   Well, it depends on many things.
                First, you have to know how many
                passengers you expect to have. Then, you
                have to know what types of passengers
                you're going to have. Oh, and you can't
                forget things like seasonality, terminal
                ownership, aircraft mix, flight-to-gate
                scheduling. Then, you have to consider the
                health of the airline industry in general --
                the number of airlines and their relative
                competitiveness in your area.

                And then ....

Traditional Approaches

Detailed, "Micro" Simulations

Use Monte-Carlo Techniques To "Simulate" Airport Environment.

Must Pre-Suppose Initial Configuration.

Large Amounts Of Input Data Required. Modification Of Fundamental Shape Time-Consuming.

Analytic Techniques

Attempt To Describe Terminal Performance In Terms Of One Or More Decision Variables. Using Differential Calculus, "Optimal" Configuration Can Be Determined.

For Example, The Equation For The Mean Passenger Walking Distance For One Particular Configuration Type Can Is :

$$W_{CSP} = (1 - P + 2P(1-Q)) \left\{ b_p + \frac{1}{2L} \left[\sum_{i=1}^{n-1} x_i^2 + (L - \sum_{i=1}^{n-1} x_i)^2 \right] \right.$$

$$+ \frac{1}{L} \left[\sum_{i=1}^{j} x_i ((j-i)S + y) + \sum_{i=j+1}^{n-1} x_i ((i-j)S - y) + (L - \sum_{i=1}^{n-1} x_i)((n-j)S - y) \right] \right\}$$

$$+ \frac{PQr}{3L} \left\{ \sum_{i=1}^{n-1} x_i^2 + (L - \sum_{i=1}^{n-1} x_i)^2 \right\}$$

Walking Distance Estimation
(Direct Transfers)
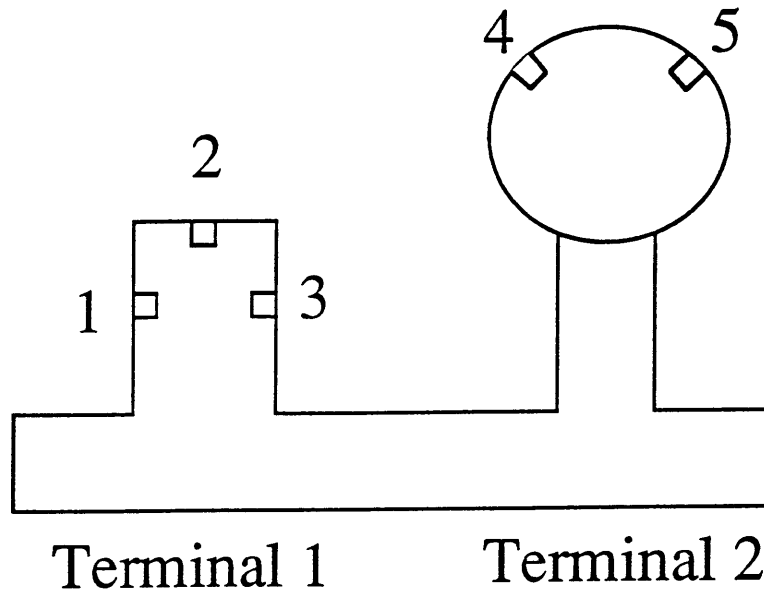
Terminal 1	Gate	Distance	P(Dept)
	1	0	.20
	2	30	.20
	3	20	.20

Terminal 2	Gate	Distance	P(Dept)
	4	240	.20
	5	240	.20

$$d_1 = \sum \left[\text{Distance} * \text{P(Dept)} \right] = \underline{106.0 \text{ m}}$$

New Methodology

In Order To Maintain Analytic Tractability, Many Operational Features Must Be Ommitted. New Technique Easily Incorporates (Svrcek '92) Such Things As :

Intelligent Scheduling

Airlines / Airport Owners Exert Considerable Control Over Flight-To-Gate Assignments.

The Result Is That Passengers May Be More Likely To Depart From Gates Within Arrival Terminal, And Even Gates Closer To Arrival Gate.

Aircraft Effects

Larger Aircraft Carry Larger Number Of Passengers, But Take Longer To Turn Around.

Transition Probabilities From One Gate To Another Heavily Influenced By Gate Specific Aircraft Utilization.

Peakiness Of Demand

Airport Owners Can Reduce The Number Of Gates/Concourses Used In Periods Of Low Demand.

Walking Distances Reduced By Judicious Gate Selection.

Configuration Concepts

	Centralized	De-Centralized
Linear		
Pier		
Satellite		
Midfield		
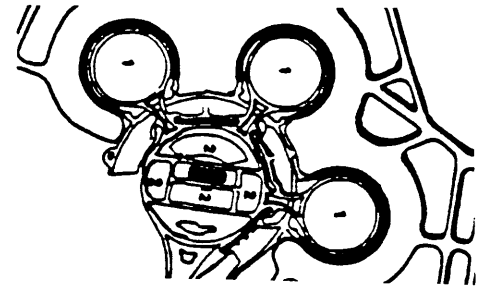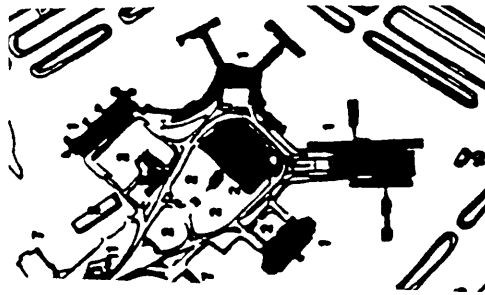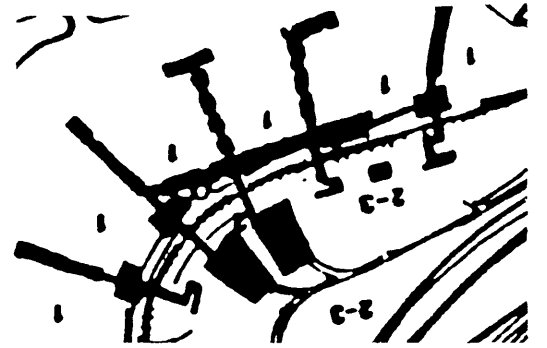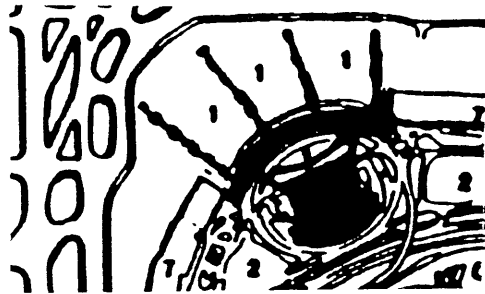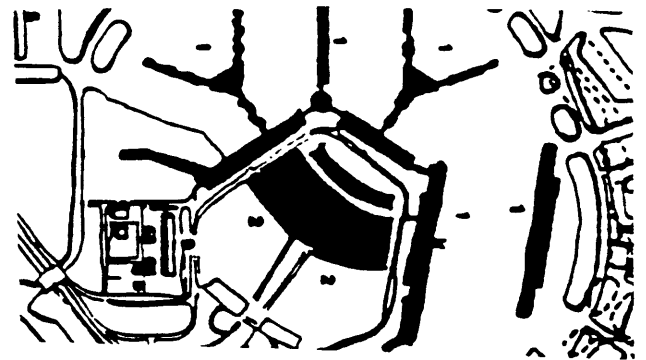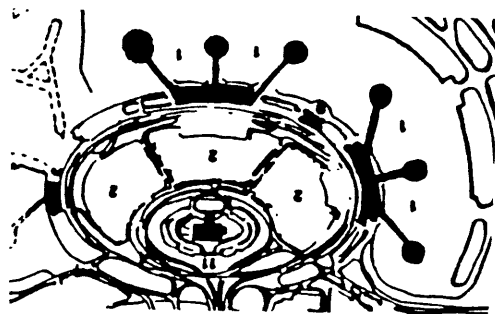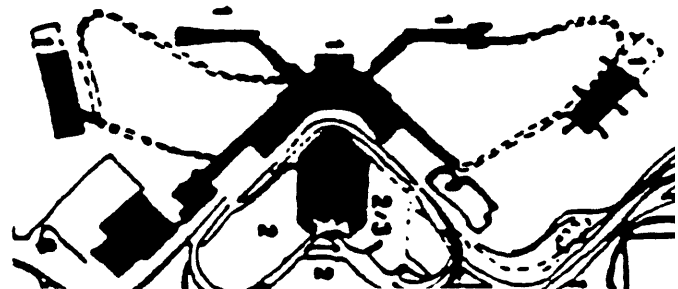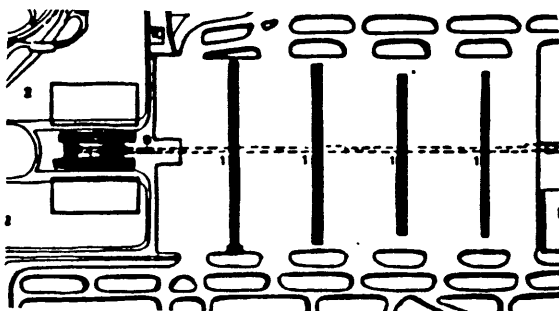
Some Definitions

Throughout This Analysis, The Following Definitions Will
Be Helpful :

Originating/Terminating Passengers : Those Passengers
Beginning / Ending Their Journeys At The Airport Under
Consideration.

Indirect or Non-Hub Transfers : Those Passengers
Requiring Intermediate Services (Customs, Transfer Desk,
Check-In) Between Arriving And Departing).

Direct or Hub Transfers : Those Passengers Who Can Go
Directly From Their Arrival To Their Departure Gate.

P : The Proportion Of Transfer Traffic.

Q : The Proportion Of Hub Transfer Traffic.

    Q = 1 : All Hub Transfers
    Q = 0 : All Non-Hub Transfers

r : The Probability Of Departing From A Gate Within
    Arrival Terminal (Measure Of Ownership).

    r = 1 : Certain To Depart From Arrival Terminal.
    r = 0 : Equally Likely To Depart From Any Gate
            In Airport.

Centralized Parallel Pier

P(Hub/Transfer) = .5, r=.5

—■— p = .1   —◆— p = .3   —▲— p = .5   —□— p = .7   —◇— p = .9
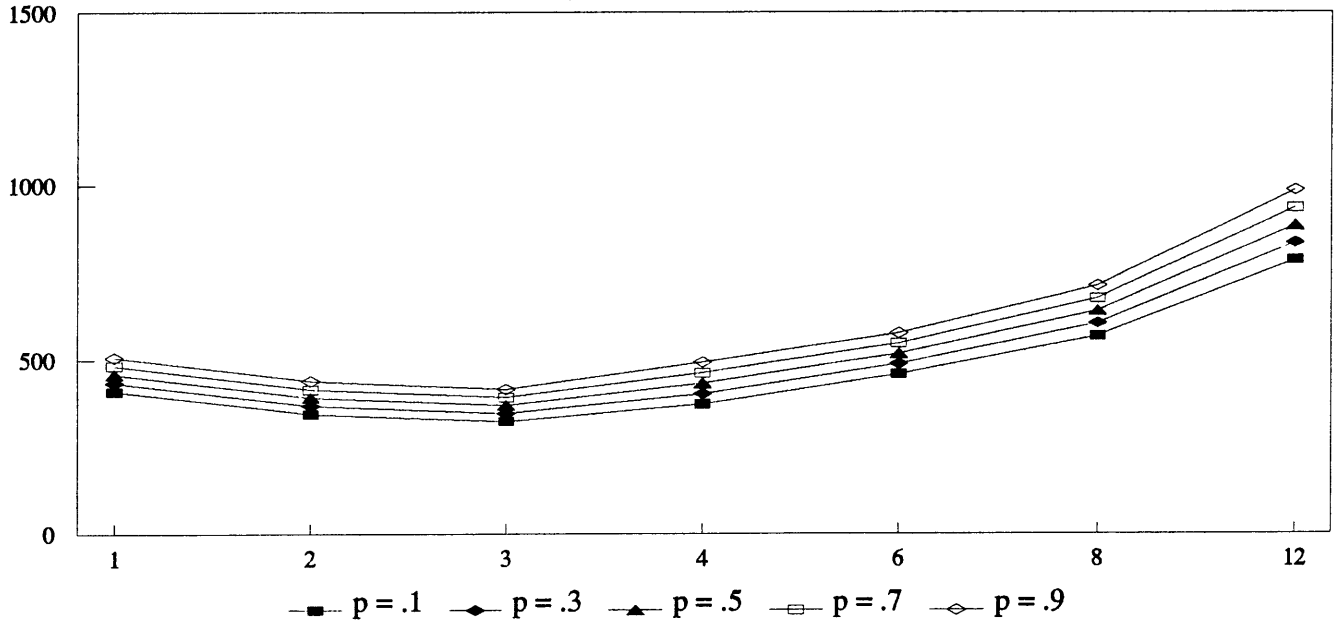
Semi-Central Parallel Pier

P(Hub/Transfer) = .5, r=.5

—■— p = .1   —◆— p = .3   —▲— p = .5   —□— p = .7   —◇— p = .9
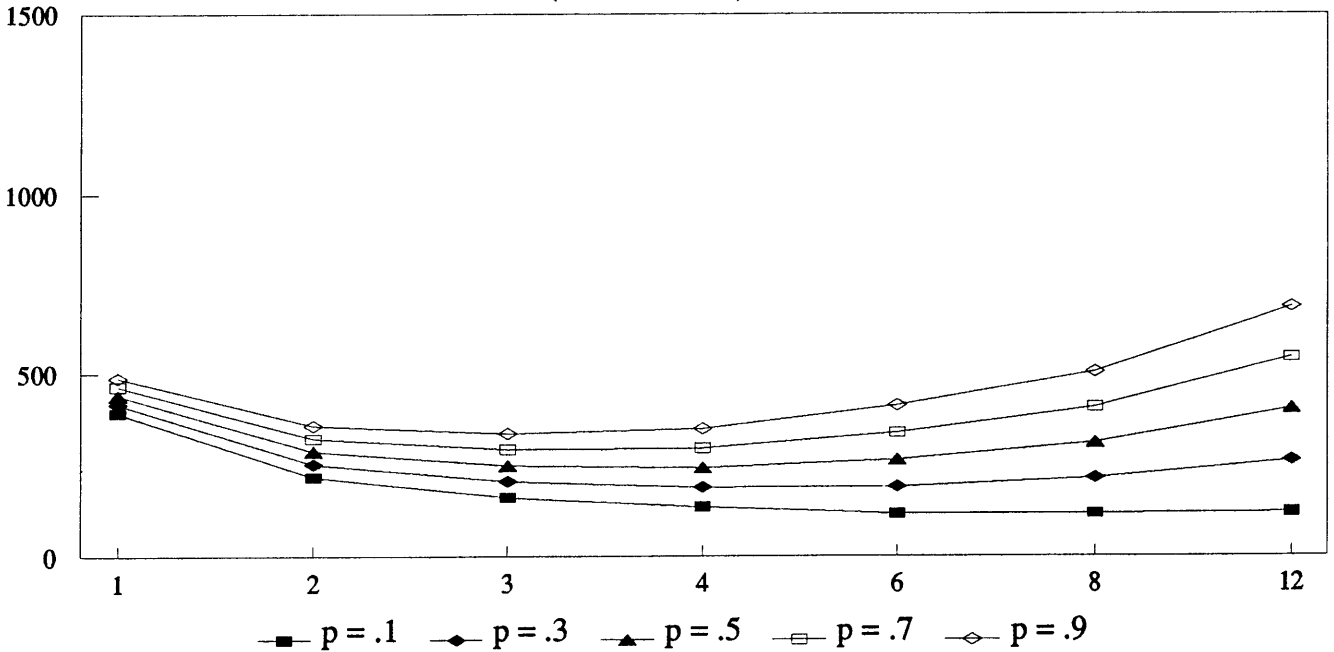
Other Performance Measures

Because Of The Way Data Is Maintained, Other Performance Measures Can Easily Be Calculated.

Standard Deviation

Centralized Parallel Pier
P(Hub Trabsfer/Transfer) = .5

Number of Terminals

—■— p = .1   —◆— p = .9

Semi-Centralized Parallel Pier
P(Hub Trabsfer/Transfer) = .5

Number of Terminals

—■— p = .1   —◆— p = .9

Probability Of Excess Walking

Centralized Parallel Pier
P(Hub Transfer/Transfer) = .5
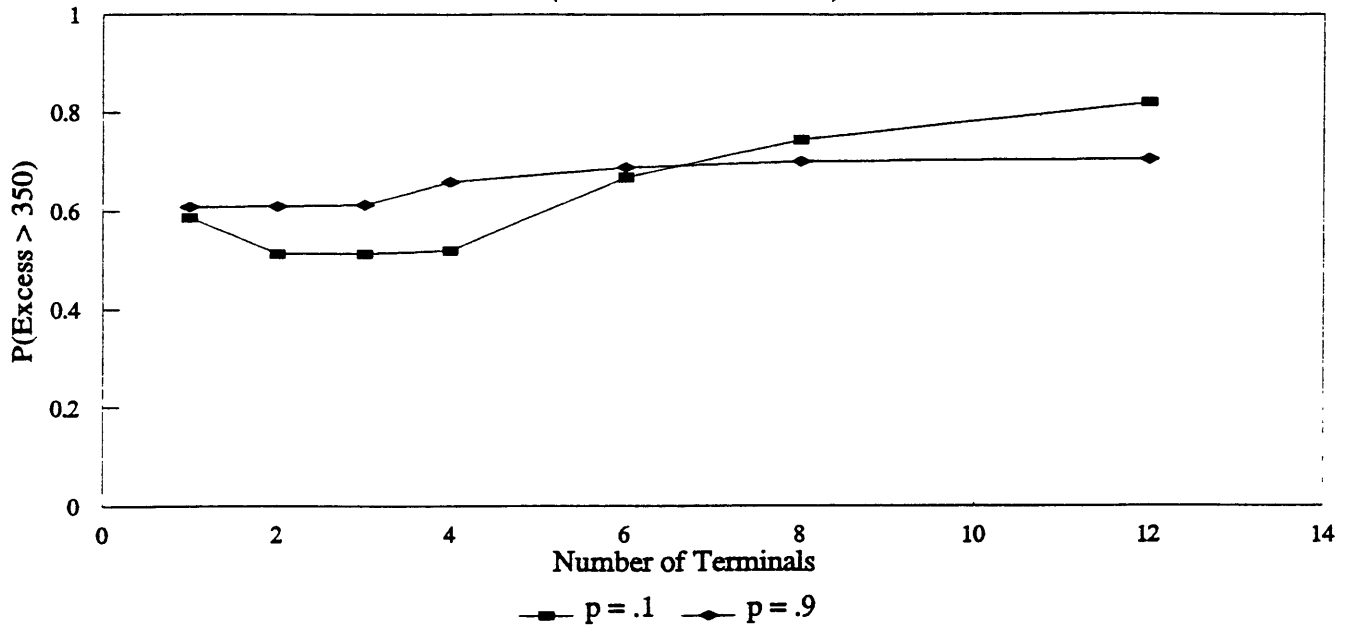
Semi-Centralized Parallel Pier
P(Hub/Transfer) = 1.0   r = .5
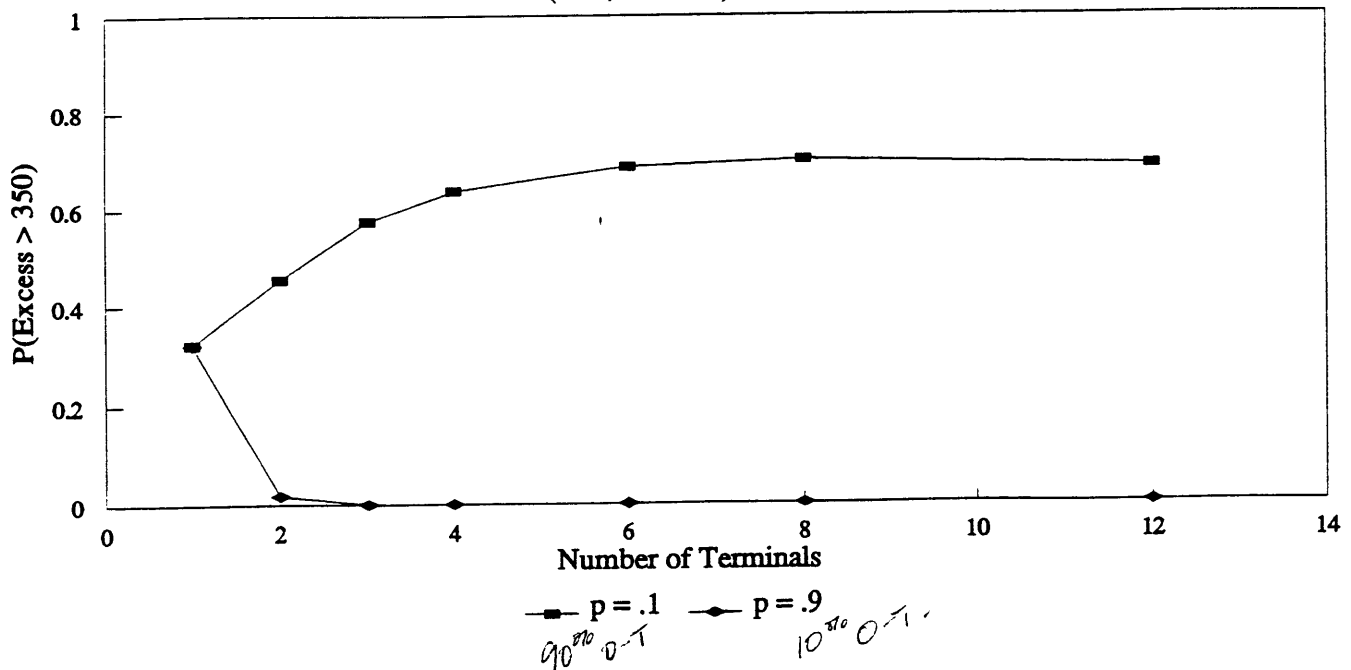
Configuration Robustness

In Addition To Selecting The Most Appropriate Number Of Terminals Or Concourses For A Given Set Of Conditions, The New Methodology Can Also Be Used To Determine How Robust Certain Values Of n^* To Changes In Forecast Conditions.

1) *Transfer Split Test* : How Robust Is Configuration To Changes In Proportion Of Transfer Traffic That Is Hub Traffic.

2) *Ownership Test* : How Robust Is Configuration To Changes In The Probability That Passenger Will Depart From Arrival Terminal.

Transfer Split Test

Centralized Satellite Circle
P(Hub/Transfer) = .5, r=.5
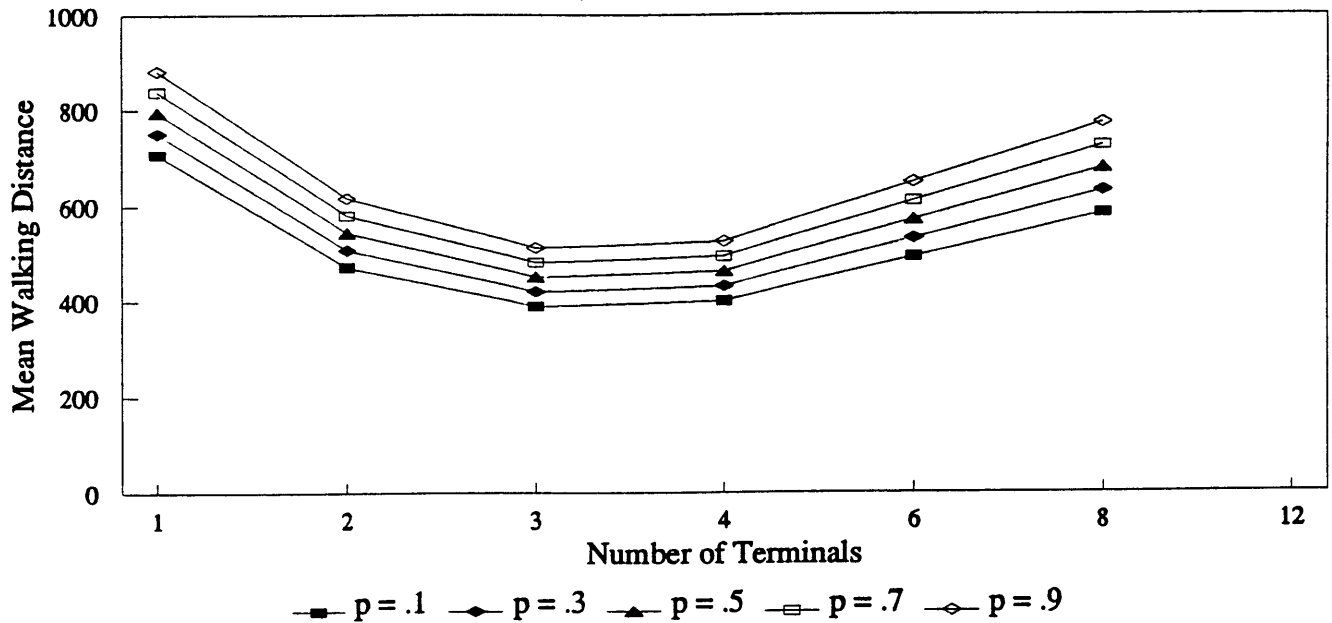
(Angle =180)

Centralized Satellite Circle
P(Hub/Transfer) = 1.0, r = .5
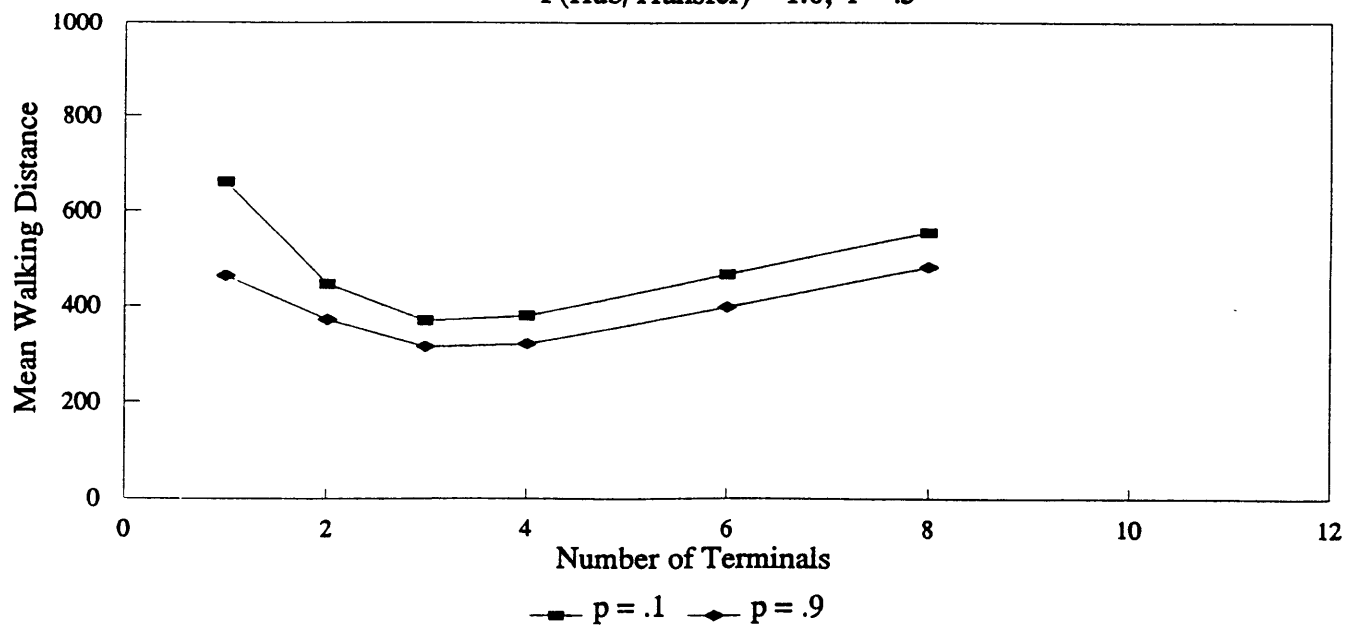
(Angle = 180)

Configuration Robustness (Part II)
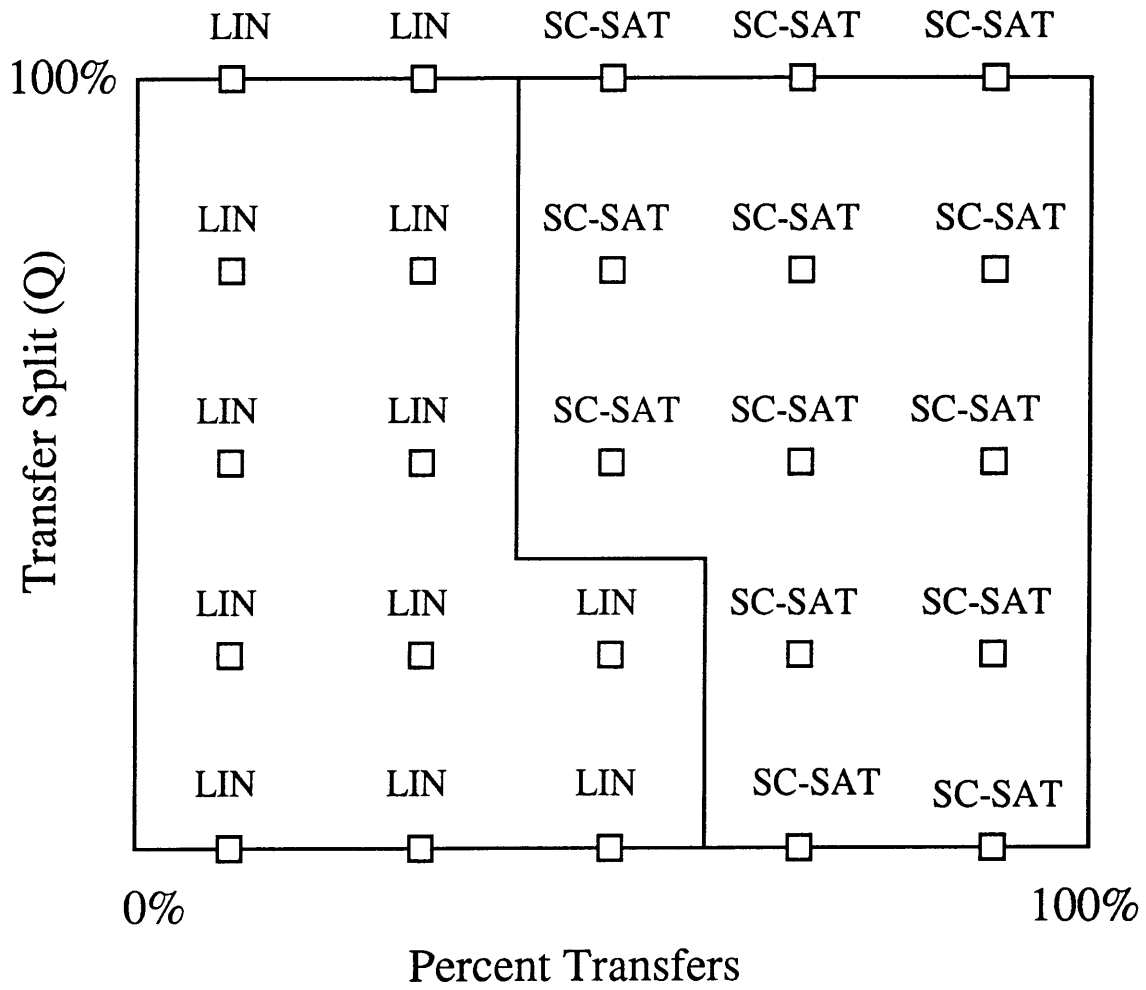
"Ownership" Test

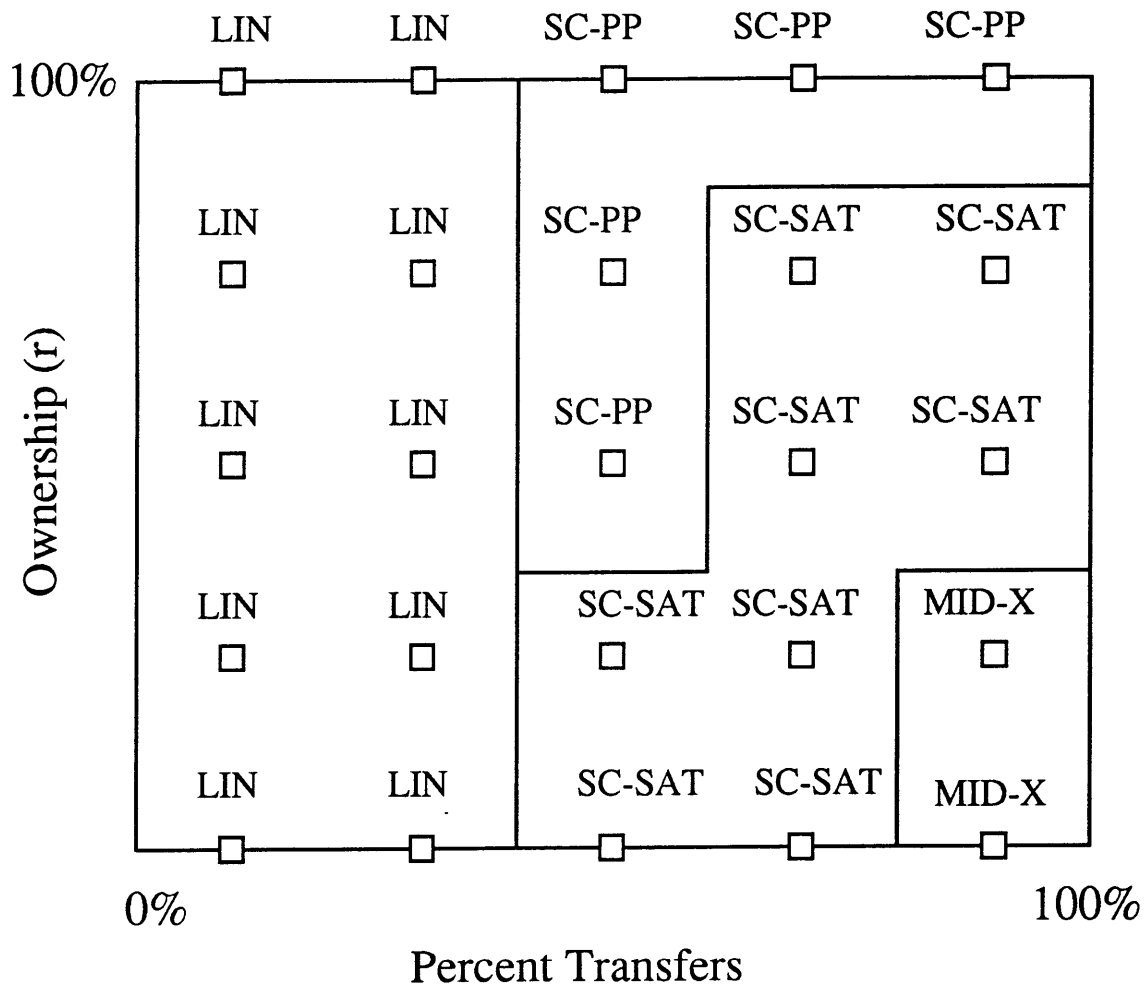# Centralized Satellite Circle
P(Hub/Transfer) = 1.0, P(Trans) = .90
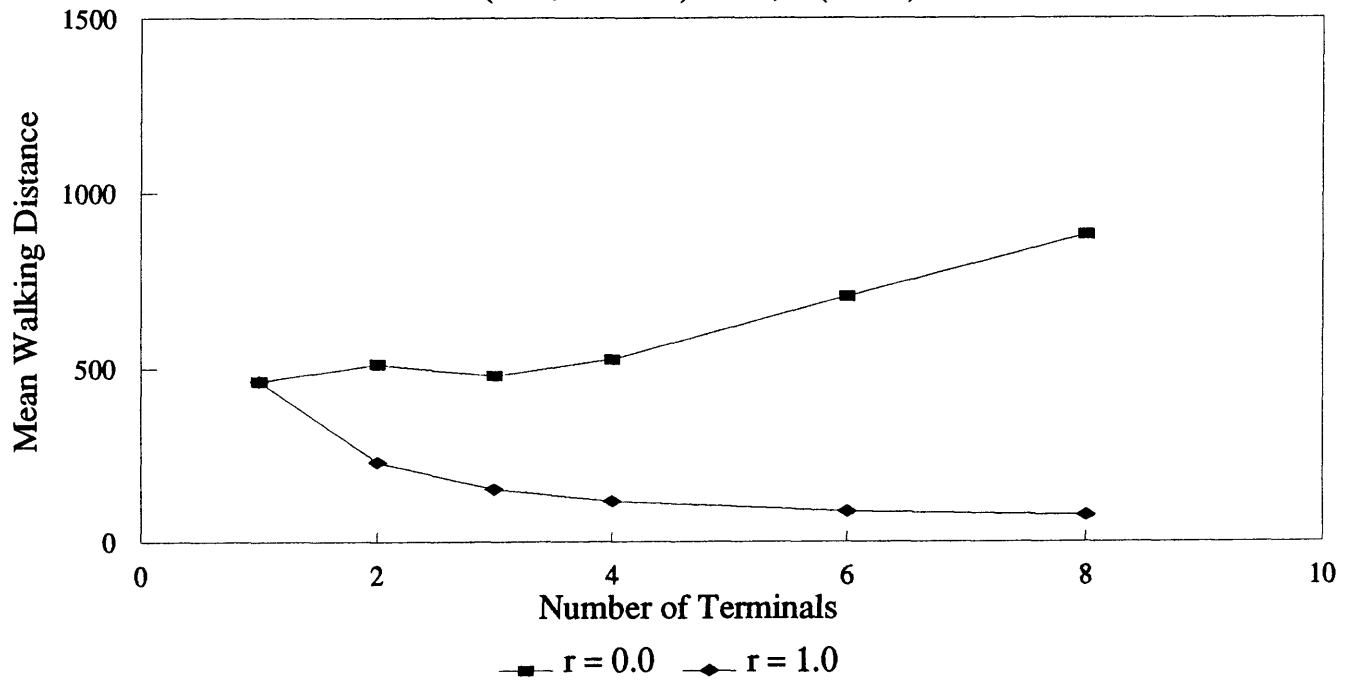
(Angle = 180)

Best Of The Best

(Walking Distance)

Best Of The Best

(Walking Distance)

Mandatory Walking Distances

As A Means Of Comparison, The Total Distance Between Points In An Airport May Be Inappropriate If Mechanical Devices Exist Which Greatly Reduce Walking Distances.

Therefore, A More Relevant Metric May Be The Mandatory Walking Distances Required Of Passengers.

Assumptions Made :

1) Mechanical Devices Exist For Transport Between Concourses In Centralized Configuration Concepts, Just Beyond The Check-In Area.

2) Underground Connectors Containing Moving Sidewalks Exist For Transport To Satellites.

3) Underground Trams Exist For All Midfield Designs.

4) For This Particular Experiment, We Do Not Include Shuttle Buses (Terminal Area Devices Only).

Best Of The Best

(Mandatory Walking Distance)
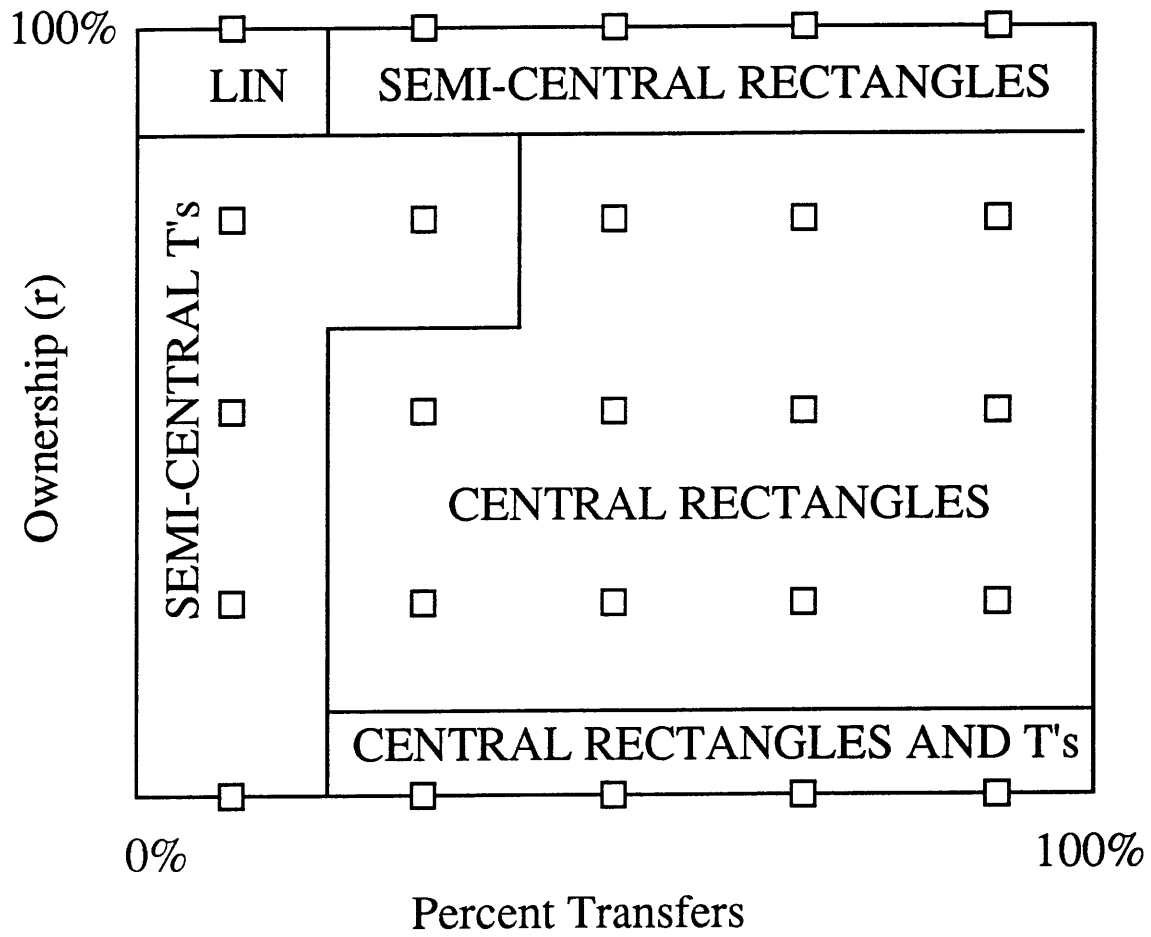
Further Research

1) Introduction Of Shuttle Buses Into Mandatory Walking Model.

2) Development Of Travel Time Model.

$$Time = \sum_{i=1}^{n} \frac{d_i}{r_i}$$

i) Rate Of Travel Is Affected By Congestion In Area.

ii) Mechanical Devices Can Reduce Both Walking Distances And Travel Times.

iii) Shuttle Buses And Trams Have A Wait Time Component That Depends On Frequency Of Service.

3) Inclusion Of Other Configuration Concepts.

4) Larger Airports (G = 72+)

Conclusions

1) Tell Women At Cocktail Parties You're A Pilot.

2) Terminal Configuration Performance Depends On Many Factors, Including :

    i)   Level Of Traffic
    ii)   Type Of Traffic
    iii)   "Ownership" Of Individual Concourses
    iv)   Flight-To-Gate Assignments
    v)   Gate Specific Aircraft Utilization
    vi)   Peakiness Of Demand

3) Given A Particular Configuration Concept, The Most Appropriate Number Of Terminals / Concourses Can Be Determined Using New Methodology.

4) Most Appropriate May Not Be Mathematically Optimal, But Rather Most Robust Over Different Conditions (Transfer Split / Ownership).

5) Armed With Most Appropriate Of Each Of The Different Concepts, The "Best Of The Best" Can Be Determined For Initial Configuration Selection.

6) Information Gathered From Selection Among Standard Terminal Concepts Can Aid In Designing Robust "Hybrid" Concepts.

Demand Driven Dispatch in Airline Hub Operations

Presented by

Gary Waldman

to

MIT - Industry Cooperative Research Program in Air Transportation

20 May 1993

Outline of Presentation

- **Background on Demand Driven Dispatch**
- **Components of a Demand Driven Dispatch System**
  - **Switching Flexibility**
  - **Revenue Management System**
  - **Optimal Assignment Routine**
- **Types of Simulations and Demand Scenario Definitions**
- **Discussion of Results**
- **Conclusions**

Background Information

- **What is Demand Driven Dispatch? Demand Driven Dispatch is an airline operational philosophy which seeks to maximize operating profits by by changing aircraft flight leg assignments to adjust for variable passenger demands.**

- **Airline requirements to run a demand driven dispatch system**
  - **A family of aircraft with common flight crew ratings**
  - **A revenue management system which tracks passenger demand (booked and forecasted) over multiple booking periods and fare classes**
  - **A detailed model of aircraft operating costs**

- **Developed by Boeing as a means to promote family of aircraft concept**

The Problem of Variable Demand

- Variability is a major cost item. While passenger demand is variable, aircraft assignments are fixed. This leads to demand spill and low load factors.

- Today's fix is differential pricing.

  - Benefits

    1. Revenues are increased on the order of 10-15% over no control situation

  - Drawbacks

    1. Unhappy Passenger - can buy a more expensive ticket or fly at a less desirable time

    2. Unhappy Airline - the passengermight fly the competition or not at all

    3. Variability Spiral - what constitutes base demand is unclear, leads to further overbooking

- Demand Driven Dispatch enhances Benefits while minimizing Drawbacks

Hub and Spoke Route Network

For this study switching opportunities exist only during a 'connecting bank' at a hub airport (right). A more sophisticated demand driven dispatch model like the one developed by Boeing allows for switching to occur at spoke stations as well (below).

Spoke City

Hub

Station A

Hub

Station B

——— Aircraft Type 1

– – – Aircraft Type 2
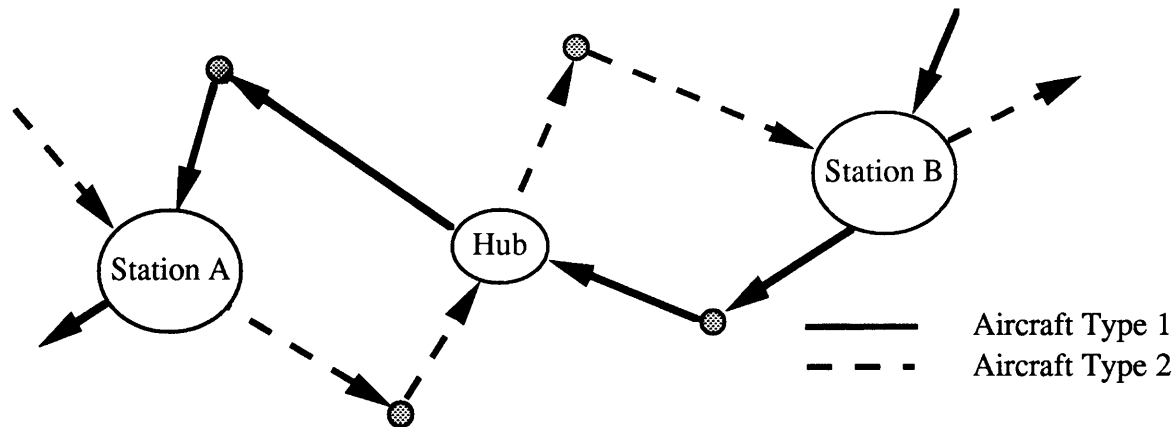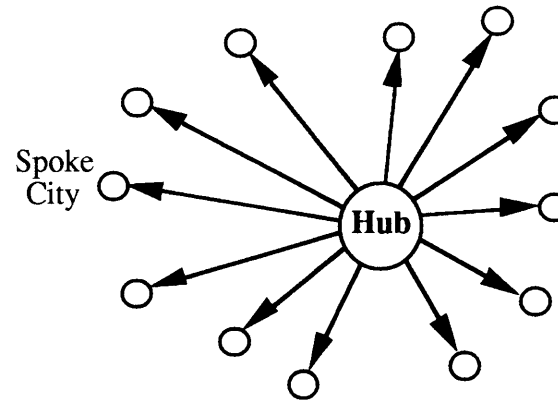
Mythical Dallas-Fort Worth Hub

- DFW hub connects with 15 spoke cities from AUS (183 miles) to SEA (1660 miles)

- 15 aircraft "assigned" to the hub in quantities of 5 each of 737-300 (128 pax), 737-400 (148 pax), and 737-500 (108 pax)

- The assigned aircraft will fly both directions between the hub and the selected spoke city with switching occuring when all aircraft have returned to the hub

- The fixed baseline assignments, which represent current airline practice, evenly distribute aircraft types over leg distances

- For the sake of realism, aircraft assigned to a city pair for the entire daily cycle fly a number of roundtrips proportional to roundtrip flying distance

Distance Category	Mileage Range	Number of Daily Frequencies
Short Haul	0 to 350	4
Medium Haul	350 to 1000	2
Long Haul	Over 1000	1

Hub Airport Load Diagram

Airport Load Diagram Throughout
Single Bank Assignment Cycle
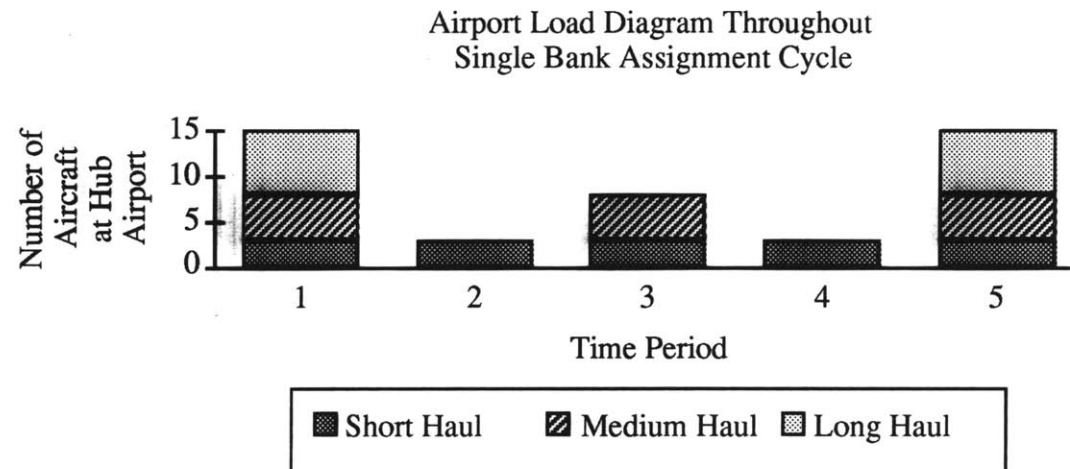
- **Aircraft are assigned in time period 1 only. Switching during other times of collocation is possible**

- **The passenger demands for each flight leg are equal in each instance of that flight leg (i.e. the demand on the 4 DFW-AUS legs are assumed equal)**

Revenue Management Modeling

- Revenue management systems determine fare class booking limits on each flight leg which will maximize revenue given

    - mean passenger demand by fare class

    - variation in passenger demand by fare class

    - seating capacity of the aircraft

- The EMSR heuristic for leg level, nested fare class seat inventory management was used in this study.

    - 7 nested fare classes

    - 10 booking periods

    - fares based upon actual flown revenue in spoke markets selected as part of mythical DFW hub

Optimal Aircraft Assignment Routine

Revenue Management Data →

$$\text{Maximize } \sum_i \sum_j C_{ij} \, x_{ij}$$

$$\text{where } C_{ij} = \sum_{n=1}^{p} BKDREV_{jn} + \sum_{n=p+1}^{f} EXPREV_{ijn} - AC\_COST_{ij}$$

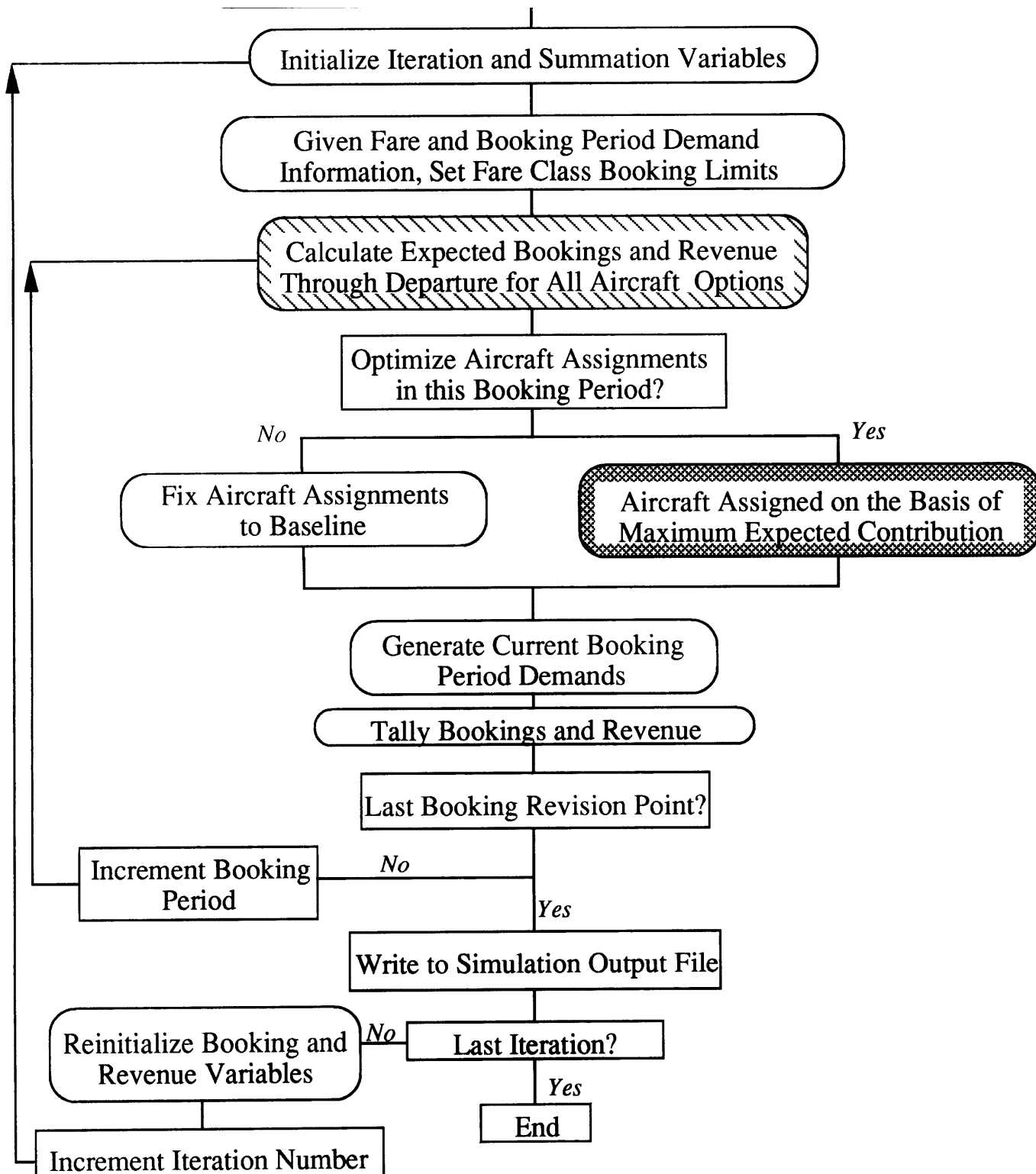**Subject to**

$$\sum_j x_{ij} = NAC_i$$

$$\sum_i x_{ij} = 1$$

$$\sum_i CAP_i x_{ij} \geq BKDPAXO_j$$

$$\sum_i CAP_i x_{ij} \geq BKDPAXI_j$$

$$0 \leq x_{ij} \leq 1$$

→ **Aircraft Assignments**

i = number of aircraft types
j = number of legs
n = number of booking periods
p = current booking period

Initialize Iteration and Summation Variables

Given Fare and Booking Period Demand Information, Set Fare Class Booking Limits

Calculate Expected Bookings and Revenue Through Departure for All Aircraft Options

Optimize Aircraft Assignments in this Booking Period?

No → Fix Aircraft Assignments to Baseline

Yes → Aircraft Assigned on the Basis of Maximum Expected Contribution

Generate Current Booking Period Demands

Tally Bookings and Revenue

Last Booking Revision Point?

No → Increment Booking Period

Yes → Write to Simulation Output File

Last Iteration?

No → Reinitialize Booking and Revenue Variables

Yes → End

Increment Iteration Number

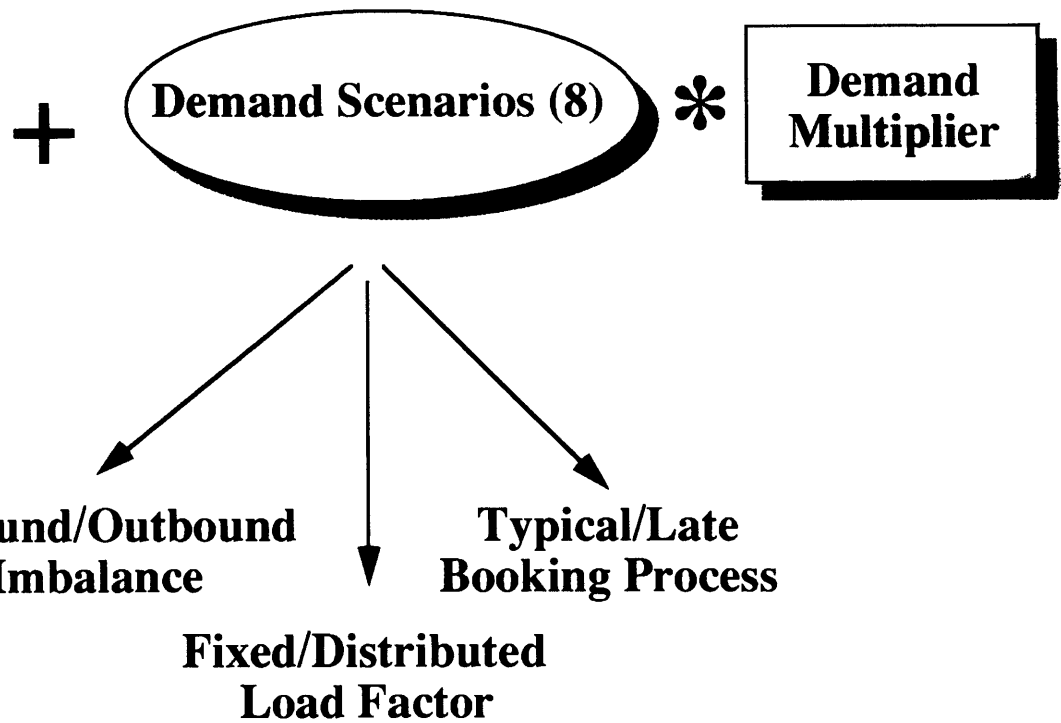# Study and Scenario Definitions

**Performance of Demand Driven Dispatch Relative to Fixed Assignment Case**

Sensitivity of Demand Driven Dispatch Process to Varying the Number of Assignment Revision Points

+

Demand Scenarios (8)

✳

Demand Multiplier

Inbound/Outbound Imbalance

Typical/Late Booking Process

Fixed/Distributed Load Factor

Demand Balance

- **Equal Demands**

    - Passenger demands on legs inbound to and outbound from hub are equal.

- **Unequal Demands**

    - Passenger demands on one of two legs connecting the hub with a spoke city are increased 10% and are lowered 10% on the other.

    - Average overall number of passengers does not change.

   - Expected revenue on leg will change because standard deviation of demand is defined to be equal to the square root of the mean demand. This will affect fare class booking limits

Booking Patterns

Cabin Level Booking Demand Curves

— Late Booking Pattern   ----- Typical Booking Pattern
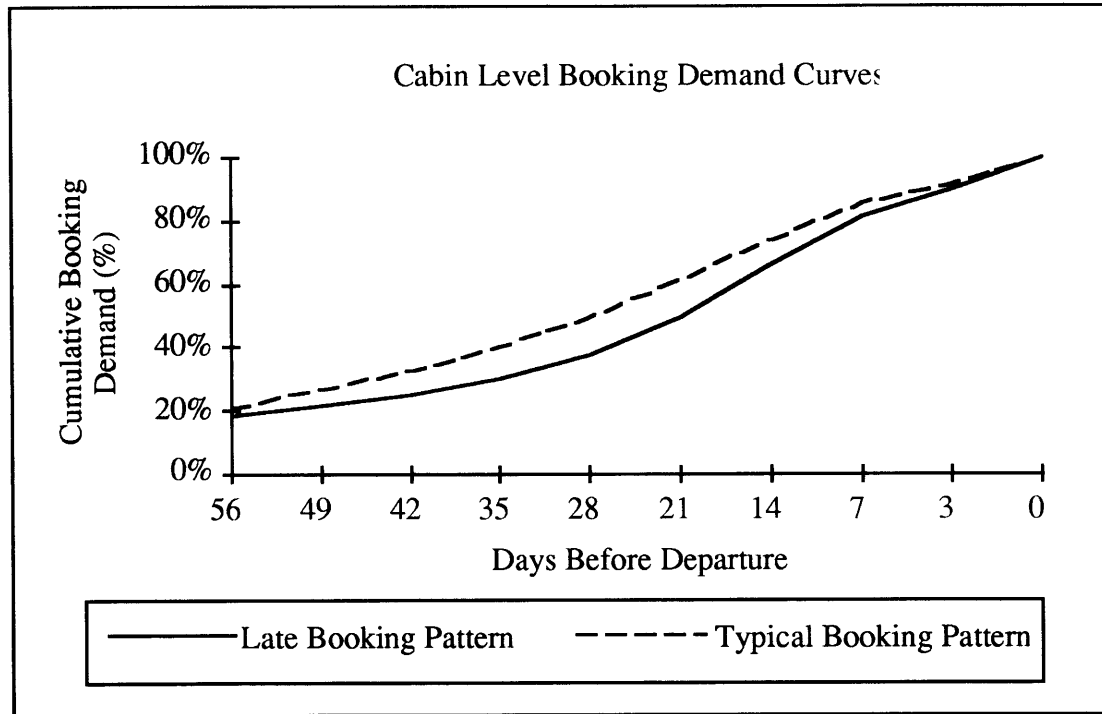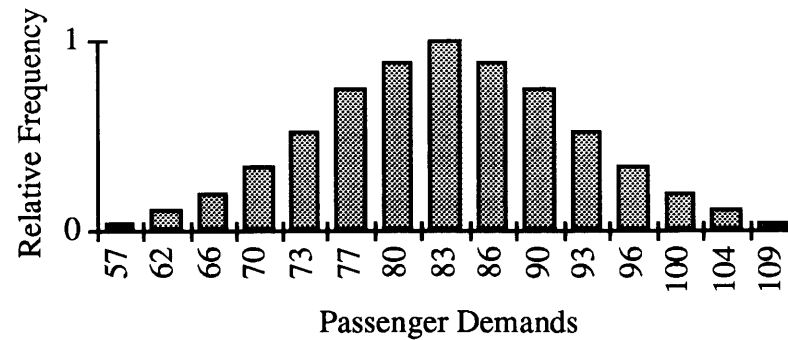
Baseline Load Factors

- **Constant Load Factor of 65%**

Histogram of 65% Planned
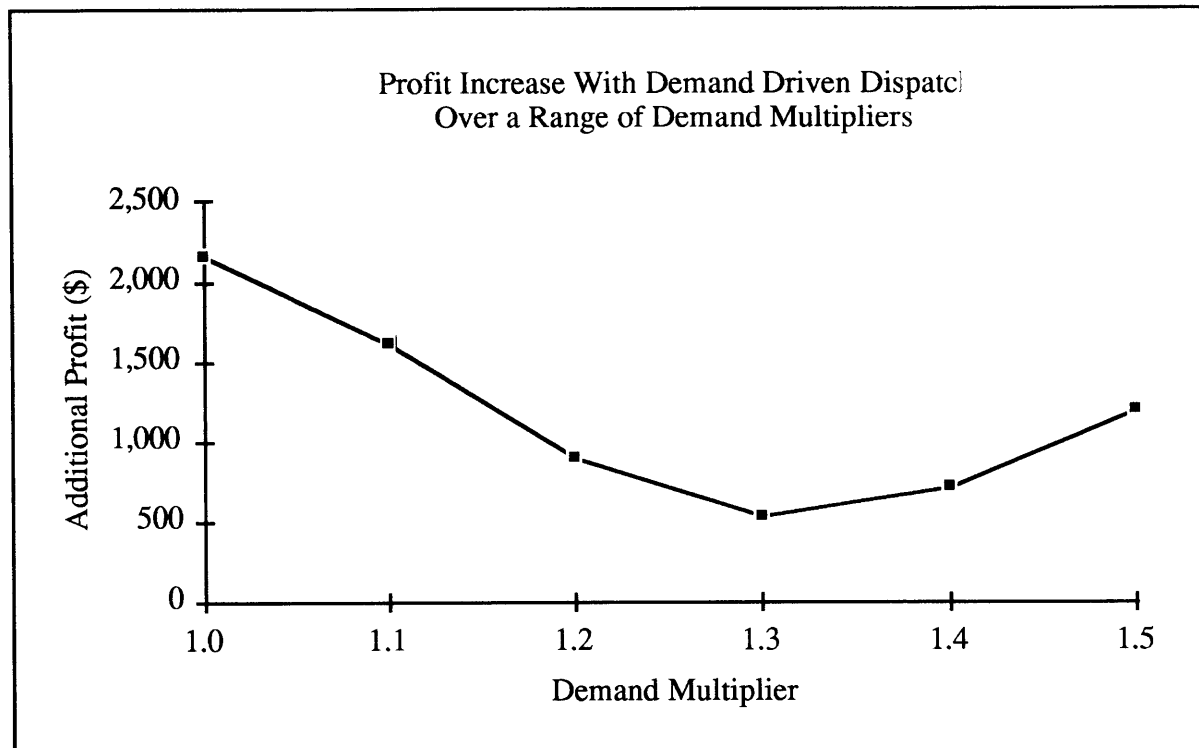Load Factor Demands
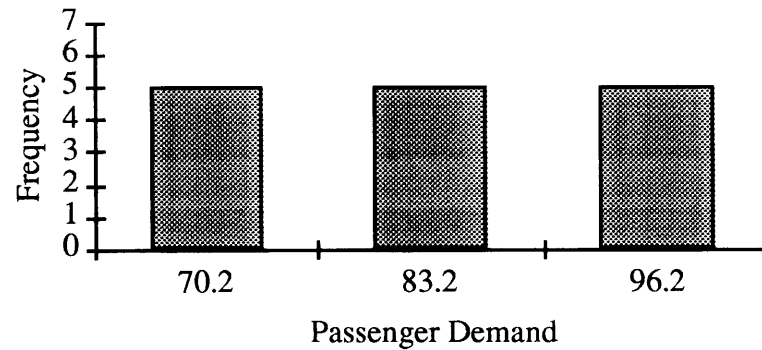
- **Distributed Load Factor with Same Mean Demand as Constant Load Factor Case**

Distributed Demand
Mu=83.2, k=0.3


140

Typical Operating Profit Results

Profit Increase With Demand Driven Dispatc
Over a Range of Demand Multipliers

**Benefits of demand driven dispatch vary in a predictable
manner over a range of demand multipliers**

Typical Aircraft Utilization Patterns

Demand Driven Dispatch Daily Aircraft
Utilization Relative to Static Model
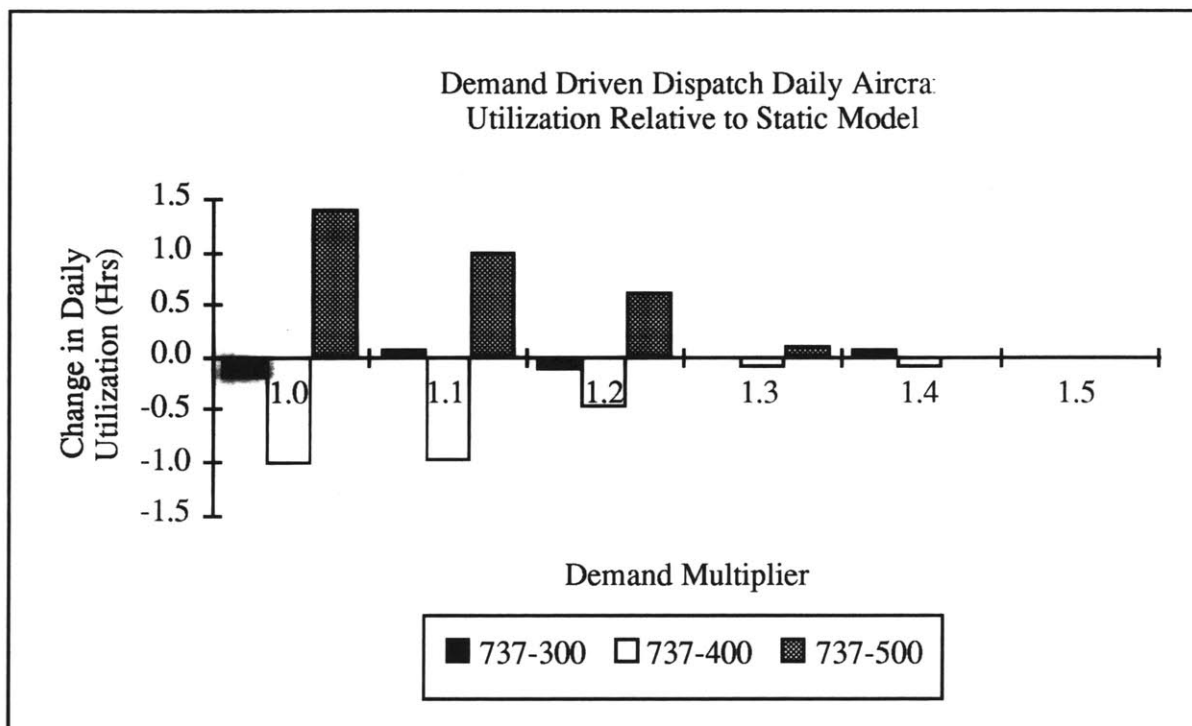
**Aircraft utilization patterns play a major role in determining
increased profitability potential of demand driven dispatch**

Demand Driven Dispatch Sensitivity

Effects on Contribution from
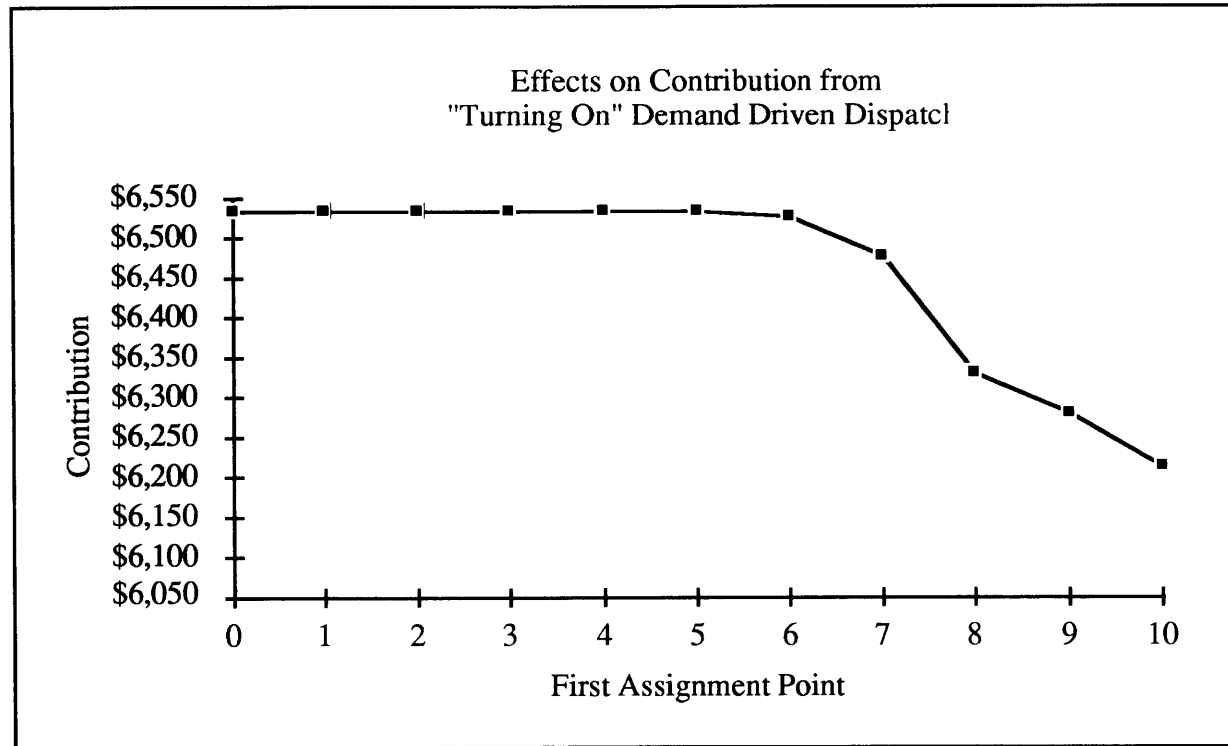"Turning Off" Demand Driven Dispatch
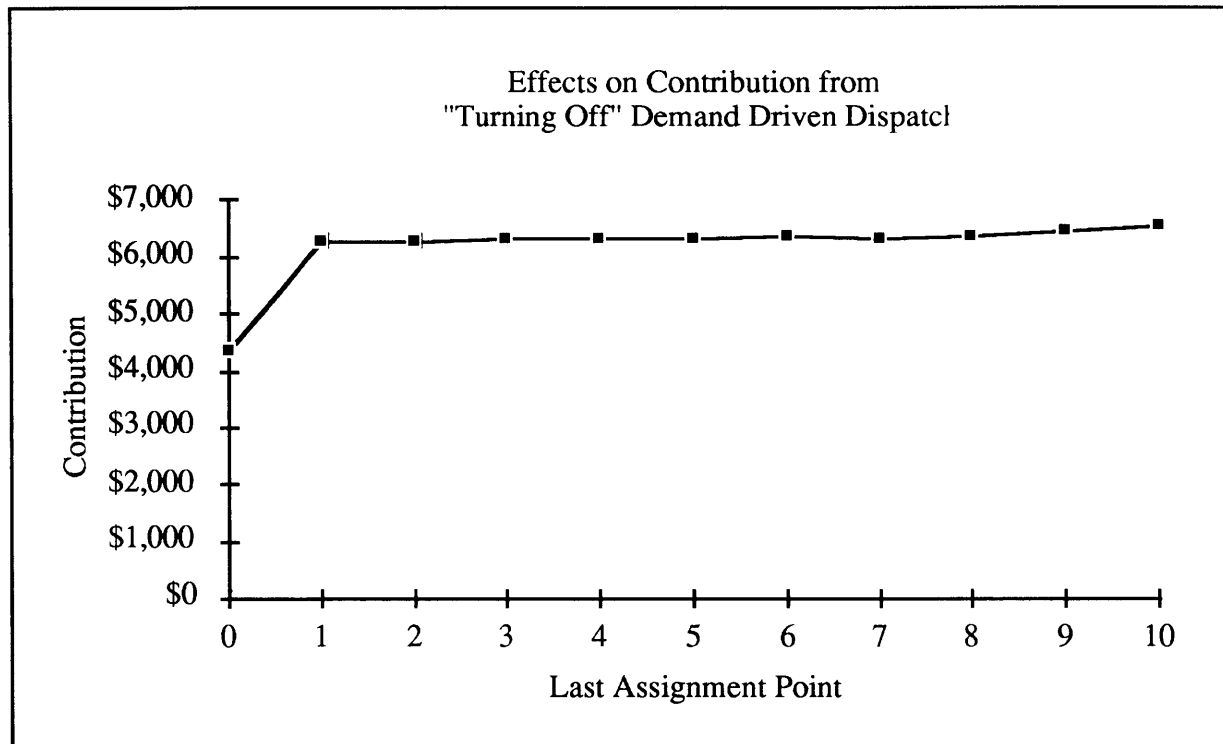
**A significant proportion of demand driven dispatch benefits
can be achieved with a one time evaluation of assignments**

Demand Driven Dispatch Sensitivity (cont'd)

Effects on Contribution from
"Turning On" Demand Driven Dispatch

**Demand driven dispatch routine can be run without performance
loss up to point of significant bookings or revenue**

Conclusions

- Increased contribution of $35-$40 million is possible at an airline the size of a major US carrier without major changes to operating procedures or indirect costs

- Demand driven dispatch benefits are greatest at average historical load factor levels and do not vary with demand composition assumptions

    - more deterministic demand patterns at high load factors

- Most of the demand driven dispatch benefit at typical demand multipliers results from lower trip costs achieved through more efficient aircraft utilization

- A large fraction of demand driven benefits can be achieved with only a single execution of the algorithm. This event can be delayed up to the booking period when heavy bookings are expected or leg bookings exceed aircraft capacities.

- The recommended number of assignment revisions is dependent upon forecasting data availability and accuracy