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#### FLIGHT TRANSPORTATION LABORATORY REPORT R 91-4

#### PRESENTATIONS FROM THE MIT/INDUSTRY COOPERATIVE RESEARCH PROGRAM ANNUAL MEETING, 1991

Belobaba, Williamson, et al.

May 1991

# DEPARTMENT OF AERONAUTICS & ASTRONAUTICS

FLIGHT TRANSPORTATION LABORATORY Cambridge, Mass. 02139

#### FTL REPORT R 91-4

#### PRESENTATIONS FROM THE MIT/INDUSTRY COOPERATIVE RESEARCH PROGRAM ANNUAL MEETING, 1991

#### TABLE OF CONTENTS

Origin-Destination/Segment Seat Inventory Control: Modeling and	
Peter Belobaba	1
Application of Network Solutions to Origin-Destination Seat Inventory Contr Elizabeth Williamson	ol. 14
Planning and Scheduling Tasks in a Dynamic Environment. Lyman Hazelton	46
Concentration in U.S. Air Transportation: An Analysis of Origin-Destination	
Markets since Deregulation. Jan van Acker	73
Pricing in the Airline Industry: Current Practice and Future Research. Theodore C. Botimer	102
Changes in Origin-Destination Passenger Traffic Flows: Newark Airport. Chung Mak and Peter Belobaba	129
Airline Seat Inventory Control for Group Passenger Demand. Peter Belobaba and Tom Svrcek	157
Airline Crew Scheduling Re-visited. Robert W. Simpson	173
Scheduling Systems: Computer Aids for Execution Rescheduling. Dennis F.X. Mathaisel	187

# O-D / SEGMENT SEAT INVENTORY CONTROL: Modeling and Implementation Issues

Professor Peter P. Belobaba MIT Flight Transportation Laboratory

MIT/Industry Cooperative Research Program Annual Meeting May 23, 1991

### PASSENGER ITINERARY CONTROL

- In contrast to the control of seat inventories by flight leg/booking class, passenger itinerary control requires methods that can distinguish among passenger itineraries vying for seats on the same flight leg, even within the same fare product "category".
- Passenger Itinerary Control concepts can be applied through:

DUAL/OVERLAP FLIGHTS: Two or more flight numbers representing different itinerary "paths" assigned to a single flight leg.

POINT OF SALE CONTROL: Seat availability is differentiated between points of sale due to currency or net revenue differences.

SEGMENT CONTROL: Seat availability is managed by booking class and passenger itinerary on a <u>multiple-leg flight</u> with the same flight number.

O-D CONTROL: Seat availability is managed by fare category <u>and</u> O-D itinerary, even across connecting flights.

-2-



NETWORK OPTIMIZATION APPROACHES

- Traditional O.R. approach to dealing with itinerary control is to perform a joint optimization over the entire network of flight legs defined by the problem.
- Network formulations and/or mathematical programming approaches are used to find the optimal <u>allocation</u> of seats to each origin-destination itinerary and fare type (ODF) on each flight leg:
  - -- requires demand forecasts and fare values for each ODF
  - -- problem representation can be deterministic or probabilistic
  - -- solution ensures balanced ODF allocations across flight legs
  - -- ODF allocations are "optimal" given assumed mathematical formulation of problem

-4 -

- Implementation of these "optimal" network ODF seat allocations as ODF booking limits, however, can have <u>substantial</u> negative revenue impacts.
  - use of partitioned or discrete booking limits <u>lowers</u> expected revenue relative to nested limits
  - -- negative revenue impact becomes larger with more ODF allocations
  - -- dynamic simulations show that use of "optimal" partitioned segment/class limits on a 3-leg flight can result in revenue <u>reductions</u> of 1% to 2% relative to simple leg/booking class control
- The <u>optimal solution</u> to an assumed mathematical formulation <u>does not</u> <u>maximize revenues</u> when implemented this way.

# NESTING OF NETWORK OPTIMAL SOLUTIONS

## 1. Nesting of ODF Allocations Within Each O-D/Segment

- Network ODF allocations for each O-D/segment are nested into a shared inventory of seats, in order of normal nested booking classes
  - -- each ODF allocation is treated as a fare class "protection level" within the O-D/segment "nest"
  - -- each flight leg still has a <u>discrete</u> allocation of seats for each segment/O-D itinerary
  - -- simply summing discrete allocations gives sub-optimal nested booking limits within each O-D/segment nest

## EXAMPLE: 2 segments on Leg A-B (Capacity = 100)

ODF	Optimal Allocation	Segment Nesting
YAB	8	42
BAB	12	34
MAB	06	22
QAB	16	16
YAC	18	58
BAC	7	40
MAC	23	33
QAC	10	10

## 2. Joint Allocation and Nesting Within O-D/Segment

- Published by Curry in Transportation Science (1990)
  - -- approach jointly finds optimal allocation to each "O-D nest" <u>and</u> nested limits on each booking class within the nest
  - -- optimal solution to the formulated problem
  - -- still a <u>discrete</u> allocation of seats to each segment/O-D (i.e., "O-D nest")
- Both approaches above can have positive revenue impacts compared to leg/booking class control provided that number of discrete O-D nests does not become large
- Otherwise, <u>negative</u> revenue impacts can result when implemented as a control methodology

## 3. Nesting of ODF Allocations on Shadow Prices

-9-

- Described in Williamson's (1988) MIT Master's thesis
  - -- optimal ODF allocations are ranked and nested in order of <u>shadow price</u> values derived from the optimization algorithms
  - -- the <u>shadow price</u> of an ODF allocation is the amount by which total expected network revenue will increase (or decrease) if one additional seat is allocated to that ODF
  - -- on each flight leg, ODFs with highest shadow prices values receive greatest availability -- ODF allocations are treated as "protection levels" for nesting purposes

EXAMPLE: 2 segments on Leg A-B (Capacity = 100)

	Optimal	Shadow	Nested
ODF	Allocation	Price	Limits
YAB	8	225	100
BAB	12	200	92
YAC	18	190	80
BAC	7	165	62
MAB	6	110	55
MAC	23	40	49
QAC	10	10	26
QAB	16	0	16

- Implementation into control structure possible through <u>virtual inventory classes</u> defined by shadow price ranges
- Nesting of optimal ODF allocations on current shadow prices results in theoretically <u>sub-optimal</u> booking limits for different ODFs
- Yet, a large number of dynamic booking simulations of this approach as a control methodology show consistent and substantial revenue improvement over leg/booking class control

### 4. Network "Bid-Price" Approaches

- Developed at MIT: Simpson (1989) and Williamson (1990)
  - -- network optimization can also produce shadow prices on the capacity constraint associated with each flight leg, or "bid prices"
  - -- Bid Price Control of seat inventories simply requires a comparison of the fare of the requested ODF itinerary and the <u>sum of the bid prices</u> involved in the itinerary.
  - -- Implementation requires frequent (realtime?) updating of network bid prices to overcome absence of booking limit controls
- Bid Price Approach is a sub-optimal control application of optimal network solution, which overcomes negative impacts of discrete ODF allocations through "implicit nesting" of availability through bid price evaluation decision.

## SUMMARY -- NETWORK OPTIMIZATION APPROACHES

- Network optimization approaches produce optimal ODF seat allocations over a network of flights:
  - -- require ODF demand forecasts and fares
  - -- generate partitioned ODF allocations that must be "nested" in sub-optimal ways to have positive revenue impacts
- Truly <u>optimal</u> solution for <u>control</u> of ODF itineraries over a network requires an approach that
  - -- accounts for nesting of ODFs explicitly
  - -- allows "desirability" of ODFs to change as demand materializes
  - -- recognizes dynamic nature of future booking process
  - -- overcomes "small number" problems of forecasting ODF demands

- Network optimization methods produce an optimal solution to an <u>assumed</u> mathematical formulation of the O-D/segment control problem
- Implementation of <u>optimal</u> solutions in actual reservations control structures can lead to <u>negative</u> revenue impacts if done incorrectly
- Nesting of optimal network ODF allocations for control purposes is a <u>sub-optimal</u> solution, although some nesting approaches consistently produce better revenue impacts than others
- No one has <u>formulated</u>, let alone "solved" the dynamic, nested ODF network seat inventory control problem

#### APPLICATION OF NETWORK SOLUTIONS TO O-D SEAT INVENTORY CONTROL

Elizabeth L. Williamson Flight Transportation Laboratory Massachusetts Institute of Technology

Presented to

MIT/Industry Cooperative Research Program May 23, 1991 Cambridge, MA

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## Introduction

Reviewing network seat inventory control techniques and applying them to three different multi-leg examples, using real airline data:



### Network Solutions Nested on Shadow Prices

- Network formulation used to find seat allocations for each ODF over an entire network of flights.
- Distinct allocations are nested according to the shadow price of each ODF.
- •Shadow Price: The amount the optimal system revenue value would change if one more seat was made available to the given ODF.

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## Nested Deterministic by Shadow Prices 3 Leg Example Leg BC - Capacity=90

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	Seats		Shadow	Booking
ODF	Allocated	Fare	Price	Limit
ACY	2	519	322	90
BCY	10	440	243	88
ADY	3	582	216	78
ACM	1	344	147	75
BCM	22	315	118	74
BDY	6	440	74	52
ACB	4	262	<b>6</b> 5	46
ACQ	14	231	34	42
BCB	12	223	26	28
ADM	1	379	13	16
BCQ	15	197	0	15
BDM	0	307	-59	0
ADB	0	302	-64	0
ADQ	0	269	-97	0
BDB	0	221	-145	Q
BDQ	0	199	-167	0
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### EXAMPLE

# Single Leg, 4 Fare Classes

	MEAN	STD	FARE
Y	20	7	500
Μ	15	5	350
B	30	10	200
Q	25	8	150

## ALLOCATIONS

	DETER	PROB	EMSR
Y	20	27	17
Μ	15	19	20
B	30	31	27
Q	25	23	36

#### **BOOKING LIMITS**

	NDSP	NPSP	EMSR	OPTIMAL
Y	100	100	100	100
Μ	80	73	83	83
B	65	54	63	62
Q	35	23	36	33

## **Initial Allocations**

# 3 Leg Example AB Leg - Capacity=75

Distinct Deterministic				Distinct Probabilistic					
	Y	Μ	В	Q		Y	М	В	Q
AB	25	3	7	26	AB	28	5	10	26
AC	2	1	4	4	AC	3	0	1	0
AD	3	0	0	0	AD	2	0	0	0

## Difference in Allocations (Prob - Deter)



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## Comparison of Allocations Over 15 Revisions

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		Deter	Prob
	Mean	Alloc	Alloc
AB Y	25.2	25	28
	25.1	25	28
	24.8	25	28
	24.0	24	28
	22.8	23	28
	22.0	22	26
	20.4	20	26
	19.3	19	26
	16.9	17	25
	15.6	16	23
	12.3	12	21
	9.2	9	19
	8.6	9	18
	5.9	6	15
	2.6	3	11

Partially Nested versus Fully Nested

Partially Nested (Curry):

- Determine discrete allocations for each OD, based on expected revenue from nested fare classes.
- Determine fare class booking limits within each OD allocation.

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Expected Revenue (\$)

-27-

## Fully Nested versus Partially Nested 3 Leg Example Leg BC - Capacity=75

	NDSP	NDSP	DOD-NFC
ODF	Allocations	BL	BL
ACY	2	75	4
ACM	1	38	3
ACB	4	31	0
ACQ	4	15	0
ADY	3	63	2
ADM	0	0	0
ADB	0	0	0
ADQ	0	0	0
BCY	10	73	64
BCM	22	60	57
BCB	12	27	38
BCQ	11	15	32
BDY	6	37	5
BDM	0	0	1
BDB	0	0	0
BDO	0 0	0	0





Percent Difference from Leg Based EMSR

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Percent Difference from Leg Based EMSR

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-31-

#### Bid Price

- Bid Price is a Shadow Price for the capacity constraints.
- Obtained from the same network formulations.
- The marginal value of the last seat of a given flight leg.
- Bid Prices establish a "cutoff" value for each flight leg, on which decisions can be made whether to accept or reject a given O-D/fare class request.
- For a single leg itinerary, a fare class is open for bookings if the corresponding fare is greater than the bid price, or shadow price, for the leg.
- For a multi-leg itinerary, fares must be greater than the sum of the bid prices from the respective flight legs.



<u>BC:</u>	<u>197</u>	<u>AC:</u>	231	<u>AD:</u>	400
Y	440	Y	519	Y	582
M	315	M	344	M	379
B	223	B	262	B	302
O	197	Q	231	Q	269




Percent Difference from Leg Based EMSR



Percent Difference from Leg Based EMSR

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□ NDSP + BID

Percent Difference from Leg Based EMSR



Percent Difference from Leg Based EMSR

-38-



Percent Difference from Leg Based EMSR

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## UPPER BOUND

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	MEAN	STD DEVI	
ABY	36.12	14.91	
ABB	9.94	13.92	
ABM	18.61	16.01	
ABQ	34.06	- 25.96	
-			

## ACTUAL DEMAND

ABY	35	28	48
ABB	14	12	8
ABM	18	18	16
ABQ	39	32	34

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Percent Difference from Leg Based EMSR

-43-



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## Summary

- Nested Deterministic on Shadow Prices outperforms Nested Probabilistic on Shadow Prices.
- Given full ODF forecasts, better to use a fully nested method, such as NDSP, rather than a partially nested method.
- Deterministic Bid Price approach performs well and uses a very simple control methodology, however it is important to be able to make frequent revisions using such an approach.
- Using Upper Bound, the true potential from better control of seat inventories over current leg based approaches can be determined.

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## Planning and Scheduling of Tasks in a Dynamic Environment

## Lyman R. Hazelton

23 May 1991

-46-

- The Strategic Control of systems requiring *planning* and *scheduling* of activities is called *Operations Management*
- Reasoning about the future in a dynamic environment.
- Determination of the time that a state or process should be maintained.
- Situation dependent objectives.
- No final system state.
- Often involve non-quantifiable parameters.

A decision was made to attempt to solve the problem with an "Expert Systems" approach. However, existing AI planning methods

- Were based on a back-chained, goal seeking technology.
- Have been shown to be NP-hard or even Non-terminating for conjunctive goals.
- Assumed a single actor, non-stochastic universe.
- Had no logic or even representation for time dependent activities.

In summary, the automatic reasoning technology necessary to attack the problem did not exist.

At the time the research was initiated:

- There were NO programs or even algorithms for temporal database management
- There were NO data representations for concurrent temporally bounded information
- Automatic plan generation was restricted to Singlé Actor Domains Determinaté Domains Instantaneous Actions

**Operations Management Model** 



-50-

LRH-90-01









Plan: PAINT LADDER Procedure: GET PAINT GET LADDER APPLY-PAINT LADDER Results: PAINTED LADDER

Plan: PAINT CEILING

Procedure:

GET PAINT Goal: NEAR CEILING APPLY-PAINT CEILING

**Results:** 

PAINTED CEILING

-53-



LRH-91-01



## • Truth Maintenance A first attempt to extend logic into a dynamic environment.

# $R: p \cdot q \rightarrow r \cdot \{R \ p \ q\} \top r$ $\tilde{p} \mid \tilde{q} \rightarrow r$



-56-

LRH-90-006

## • Inferred evolution $R: p \cdot q \rightarrow r \cdot p \cdot$ $\{R \ p \ q\} \top r$ $p \mid q \supset r$ (TM) R

-57-

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## • Introduce EXPLICITLY the TIME INTERVAL during which a proposition (was, is, will be) true:

## $p(\tau)$

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where  $\tau$  is a time interval having a starting time and an ending time.

## • Persistence:

## $\begin{array}{cccc} R: p \rightarrow q \\ \tilde{p} \tilde{\boldsymbol{5}} q & (\text{NO TM}) \end{array}$

If it is raining (*P*), the roads will be wet (*q*).
But if it stops raining (*P*), the roads do not instantly become dry. Wet roads persist. \* assachusetts stitute of Flight Transportation Laboratory

- Temporal Logic (continued)
  - Rules of Inference

Modus Ponens:

 $p \rightarrow q$   $p(\tau)$   $\therefore q(\tau) \text{ Non-persistent}$   $\therefore q(\operatorname{start}(\tau), \infty) \text{ Persistent}$ 

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• Inferred evolution revisited  $R: p(\tau_1) \cdot q(\tau_2) \rightarrow r(\tau_1 \cap \tau_2) \cdot$  $\tilde{p}(\tau_1 \cap \tau_2)$  $\{R \ p(\boldsymbol{\tau}_1) \ q(\boldsymbol{\tau}_2)\} \top r(\boldsymbol{\tau}_1 \cap \boldsymbol{\tau}_2)$  $\{R \ p(\tau_1) \ q(\tau_2)\} \top \tilde{p}(\tau_1 \cap \tau_2)$  $\tilde{p}(\tau) \mid \tilde{q}(\tau) \supset r(\tau)$  $R p(\tau_1) q(\tau_2)$  $\downarrow \downarrow \checkmark$  $r(\tau_1 \cap \tau_2) \cdot \tilde{p}(\tau_1 \cap \tau_2)$ LRH-90-023

-6]-

 The problem stems from the fact that the reasoner's BELIEF (i.e., knowledge) changes during the reasoning process.

There are TWO time intervals involved in temporal reasoning.

• The ACTIVITY interval, during which the proposition (was, is, will be) true

• The BELIEF interval, during which the reasoner believes a proposition about some activity interval to be true

-63







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**ABUTS-BEFORE** (STARTS-BEFORE ENDS-DURING) (STARTS-BEFORE ENDS-EQUAL) CONTAINS (STARTS-EQUAL ENDS-DURING) EQUAL (STARTS-EQUAL ENDS-AFTER) IS-CONTAINED-BY (STARTS-DURING ENDS-EQUAL) (STARTS-DURING ENDS-AFTER)

ABUTS-AFTER

BEFORE

AFTER

Figure 3.2: Temporal Relations

68

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-66-

FACT: thing attribute

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-67-



- Extension to Non-monotonic Temporal Logic
   by introducing Belief Intervals
- Introduced Persistence as rule specific knowledge
- Designed structures to represent time dependent knowledge
- Implemented an efficient temporal database management program

## CONTRIBUTIONS (continued)

- Implemented a Temporal System Analyzer employing
   Extended Temporal Logic and Persistence
- Created a Scheduler Program, thereby extending
   Domain Independent Planning to include
   Parallel, Time Bounded, Non-Instantaneous Actions
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Novel ideas and methods developed for this system include

- A highly compact representation for the description of descrete time dependent processes.
- An efficient time based logical inferrence system.
- Deeper understanding of human cognitive and communication processes involved in Command and Control Systems.
- A replacement of "Truth Maintenance" by "History Maintenance", and a better understanding of default versus dynamic logic.

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LRH-90-068

Concentration in U.S. Air Transportation: An Analysis of Origin-Destination Markets since Deregulation

Jan Van Acker

Flight Transportation Laboratory May 23, 1991

# Agenda

- I. Thesis Objective and Methodology
- II. Analysis of Top 100 Markets
- **III.** Analysis of Dominated City Markets
- **IV.** Conclusions

# I. Thesis Objective

- Study effects of deregulation on concentration
- Focus on Origin-Destination City-Pair Markets

# Focus on Concentration in O-D City-Pairs

- Other studies found:
  - Fares are positively related to concentration
  - Concentration levels have decreased on average
- Our study looked at:
  - Top 100 domestic O-D markets
  - Markets out of dominated cities

# Measurement of Concentration

- Concentration indices used:
  - Hirschman-Herfindahl Index (HHI)
  - 2-Firm Concentration Ratio (C2)
  - Number of Competitors with >5% Market Share (Number of Effective Competitors)
- Market share is measured in terms of <u>local</u> passengers transported in market

## II. Changes in Concentration in Top 100 Markets

- Markets ranked 1-100 in terms of local passengers transported in 1989
- Cumulative number of passengers was 31% of U.S. domestic total in 1989
- Years studied: 1979, 1981, 1983, 1985, 1987, 1989
- With focus on 1979, 1985, 1989

### Average Number of Effective Competitors was One more in 1989 than in 1979

Year	Average Number of Effective Competitors
1979	2.7
1981	3.3
1983	3.5
1985	3.8
1987	3.6
1989	3.7



### 56 Markets Were Served by Four or More Effective Competitors in '89, as Compared to only 16 in '79

# Carriers With >5% MS	1979	1985	1989
1	8	0	1
2	38	17	19
3	38	30	24
4	11	24	29
5 to 6	5	28	24
7 to 8	0	1	3



-80-

### 62% of the Passengers Flew in Markets Served by 4 or More Effective Competitors in '89 - - only 18% in '79

# Carriers With >5% MS	1979	1985	1989
1	5.5%	0.0%	0.7%
2	30.9%	12.6%	16.5%
3	45.8%	29.1%	20.5%
4	11.3%	26.3%	28.9%
5 to 6	6.5%	30.7%	30.2%
7 to 8	0.0%	1.2%	3.3%



### Average HHI Was Lower in 1989 than in 1979

Year	Average HHI
1979	4917
1981	4077
1983	3913
1985	3361
<b>1987</b>	3705
1989	3586



-82-

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### The Majority of the Markets Experienced a Decrease in HHI from 1979 to 1989

Change in HHI	1979-1989	1979-1985	1985-1989
-8000 to -6000 -6000 to -4000 -4000 to -2000 -2000 to 0 0 to 2000 2000 to 4000 4000 to 6000	1 9 19 47 20 4 0	0 7 29 49 13 2 0	0 0 4 37 54 4 1
Total Decreased Total Increased	76 24	85 15	41 59
Average Change	-1330	-1555	225



# The Non-Hub Markets Were Served on Average by a Greater Number of Effective Competitors in '89 than the Hub Markets

·	Year			Ma	Hub Non-Hu Markets Marke		
	19	979			2.7		2.6
	19	981	Ň		3.3		3.4
	19	983			3.7		3.4
	19	985 No <del>7</del>			3.9		3.7
	19	987 989			3.5 3.5		3.7 4.0
L	5	<b></b>	L		1		J
	4.5	-					
SM %	4	<b>-</b>					
th >5	3.5	-				-	
i W i	3						- 1
ırrier	2.5						
3 *	2	-					
	1.5	-					
	1	1979	1981	1983	1985	1987	1989
			º Hub	Markets N	lon-Hu	b Market	R +

### Concentration Decreased from '79 to '89 in All but One of the Non-Hub Markets

Change in # Carriers With >5% MS	'79-'89	<u>'</u> 79-'85	'85-'89
-4 to -3	0	0	0
-2 to -1	1	5	11
0	8	11	19
1 to 2	33	24	17
3 to 4	7	9	2
5 to 6	0	0	0
Total Decreased	1	5	11
Total Increased	40	33	19
Average Change	1.10	0.33	1.43

### But Was Higher in '89 than in '79 in 30% of the Hub Markets

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Change in # Carriers With >5% MS	'79-'89	<b>'</b> 79-'85	'85-'89
-4 to -3	1	0	1
-2 to -1	11	7	26
0	9	8	16
1 to 2	25	28	8
3 to 4	4	8	0
5 to 6	1	0	0
Total Decreased	12	7	27
Total Increased	30	36	8
Average Change	1.12	-0.41	0.71

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### The Top 10 Markets Were on Average Less Concentrated than the Top 50 and Top 100 Markets

Year	Top 100 Markets	Top 10 Markets	Top 50 Markets
1979	86.6%	79.5%	83.9%
1981	79.2%	74.8%	77.7%
1983	78.4%	75.0%	77.0%
1985	73.3%	70.6%	71.8%
1987	74.7%	72.2%	74.3%
1989	73.6%	66.2%	73.3%



# **Conclusions of Top 100 Markets Analysis**

- Average concentration was lower in '89 than in '79
- Concentration was lower in 70% of the markets
- Non-hub markets were better off on average in 1989 than hub markets
- Top ten markets were less concentrated on average than top 100 markets

### III. Changes in Concentration in Top Ten Markets out of Dominated Cities

• Cities at which 60% of total passenger enplanements in 1985 were carried by one airline, or 85% by two:

Atlanta	Detroit	Pittsburgh
Charlotte	Greensboro	Raleigh/Durham
Cincinnati	Memphis	St. Louis
Dayton	Minneapolis	Salt Lake City
Denver	Nashville	Syracuse

• Markets ranked 1-10 in terms of local passengers transported in 1989 out of each of the cities

### Changes in Concentration in Top Ten Markets out of Dominated Cities

- Years studied: 1979, 1981, 1983, 1985, 1987, 1989
- With focus on 1979, 1985, 1989

### Average Number of Effective Competitors in 150 Markets Peaked in '85, but Was Still Higher in '89 than in '79

Year	Dominated Airport Markets
1979	2.2
1981	2.8
1983	2.8
1985	3.1
1987	2.9
1989	2.5



-91-

# Average Number of Effective Competitors for each of the Dominated Cities



### Average Number of Effective Competitors for each of the Dominated Cities



### Average Number of Effective Competitors for each of the Dominated Cities



# Average Number of Effective Competitors for each of the Dominated Cities



-95-

### Changes in Concentration in the Top Ten Atlanta Markets

O-D City-Pair Markets		нні	Change in HHI		
		1989	`79-`89	`79-`85	'85-'89
Atlanta Atlanta Atlanta Atlanta Atlanta Atlanta Atlanta Atlanta Atlanta	Boston Chicago Dallas/Fort Worth Los Angeles Miami New York Orlando Philadelphia Tampa	5446 2949 5932 5089 3737 3913 5608 4097 6002	455 -2538 -350 -219 -1004 -935 482 -995 955	-547 -2031 -1968 -656 -885 -1294 -880 -410 -637	1002 -508 1618 437 -119 359 1362 -585 1593 528
Atlanta	Washington	4701	-193	-/21	528
Total Decre Total Increa	ased sed		7 3	10 0	3 7
Average		4747	-434	-1003	569

### Concentration Levels Decreased Substantially in Most of the Top Ten Syracuse Markets

O-D City-Pair Markets		HHI	Change in HHI		
		1989	`79-`89	'79-'85	'85-'89
Syracuse	Atlanta	4418	-5552	-4()65	-1487
Syracuse	Boston	9045	175	-4091	4266
Syracuse	Chicago	4119	-5473	-5889	417
Syracuse	Detroit	8942	3967	-740	4707
Syracuse	Los Angeles	1585	-5234	-4924	-310
Syracuse	New York	5820	653	-1756	2409
Syracuse	Orlando	3047	-6014	-5507	-507
Syracuse	Philadelphia	9741	790	493	296
Syracuse	Tampa	2695	-5875	-5178	-697
Syracuse	Washington	8289	-1406	-4879	3473
Total Decreased			6	9	4
Total Increased			4	1	6
Average		5770	-2397	-3653	1257

### Concentration Increased in all Top Ten St. Louis Markets after the TWA-Ozark Merger

O-D City-Pair Markets		нні	Change in HHI		
		1989	'79-'89	'79-'85	'85-'89
St. Louis St. Louis	Chicago Dallas/Fort Worth	3347 4528	-2161	-3019 -2037	858 1530
St. Louis	Denver	4671	-238	-2333	2095
St. Louis	Detroit	3306	-2180	-2200	20
St. Louis	Houston	3561	-916	-1626	710
St. Louis	Los Angeles	5486	-48	-654	606
St. Louis	New York	8860	2650	-1356	4006
St. Louis	Phoenix	4780	-320	-1360	1040
St. Louis	San Francisco	6567	155	-547	701
St. Louis	Washington	8252	302	-3798	4100
Total Decreased			7	10	; 0
Total Increased			3		10
Average		5336	-326	-1893	1567

# Conclusions of Dominated City Markets Analysis

- Single trend of hub development led to decreased concentration through '85 at most of the cities, but to increases from '85 on
- Two-hub markets were less concentrated than one-hub markets in 1989
- Average concentration across the 150 markets was slightly lower in '89 than in '79

# **IV.** Conclusions

- Concentration was lower in top 100 markets, both on average and in most of the markets
- Concentration in non-hub markets decreased throughout period '79-'89 because of development of hub-and-spoke networks
- These networks led to increases in concentration in most hub markets after 1985

# Conclusions

- Single trend of hub development led to decreases in concentration through '85 at most of the dominated cities, but to increases from '85 on
- Concentration was on average slightly lower in the 150 markets out of dominated cities in 1979 than in 1989, and was lower in half of the markets

### Pricing in the Airline Industry Current Practice and Future Research

Theodore C. Botimer MIT Flight Transportation Laboratory Presentation to Cooperative Research Program May 23, 1991

### **Presentation Outline**

### **Overview**

- Nature of Airline Competition
- Fare Product Differentiation
- Seat Inventory Management
- Pricing Strategies
- Role of the Pricing Analyst
- "The Ultimate Pricing Model"
- Theoretical Issues for Investigation

### Case Study Analysis

- Case Study Overview
- Case Study Objectives
- O/D Market Choice
- ATL BOS Market
- ATL STL Market
- Conclusions

### Nature of Airline Competition

- Hub and spoke route structures prevail in the industry allowing almost every major carrier to serve any O/D market
- Most competition on non-price level
- Dollar value of nonstop service is unclear
- Must consider strength of competitive position in each O/D market separately
- Characterize competition in all markets:
  - major players
  - level of service offered
  - number of flights per day offered
  - nonstop vs. nonstop competition
- Anticipate response to price changes:
  - who are the competitors?
  - do the competitors offer comparable service in the market?
  - how have competitors reacted to fare changes in the past?
  - what response will be given to hostile reactions by competitors?

### Fare Product Differentiation

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- Airlines seek to segment demand by offering differentiated fare products in different fare classes
- Delta offers tickets in 10 fare classes:
  - 1) F full fare first class
  - 2) Y full fare coach class
  - 3) B reserved for military/ convention/negotiated fares
  - 4) M highest discount coach fare
  - 5) H discount coach class fare
  - 6) Q discount coach class fare
  - 7) K reserved for competitive filings
  - 8) L reserved for competitive filings
  - 9) A first class free tickets
  - 10) W coach class free tickets
- Differentiation occurs within fare classes
  - peak vs. off-peak fares
  - weekday vs. weekend fares

### Fare Product Differentiation (con't)

- Fare restrictions or "fences" used to control which type of consumer is able to purchase which type of ticket
- Common fare restrictions include:
  - advanced purchase requirements
  - Saturday night stayover
  - blackout periods
  - flight validity restrictions (good for travel between...)
  - ticket purchase restrictions (purchase tickets by...)
  - availability limits for discount fares
  - military discount fares
  - senior citizen discount fares
## Seat Inventory Management (IM)

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- Pricing sets O/D prices and restrictions
- IM decisions made with fixed prices and restrictions
- IM seeks to maximize revenue given fixed prices and restrictions
- IM controls price/seat quantity decisions
  - protect full fare seats
  - limit discount fares
  - strictly limit deep discount fare seat availability
- Matching stances require booking limits
  - strictly limited availability on competitive fare filings

## **Pricing Strategies and Their Effects**

- Matching a fare
  - retain market share
  - possible drop in yield
  - remain listed on Page 1 of CRS
  - often done to remain competitive
  - viewed as price taker in the market
- Not matching a fare
  - possible loss of market share
  - maintain yield
  - may lose competitiveness
  - loss of goodwill
- Partially matching a fare
  - attempt to retain market share
  - reduce non-matching yield loss
  - market factors influence strategy
  - will be non-competitive at peak
  - accept that competitor offers low fare on <u>all</u> flights

## Role of the Pricing Analyst

- Analysts do not look at operating costs
- Consider strength of competitive position in each O/D market
- Add routing restrictions to discount fares
- Pricing analysts should be familiar with own market and relevant hub:
  - traffic flows
  - flight load factors
- Be aware of fare differential effects
  - high differentials not seen on CRS
  - business travelers susceptible to higher differentials
  - not all fares registered in ATP listings are available in reality
- Must monitor the number of bookings to determine the effect on yield of changes

# Ultimate Pricing Model

- Inputs:
  - published daily fare changes
  - system-wide flight schedule
  - price level (by O/D market & flight)

#### - Outputs:

- Suggested strategy
  - -- matching
  - -- partial matching
  - -- not matching
- Projected impact on market share
- Projected impact on revenue
- Management reports telling:
  - -- suggested matching decision
  - -- implemented matching decision
  - -- reasons for matching decision
- Ability to run simulations
- Ability to do what-if scenarios

# Theoretical Issues for Investigation

- Joint seat/price optimization problem
- Optimal differential pricing strategies
- Model development for pricing strategies
  - matching

•

- not matching
- other pricing strategies
- Impacts of price changes
- Measurements of price elasticity
- Explore impacts of pricing strategies on:
  - profitability
  - load factor
  - yield
  - customer satisfaction

## **Case Study Overview**

- Close look at 10 O/D markets
- Representative cross section of markets flown by Delta Airlines
- Quarterly analysis
- Examine quarterly data 1986:1 1990:2
- Give consideration to:
  - published fares
  - competitive responses
  - major price level changes
- Use information from several data bases:
  - PIPPS (Historical ATP data)
  - DOT O/D traffic stats (10% sample)
  - Official Airline Guide
- Preliminary analysis on two markets:
  - ATL BOS
  - ATL STL

# Case Study Objectives

- Initial look at revenue management from pricing perspective
- Develop market by market case studies
  - Present a market overview
  - Characterize pricing practices
  - Analyze competitive environment
  - Uncover competitive characteristics
  - Highlight major market events
- Analyze the quality and level of detail of the available data sources
- Relate market strength to fare level
  - between carriers
  - over time
- Develop a measure of the sensitivity of travelers to changes in fare level
- Determine selling fares during the period
- Use available data to determine the effects of pricing decisions
- Discuss future directions for research

# O/D Market Choice

### Length of Haul

- Short Haul (<1000 miles)
- Medium Haul (1000-2000 miles)
- Long Haul (>2000 miles)

#### Nature of Competition

- Delta offers non-stop service
- Only competitors offer non-stop service
- No one offers non-stop service

Markets Chosen

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

### ATL - BOS Market Characteristics 1986:1 - 1990:2

- Two non-stop carriers during the period
  - -- Delta

- -- Eastern
- Non-stop carriers flew 93% of all pax
- Frequency of approximately 12 daily non-stops each way
- Total traffic level of 925 passengers per day in both directions
- Carriers with ATL hub
  - -- Delta
  - -- Eastern
- Eastern Airlines strike in 1989:2









#### ATL - BOS Summary Table

	Passengers	Revenues	Average	Coupon	Passengers	Market	Revenue	Yield
			Fare	Mileage	Per Day	Share	Share	Per CPM
Delta 88:2	6118	1152456	188	5872057	67.2	59.74	62.63	19.63
Delta 89:2	7676	1584791	206	7372559	84.4	74.95	88.01	21.50
% Change	25.47	37.51	9.60	25.55	25.47	25.47	40.51	9.53
Eastern 88:2	3508	599469	171	3348572	38.5	34.25	32.58	17.90
Eastern 89:2	9	1674	186	8514	0.1	0.09	0.09	19.66
% Change	-99.74	-99.72	8.84	<b>-99.7</b> 5	-99.74	-99.74	-99.71	9.83
OA 88:2	615	88075	143	653125	6.8	6.01	4.79	13.49
OA 89:2	1387	214329	155	1429440	15.2	13.54	11.90	14.99
% Change	125.53	143.35	7.90	118.86	125.53	125.53	148.65	11.19
Market 88:2	10241	1840000	180	9873754	112.5	100.00	100.00	18.64
Market 89:2	9072	1800794	199	8810513	99.7	100.00	100.00	20.44
% Change	-11.41	-2.13	10.48	-10.77	-11.41	0.00	0.00	9.68

### ATL - STL Market Characteristics 1986:1 - 1990:2

- Four non-stop carriers during the period -- Delta
  - -- Eastern
  - -- Ozark
  - -- TWA
- Non-stop carriers flew over 90% of all pax
- Frequency of approximately 15 daily non-stops each way
- Total traffic level of under 450 passengers per day in both directions
- Carriers with ATL hub
  - -- Delta
  - -- Eastern
- Carriers with STL hub
  - -- Ozark
  - -- TWA
- Eastern Airlines strike in 1989:2
- Ozark TWA merger in 1987



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#### ATL - STL Summary Table

	Passengers	Revenues	Average	Coupon	Passengers	Market	Revenue	Yield
			Fare	Mileage	Per Day	Share	Share	Per CPM
Delta 88:2	1799	259057	144	881790	19.8	44.20	44.15	29.38
Delta 89:2	1882	320589	170	919694	20.7	46.24	54.47	34.86
% Change	4.61	23.75	18.29	4.30	4.61	4.61	23.39	18.65
Eastern 88:2	1049	149500	143	510126	11.5	25.77	25.48	29.31
Eastern 89:2	1	94	94	484	0.0	0.02	0.02	19.42
% Change	-99.90	-99.94	-34.04	-99.91	-99.90	-99.90	-99.94	-33.73
TWA 88:2	1155.00	172264.00	149	560872.00	12.7	28.38	29.36	30.71
TWA 89:2	1631.00	261282.00	160	793400.00	17.9	40.07	44.52	32.93
% Change	41.21	51.68	7.41	41.46	41.21	41.21	51.68	7.22
OA 88:2	67	6003	90	48980	0.7	1.65	1.02	12.26
OA 89:2	57	6560	115	38358	0.6	1.40	1.11	17.10
% Change	-14.93	9.28	28.45	-21.69	-14.93	-14.93	8.96	39.54
Market 88:2	4070	586824	144	2001768	44.7	100.00	100.00	29.32
Market 89:2	3571	588525	165	1751936	39.2	100.00	100.00	33.59
% Change	-12.26	0.29	14.30	-12.48	-12.26	0.00	0.00	14.59

## Conclusions

- Carrier strength varies by O/D market
- Delta holds a stronger position in ATL BOS than in ATL STL
- Delta fare levels may have been too high in ATL - STL during the strike given its competitive position

## **Future Directions**

- Quantify consumer price sensitivity and market share changes

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- Determine relationships between market strength and fare levels
- Develop a model to characterize competitive structure of markets

### CHANGES IN O-D PASSENGER TRAFFIC FLOWS

#### NEWARK AIRPORT

### Chung Y. Mak and Professor Peter P. Belobaba MIT Flight Transportation Laboratory

MIT / Industry Cooperative Research Program Annual Meeting May 24, 1991

### **BACKGROUND : PREVIOUS ANALYSIS**

- Removal of PeoplExpress from the New York (EWR) market has had the most significant impact on traffic flows.
- Domestic connecting passengers have dropped in both absolute and percentage terms at all three airports, suggesting a shift by carriers away from New York airports as domestic hubs.

Newark Airport (EWR)

- Stable departure levels since PE withdrawal, but fewer seats and reduced aircraft sizes.
- Major drop in on-board passengers after 1986-3; downward trend continues through 1989-3 for virtually all carriers.
- Local originating passengers cut by half when PE failed; levels have barely returned to pre-1984 levels.
- Domestic connecting passengers were similarly affected by PE withdrawal from EWR.



Figure 1.2







Figure 1.9



Figure 2.3



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Figure 2.6

#### **Total Connecting Pax (EWR)** (Ten Percent Sample) 13 12 11 10 9 8' Ð 7 6 1Q84 1Q86 1Q85 1Q87 1Q88 1Q89 3 3 2 2 Ż 2 Quarter

Total Pax (Thousands)

Figure 3.5



## **Total Connecting Pax (EWR)**

Figure 3.8

# <u>NEWARK AIRPORT</u> <u>TRAFFIC FLOW ANALYSIS (Phase 2)</u>

#### **OBJECTIVE**

- Identify and evaluate changes in O-D passenger traffic flow patterns through Newark (EWR) <u>and</u> alternative hub routings.
- Determine shifts in connecting traffic away from EWR in O-D markets previously served by PeoplExpress.

#### HISTORICAL DATA

- Ten percent ticket coupon sample provides passenger itinerary information by quarter from 1985 to 1989.
- Database Products Inc. "OD Plus" database used to extract data.
- Official Airline Guide (OAG), schedule data for each of the periods.

### PASSENGER TRAFFIC FLOW ANALYSIS

#### DEMAND AND SUPPLY MEASURES

- Ten percent O-D passengers travelled between each selected city pair by carrier.
- Scheduled service in each city pair by carrier.

#### AIR CARRIERS

• "Major" U.S. carriers offering service to domestic destinations, defined to include smaller airlines with large market presences (e.g. Midway).

### ANALYSIS METHODOLOGY

- Obtained top 500 US Domestic O-D markets in terms of passenger traffic for 1989.
- Selected markets served by PeoplExpress in 1986.
- Discarded all city pairs with New York as an Origin/Destination, leaving 50 sample markets.
- Used O-D Plus to obtain passenger traffic data for 3rd quarter 1986 for all major carriers serving these city pairs.
- Selected O-D pairs based on market share and passenger information for detailed analysis :
  - markets with greater than 5% market share by PeoplExpress in 1986 or;
  - markets with more than 20 passengers carried by PeoplExpress per day.
- A total of 20 markets were chosen based on these criteria.
- Used O-D Plus again to obtain detailed passenger traffic information by individual market and carrier from 1985-3 to 1989-3.

### **20 SELECTED O-D MARKETS**

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	1986-3	1986-3
	<u>PE Share</u>	Pax/Quarter
CHI-BDL	3.30%	5440
ORL-CMH	2.25%	280
PIT-HOU	4.95%	3240
PIT-LAX	4.91%	1810
WAS-MIA	5.74%	7950
WAS-BUF	9.36%	3500
WAS-DEN	8.73%	7500
WAS-PVD	4.99%	1670
<b>BOS-CHI</b>	6.02%	11960
BOS-DFW	4.18%	2960
BOS-DET	2.36%	2120
BOS-FMY	5.16%	570
BOS-HOU	5.41%	2600
BOS-LAX	1.14%	1920
BOS-ORL	1.80%	2110
BOS-PIT	16.45%	9490
<b>BOS-SFO</b>	1.86%	2530
BOS-WAS	3.44%	9220
BOS-DEN	12.10%	9320
<b>BWI-DEN</b>	6.45%	1930

### **FINDINGS**

#### Aggregate : 20 O-D Markets

- Total traffic in selected O-D pairs decreased slightly since withdrawal of PeoplExpress in 1986-3.
  - aggregate traffic decreased by 5.94% from 1986-3 to 1989-3.
- However, proportion of this traffic connecting through EWR dropped from 4.84% to 0.71% during the same period.
- In 1985, PeoplExpress carried 8% of total traffic in these markets.
- By 1989, Continental carried a total of 10% of traffic in these markets.
- However, only 1% was carried by CO via EWR.


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## Disaggregate Market Analysis

Examples of market share changes 1985 to 1989 follow, showing PE, CO and the two competing carriers with the greatest increase in market share :

- "CO - Other" refers to Continental traffic routed primarily through other CO hubs.



-146-

#### **BOS-PIT**:

- PE had 28% market share in 1985, virtually all of which was taken over by USAir (non-stop service).
- CO never recaptured significant market share.



#### **BOS-FMY**:

- PE had peak market share of 45% in 1985, of which CO now carries only 9% via EWR.
- AA market share grew from 0 to 24% (CNX via RDU).
- DL also took over market share (via ATL and CVG).



#### **BOS-DEN**:

• CO has captured most of PE's 12% market share, but on non-stop service. UA also shows market share growth (non-stop service).





#### **BOS-WAS**:

- PE had 10% market share in 1985. CO did not capture any of this traffic (via EWR), except in 1987 when CO offered non-stop service to IAD.
- Greatest MS growth by US and UA (both non-stop services).



#### CHI-BDL :

• PE's 9% market share in 1985 was captured by CO via EWR until 1988, when UA increased non-stop service.



### PIT-LAX:

- PE carried up to 5% of market share in 1986 via EWR.
- CO increased its MS from 0 to 16% in 1987, but <u>not</u> via EWR (i.e. via IAH, DEN, CLE).



#### WAS-BUF:

- PE carried 37% of market share in 1985, only 7% of which was captured by CO via EWR in 1987.
- Biggest market share gains went to UA (non-stop to IAD) and US (non-stop to BWI/DCA).

-152-

### SUMMARY OF FINDINGS

- O-D routings with PeoplExpress in 1986 were almost exclusively through EWR, and PE had an average of 8% MS in 20 selected markets.
- After withdrawal of PeoplExpress from EWR :
  - CO became an effective competitor in many of these markets, but traffic was split between EWR, CLE, DEN, and IAH hubs.
  - Growth of alternative and new hubs operated by other carriers further reduced attractiveness of EWR connections.





O-D Routings After PeoplExpress 1989 (via Continental Airlines)

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O-D Routings After PeoplExpress 1989 (Other Carriers)

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## **CONCLUSIONS**

- Withdrawal of PeoplExpress has had significant negative impact on connecting traffic levels at Newark.
- Continental took over from PeoplExpress, and Newark (EWR) became one of the 4 hubs operated by Continental with CLE, DEN, IAH.
- CO now serves many O-D pairs through it alternative hubs, providing a bigger choice of departures and more direct routings.
- CO did not replace PE as a competitor, its replaced PE as the hub operator of EWR.
- Development of existing and new hubs by other carriers captured additional EWR market share.

# Airline Seat Inventory Control

## For Group Passenger Demand

Presented by

Peter Belobaba Tom Svrcek

May 1991

# Individual Passenger Seat Inventory Control

Assumes Demand For Each Individual Fare Class Is

Independent And Normally Distributed.



#### **Definition**

Expected Marginal Revenue (EMR) Of An Additional Seat

Allocated To A Particular Fare Class Is

EMR(i) = Fare Class Revenue \* Probability of Selling Seat i.



# Individual Passenger Seat Inventory Control

## Example : Setup

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Total Fare Classes :	4
Aircraft Capacity :	100

Fare	Demand	Demand	Average
<u>Class</u>	Mean	Stdev	Revenue
Y	14	5	380
В	12	6	320
М	35	10	270
Q	42	12	220

# Individual Passenger Seat Inventory Control

## <u>Results</u>

Seat					Highest
<u>No.</u>	<u>Y</u>	<u>B</u>	<u>M</u>	Q	EMR
1	378.94	312.78	269.90	219.92	378.94
2	378.16	309.39	269.87	219.90	378.16
3	376.86	304.77	269.82	219.87	376.86
4	374.74	298.65	269.76	219.83	374.74
5	371.43	290.79	269.68	219.78	371.43
6	366.43	280.99	269.57	219.73	366.43
7	359.24	269.16	269.43	219.65	359.24
8	349.31	255.22	269.25	219.56	349.31
9	336.20	239.24	269.00	219.44	336.20
10	319.63	221.34	268.69	219.30	319.63
11	299.47	201.81	268.29	219.19	312.78
12	275.85	181.12	267.77	218.89	309.39
13	249.13	160.00	267.10	218.61	304.77
14	220.07	138.88	266.26	218.26	299.47
15	190.00	118.19	265.21	217.83	298.65
16	159.93	98.66	263.91	217.32	290.79
	•••	•••	•••		

Fare Class Allocations				
Y	16			
В	13			
М	34			
Q	37			

378.94
378.16
376.86
374.74
371.43
366.43
359.24
349.31
336.20
319.63
312.78
309.39
304.77
299.47
298.65
290.79
•
•
•
158.48
156.37
152.17

## Group Passenger Demand

Why Is Group Demand Different From Individual Passenger Demand ?

- Group Demand Is Realized Many Months In Advance Examples : Rose Bowl, Mardi Gras ...
- Groups Negotiate For A Lower Fare (Bulk Pricing)
- Unused Bookings Are Absent From Seat Inventory For Months, Potentially Displacing Individual Passengers
- Cancellation Penalties Often Difficult To Enforce
  Due To Competitive Environment

## Problem Statement

Given We Receive A Request For A Group Request Of Size S For A Specific Origin/Destination And Date.

What Is The Minimum Group Fare An Airline Should Charge Given That We May Potentially Displace S Individual Passengers ?

"Answer:"	
Min Group Fare =	Total Expected Revenue Of Displaced Individual Pax
	Size Of Group Request

	\$ 2,200			
Example:		=	\$ 110	Per Group Pax
_	20			

### Two Solution Methodologies

<u>Case 1:</u>

Assume Group Is Indivisible. Find The Itinerary With The Smallest Displacement Cost Of Individual Passengers.

<u>Case 2:</u>

Relax Indivisibility Constraint. Find Optimal Split Over

N Possible Alternatives For Each Group Request.

Large Hub and Spoke Networks Operated by Today's Major

Carriers Allow for Several Different Routings (with

Similar Departure and Arrival Times) For Many Origin -

Destination Pairs.

### For Example, Delta Air Lines Service Between:

New York (EWR/LGA/JFK) and Seattle (SEA)

Dept	Arr	Flts	Stps/Via
5:20aE	11:35a	377 / 835	ATL
7:05aJ	12:30p	1429 / 1655	SLC
8:15aL	1:45p	467 / 233	DFW
8:20aE	1:45p	281 / 233	DFW
9:30aL	2:45p	937 / 623	CVG
9:50aE	2:45p	583 / 623	CVG
11:00aJ	8:23p	1601 / 301	MCO
11:29aL	5:10p	983 / 833	DFW
11:55aE	5:10p	887 / 833	DFW
3:29pL	8:25p	1187 / 367	CVG
3:29pL	10:40p	1187	2
4:15pE	8:25p	1038 / 367	CVG
5:10pE	12:25a	237 / 300	LAX
5:20pJ	10:40p	1425 / 1187	SLC
6:45pL	1:33a	729 / 625	ATL
6:50pE	1:33a	1421 / 625	SLC

### Numerical Example : Setup

Dept Date : 12 JUL 91 Group Size : 15

#### Possible Outbound Itineraries

DL    583    EWR    950A    CVG    1142A    72S      DL    623    108P    SEA    245P    72S      DL    99    EWR    340P    ATL    640P    757      DL    197    652P    SEA    910P    757      DL    887    EWR    1155A    DFW    226P    72S      DL    883    312P    SEA    510P    72S      DL    281    EWR    820A    DFW    1055A    72S      DL    233    1152A    SEA    145P    72S								
DL    623    108P    SEA    245P    72S      DL    99    EWR    340P    ATL    640P    757      DL    197    652P    SEA    910P    757      DL    887    EWR    1155A    DFW    226P    72S      DL    883    312P    SEA    510P    72S      DL    281    EWR    820A    DFW    1055A    72S      DL    233    1152A    SEA    145P    72S	[]	DL	583	EWR	950A	CVG	1142A	72S
DL    99    EWR    340P    ATL    640P    757      DL    197    652P    SEA    910P    757      DL    887    EWR    1155A    DFW    226P    72S      DL    833    312P    SEA    510P    72S      DL    281    EWR    820A    DFW    1055A    72S      DL    233    1152A    SEA    145P    72S	I	DL	623		108P	SEA	245P	725
DL    99    EWR    340P    ATL    640P    757      DL    197    652P    SEA    910P    757      DL    887    EWR    1155A    DFW    226P    72S      DL    833    312P    SEA    510P    72S      DL    281    EWR    820A    DFW    1055A    72S      DL    233    1152A    SEA    145P    72S	_							
DL    197    652P    SEA    910P    757      DL    887    EWR    1155A    DFW    226P    72S      DL    833    312P    SEA    510P    72S      DL    281    EWR    820A    DFW    1055A    72S      DL    233    1152A    SEA    145P    72S	Ī	DL	99	EWR	340P	ATL	640P	757
DL    887    EWR    1155A    DFW    226P    72S      DL    833    312P    SEA    510P    72S      DL    281    EWR    820A    DFW    1055A    72S      DL    233    1152A    SEA    145P    72S	I	DL	197		652P	SEA	910P	757
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	I	DL	233		1152A	SEA	145P	72S

Published Fares for							
EW	EWR/SEA on 12 JUL 91						
Y	\$642.00	O/W					
В	\$425.00	O/W					
М	\$325.50	O/W					
Q	\$277.00	O/W					

### Numerical Example: Results

#### Itinerary #1

· .

<u>Seat</u>	<u>Flt 583</u>	<u>Flt 623</u>	<u>Itin #1</u>	
134	24.40	97.20	121.60	
135	24.24	93.80	118.04	
136	24.21	93.10	117.31	
137	21.59	92.99	114.58	
138	20.83	88.88	109.71	
139	19.53	83.76	103.29	
140	19.41	83.51	102.92	
141	19.25	81.42	100.67	
142	17.72	78.50	96.22	
143	16.21	77.91	94.12	
144	14.99	77.55	92.54	
145	14.92	74.68	89.60	
146	12.58	74.19	86.77	
147	12.42	73.15	85.57	
148	11.79	67.81	79.60	
149	11.51	66.82	78.33	
150	10.23	65.29	75.52	φ.
	Leg 1	Leg 2	Total	

Min. Group Fare Calculation  $\Rightarrow$  1426.75 / 15 = \$95.12

		Displacement C		Min. Group	
		Estimate Per Pa		Fare	
	Itin Outbound				Request for
Rank	Out	<u>Leg 1</u>	Leg 2	Total	<u>15 Pax</u>
1	4)	0.00	87.80	87.80	\$87.80
2	1)	16.48	78.64	95.12	\$95.12
3	3)	0.00	137.93	137.93	\$137.93
4	2)	79.38	157.13	236.51	\$236.51

## Group Booking Model Output

Lowest Published Fare		
for EWR/SEA on 12JU	L91 :	\$277.00
Minimum Group Fare	:	\$87.80

Negotiation Does The Rest !

What Is The Optimal Reduced Fare ?

For The Carrier:

\$277.00

For The Group:

\$87.80

Competitive Advantage

Carrier Implementing Displacement Cost Strategy Has

277.00 - 87.80 = 189.20

Of "Competitive Leverage".

# Case 2: Relaxation Of Indivisible Group Constraint

<u>Seat</u>	<u>Itin 1</u>	<u>Itin 2</u>	<u>Itin 3</u>	<u>Itin_4</u>
15	117.31	259.11	139.99	104.97
14	114.58	255.68	139.97	102.82
13	109.71	247.17	139.95	99.52
12	103.29	246.32	139.92	96.09
11	102.92	245.43	139.85	92.52
10	100.67	244.42	139.73	88.85
9	96.22	234.76	139.52	86.32
8	94.12	232.73	139.16	85.08
7	92.54	230.30	138.55	84.85
6	89.60	228.77	138.44	84.46
5	86.77	226.53	137.59	82.47
4	85.57	226.22	136.08	81.23
3	79.60	224.97	135.31	77.34
2	78.33	224.46	133.84	77.05
1	75.52	220.83	131.09	73.42

## Model Output

Optimal Split Over All Itineraries	
Itinerary 1 5 Pax Itinerary 4 10 Pax	
Minimum Group Fare (Divided) Minimum Group Fare (Undivided)	<u>\$81.79</u> <u>\$87.80</u>

### Question:

Why Are Groups Different From Traditional Bulk Pricing ?

### Answer:

In Bulk Pricing, Marginal Cost Of Each Additional Item Is Non–Increasing.

### Example:

6 Bagels at \$ 0.40 / item 24 Bagels at \$ 0.30 / item

### But:

6 group pax at \$ 175.00 / pax 24 group pax at \$ 189.00 / pax

Each Additional Passenger We Displace Has A Higher Expected Marginal Revenue Than The Previous One.

The Larger The Group, The Higher The Average Fare

### User Optimal Strategy

- Be Flexible In Times / Dates
- Be Willing To Split Up
- Book Only As Many Seats As You Need

Carrier Optimal Strategy

- Find "Minimum Displacement" Seats For Each Requested Itinerary
- Try To "Split" Groups When Possible
- Book Only "Genuine" Seats

## Conclusions

- Minimum Group Fare Based On Displacement Of Individual Passengers
- No Distribution Assumptions Necessary For Group Passenger Demand
- Given N Outbound Itineraries And R Return Itineraries, We Can Find The Best Of N \* R Possible Combinations
- Optimal Mix Of Divisible Group is No More
  "Difficult". All Necessary Information Exists !
- Better Utilization Of Excess Capacity Means Greater Revenue Potential For Airlines

#### FLIGHT TRANSPORTATION LABORATORY, MIT



## Problem Statement

#### GIVEN:

1. A fixed schedule of flights F for one type of aircraft

- a flight is one or more flight legs
- arrival / departure times are fixed
- schedule is cyclic over a day or week, C
- schedule remains in effect over planning horizon,H
- 2. A set of crew bases B where a number of crews  $N_B$  are domiciled to fly this type of aircraft

#### FIND:

the cheapest set of work schedules, or "bidlines" b for these crews during H which does not violate work rules imposed by regulations or airline/union agreements;

- a crew trip t consists of a series of flights to be flown starting from base and returning within one or more days
- a work schedule b is a set of trips away from base on various days of the planning horizon, H

### Typical Crew Work Rules - 1

## 1. Regulatory Rules

(imposed by civil aviation authorities for safety)

- Maximum Daily Flight Hours
- Maximum Weekly (or 7 day period) Flight Hours
- Maximum Monthly Flight Hours
- Maximum Duty Hours (duty time is time without rest)
- Minimum Off-Duty Interval
- Note- Crew trips and bidlines which conform to these rules will be called legal or feasible.

These rules limit crew utilization to be substantially less than that expected by airlines from their aircraft, and mean that crews and aircraft cannot remain together during trips away from base. It is desirable to estimate the minimum number of crews required to cover one cycle of a given schedule as it would give a lower bound on the number of crew trips which must be generated. It is easy to compute the maximum number of airborne crews, but due to these constraints it is less than the minimum required crews.

Due to the aircraft flying perhaps 18 hours per day, and a daily duty limit of 12 or 14 hours, some crews must start their duty in the middle of the day to cover late night flights. Due to the minimum off-duty interval of 8-10 hours, crews on late night flights cannot start flying on the earliest flights the next morning

### **Basis for Crew Costs**

There are two kinds of crews: cockpit and cabin.

The cockpit crew flies together for one month, paired differently each month. Each aircraft requires a fixed crew.

The cabin crew complement has a minimum, but higher loads causes more members on certain legs. Changing reservation information can change work schedules dynamically.

There are three components which determine the monthly pay of crew members at a US Airline:

1. Monthly Base Pay -	independent of hours flown
	- depends on grade and longevity

2. Hourly Flight Pay	- \$ per flight hour
	- depends on aircraft type

3. Trip Credit Pay - \$ per trip away from base - depends on details of trip itinerary - may be zero

4. Overnight Costs - costs of meals,food, and transport to overnight crew away from base



-178-

### Typical Crew Work Rules - 3

#### 3. Airline/Union Bidline Agreements

- Max. Monthly Flight Hours
- Min. Monthly Flight Hours
- Min. Days Off per month
- Min. Weekends Off per Month
- Max. Duty Hours per Week
- Min. Off Duty Time at Base
- Max. Percentage for Reserve Crew Bidlines

These rules affect the monthly pattern of work for crews but generally do not cause extra costs. Whereas an aircraft may fly 300 hours per month, crews are limited to less than 100, so there are 3-5 times as many crews as aircraft.

Note- Due to schedule deviations caused by weather, crew sickness, or aircraft equipment failures, reserve crews are given bidlines which mainly consist of periods when they are "On-Call" and must be able to report for duty within 1 or 2 hours. There may be a few flights actually scheduled into a reserve bidline, caused perhaps by holidays or schedule changes.
-179-

## The Current Airline Crew Scheduling Process

Stage 1. - Generation of Feasible Crew Trips from Bases

Stage 2. - Selection of "Optimal" Trips from Bases

**Stage 3. - Construction of Crew Bidlines for Bases** 

**Stage 4. - Construction of Reserve Crew Bidlines for Bases** 

Stage 5. - Execution of Crew Bidding Process

- Note: 1. It is a sequential, heuristic Process and is not optimal, even if some of the stages are done optimally.
  - 2. There should be some feedback of crew scheduling problems into the aircraft scheduling and airline market service planning. At present, this feedback does not exist since crew scheduling is done by airline flight operations personnel late in the airline schedule planning process. There is a need for some early assessment of crew scheduling problems in airline schedule development.
  - 3. The availability and continual use of reserve crews affects the desirability of detailled optimal planning of fixed monthly bidlines.
  - 4. A related process is crew re-scheduling by flight operations personnel when deviations from schedule plan are occuring. There is a need for good methods of solving real time, operational crew scheduling problems to minimize additional costs from disruptions.

## Stage 1 - Generate Feasible Crew Trips

#### STEP 1 - Establish "Flights", F

For various reasons, it may be desirable to have an unbroken sequence of flights or flight legs; ie., there may be some arbitrary specification of where crew connections can be made. Even though their flight number may change for marketing reasons, here these sequences will be called flights, f, belonging to a set F. Every crew trip t will now consist of a sequence of these flights.

### STEP 2 - Generate feasible (or legal) Crew "Trips", T

Since there are a number of necessary and desirable attributes for a crew trip, it is necessary to generate each trip individually. It is not possible to create a crew "circulation flow". The number of feasible crew trips may be of the order of a million for a typical US domestic fleet of 100 aircraft, and in the next step,( the selection of the best trips to "cover" the schedule), the solution may only involve a set of trips of the order of twice the number of aircraft in the fleet, ie., we are looking for the best 200 crew trips. Furthermore, there may not be much difference between the top 1000 solutions. It is desirable to find some "efficient" way to generate only the "best trips" as top candidates for a "cover" or solution.

Thus, it is vital to find some new way to generate trips which:

- 1) have zero trip penalty costs and good crew utilization
- 2) start from a given crew base after a specified start time
- 3) involve a specified flight or combination of flights
- 4) overnight at a specified location

# Stage 2 - Select a Set of Crew Trips for each Base

- 1. All flights in the aircraft schedule must be covered by the selected set of crew trips.
- 2. Since each trip starts at a given crew base, the flying assigned to that crew base by selecting a set of trips must be proportional to the number of crews domiciled at that base.
- 3. The Selection Problem takes two mathematical forms:
  - a) The Set Covering Version;

Minimize [C.T] given constraints  $\begin{bmatrix} E.T \ge 1 \\ H.T \ge B \end{bmatrix}$ 

- where E is a zero-one matrix where columns j correspond to possible trips, and have a one in rows if the trip uses the flight corresponding to that row
- where H is a matrix of flight hours per trip, and B is the total number of flight hours desired to be assigned to a crew base corresponding to that row
- where T is a zero-one row variable to select trip j such as to minimize costs

Since the constraints allow the row sum to be greater than unity, deadheading is allowed and the costs include all components.

b) The Set Partitioning Version;

In this form, no deadheading is allowed and the constraints are equalities. The costs may be reduced to only the penalty costs associated with the guarantees.



solve exactly. With a few hundred rows and columns, there are a number of interesting ways to get solutions. If the lowest cost columns can be produced easily, and the lowest cost column which provides needed cover could be generated, good solutions may be found quite quickly.

The trip characteristics which are desirable depend on the bidline constraints and the number of crew available. It might seem important to generate trips which do as much flying as legally possible in a duty period, but this would just mean more days off per month for each crew. It is always important to avoid incurring penalties from the guarantees.

## The Crew Tree -A New Method for Constructing Crew Trips

It is possible to create methods which generate any crew trip from a given base and evaluate it for feasibility and cost. Such methods may be controllable by the analyst in creating new trips with particular characteristics which can be added to the cover matrix as desired to obtain better solutions.

An efficient method of finding "best" crew trips from a base is to create a labelling method which constructs a "crew tree" on the Schedule Map for the aircraft. This tree is rooted in the departures from that base, and finds the best crew routing for any flight in the schedule if it were to be flown by a crew from that base. The definition of "best" can be varied but maximizing the flight time achieved is a good basis.

The tree stops whenever the daily limits of flight and duty time are reached, so that it describes the "scope" of feasible crew routings from that base in one duty period. The labels indicate the routing used to reach any flight and the starting departure from base.

Whenever a crew routing returns to its base on some arrival flight a "best" crew trip has been found. The crew can go off-duty at that time. The analyst knows that for that pair of departure-arrival flights at this crew base a crew trip has been found which maximizes the amount of flying achieved. It is possible to extend the tree construction to find the second best and third best trips at the same time.

Crew Trees can be constructed for each base. Best trips can be extracted and the next tree constructed to generate more trips. It seems possible to generate a Crew circulation for one base at a time if needed.

## Handling Overnight Trips

For discussion purposes, assume that there is a daily cycle in the aircraft schedule. Since there is usually a small number of crew bases and the aircraft schedule requires flights into secondary cities later in the evening with an early departure the next morning, there are identifiable "overnight" visits for aircraft and crew. Since these overnight visits cause out of pocket cost, they require special handling. There may be more than one crew overnighting at certain cities.

The crew tree will show the "best" way to route a crew from any base into the overnight arrival flights (if it is possible). Since there will be crew duties starting the next day at these bases, A crew tree is constructed from these overnight bases showing the best way to route crews back to base. By examination, it is easy to find the best two day trip for overnight crews. The search can be extended to three day trips if it is allowable or desirable.

The selection of low cost, efficient overnight trips can be made first. Once they are fixed, then all other trips must start and end at their crew bases within one day. The departure and arrival flights used for overnighting are then removed from the Schedule Map before constructing the one day trips.

The crew tree method is a new way to generate candidate trips for the second step of selection using some search methods of solving the set covering or partitioning problem. It is designed to only put forward the best candidates and keep the selection matrix very small. The process is not optimal, and it is intended that the analyst should be able to participate interactively in these searches, and return to this stage after the monthly bidlines have been initially constructed .

## Stage 2 - Constructing the Bidlines

Given the trips that are to be used for constructing the bidlines, there are a variety of techniques to generate potential bidlines which obey all or most of the bidline rules. These rules may be soft in the sense that crew schedulers may know where and how often they can be bent.

There are research problems in beginning and ending the monthly bidlines, or"transitioning" between months. For domestic schedules, there are also problems arising from weekend deviations in the daily schedule. These problems may be handled by Reserve Crews, but if good methods of constructing bidlines can be automated, there are likely to be efficiencies in the number of reserve bidlines used (and therefore the crews required to support the fleet).

One method used to generate bidlines is to create an efficient "pattern" of trips over 7 days, and to involve 7 crews in flying exactly the same bidline for the month. This reduces the size of the selection matrix. A much smaller matrix of trips versus patterns is used to select the "best" set of patterns to be used. The focus then changes to finding good candidate patterns for the bidlines. The patterns can be "mixed" to provide some variety in the crews' monthly work if desired.

The solution of the bidline selection process once again requires a good heuristic search methods of quickly"solving" set covering and set partitioning problems.

-186-

## Conclusions

- 1. There are some new approaches to creating interactive methods to support the crew scheduler in finding good low cost schedules for the crews.
- 2. There is a need to create methods for re-scheduling crews when deviations occur in executing the schedule. This should affect the current use of reserve crews
- 3. There seems to be a need to create similar methods for the cabin crews which are responsive to their differences in scheduling rules.
- 4. There is a need to provide some "early warning" methods for market and aircraft schedulers to cause a feedback of expensive crew scheduling problems before the aircraft schedule is finalized.

# COMPUTER AIDS FOR EXECUTION RESCHEDULING

- 1. Execution Rescheduling
- 2. The Influence of Rapid Advances in Computer Technology
- 3. The "Airline Scheduling Workstation" (ASW)
- 4. A 2-Stage Development Approach for An ASW
- 5. STAGE 1: A Manual, Interactive Graphics Scheduling System
- 6. STAGE 2: Automated Decision Support
- 7. Conclusions

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Flight Transportation Laboratory Massachusetts Institute of Technology Cambridge, Massachusetts 02139 USA (617) 253-1761

### I. EXECUTION RESCHEDULING

GOAL:

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- execute the operational schedule at least extra "cost" due to schedule aberrations

**INPUTS**:

Operational schedule
Operational deviations

Weather, breakdowns

- - Late arrivals
- Expected traffic loads and revenues
- Short term operating costs

OUTPUTS:

- Modified execution schedule
- Cancellations
- Delays

### II. The Influence of Rapid Advances in Computer Technology

### Old Approach

- "Techniques in search of an Application"
- use mainframe: large, fast supercomputer
- construct fixed code for technique
- user submits data, receives solution
- user reviews solution to comprehend it
- causality: user cannot ask for explanation of solution
- user may interface with OR analyst

<u>New Approach</u> - "Customize techniques to the Application"

- smaller, interactive graphic workstations on common network
- create various fast heuristics to solve subproblems
- create links to solve large scale problems on mainframe
- user is master, computer is servant, direct interface
- processes are custom built to meet application needs
- systems to match existing procedures and organization

### III. THE AIRLINE SCHEDULING WORKSTATION (ASW)

A COMPUTER TOOL FOR AIRLINE SCHEDULERS BASED ON THREE NEW TECHNOLOGIES:

- 1. Table top Engineering Workstations with a speed of 1-4 mips and disk storage of 100 -1000 MB working together on a local area network, interfaced with existing airline mainframe systems.
- 2. Large (19 inch), high-quality color displays with interactive, instantaneous, manipulation of schedule graphics information using a "mouse".
- 3. Object-oriented programming to provide modular code, easily extendable to handle time-varying scheduling constraints, policies, etc., and to reduce programming support.

We shall call this tool the ASW (Airline Scheduling Workstation)

### IV. DEVELOPMENT APPROACH FOR AN ASW

### GENERAL DEVELOPMENT STRATEGIES

- Involve schedulers at all development stages-- (there will be cultural and organizational shock)
- provide familiar systems and reports first to ensure that the new system will not preclude doing certain schedule subprocesses by old methods.
- Expect changes in organization and procedures as workstation capabilities are perceived.
- Establish a local area network of workstations in scheduling area, capable of interfacing with the airline's existing mainframe system. (e.g., 3 workstations at \$15,000 each). (Establish a "Schedule Generation" workroom).
- Develop modern, transportable, modular, object-oriented software, for automation of sub-processes in scheduling
  - easily extendable
  - easily supported
  - C, PÁSCÁL, LISP language
  - good data structures
- A Two-Stage development process
  - STAGE 1: introduction of manual, interactive graphics scheduling system
  - STAGE 2: introduction of automated decision support

### V. STAGE 1 - A MANUAL, INTERACTIVE GRAPHICS SCHEDULING SYSTEM

- A) Provide computer graphic displays of schedule information - instantaneously modifiable by mouse
  - global data base modification
  - selectable screen data -- by fleet, station
  - save alternate solutions
  - audit trail
  - memo pad for scheduler
  - keyed to input data, and assumptions used
  - automated search routines, etc. to minimize keyboard and mouse work
- B) Provide instantaneous error flagging (even if error occurs off-screen)
  - e.g., insufficient gates, flow imbalance, double crew layover, violation of turnaround or transit times, insufficient aircraft.
- C) Integrate crew, gate, maintenance schedule with aircraft schedule
- D) Provide familiar printed reports and graphics for distribution around airline
- E) Provide interface to mainframe data system to maintain current scheduling processes.

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-198-

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ROTATION CHART         delta_n           CHT         00         01         02         03         04         05         06         07           OO1         08         08         DFW         90'         etc.         90         105         02         03         04         05         06         07           OO1         08         DFW         90'         etc.         90         etc.         90         ENR:           OO2         08         08         DFW         92'         :LAX         1255'         1251'           OO3         08         08         152'         1745'         2988         00'           OO4         08         1881         152'         1745'         2988         00'           OO4         08         1881         ENR         261'         ATL         261'         MCO	COPY DELETE DELETEALL INTERCHANGE MOVE ALL MODIFY SWAP UNDELETE ZOOM	12 13 14 TPA 93 9733 SFO 9431 SEA 170 1A 9356 961	15 16 връв в АТ X 140 10543 576 ВО	17 18 19 DFN 89 1152 FL 155 MCO 37287 1328 1 1122 S 111	28 21 190 158 158 DFI MCO 111 1451624	Monday 22 23 24 LAX 98 DI 1415 1415 1555 1988 1524 179 L1 1524 1641 EI 1641713 988
010     88100     505     2010     2218     2335     2450       015     88100     1943     2013     12215     MC0 261       016     88100     1943     2013     12215     MC0 261       016     88100     0130021       017     88100     1920     2020     2326       018     88100     1920     2020     2326       003     88100     1730     2255       009     88100     1730     2255       019     88100     1730     2255	MIA 394 0454 MCO 0400 154 0400 2 AX 56 ATI 055	ORD 0RD 08 08 08 08 08 08 08 08 08 08	79 ATI 15 1100 SJ 105 105 105 105 105 105 105 105	L 83 1)57 U 82 1988 BDA 85 1355 NIA 97 1)58 1258 1 17	SJU 1600 (7 A 1530 ATL 433 1536 LAX	96 A 1674 1735 ATL 70 ORD 1674 1735 ATL 74 B 193 1705 19 146 A
110     00100     1933     2036     1190       010     881881     1955     22240       011     881881     1955     2980       012     881881     1955     2980       013     881881     1912     2125       013     881881     1912     2125       014     881081     1912     2819       215     881881     1912     2819       213     881881     180     DFW       100     DFW     100     MCO       110     BFK     721     FLL       015     881881     1934     2855     2328	FLL 364 0434 FLL 11MCC 04460538	JFK 95600639 10815 07 149 149 501 0730 FLL 176 ATL 1 96542 08230650	LAX 95 151 95 15 195 1958 195	134' FLL 144 142 1988 793 PBI 1158 1328 1 149 ATL 88 1221252 EWR 1215 1335	1543 J 1529 74 128 16 BDA 1612 69 87	AIL: 158 L 1635 1455 FK 153 F 1635 199 ATL: 102 MCO 00 1655 1912 19 SFO 1428 62' BOS 62 0 1757 18441 FLL 60 J 1720 829' ATL

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0         ROTATION CHART         delta_new         Monday           cm1         ap         01         22         32         42         23         24         22         23         24         22         23         24         24         2		•		• 0	THERS	REPO	rts	EDIT	SE	ARCH	FILE	s	WINDO	w	WEEK	DAY			GORITH	нм
	00           CHI           0001 <td>ROTA 90 01 90 1 90 1 90 20 1854 DFM 190 190 200 1920 20 97 1920 20 97 1933 LGA: 1933 LGA: 1933 LGA: 1933 LGA: 1933 LGA: 1933 LGA: 1933 LGA: 1933 LGA: 1933 LGA: 1933 LGA: 1933 LGA: 1933 LGA: 1933 LGA: 1933 LGA: 1933 LGA: 1933 LGA: 1933 LGA: 1933 LGA: 1935 200 120 120 120 120 120 120 120</td> <td>TION C 32 1955 32 1955 32 1775 261 1775 261 1775 261 10 2038 777 76 2038 777 76 2038 777 76 2038 777 76 2038 777 76 925 6 EWI 10 2038 777 76 925 6 EWI 10 10 10 10 10 10 10 10 10 10</td> <td>HART 93 04 27555 27999 4TL 22759 ATL 22779 2 PBI 2279 BOS 2259 FLL 2279 23999 100 2259 100 2259 100 2259 100 2259 2259 100 2259 100 2259 100 2259 100 2259 100 2259 100 2259 100 2259 100 2259 100 2259 100 2259 100 100 100 100 100 100 100 10</td> <td>05 0 30 325 X A 261 M 335 24 A 100 335 24 A MCO 330 244</td> <td>delta 6 07 EMR 2517 CO 261 0 130021 SFO 2755 L</td> <td>Tew OB LG</td> <td>09 1 MIA 0 As 6400 55 FLL 0433 FLL 1 0433</td> <td>394 54 MCO 84 494 f 25 494 494 f 25 364 14/CO 160530</td> <td>1 12 TP SEA: 035 60397 11: 556 137: 14 604 9600639 14 604 157: 14 604 157: 14 604 157: 14 604 10 157: 14 604 11: 14 604 10: 14 604 11: 14 604 10: 14 14 14 14 14 14 14 14 14 14 14 14 14</td> <td>13 PA 1 0733 0 0431 170 6 F 6 6 170 6 170 6 170 6 170 170 170 170 170 193 194 195 198 198 198 198 198 198 198 198</td> <td>14 13 14 13 14 15 14 15 16 16 10 10 10 10 10 10 10 10 10 10</td> <td>15 09558 79 1005 13 1012 1012 1012 1012 1012 1012 1012 1</td> <td>16 ATI 113 40 BO: 113 ATL 155 5 11 117 55 5 11 117 ATL 0 80 117 ATL 984 ATL 984 ATL 984 117 117 117 117 117 117 117 117 117 11</td> <td>2 18 DFW 1155 1207 1122 1207 1122 5 157 50 157 50 157 50 1256 7 50 1256 7 50 1256 7 50 1256 7 50 1256 7 50 1256 7 50 1256 7 50 1256 7 50 1256 7 50 1256 7 50 1256 7 50 1256 7 50 1256 7 50 7 50 7 50 7 50 7 50 7 50 7 50 7</td> <td>15 83 MCO 320 14 111 33 82 82 97 17 1955 97 17 1955 88 1955 88 1955 88 1955 88</td> <td>20 2 158 25 154 25 154 25 154 25 154 153 4 TL 153 153 153 153 153 153 153 153</td> <td>Mor 1 22 LAX 300 14 ATL 2 1655 FW 1524 1555 1</td> <td>173 173 173 174 173 174 175 153 153 153 153 153 153 153 15</td> <td>24 DF DF DF LF LF CO 2 1910 CO 2 1917 CO 2 191</td>	ROTA 90 01 90 1 90 1 90 20 1854 DFM 190 190 200 1920 20 97 1920 20 97 1933 LGA: 1933 LGA: 1933 LGA: 1933 LGA: 1933 LGA: 1933 LGA: 1933 LGA: 1933 LGA: 1933 LGA: 1933 LGA: 1933 LGA: 1933 LGA: 1933 LGA: 1933 LGA: 1933 LGA: 1933 LGA: 1933 LGA: 1933 LGA: 1935 200 120 120 120 120 120 120 120	TION C 32 1955 32 1955 32 1775 261 1775 261 1775 261 10 2038 777 76 2038 777 76 2038 777 76 2038 777 76 2038 777 76 925 6 EWI 10 2038 777 76 925 6 EWI 10 10 10 10 10 10 10 10 10 10	HART 93 04 27555 27999 4TL 22759 ATL 22779 2 PBI 2279 BOS 2259 FLL 2279 23999 100 2259 100 2259 100 2259 100 2259 2259 100 2259 100 2259 100 2259 100 2259 100 2259 100 2259 100 2259 100 2259 100 2259 100 2259 100 100 100 100 100 100 100 10	05 0 30 325 X A 261 M 335 24 A 100 335 24 A MCO 330 244	delta 6 07 EMR 2517 CO 261 0 130021 SFO 2755 L	Tew OB LG	09 1 MIA 0 As 6400 55 FLL 0433 FLL 1 0433	394 54 MCO 84 494 f 25 494 494 f 25 364 14/CO 160530	1 12 TP SEA: 035 60397 11: 556 137: 14 604 9600639 14 604 157: 14 604 157: 14 604 157: 14 604 10 157: 14 604 11: 14 604 10: 14 604 11: 14 604 10: 14 14 14 14 14 14 14 14 14 14 14 14 14	13 PA 1 0733 0 0431 170 6 F 6 6 170 6 170 6 170 6 170 170 170 170 170 193 194 195 198 198 198 198 198 198 198 198	14 13 14 13 14 15 14 15 16 16 10 10 10 10 10 10 10 10 10 10	15 09558 79 1005 13 1012 1012 1012 1012 1012 1012 1012 1	16 ATI 113 40 BO: 113 ATL 155 5 11 117 55 5 11 117 ATL 0 80 117 ATL 984 ATL 984 ATL 984 117 117 117 117 117 117 117 117 117 11	2 18 DFW 1155 1207 1122 1207 1122 5 157 50 157 50 157 50 1256 7 50 1256 7 50 1256 7 50 1256 7 50 1256 7 50 1256 7 50 1256 7 50 1256 7 50 1256 7 50 1256 7 50 1256 7 50 1256 7 50 1256 7 50 7 50 7 50 7 50 7 50 7 50 7 50 7	15 83 MCO 320 14 111 33 82 82 97 17 1955 97 17 1955 88 1955 88 1955 88 1955 88	20 2 158 25 154 25 154 25 154 25 154 153 4 TL 153 153 153 153 153 153 153 153	Mor 1 22 LAX 300 14 ATL 2 1655 FW 1524 1555 1	173 173 173 174 173 174 175 153 153 153 153 153 153 153 15	24 DF DF DF LF LF CO 2 1910 CO 2 1917 CO 2 191

	REPORTS	EDIT	SEARCH	FILES	WINDOW	WEEKDAY	QUIT	ALGORITHM
ROTATION CHART           GHY 00 01 02 03 04 05           001 881883         0 DFW         90 AtL         30           001 881883         1955         2700325           002 881883         1955         2700325           003 881883         1955         2700325           004 881883         1955         2700325           005         1955         27005           004 881883         1628         1745         2608           004 881883         1628         1745         2608           004 881883         1629         1745         2608           005         107         2018         2335           005         108         2018         2335           006         881883         1743         2643         2218           0107         881883         1793         2038         2326           0108         881883         1793         2038         2256           010         881883         1793         2038         2256           010         881883         1933         2256         2396           011         881883         1933         2038         2256      <	delta_new 66 97 98 EWR 12517 MCO 261 01308214 SFO LAX 0566 TPA 2444	09 10 MIA 04 64 64 64 64 64 64 64 64 64 64 64 64 64	0RD 79 0RD 79 0456 394 ATL 54 0630/6 MCO 111 0556 494 ATL PB 2956 0/0 ATL 197 M 0530604 0 364 ATL 4 9609539 1MCO 14 160530601 FLL 1 06532	13 14 13 14 13 14 14 13 14 9 7 7 7 7 7 7 7 7 7 7 7 7 7	15 16 8858 AT X 140 CC 43 576 BO ATL 55 ATL 65 1912 1 15 1952 LAX 9728 LS MCO 80 1909 105 0FW 9728 LS MCO 80 1909 105 0FW 1909 105 1958 105 105 105 105 105 105 105 105 105 105	17       18       19         DFW       83         1152       MCO         31287       1328         1122       1328         1122       111         31287       1328         1122       111         31287       1328         1122       111         31287       83         157       82         1388       1355         NIA       97         158       1258         134       134         149       1988         1288       1328         1288       1328         1288       1328         1388       1988         1288       1988         1288       1988         1288       1988         1288       1988         1288       1988         1288       1988         1288       1988         1288       1988         1288       1988         1288       1988	20 21 198 158 25 1542 DFI MCO 111 1451624 SJU 1538 ATL 433 1538 LAX 1 1528 74 1528 74 1528 74 1528 74 1528 87 EMR 1432 154	Monday         22       23       24         LAX       90       DF         1415       91       DF         1415       1415       16         1555       1998       173         1524       16       16         1524       16       16         164       173       98         96       96       17         96       96       17         96       96       17         96       179       16         97       96       17         96       1795       19         97       146       A         93       1795       19         146       A         93       1795         146       A         93       1795         146       A         94       1555         1955       1955         1420       1979         97       1757         97       1743         97       1743

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005881881	15 2458 MC1	] 261		MTA	0RD 84	79 ' 56 : 87 ATL	ना 66		ATL:	205 83 57	14	50524 SJU 500 1765 ATL	96' 70	I 985	ATL 73 204	116 P	BI 15	D
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008 881881 L10 009 881881	S	F0; 2755	LG Lax	0400 6460	494 A 29 ATL	TL PBI 56 870073 197:MCO	194 ; 9 py 112 AT	ATL ( 18 1812	5 ; 115 117	MIA 97 9 1250	1433	1536 _AX	97		1738 ATL	805'	BOS	Sł
010 881881 010 881881			0000		0530	684 187102	45 890 IFK	932	LAX 0840	FI I	1101 14'	1240 ; ATI 1543 JFK	15 <b>8</b>	193 LGA 1855 1	3 2036 7 955	75	FLL 2240 LGA	•
011 10 012 881887				FLL 0434	364 A	TL 449	0976 NIA 19815 09	8'39 15	1142 ATL 958 115	1988 799	PBI 7	1528 16 4 ATI 1688	35 102 / 1655	1982 ICO 2 1912	2025 126	EHR 2125	2386	
013 118 014 181 181	þ			FLL 1	14CO 685396	149 LL 176	8736 ATL 1	DFN 0921 15 MC	14 0 80	IS ATL	1955 8	BDA s	FO 1 1420 2' BOS	Sez BDI	DF 1918	2019 2019	• MCI 2336	0
сто 981007 015 110 881889	se TPA					0642	FWR	1993 ATL 1923	195 194	EWR 215 1 3	<b>87</b>	ET2 50 F EWR 504	LL 60	1941925	JFK 48 20	721 55 128'	FLL 2328 ATL 1	56
<b>016</b> 100 881881	2444	;	4 1 1				0850		112012	00	1432	1540	1743	1848 :	2005 2	105 22	22 2330	,

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33	ROTATIO	)N CH	ART	18	delt	a_new 213	141	15 16	17	. 18 1.	9 20	21	22 23	24	<del>0,1 0,2</del>	<u>Мс</u> 2013	onday e4	05
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	2450			0	ID		0 <mark>988</mark>		лар АТІ ч	205	145	1624 16 SJU	a1713	905	2818 ATL	116	2218 i PBI	2335
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<b>006</b> 881884	0136	U 0214	, I.	птн; 6454 • Ма	,U, , 0e3 , 11	6784	BOS	105	1	BDA:	85	1538 IL	144 L 74	1735 : B	IOS	183	ł	FLL
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<b>008</b> 881884	5F U 2	255	- LUNS 841	98 18	2956 ( TI 10-	985400736 MCU	β916 112 ATI	1012	117	58 1258	1433	1536 AX	146		1736 ATL	805'	BOS	
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010 L10 881881							JFK	151	984	FLL	144	1543 JFK	1655 <b>153</b>	1855	1955 FLL	76	2249 LG	A
011 881881			- -	1		444	е <mark>9985</mark> МТА	829	ATI	7 1 <mark>960 799 : Pi</mark>	<b>ŠI 74</b>	1529 16 ATL	35 _ 102	1982 MCO	2025 1 <b>26</b>	ENR	238	9
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<b>014</b> 881881					θ6	42	6820850	1003 i 111	105	1221252 ENR	87'	6T21650	تورا LL 6	71844192	JFK		21	FLL
<b>015</b> 881884	TDA						EWR	1023 801	FLI	1215 193	35 E	1604 WR 82	1720 S'A	TL 761	948 24 MCO	955 ) 128	ATL	7328 - <b>1'56</b>
016 110 88188 <sup>151</sup>	2444	1 1 1		1 1 1	•		0850		TIZOI	200	1432	1540	1743	1848	2005 :	2105 1	2222	2330

-203-

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	RC	)TATI	ION C	HART		(	delta_	ายม											M	londay	
<b>001</b> 967 881883	30	06 EWR 2517	<u>97 (</u> {; ;	28 9	<u>9 19</u>			13   8! /33	14 15 9 9 8	58	DF	18   N   1 152	9 2 89	0 21 13		2 23 X 9 1415	24 0	01 DFW	92 0 955	3 04 AT 275	05 L 2325
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		1 1 1	1 1 1	( )   )   }   }	1 1 1	:	SEA;	170		140	-	<b>,</b>		DF	W :	175	1676	LAX	71	s S	EA :
004881884	261 P	00) 100			•			PB	I <b>5</b> 0900	76	0\$ 131285	111	<b>M</b> (	CO 111	1 AT	1/11	E1	NR 2010	261	Å	L 261
005 881881						0KD; 075	79' 56 ! 6	AIL जिस् 683	83		SJU 236 1	41	96		AT Fetal	L 116					-
006 881884	•	0130 0130	1 9214		MIA 045	394	ATL 8634784	66	1	ਤ ਹਤ	JU 1,990	82		A 1539	154	78	ORD 736				-
007 L10 881884	-					ינט; פקנ		, DUS 982	63 1955	1155	BU	365	85	16	AIL ឆ្លាំ	74 785	1926	US 2920	18		1 LL 2326
008 88188		SFO		LGAG		494 Å	TL PBI	194	ATL	65		97	Á	TL		57				į	SF
009 10 <sup>0</sup> 881884		2	LAX	388 <b>1</b> 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	6	ATL 85306	197;MC( 84  8710	34   112   45	ATL	1	.17	250		AX : 1240		146	193	ATL 203	88 <b>6</b> '	<b>BO</b> 2250	S
<b>010</b> 881884								IF		LAX •	840	134		1543	ATL 1	158	LGA 1855 1	955	77	FLL 2240	
011 001001								Jr	4985 I	51		L 1 1999	.44	Jr 1528	1635	153	1982	LL 2025	76	2,36	
012 110 881881				Fl	L  3( 0434	64 A	TL 449	8815	IA 839	i AT	L 799	PB 1320	I 7	1 160	ATL:	182	ICO 1912	126	<b>EWR</b>		MCO
013 881884				1	LL 111 8446	NLU 953866	149	873		8928 8928	149	19	55		51	U 1 1420	.80	וע ; דידין	2019		MLU 2330
014881881						F	LL 17( θ642	0820	115 350 100	MCO a Tot	• ATL	252	1	BDA	62 <sup>1</sup>	309 1757 1	62 BD				
015 881884							8		; AIL	. <b>194</b> 923	1215	1335	87'	let Let	다. 다	- <b>60</b>	19	JFK 748 20	77 55	21	FLL 1328
<b>016</b> 110 881881	56 TP 244	PA 7			, , , ,			EWR	<b>801</b> 359	FL	L 01200	300	1432	NR   1540	829	ATI	- <b>761</b>	MC0 2005 2	128 105	AT 2222	_ <b>1'56</b> 2330

-204-

ROTATION CHART         delta_r         DELETE           CHT         05         06         07         08         09         10         11         12         DELETE		
	24 01 02	Monday 2 03 04 05
001         88188         TPA         INTERCHANGE         DFN         89         LAX         90           767         88188         2517         1988         1152         1988         1415         1415	DFW;	55 2252925
002 881883 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	1901 LAX	2005 715 SEA
003 881881 L10 UNDELETE BOS 111 NCO 111 ATL 141	1620 174 ENR 2	15 2988 161 ATL 261
CIG 881887, 2458 ORD 79 AIL 83 SJU 96 ATL 116 P	1985 2818 PBI 751	2218 2335
00100         MCO 261         MIA         394'         ATL         56         510'         1236'         134'         161'9'         171'9'         189'           006         88188         01300214         0454'         0632/04'         1105'         1500'         1538'         1538'         1538'         1538'         1538'         1538'         1538'         1538'         1538'         1538'         1538'         1538'         1538'         1538'         1538'         1538'         1538'         1538'         1544'         1738'	ZD T	
007 881881 100 881881 0556 0823855 1155 1355 1355 1355 1355 1355 1355	BOS 1920 2020	183 FLL
OO8         881881         SFU;         LGRs         494 A IL         PDL         1294         HIL         55         MLH;         57         HIL         57           1008         881881         2255         8466         2956         67662739         8916         1012         1186         1256         1433         1536           1 AX         Ks         ATI         197 MCO         112         117         AX         146	1736 ATL	sec BOS
009 881884 0000 0530604 '0710745 07002932 1101 1240	1933 283 LGA	8 2258 77 FLL
U10 <sup>-881887</sup> 911 881884 911 881884	855 1955 FLL	76 LGA
FLL 364 ATL 449 MIA \$39 ATL 799 PBI 74 ATL 102 MC	0 126 1912	ENR 2128
013881881 04468533601 8736 8928 1855 1420		M 188 MCO 2019 2338
014881889 014881889 0642 0820850 1903 1105 1221252 1612650 175718 ATI 194 FWR 87 FLL 60	441925 JFK	721 FLL
015 881883 L10 ENR 801 FLL 808 ENR 823' ATL	1948 20 761 MCO	128' ATL 1'56

-205-

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42 CMT	R	OTATI	ION CI	HART	<u>a 10</u>	0	lelta	_new	14	15	16 1	7	18 1	9 26	) 21	22	23 2	4 01		Mon	day 04 0	95
<b>901</b> 967 88186	30	EW	<u>₹</u>		<u> </u>		ŤP ¦	A . 9733	3	858		DFW	152	89	130		5	185	DFW	<b>38</b>	ATL 2752325	
002 88180 L10	14						SF	0 0431	38		ATL ATL	<b>15</b>	5' M( 1320	1425	€ ¦A	TL: 1655	8 <b>2</b>	DFW	91	82	LAX	
003 110 88188	4						SEA;	178	1.AX 96106	3		1122		M		24!	179	Teze	.AX ¦ 1745	713	2999	
004 L10	261 5 2	HCU 450				000		ATI	6 <mark>966</mark>	576	I I I I	285	111	IIL I 45	U 111	A IL 1641713	141	905 2	20	221	8 233	261 P
005 L10 88188	ł	NC0			MTA	UKU; 845	73 · 6 · ·	HIL 8741 8	33		1236 S III	5JU 134		36	, 16 A T	HIL 17 171	110 P					
006 88188 L10	ł	e13	9214		942 1	121 1	863Q76	R I	s .	105	1	390 RDA		85	1536	1644 1644	173	ROS		183	FLI	
007 88188 L10	ł	SEN		I GAG		855 494 Å		1 082 T 1194	10855 A		5	MTA	355	Å	1583 TI	1785		1926 2	828		2326	SF
008 88188 L10	*	2	255 LAX	84	88 6	296 ATL	іс ө <del>ү</del> ө 197 М	er3e CO :112	ATL	1912	117	50 12	50	1433	1536 AX	14	6	Â	1730 TL	886	BOS	     
UUA 88188			θ	999		85396	84  97	10745	090093	2	LAX		11 134	ਜ	1240 Å	TL 1	158	1933 LGA:	2838 77		2250 FLL	
								J	FK	  151	884	FLL	: : 1	.44	1543 JFI	1655 1	18 53	55 195 FLI	5	76	ZARI LGA	
				FI	L <b>L 3</b>	64 A	П. 4	49 1	998 IA (	; ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;	ATL	2 1 799	see PB	I 1	1529 A	635 TL¦ 102	2 MC(	902 : ]1;	2825¦ 26	EHR	2386	
				ſ	ө <sup>434</sup> LL 111	PG MCO	14 14	9811 9	9915 0	DFW	958 11 1	50 <b>49</b>	1320	1420	1686	1655 SF0	1812	912	DFW	125	MC	0
<u>čio</u> 88168 014 88166			, I I I I I I I		8446	853866 F		.76 ATI	उद - ¦ 115	6928 MC	0	ATL	1 qı 88	55    ]	DA .	142) 62'	BOSsz	BDL	918 2	819	2330	
01588188							8642	082	A	11 11 11	1 <del>105</del> 194		EWR	87'	612) 600	FLL	1757184 60	41925	JFK	721	FLL	
	56 T	PA TA					8 8 9 8	ENI	850	; 1023 01	FLL	200	1335	1432	1684 WR   1 1540	29 <sup>1</sup>	ATL	761 8 20	MCO 15 210	1 <b>28</b> 95 222	ATL 1 2 2330	56

-206-

	₽)	4			OTH	ERS	REF	PORTS	5 E	DIT	SE	EARCH	1 ) [ F	FILES	) ( •	/INDO	•	WEE	KDAY	QUI	т](,	ALGOR	ШТНМ	
CHT	ROI		N CH	ART	21	<u>0                                    </u>	delta	a_nei 21	<b>1</b> 3 14			<u>ie 1</u>	2		2 2	0 2	12	2 23	24	01	02 C	Nonda <u>ı</u> 23 q	y Let	5
001 767 88188	38	ENR 2517	¥		1		1	PA 0733	83	8	1958	AT.	DFN 11	152	85	1		X 1415	<b>30</b>	; DF 1854 ⊮F₩	N 91 1955	22 22	1L 52825 AY	
002 88188	4						S CEA	0431	70	. 38 			L 15	5 N	1425	.əə 154 Di		55 174	1886	1,501 LAX	71		SEA :	1
003 88188		0		. ( ) ) ) ) ) ) ) ) ) ) ) ) ) ) ) ) ) ) )	   		, JLH 0;	1 356	PRT	96 196	13 1676	BOS	1122	111	M	CO 11	1524 11 AT		11	EWR	261	2 A	ITL 2	261
<b>004</b> 88188	261 M	50			• •	Ubu	74	A	н 1 1	700 <b>1</b> 0	13	113	- 1285 SJU		96	4511624	164 A)	1713 IL 11	190 IS PBI	5 2016		2218	233	5
005 88188: L18		<u>[]</u>			MTA	394	ATI	874	1 0833 66	-		123 SJU	F 13	<b>#</b> 1 82			ATL	1719 <b>70</b>	ाङ्गा ORD					
006 88188 L18	* "	013Q	0214			454 • NCO	863. 1	784 [18	BOS	63	1 1 1 1 1 1	1	BDA		85	155	HTL	14	1735	GA	ן זל	FL	Ļ	
007 88188	4	SFO		LGA	5	0 494 f	756 1TL P	BI	0820 194	155 A]	TL 6	1155 ; <b>5</b>	1 MIA	355 <b>97</b>		ήTL	1683 1	655 <b>9</b> 7	1855	1955		224	10	si
<b>408</b> 110 000	1	22	LAX	6	400 56	ATL	756 B	MCO	112 A	FFTE TL	1912	111	150 1. 1	250	143	15 153 LAX	16	146		ATL	736 801	s B	OS	
UU3 88188			θ	900		853	694	187 187	45 B	9009	32	LAX		134	រុំ រុ	12: <u>f</u>	~ 기L	74	BO	1933 2 IS :	:03 <mark>9</mark> 189	222 F		
C10 011 011 011					* * *				JFK		151	68	FLI	l	144	15	JFK	e 151	1845	1995 FLL	76	22		i     
				F		364 (	ATL	449	NI	9985 A 1	653	ATL	42   799	1988 P	BI	1521 74		102		2 28 126	EN	12 12 13	्रुए७ । ।	
					e <b>4</b> ء FLL	14 LIMCO	96096% }	399 149	9815	8915	DFW	1958 1	150 149	1326	1426	'	1600 1 S	FO	180			188	2334	<b>.</b> 0
014ee1ee	1				Ð	46853	IGOI FLL	176	8736 ATL	115	092 MC	.0	ATL		18 18	BDA	<b>61</b>	2 <sup>1</sup> 428	BOS 62	BDL 925			1 1 1	
<u>či</u> в'88188 015 ввтом	יין ד	. l . l . l	1 ( 1 ( 1 ( 1 ( 1 ( 1 ())))	1 1 1 1			96	42	<b>9820</b> 8	1	1983 ATL	195 194	1221	ËNR	87	, o 1 41.	F.	LL 1720	60	JF T948	-K 2955	721	FL	Ĺ
016 016	<b>56</b> Tl	PA	• • · · ·	6 6 1					ENR	50	801	FL FL	1200	300	143		82 40	9' 174	ATL 7	61 M	ICO 12 2105	2222	ATL 233	1'56 0

-207-

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	RO	TATI	ION CI	HART			delta	a_u	DEL	ETE							~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~		01		Monda	y A A	5
	05 ( ] 30	e Emr	<u>07 (</u>	98 6	9	0 1	I I	PA	INTERC	HANGE		DFW		<u>y 2</u> 89	<u>a 21</u>		23	50	DFI	1: 3		TL	
767 <sup>+</sup> 88188		2517			, , ,		S	07 F0	MON MOVE	/EI ALL	ATL	. 155	1 <sup>52</sup> /	:0 15	136 136	រថ i ATL	415   82	D	1854   FW	1955 82	22	252325 LAX	
UU2 88100	7				     		SEA	0 <b>4</b> 1	MOD	IFY	113	207	1320	1425	1542 DF1	165	5	1800	1901 1 AY	71		2005 SEA	
003 L10 88188	1		1 1 1		1 1 1		ЭСП, 03	56	SWA UNC EI	4 P LETE		1122				1524	113	162		745	2		
<b>004</b> 88188	261 M	031 50							zoo	м	BUS TT30	295	; 111 ¦	14 14	U 111	H I)L 1641	14 /13	1 1985	2010	261	2218	233	261 P
005 110 88188	+	1 1 1				ORD ®	79'	674	HIL ; T 6833	83	1236	5JU 1 34	  1	96	1	אדע י¦נים	. <b>11</b> 0 719	FBI Test					
<b>006</b> 88188	H H	СО 25 013	1 99214		MIA 0	<b>394</b>	ATL 8634	784	56	185	SJU 1	300	82		A 1536	TL   1644	78	0RD					
007 88188 L10	ł	1 1 1				NCO: 0	1 56 !	18	: BOS: : 0820855	63'	155	BUA 1	55	85	1,60	AIL; 53 165	158 5	LG 1855	H; 1955	77	: FL 224		
	ł	SFO	255	LGA	6	<b>494</b>	TL P		194 	ATL (	5		<b>97</b>	À 1 1 3 3	TL 1536		97		173				SF
00988188	1	, 2. 1 1	LAX		56	ATL	197	NCO	112 ATL		117				AX		146		ÁTL	38	, B	0S ភា	
010 88199	1	1 1 1 1	θ	999		0530	1684 ( 1 1	97102	95 87966 	1 1 1	LAX		111 134	.01	ÂT	L	74	BO	S	189	F	<u> </u>	
<u>110</u> 88199	]								JFK	151	0840	FLL		44	JF	1639 K	153	1845	FLL	76	22	LGA	
				F	11	364	ATL	449	e <sup>90</sup>	5 <b>8'3 9</b>	ATL :	2 1 799	see PB	I Ż	1528 1 f	1635 ATL:::	182	1982 MCO	282 126	EWI	R 2	300	
					843		600637		8815 89		958 115	50	1320	1420	160	165 CEA	5 18	172 191	2   	2125 FM	1.00	мс	n
013 L10					r L L 1 04	100530	1	13	8736	07 M		<b>13</b>	19	55			420		1918	2019	1.00	2336	
01488188							FLL ¦ 0642	176	ATL 11	5   MC	U 80 '	A I L 12212	52	1	BUA ; 613 650	62'	<b>ם:</b> זקז	US 62 B				<b>F</b> 11	
015 88188		8 								AIL 1823	194	218	. <b>ИК</b> 1335	87'	Lee	ਾLL ਜੋ¦ਾ	728		; JFK 1948 2	955		2328	-
<b>016</b> 88188	56 TF	PA R							8850	801	; FLL	200	200	1432	WR :	829'	A    743	TL   761 1848	2005	0 121 2105	r' A 1 2222	2336	56

-208-

	•)			отні	ERS	REF	°ORTS	;	DIT	SE	ARCH	I F	FILES	)[ •	INDO	* ][	WEE	KDAY	) G	דוטג	AI	LGORI	ТНМ	
	ROT	ATION	CHART			delta	a_new	J 314	15		<u>6</u> 1	21	8 1	9 20	221	2;	23	24		0	M( 203	onday	 	
<u>CHT</u> 901881883 002881883 003881883 004881883 004881883 005881883 005881883 006881883 006881883	261 M( 30 261 M( 5 245	EWR: 2517 CO 13 0130021	7	99 MIA 6	16 ORD e! 334 154 MCO e	79 756 SEA 9 8 7 8 6 6 3 1	4 1 874 FO 9431 1 356 PA 9733 764 [18		98 98 LAX 961064 988 898 898 898 898 898 898 898 898 89	3 3 576 158 105	123 AT 113 80: 113 SJU	SJU F 13 L 15! 1207 1122 S 1205 DFH 1 300 BDA 1 1	11 5' M 11328 1111 152 82 455	96 CO 1! 1425 M( 85	58 154 DF 20 11 51624 1535	ATL 7619 ATL 7 16 1524 1524 1524 1524 1524 1524 1524 1524	L 11 1719 82 55 175 175 1719 X 1415 70 4 705	185 185 185 185 185 185 185 185 185 185	DFN 0FN 1520 187 187 187 19770 19770	01 LAX 17 DFW 54 19 S 2929	82 713 261 555	275 275 275 AT 22775	LAX 9995 XEA 7997 2935 L 2935 L 2935 L 2935 L	51 S
008 0000 009 00100 010 00100 011 00100	1	SF0 2755 L	LG .AX 9999	66 6488	494 2 ATI 853	HIL   956 6 _ 197 9684	788738 788738 MCO 187167	,194 112 A 75 0	HI PTT TL 900932	1912	11 LAX 08.		258 134	143 1181	153 LAX 124	ATL JFK	146 15 55 153		F 1993 LGA: 58 19 FL	1730 1TL 283 55 -L	<b>806</b> 77 76	223 FL 224 224	OS 	
210 <sup>1</sup> 88180 012 88180 013 88180 013 88180 014 88180	7 17 17			FLL 675 FLL 61	364 11 MC(	ATL 960961 ) ;601 FLL 96	449 37 149 176	MI 8815 8736 ATL 68298	e998 [A : 0916 D 115 50 1	FN 8972 MC 6073	ATL 1958 1 0 80 1105 194	42 791 158 149 ATL 1221	1988 P 1928 1928 1 262 EWR	BI 1420 155	1628 74 BDA 161216	153 ATL 500 50 Fl	102 555 0 1429	HC( 1812 186 BOS 62 57 184	912 BDL	126 126 1918	ENR 2128 FN 2019	180	MCO 2330	)
015 L10 016 L10 88188	56 TI	PA 금				, , , , , , , , ,		EWR 08	350	192	<sup>3</sup> FL 1120	1215 1200	13:	35		1604 829 70	1720 1720	ATL	19 761 18 2	48 2 MC 2005	0 128 2105	A 22222	2328 1TL 1': 2330	5(

-209-

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	RO	TATI	ION CI	IART		delta_	new						WEDNES	SDAY DAY	- 01 - 0	Mon	day A4 A5
<b>001</b> 967 88188	30	EWR	<u>97 (</u>	08 09		1 12 79' 456	13 ATL 747 083	14 15 ; 83 ;;	16	SJU ;	96		FRID/ SATUR	AY DAY			
002 88188	*		1			SFO	131	58     0Y		L 155'	MC0	158 f 5 1542 DEL	SUND WEEK	AY LY	1501 1901 1 AX	82	2005 SEA
	1					ЭЕН. 0356	170	0610643	110	1122			524	16	28 17	5	2000
004 10 <sup>4</sup> 88188	261 P	00) 150					PB	[ s 9788	76 BO	S 1		HCU 111	AIL 14	1901	EWK 2010 DEM	261	HIL 261
005 110 110	8	1				1 <b>PH</b> 0	; <b>83</b> /33	68	58	ОГИ 1152	, 83	130		30	1854 19	55	2252325
006 88188		0130	1 9214	N]	A: 394	ATL 0630204	66 1000		ा जन्म	J 1966 100	82'	1538	1644 ; ATI 2	UKU 1735	ROS	18	FII
<b>007</b> 881884	ł				HLU 8	56	0820	655	1 155	1355	. 83	1,60	13 1785	19	20 2020		2326
<b>008</b> 88188		SFO	255	LGAs	494 6	TL PBI	<b>194</b>	; ATL 9918 1	65 812 ! 1	NIA : :	97 ' 143	AIL : 33 1536	57		1736		51
009 110 110		·	LAX	<b>699</b>	ATL 8530	197 MC	) 112	ATL	11	1	1,101	LAX 1240	146		ATL 933 203	<b>806'</b> 9	BOS 2258
<b>010</b> 10 88188		)         								¥0	134'	1543	17L: 15	1855	1955	77 2	
011 88188		)       					JF	6985	51	FLL 42 1388	144	JF 1528	K 153 1635	1982	FLL 2825	, /b	2300
012 L10 88188		1 1 1		FLL	<b>364</b>	ATL 449	0816	LA 83	9 AIL 1958 1	799 50 13	PB1 20 1420	74 fi 160		812 191	125 2	2125	мсо
013 10 <sup>9</sup> 881881	P			FLI	_ 11 <b>4</b> 1CO 4460530	149 601	873		M ; 0928	[49	1855		5FU ;	188	1918	2819	2336
<b>014</b> 881884						FLL   17 8642	08206	115 50 10	MCU 80 03 1105	AIL		IEINE50	62   17	0362 D	75 15	231	FLI
015 10 10	ŀ	1 1 1							1023	1215 ENI	1335	160	1720		1948 26	55	2328
<b>016</b> 881887	56 TI 244	PA 77		, , , ,			E WR	<b>80</b> 1 350	L ; FL	200	143	EWK   32 1540	829'      1743	11L ; 76 1848	1 ; MU 2005 2	105 222	HIL 156

-210-

	•••	OTHERS	REPORTS	EDIT	SEARCH	FILES	WIND	oow )	WEEKDAY	γ ) QUIT	ALG	ORITHM
	ROTATION CHART	<u></u> ́	delta_new							4 81	Weel	(ly
CMT 0	5 96 97 99	69 10 1	1 12 13	14 15	16 17	18 1	9 20	_212	<u>2 23 2</u>	n U		
001	se EMR	ORD	79' ATL	83	SJ		96 ;					
YU1 8188	2517	8	56 8741 0	33	1236	1341		1617 Δ	1/19; 19 [] 196 P	AT		
	se EMR	ORD	79' AIL	83			36 1					
881887	2517	0	56 8741 8	33	1236	1341 	96	A	TL 116 P	BI		
Ne 881881	se ; ENR;	עאט	79' HIL	, 83					1719 18	চা		
	2617	חסט 100	56 0741 01	533 <b>8</b> 3	SJ	U .	96	A	TL 116 P	BI		
Th 881884	SO EMK			1	1236	1341		1619	1719 18	जा		
99100/	2517 FWD	<b>NRU</b>	79 ATL	83	ŚJ	U	36	<u> </u>	TL 116 P			
Fr 881884			56 8741 8	833	1236	1341		1619	1719 18	51		
00100	SI FWR		ÁTL	83	<u> </u>	U <u>:</u>	96	<u> </u>				
Sa 881884	2517		θ	833	1236	1341		1619	1719 18	51		
	SO EWR	ORD	79' ATL	1 83	<u>;</u> SJ	U <u>:</u>	96 ;	<u> </u>				
Su 881881	2517	9	456 0741 0	833	1236	1341		TET9	1719 18			1 AX
002.0000			SF0	58		155 1						2005
	1 1 1		0431		113120	1328	1425	1542 I • ATI	400 I		82	LAX
Tu 001001			SFU	; 38 ;		722 N						2005
88188	4		0431		ΔTI	155' M	CO 150	ATI	82	DFW	82	LAX
We 88100			Sru	1 38 1		7 1328	1425	1542 1	655	888 1981		2005
88100	1		643L	98	ATI	155' M	CO 158	ATL	82	DFW	82	LAX
Th agaaga					11312	7 1320	1425	1542 1	655 j	1986 1981		2005
88198			SFO	58	ATL	155' M	CO 158	ATL	82	<u>: D</u> FN	82	LAX
Fr 88188	1		8431		11312	1320	1425	1542 1	655 i i	888 1981		2005
00100			SFO	98	ATL	<u>155' M</u>	CO 158	: ATL	82		82	
Sa 88188	1		<b>8</b> 431		1132	37 1320	1425	1542 1	655	1986 1981		2005
_			SF0	98	<u>; atl</u>	155' M	CO 158		.; 82		102	
Su 88188	1		0 <b>4</b> 31		11312	97 1320	1425	1542 I	655 I	1988 1981 ΙΔΥ	71 4	SFA
002			SEA: 170	LAX :	140			UF M 	1 1/3		745	2986
LT0 88188	7		8356	9619643		122		152 NFM	17		( 71)	SEA
			SEA 170	1.HX ;	140				1 KUU 21	1626	745	2000
in 88188	ין אין אין אין אין אין אין אין אין אין א	i i	0356	0610643		122 '	• •	152	T			

-211-

				OTHER	S	PORTS	EDIT	SEARCH	FIL	WINDOW ROTATION_CHART SCHEDULE_LISTING	EEKDAY	QUIT	ALGORITHM
ELI	A/C	EREQ	FROM	<u>10</u>	DEPT	ARRY	CLASS	MEAL	EFFE	STATION CHART	ROTN#		
60	L10	X6	FLL	JFK	1720	1948			8511	SUB PROFILES	015-015-	015-015	-000-015
62	L10	Xe	BDA	BOS	1650	1757			85111	0-999999 014	-014-014-0	014-014	-000-014
62	L10	X6	BOS	BDL	1844	1925			85111	0-999999 014	-014-014-(	)14-014	-000-014
63	L10	X6	BDL	BOS	0700	0744			85111	0-999999 021	-021-021-(	021-021 <sup>.</sup>	-000-021
63	L10	X6	BOS	BDA	<b>08</b> 55	1155			85111	0-999999 007 <sup>.</sup>	-007-007-0	07-007-	-000-007
65	L10	X6	ATL	MIA	1012	1150			85111	008-	-008-008-0	08-008-	-000-008
66	L10	X6	LAX	ATL	0000	0534			85111	}-999999 009·	-009-009-0	09-009-	-000-009
66	L10	X6	ATL	SJU	0704	1105			851110	)-999999 006-	-006-006-0	06-006-	-000-006
67	L10	Xe	ATL	FLL	1326	1505			851110	)-999999 023-	-023-023-0	23-023-	-000-023
70	L10	X6	ATL	ORD	1644	1735			851116	)-999999 006-	-006-006-0	06-006-	·000-006
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		SEARCH FILE	S WINDOW	WEEKDAY		ALGORITHM
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-219-

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### VI. STAGE 2 - AUTOMATED DECISION SUPPORT

INTRODUCTION OF AUTOMATED ALGORITHMS, EXPERT SYSTEMS

- to assist human schedulers with certain sub-problems
- to eliminate manual effort at certain steps of process
- to broaden search for optimal or good solutions to scheduling sub-problems
- may introduce mainframe, large scale optimization algorithms

EXAMPLES OF EXISTING AUTOMATED DECISION SUPPORT ALGORITHMS

- a) Best cancellation of flights given breakdowns and spares
- b) Least revenue loss when reducing available fleet
- c) Optimal switching of flights between types of aircraft
- d) Automatic switching for transition to new schedule plan
- e) Automatic weekend schedule cancellations
- f) Automatic holiday period rescheduling
- g) Minimum fleet size for given services with time windows
- ň) Automatic gate assignment at all stations
- i) Automatic aircraft rotation generation (with maintenance constraints)

### VI. AUTOMATED DECISION SUPPORT

- a) Best cancellation of flights given breakdowns and spares
- b) Least revenue loss when reducing available fleet

# Fleet Routing Models

- use network flow algorithms

# OBJECTIVE:

Maximize Operating Income

GIVEN:

- Set of potential services to be flown with fixed operating times and known net operating income
- Daily ownership costs of aircraft
- Desired overnights
- Fixed number of available aircraft
- OUTPUT:
  - "Best" services to be flown
  - Marginal value for services not flown
  - Marginal value of adding an aircraft to fleet

# WEAKNESS:

- Fixed service times
- Fixed net income for services i.e.no spill if not flown
- Single type of aircraft-solved sequentially

#### SCHEDULE MAP



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### **Conclusions**

- 1. We cannot create analytical models which are adequate to describe mathematically the complete airline scheduling problem.
  - 2. For existing models which promise utility, we generally do not have the correct data inputs, and it is difficult to conceive of creating the necessary models for passenger behavior in today's competitive markets. The existence of large scale solution techniques is not sufficient to justify their use at present.
  - 3. We can provide quick, accurate answers to many subproblems which occur in the complete scheduling process, but we need an environment which allows these techniques to be available to human schedulers. This environment is now available in the form of a network of computer workstations.
  - 4. It is attractive to consider a single, integrated system to be used by various airline personnel as the scheduling process moves from initial planning to final execution.
  - 5. People will remain an important part of the airline scheduling process. They are responsible for generating good schedules, and need "decision support" in their activities. There never will be a "push - button" scheduling system.
  - 6. The desired approach is an incremental introduction of computerized assistance via graphic workstations. The strategy should be to create evolutionary stages:
    - Stage 1 Introduce the Scheduling Workstations
    - Stage 2 Introduce Automated Decision Support
    - Stage 3 Extend to real time Execution Rescheduling

-227-

#### VI. SUMMARY - STATE OF THE ART IN COMPUTERIZED SCHEDULING (con't)

- 7. The scheduling process is not permanent
  - as time goes by, the problems change (perhaps temporarily), and the markets evolve, and there will be emphasis on different aspects. It will not be possible to create a completely automated decision maker which keeps up with changes.
- 8. As these tools are developed, they have their impact on the Scheduling Process
  - it will change in its flow of information, the sequence of processing will change, and eventually the airline's organizational structures will change. The introduction of computer automation must be adaptive to allow these changes to occur.
- Every airline will have to develop its own automated scheduling system and manage the evolutionary impact on its operations. There is no single, turnkey solution to be provided by outsiders. A conceptual, long term plan is needed to direct the evolutionary effort and prevent building an incoherent set of subsystems.