

FLIGHT TRANSPORTATION LABORATORY
REPORT R94-4

PRESENTATIONS FROM THE
1994 MIT / INDUSTRY
COOPERATIVE RESEARCH PROGRAM
ANNUAL MEETING

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**A State of the Art Review and Critical Analysis of
World Jet Transport Safety**

by

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Primary Objectives

- I. Review jet transportation safety (1970-date)

- II. Review and critique the current state of the art in world jet transportation safety, with emphasis on in-flight and post-crash fire safety.

- III. Identify current and future R&D needs in world jet transport fire safety.

- VI. Provide a comprehensive road map for future research into specific aspects of jet transportation fire safety.

Milestones

- I. Assess current levels of safety and risk.
- II. Identify and correlate comprehensive sources of accident data.
- III. Define and rank major causes of accidents.
- IV. Develop case studies of significant accidents involving fire.
- V. Evaluate in-flight and post-crash fire risk.
- VI. Identify and evaluate fire prevention, hardening measures, rule-making, and advances.
- VII. Identify and evaluate fire management practices and development.

I. Current Levels of Risk in World Jet Transportation

- Civil aviation continues to be one of the safest modes of transportation on an hourly basis
- Jet transportation, a subset of civil aviation, boasts an even higher level of safety
- Third-party risk is minimal

Table 1.1: The Danger of Several Common Transportation Activities: Netherlands 1989 [1]

Activity	Casualties per 100 million hours of exposure
Public Transportation	10
Walking	30
Bicycling	30
Civil Air Transport	55
Driving an automobile	65
Driving a moped	250
Driving a motorcycle	1400
Flying light aircraft	1300
Flying gliders	3000
Average lifetime fatal accident risk ¹	4

¹Based on 75 year (650,000 hour) average human expected life span.

- Comparisons made with respect to passenger-miles further support this assertion...

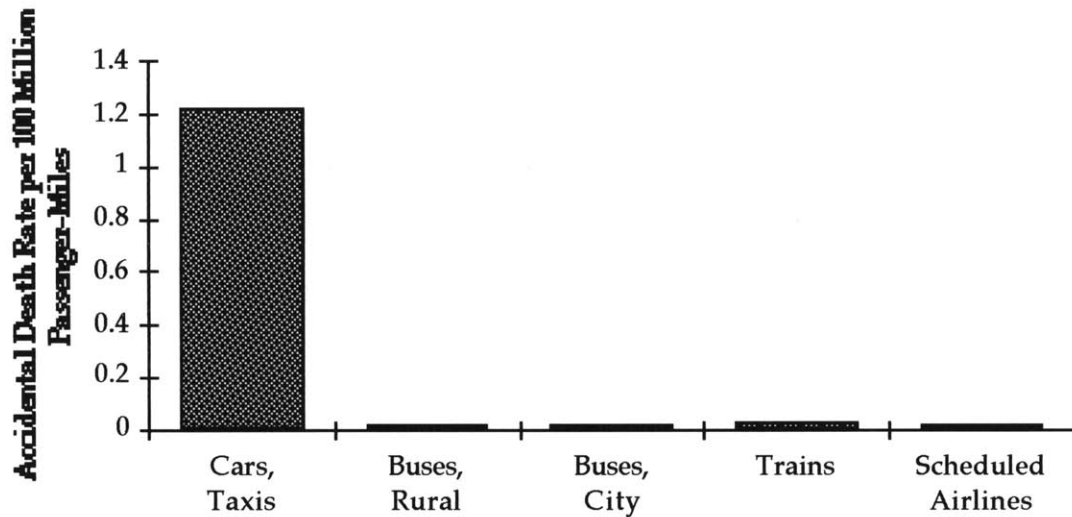


Figure 1.1: Accidental Death Rate per 100 Million Passenger Miles by Mode of Transportation, United States, 1989-1992 [2]

II. Comprehensive sources of world jet accident data

- Until recently no comprehensive listings of world jet accident data have been made publicly available.
- Past sources of accident data have been long-format reports (NTSB) or pre-processed statistics (Boeing, McDonnell-Douglas).
- Data on [former] iron-curtain carriers has been limited or omitted in its entirety.
- A new, comprehensive database is now available from the Department of Energy (DOE) [Kimura]. This data, however, is not broken down by accident cause.

II. Comprehensive sources of world jet accident data (continued)

- A. U.S. NTSB Accident Report Database
- B. U.S. Department of Energy (DOE) accident database**
- C. U.S. FAA Incident Report Database
- D. British Civil Aviation Authority (CAA) accident reports
- E. Airframe manufacturer accident *statistics* (Boeing, McDonnell-Douglas)
- F. Flight International Annual Accident Summaries
- G. U.S. National Fire Protection Association (NFPA) reports

III. Major Causes of Jet Transport Accidents

- 14 causes of jet transport are investigated.
- Accidents are also reviewed by stage of flight.

Table 2.1: Fourteen Generic Jet Transport Accident Causes

Accident Cause/Scenario	Examples, Factors, Related Events
Bird-Strikes	→ Structural damage, engine failure, etc.
Collision	→ Collision with another airborne object; mid-air collisions → Collision with man-made or natural obstacles; controlled flight into terrain (CFIT)
Dangerous Weather	→ Fog, icing, lightning, windshear, etc.
Decompression	→ Equipment malfunction, structural failure, etc.
Ditching	→ Equipment failure, fuel exhaustion
Failed Take-Off or Landing	→ Crew error, foreign object ingestion, etc.
Fuel Exhaustion	→ Ditching, ground impact
Ground Stationary Accidents	→ Hangar fires, stationary fires
Ground Taxiing Accidents	→ Crew error, ground traffic control error, etc.
In-Flight Explosion	→ Terrorism, missile strike, fire, etc.
In-Flight Fire	→ Engine, electrical, waste fires, etc.
Major Mechanical Failure	→ Avionics failure, engine failure, control failure, structural failure, etc.
Post-Crash Fire ¹	
Wake-Vortex Upset	→ Insufficient aircraft separation
¹ Usually occurs as a result of some other generic accident cause.	

III. Major Causes of Jet Transport Accidents (continued)

- In-flight fires are the least survivable...

Table 2.14: Ranking of World Jet Transport Accident Passenger Survivability Based on Accident Cause 1970-1992

Rank ¹	Accident Cause	Total Fatalities ²	Survivability ³	No. of Accidents	Aircraft Destroyed
1	Ground Stationary Accidents	1	≈100.0%	15	60.0%
2	Decompression	33	95.4%	8	25%
3	Failed Take-Off or Landing	2,326	84.5%	316	65.1%
4	Bird-Strikes	49	82.6%	8	87.5%
5	Fuel Exhaustion	172	68.4%	7	100.0%
6	Ditching	110	67.7%	8	100.0%
7	Major Mechanical Failure	3,429	56.0%	78	76.9%
8	Ground Taxiing Accidents	745	55.2%	14	57.1%
9	Dangerous Weather	3,851		101	83.2%
10	Collision: CFIT	13,931	32.5%	362	92.3%
11	Collision: Mid-Air	721	31.1%	13	80.7%
12	In-Flight Explosion	2,751	20.9%	31	83.9%
13	Wake-Vortex Upset	19	17.4%	4	75.0%
14	In-Flight Fire	1,551	12.2%	24	87.5%
Ave			%		%

¹Based on survivability.
²Includes third party deaths.
³Survivability = (Total pax - pax killed)/total pax

IV. Case Studies

- Consider 10 major fire-related accidents

Table 3.1: Jet Transportation Accidents Involving Fire 1980 - 1989 [21]

Date	Operator	Aircraft	Relation to Transport Safety
08/19/80	Saudia	L1011-200	Led to cargo rule changes
11/19/80	Korean Airlines	B747-2B5B	Review of cabin materials fire
09/13/82	Spantax	DC-10-30CF	Review of evacuation and cabin materials fire
06/02/83	Air Canada	DC-9-32	Led to wide-reaching cabin safety rule changes
09/23/83	Gulf air	B737-2P6	Review of the problem of incendiaries
03/16/85	UTA ¹	B747-3B3	Review of cargo compartment seams, fasteners, joints, and rapid fire involvement
08/22/85	British Air Tours	B737-236	Research into smokehoods and cabin misting systems
08/10/86	ATA ¹	DC-10-40	Review of cargo compartment seams, fasteners, joints, and solid oxygen systems
11/28/87	South African	B-747-244B	Proposed rule change for Class-B (Combi) cargo compartments
08/31/88	Delta AL	B727-232	First aircraft, involved in a survivable accident with post-crash fire, equipped with fire blocked seats
¹ Classified as incidents by the NTSB and FAA			

VI. Fire prevention and hardening measures, advances, and rule making

- A. Designing for fire
 - i. General approaches
 - ii. Numerical methods
 - a. EXODUS, DACFIR, PHOENICS, Vulcain, SINTEF, etc.
- B. Interior construction
- C. Cabin materials
- D. Fire blocking of passenger seat cushions
- E. Fire resistant fuselages
- F. Cargo lining materials
- G. Advanced fuels and misting agents
- H. Economic considerations
 - i. Increased cabin weight
 - a. 15% reduction in materials weight
 - b. 84% increase in cabin weight

VII. Fire management practices and development

- A. Cabin water misting systems
 - i. "Unzoned" systems
 - ii. "Zoned" systems
 - iii. On-board vs. "Tender" systems

- B. Passenger smokehoods
 - i. Protection vs. increased evacuation time-- validity

- C. Advanced fire suppression agents
 - i. Halon™ replacements
 - ii. AFA's¹ (foam replacements)

- D. Advanced Command in Emergency Situations (ACES) System

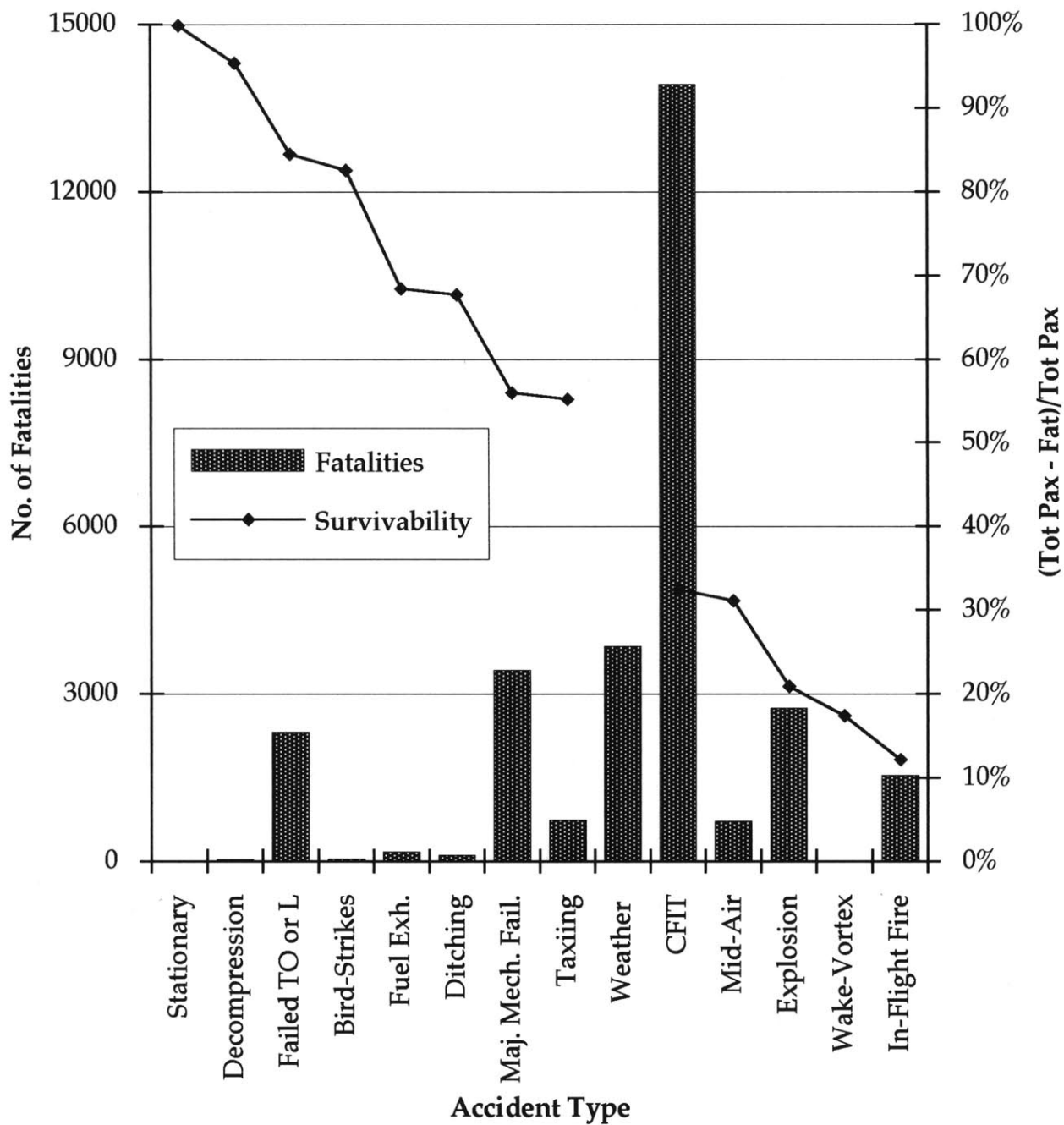
- E. Miscellaneous
 - i. Driver's Enhanced Vision System (DEVIS)
 - ii. U.S.A.F. Penetrator Nozzle

¹AFA = Advanced Fire-fighting Agent

Conclusions

- I. Jet transportation is, relatively speaking, very safe. However, it is subject to an undue amount of media coverage and scrutiny w.r.t. the low number of passenger fatalities.
- II. Improvements in fire survivability are necessary and should be based on improved passenger protective equipment and more effective fire detection and management systems, not necessarily cabin material changes.
- III. Based on FAA test data, "zoned" cabin misting systems may prove to be effective and economically viable for extending available evacuation time. "Unzoned" systems do not appear to be economically feasible.
- IV. The mandating of passenger smokehoods needs to be reevaluated. Invalid arguments?
- V. Though the search for HalonTM replacements appears to be well directed, a more specific R&D plan needs to be applied to the development of environmentally safe AFA's.

Fatalities and Survivability Rates for 14 Jet Accident Types: 1970 - 1992





Leg-Based Heuristic Methods for Network Seat Inventory Control

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**Presentation to the
MIT FTL Cooperative Research
Program**

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Presentation Outline

1. Current Leg-Based Fare Class Control
2. Obstacles to Network Optimization
3. Leg-Based O-D Control Structures
 - A. Stratified Bucketing
 - B. Virtual Nesting
4. Local Displacement Cost Heuristic
5. Static vs. Real-Time Displacement
6. O-D Control Without Virtual or Stratified Buckets
7. Conclusions

1. Current Leg-Based Fare Class Control

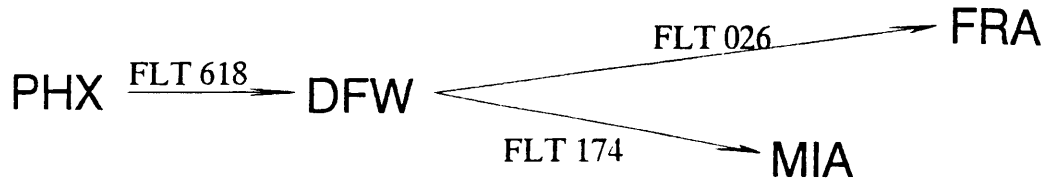
- Most airlines manage seat inventories by flight leg:
 - Fare types assigned to booking classes.
 - Class booking limits, BL_k^* , determined for each leg independently.
 - BL_k^* are nested, such that $BL_k^* \geq BL_{k+1}^*$
- Seat availability for multiple-leg itineraries is determined by:

$$BL_{ik}^* = \text{Min}[BL_{kl}, \forall l \in i]$$

for itinerary i, class k, flight legs l.

- Determination of BL_{kl}^* values based on expected marginal seat revenue analysis.

CURRENT LEG BASED SEAT AVAILABILITY



FLIGHT LEG INVENTORIES

FLT 618	PHX-DFW
CLASS	AVAILABLE
Y	32
B	18
M	10
Q	0
V	0

FLT 026	DFW-FRA
CLASS	AVAILABLE
Y	142
B	118
M	97
Q	66
V	32

FLT 174	DFW-MIA
CLASS	AVAILABLE
Y	51
B	39
M	28
Q	17
V	0

O-D MARKET AVAILABILITY

PHX/DFW	FTL 618	Y	B	M		
PHX/FRA	FLT 618	Y	B	M		
	FLT 026	Y	B	M	Q	V
PHX/MIA	FLT 618	Y	B	M		
	FLT 174	Y	B	M	Q	

CURRENT LEG CONTROL DOES NOT MAXIMIZE NETWORK REVENUES

O-D MARKET AVAILABILITY

PHX/DFW	FLT 618	Y	B	M		
PHX/FRA	FLT 618	Y	B	M		
	FLT 026	Y	B	M	Q	V
PHX/MIA	FLT 618	Y	B	M		
	FLT 174	Y	B	M	Q	

O-D FARE AVAILABILITY: SHORT HAUL BLOCKS LONG HAUL

PHX/DFW	
CLASS	FARE (OW)
Y	\$520
B	\$320
M	\$165
V	\$145

PHX/FRA (via DFW)	
CLASS	FARE (OW)
Y	\$815
B	\$605
Q	\$470
V	\$339

PHX/MIA (via DFW)	
CLASS	FARE (OW)
Y	\$750
B	\$480
M	\$270
Q	\$225
V	\$195

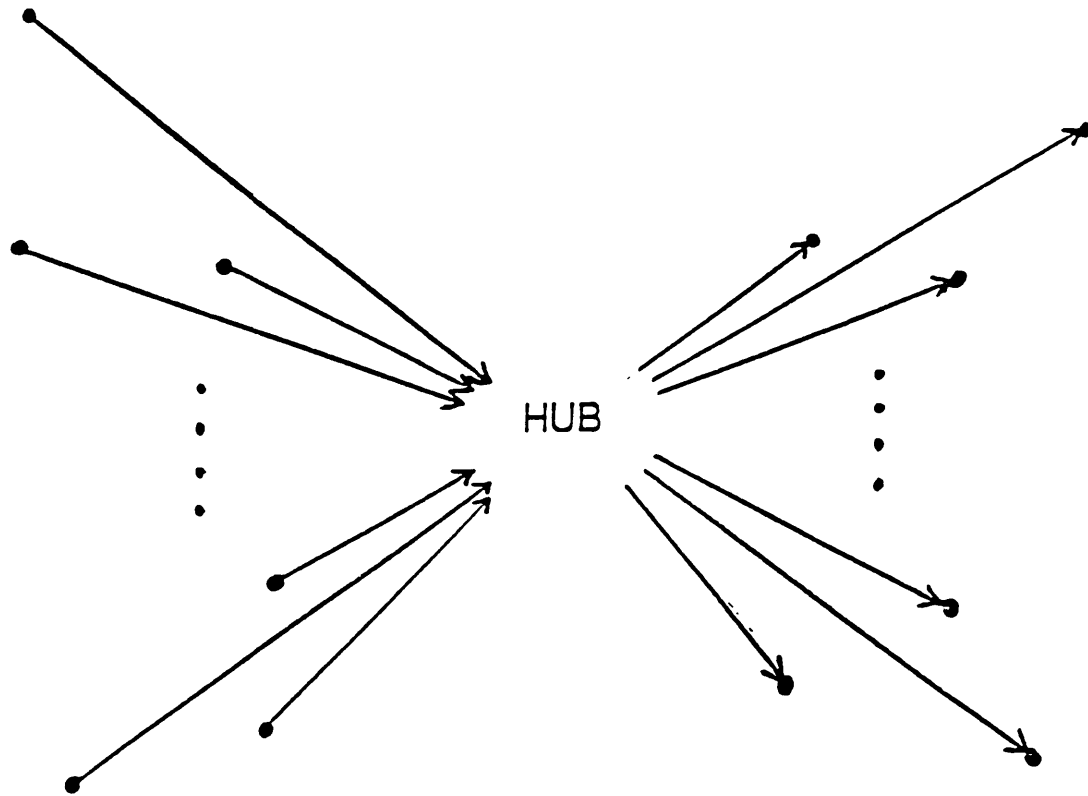
O-D FARE AVAILABILITY: LOCAL VS. CONNECTING PASSENGERS

PHX/DFW	
CLASS	FARE (OW)
Y	\$520
B	\$320
M	\$165
V	\$145

DFW/MIA	
CLASS	FARE (OW)
Y	\$620
B	\$370
M	\$215
Q	\$185
V	\$115

PHX/MIA (via DFW)	
CLASS	FARE (OW)
Y	\$750
B	\$480
M	\$270
Q	\$225
V	\$195

"TYPICAL" AIRLINE CONNECTING BANK



30 flight legs in; 30 flight legs out:

- 60 flight legs, l
- 960 possible O-D itineraries, i
- 7 coach fare classes, k for each i

Total of 6,720 possible (i, k) combinations.

Each leg l serves 217 possible (i, k) combinations.

2. Obstacles to Network Optimization

THEORETICAL

- Need to incorporate stochastic dynamic demand for each (i,k)
- Network optimization produces partitioned seat allocations, S_{ik}^*

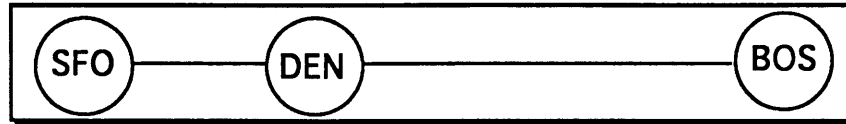
Practical

- Need historical data by (i,k)
- Difficult to forecast demand by (i,k)
- Impossible to implement S_{ik}^* in reservations systems
- Use of S_{ik}^* to actually control bookings leads to negative revenue impacts

3. Leg-Based O-D Control Structures

- **Stratified Bucketing Concept:**
 - Abandon "fare type = booking class"
 - Define stratified buckets based on revenue value, regardless of (i,k)
 - # of stratified buckets = # of fare classes
 - "Re-file" fare for each (i,k) to stratified bucket
 - Seat availability for (i,k) depends on corresponding stratified bucket availability

Stratified Bucketing



Multi-Leg Flight from San Francisco through
Denver to Boston

Conventional Fare Class Bucketing

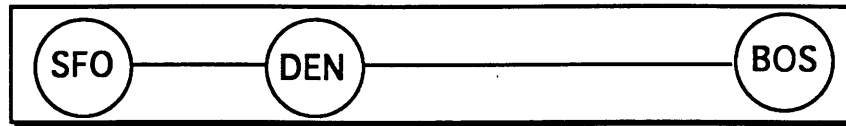
	Definition	Short Haul SFO - DEN	Long Haul DEN - BOS	Connection SFO - BOS
Y	Full Fare	\$467	\$648	\$724
B	Discount One-Way	\$259	\$440	\$467
M	7 Day Non-Refund.	\$204	\$324	\$357
Q	14 Day Non-Refund.	\$184	\$302	\$269
H	21 Day Non-Refund.	\$164	\$257	\$251
K	"Sale" Fares	\$140	\$179	\$199
L	Special Promotions	\$110	\$149	\$179

Stratified Bucketing

	Revenue Range	Short Haul	Long Haul	Connection
Y	\$650 +			Full-Fare
B	\$550 - \$649		Full-Fare	
M	\$450 - \$549	Full-Fare		One-Way
Q	\$350 - \$449		One-Way	7 Day
H	\$250 - \$349	One-Way	7/14/21 Day	14/21 Day
K	\$150 - \$249	7/14 /21 Day	Sale	Sale
L	\$0 - \$149	Sale/Special	Special	Special

- **Virtual Nesting Control Concept**
 - Same concept as stratified bucketing
 - Develop virtual "mapping" tables
 - # of virtual buckets \neq # of fare classes
 - "Map" each (i,k) to virtual class
 - Availability depends on corresponding virtual class availability
- Both control structures have major advantages over network optimization.
 - Data storage and demand forecasting by booking class on each leg.
 - Booking limits by booking class based on simple leg optimization.
 - Different (i,k) requests receive different seat availability.

Virtual Nesting



Multi-Leg Flight from San Francisco through
Denver to Boston

OD Market Revenue Tables

<u>SFO - DEN</u>	
Class	Fare
Y	\$467
B	\$259
M	\$204
Q	\$184

<u>DEN - BOS</u>	
Class	Fare
Y	\$648
B	\$440
M	\$324
Q	\$302

<u>SFO - BOS</u>	
Class	Fare
Y	\$724
B	\$467
M	\$357
Q	\$269

Network Virtual "Mapping" Table

Virtual Class	Virtual Range	Mapping of ODFs
V1	700 +	SFOBOS Y
V2	550 - 699	DENBOS Y
V3	450 - 549	SFODEN Y/SFOBOS B
V4	400 - 449	DENBOS B
V5	350 - 399	SFOBOS M
V6	300 - 349	DENBOS M/DENBOS Q
V7	260 - 299	SFOBOS Q
V8	200 - 259	SFODEN B/SFODEN M
V9	150 - 199	SFODEN Q
V10	0 - 149	

4. Local Displacement Cost Heuristic

- Disadvantages to using virtual nesting or stratified bucketing.
 - booking class limits set on each leg independently (not a "network" solution)
 - mapping based on O-D itinerary fare values leads to "greedy" solution
- Virtual class mapping with "greedy" algorithm still generates positive revenue impacts in many situations.
- Problems occur only when two "local" passengers should be taken over a connecting passenger:
 - sum of two local fares is generally greater than a single through fare

4. Displacement Cost Calculations

- Network revenue value of each (i, k) depends on demand/capacity and traffic flows across all flight legs in network.
- PROBLEM: How to determine network "value" and/or displacement cost of (i, k) without network optimization tools:
 - can't rely on network shadow prices
 - data available by virtual class/leg only
 - forecasting/optimization/control by virtual class/flight leg
- Under leg-based virtual class control, need to reduce value of (i, k) by forecast revenue displacement on connecting flight legs.

Displacement Cost Heuristics

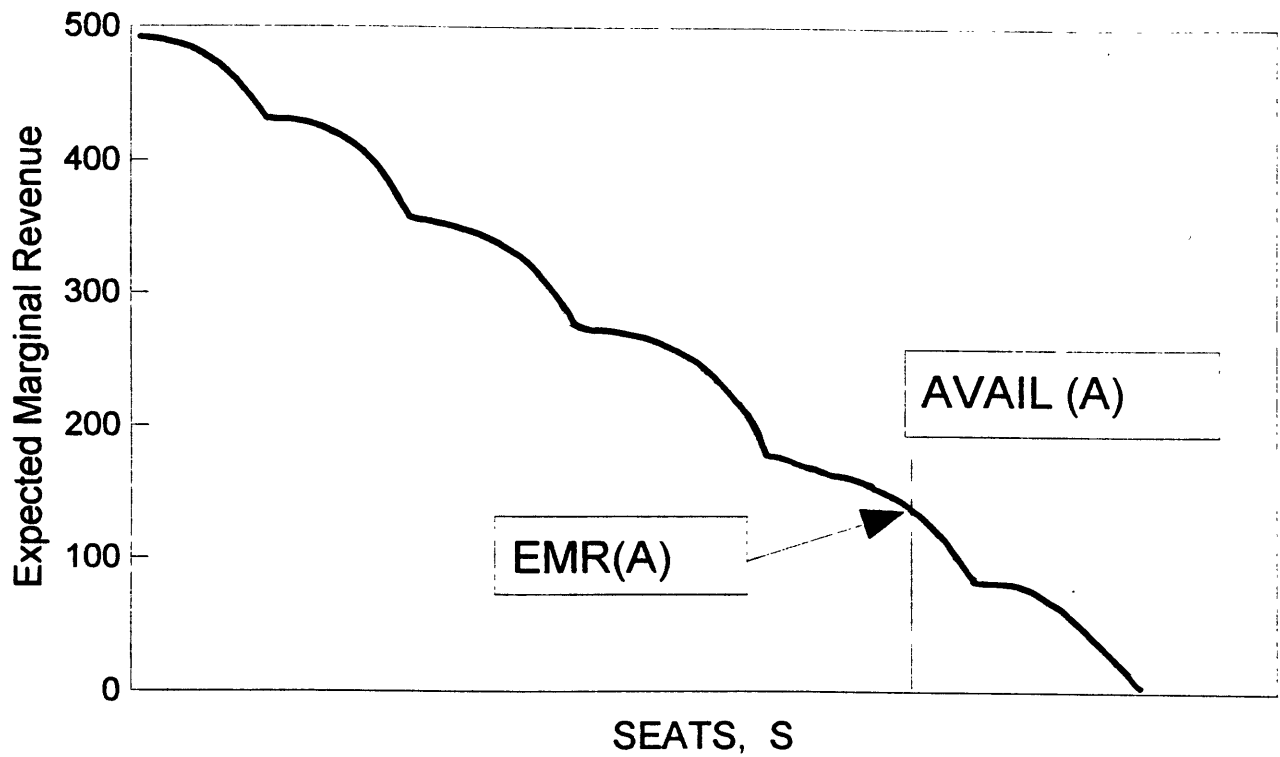
- For any (i, k) utilizing FLT 618 PHX/DFW, network value is its fare, F_{ik} , minus expected revenue displacement on connecting legs.
- Expected revenue displacement on any connecting leg is a function of forecast demands and fares for all (i, k) on the leg:
 - forecast leg demand relative to capacity
 - proportion of local traffic
 - amount of connecting traffic from other "full" flights
- Expected demand and revenue on each leg j is summarized by expected marginal revenue function

$$EMR_j(S) = \frac{\delta R}{\delta S}$$

Virtual class demands and fare values can be used to derive $EMR_j(S)$.

Down-Line Displacement Costs

Second Leg of Two-Leg Itinerary



Displacement Cost Heuristics (cont.)

- Approximation of displacement cost on any leg j is a function of $EMR_j(A_j)$, where A is available capacity.
- Network revenue value to leg 1 of (i, k) which traverses legs 1 and 2 can be approximated as:

$$N_{ik1} = F_{ik} - \text{fn} [EMR_2(A_2)]$$

- Problem is that $EMR(A)$ contains aggregated information about total fare value of seat A to the leg, not just network displacement cost:

$$EMR(A) = \bar{P}(A) * \overline{REV}$$

where $\bar{P}(A)$ = probability of selling seat A
 \overline{REV} = mean revenue of all ODFs on
leg

Displacement Cost Heuristics (cont.)

- Both components of EMR(A) are over-estimates of downline displacement cost.
- We need to estimate:

\bar{P}_{LOC} = probability of selling seat A to a local passenger on the leg [less than $\bar{P}(A)$]

RPROP_{LOC} = proportion of mean revenue on leg attributed to local passengers (less than 1.0)

- The down-line displacement cost on a leg can then be approximated as:

$$\text{DISP} = \text{EMR}(A) * \bar{P}_{\text{LOC}} * \text{RPROP}_{\text{LOC}}$$

Displacement Cost Heuristics (cont.)

- The network revenue value of itinerary (i, k) on Leg 1, adjusted by displacement cost on Leg 2 is then:

$$N_{ik1} = F_{ik} - DISP_2$$

$$N_{ik1} = F_{ik} - [EMR_2(A) * \bar{P}_{LOC} * RPROP_{LOC}]$$

- Each (i, k) can then be mapped into a virtual class based on its network value, N_{ik} , rather than simply its fare:
 - under low demand conditions,
 $N_{ik} = F_{ik}$, and no re-mapping required;
 - on high demand flights, $N_{ik} < F_{ik}$ for connecting itineraries, which are mapped to lower virtual classes.

Simulated Revenue Impacts

- Integrated airline yield management optimization/booking simulation routine developed at MIT:
 - actual airline hub scenario (15 leg in, 15 legs out)
 - approx. 200 itineraries; 7 fare types
 - interspersed bookings by class over 10 periods prior to departure
 - 100 iterations of each "connecting complex," at different demand levels
- We tested the revenue performance of leg-based heuristic methods for O-D control.
- Compared to current base case -- leg-based EMSRb fare class control.

5. Static vs. Real-Time Displacement

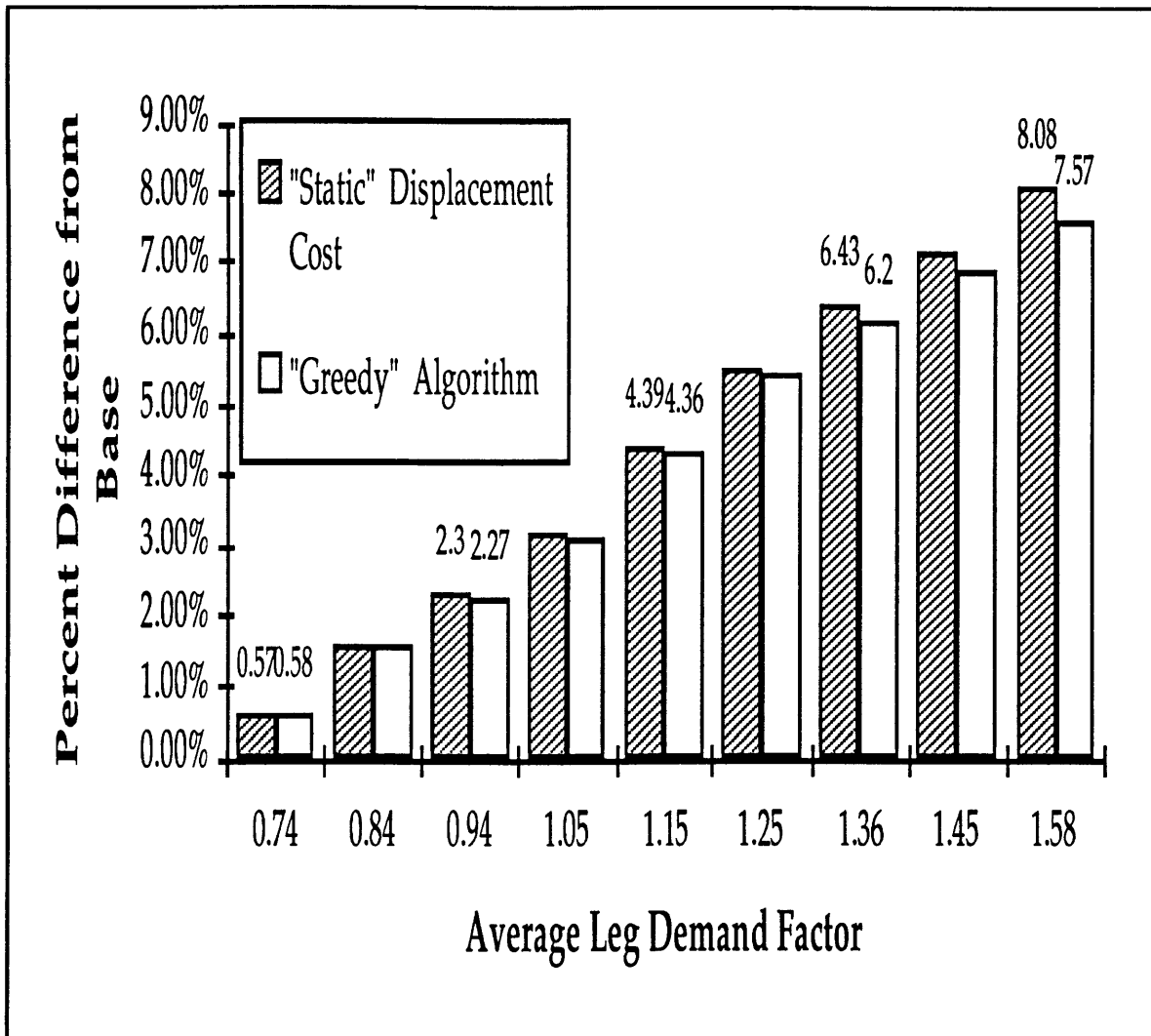
- Re-mapping of (i, k) to virtual classes should ideally be done:
 - for each future departure/date
 - dynamically prior to each departure
- Major obstacles to frequent re-mapping:
 - results in inconsistency of historical data by virtual class
 - requires huge "mapping tables" for each flight leg/departure date.
- Previous descriptions of virtual nesting in practice have focused on relatively static virtual classes, with periodic re-mapping.

Real-Time Displacement Cost Adjustment

- Seamless CRS availability communication allows (i, k) requests to be evaluated by the selling airline on a real-time basis.
- Simple displacement cost calculations can be performed at time of request to determine seat availability for (i, k):
 - (i, k) mapped initially to a "default" virtual class
 - when (i, k) request received, calculate N_{ik} based on current conditions
 - return seat availability for virtual class corresponding to N_{ik}
- Reduced availability for connecting (i, k) when demand/capacity is high on both legs — preference given to local passengers.

COMPARATIVE REVENUE IMPACTS OF VIRTUAL LEG-BASED OD CONTROL ALGORITHMS

Average Local Demand per Leg = 40%



6. O-D Control Without Virtual Classes

- Real-time displacement cost concept can also be applied to existing booking classes:
 - without virtual class mapping
 - without fare type "re-filing"
- Basic approach requires seamless CRS and real-time ODF availability evaluation:
 - keep fare assignments and booking classes intact;
 - at time of ODF request, calculate displacement costs based on EMR analysis;
 - deduct DISP from ODF fare value, and return seat availability for "adjusted" network value of ODF.
- Following example illustrates this basic approach.

ODF Availability From Booking Classes

1. Existing Booking Class Information

CLASS	<u>LEG 1</u>		<u>LEG 2</u>	
	Rev	Avail	Rev	Avail
Y	\$450	123	\$320	62
B	400	96	270	48
M	325	80	240	27
Q	280	62	190	9
V	180	45	145	0

$$\begin{aligned} \text{EMR}_1(A) &= \text{EMR}_1(123) \\ &= \$120 \end{aligned}$$

$$\begin{aligned} \text{EMR}_2(A) &= \text{EMR}_2(62) \\ &= \$168 \end{aligned}$$

2. Evaluate request for \$220 V fare over Legs 1, 2

On Leg 1:

$$\begin{aligned} N_{ik1} &= \$220 - [\$168 * \bar{P}_{LOC} * RPROP_{LOC}] \\ &= \$220 - \$42 = \$178 \end{aligned}$$

Availability for \$178 on Leg 1 is a maximum of 45 seats.

On Leg 2:

$$\begin{aligned} N_{ik2} &= \$220 - [\$120 * \bar{P}_{LOC} * RPROP_{LOC}] \\ &= \$220 - \$30 = \$190 \end{aligned}$$

Availability for \$190 on Leg 2 is a maximum of 9 seats.

3. Return ODF Specific Availability

Seats available to \$220 V fare on Legs 1, 2

$$= \text{Min}(45, 9) = 9$$

Current V class availability = 0

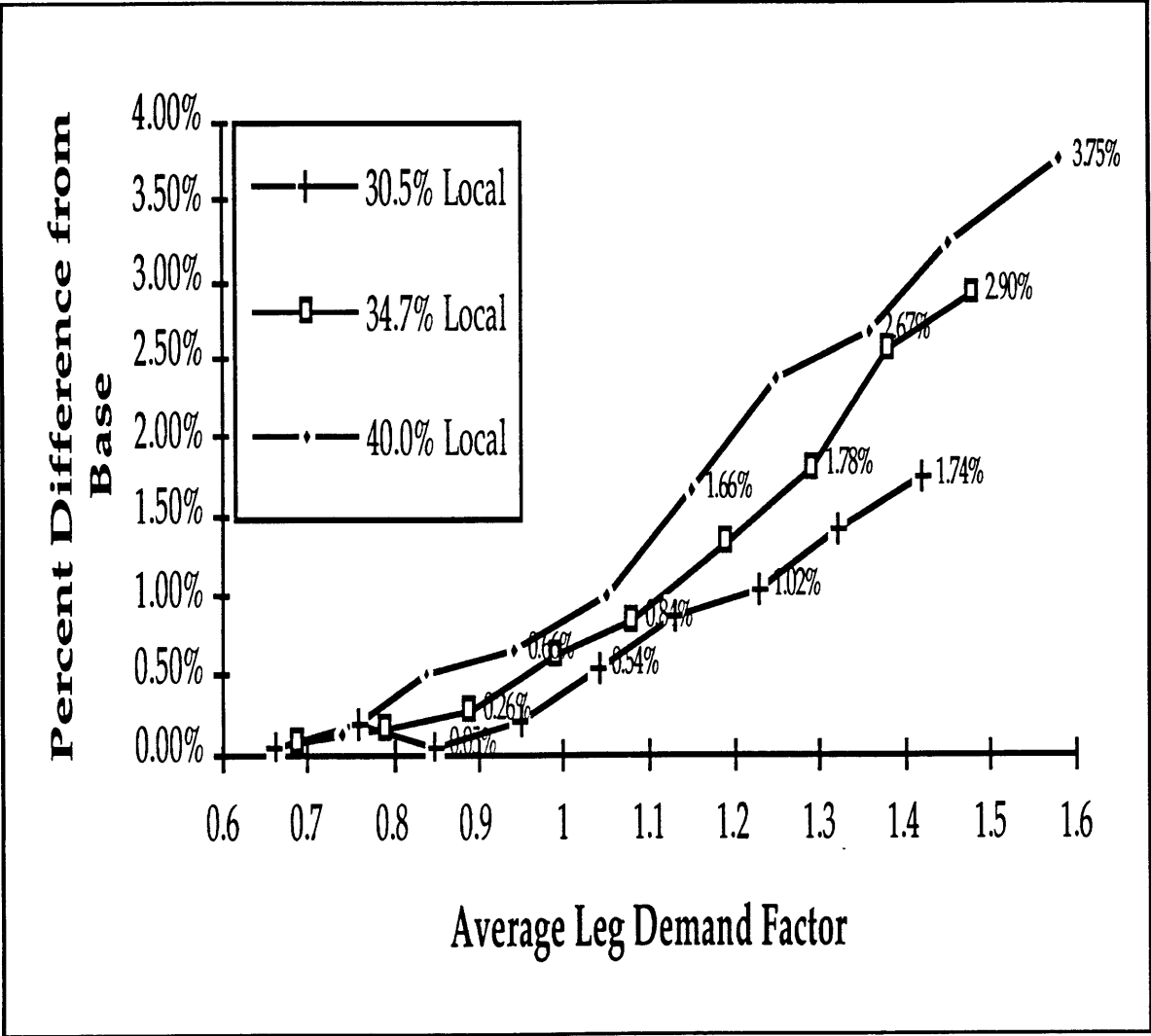
In this case, a \$220 V fare is worth more to the network than "average" V-class fare on Leg 2. ODF-specific availability is therefore higher.

Lower V-class fares (e.g., local fares) would receive lower seat availability.

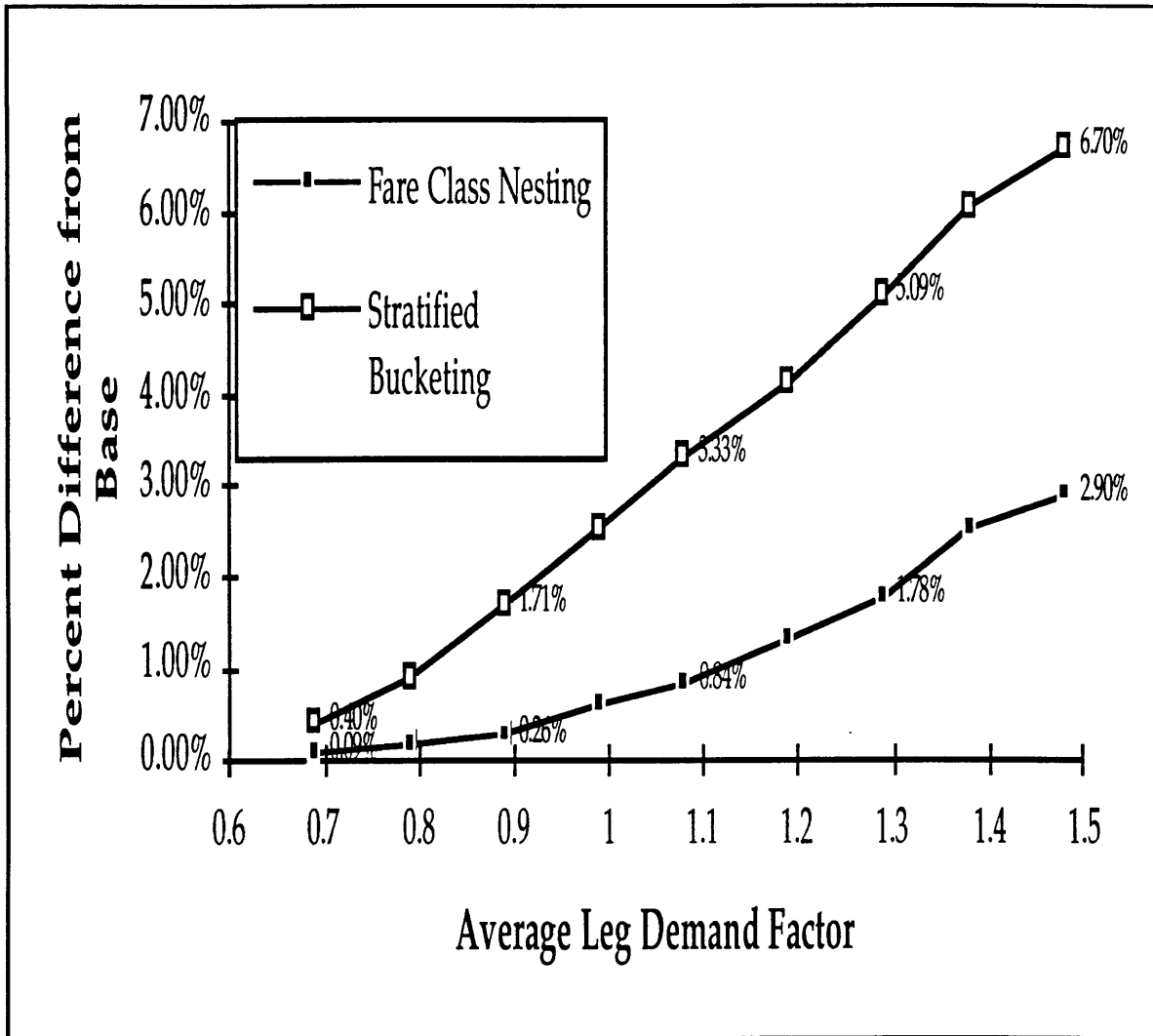
- This basic approach uses only existing leg booking class limits for determining ODF availability.

"Fine tuning" of ODF availability possible with individual seat EMR values/slopes.

REVENUE IMPACTS OF FARE CLASS DISPLACEMENT COST ALGORITHM



COMPARATIVE REVENUE IMPACTS OF
FARE CLASS VS BOOKING CLASS
DISPLACEMENT COST ALGORITHMS
Average Local Demand per Leg = 34%



Revenue Impacts

- "Real-time" displacement cost adjustment provides substantial revenue gains over "static" virtual class control.
- Application of same displacement cost logic to existing booking classes provides smaller gains, but without either virtual class investment or fare "re-mapping."
- Revenue gains affected by
 - initial definitions of virtual classes (number of classes, value ranges)
 - specific displacement cost algorithm
 - proportion of local traffic on legs
 - amount of short- to long-leg connections
 - behavior of (i,k) booking patterns.

Summary: Leg-Based Approaches for O-D Control

- Until ODF network optimization obstacles are resolved, leg-based approaches for O-D control represent an effective alternative:
 - made possible by "seamless" CRSs
 - based on leg EMR analysis
- Traditional approach of "static" virtual class nesting based on network ODF values can be:
 - enhanced by real-time displacement cost adjustment, or
 - avoided, in favor of existing booking classes with real-time ODF evaluation.
- Based on our research to date, relative revenue gains are summarized on the next slide.

SUMMARY: RELATIVE REVENUE IMPACTS

Based on Demand Factors of 0.90 to 1.10

METHODOLOGY

REVENUE IMPACTS

Nested Applications of ODF Allocations from Network Optimiz'n [NDSP, Network Bid Price Control]	4 to 6 %
Virtual Class Nesting with Real-time Displacement Cost Adjustment	2 to 4 %
Virtual Class Nesting with Static Displacement Cost Adjustment	1 to 2 %
Booking Classes with Real-Time Displacement Cost Adjustment	-
Nested Leg Booking Class Control [OBL, EMSRb]	BASE
Direct Applications of Non-nested ODF Allocations from Network LP	-2 to -5 %

A Dynamic Approach for Air Traffic Flow Management of Arriving Aircraft at a Congested Airport

by

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Thesis Adviser: Professor Robert W. SIMPSON

**Submitted to the Department of Aeronautics and Astronautics
in Partial Fulfillment of the Requirements for the Degree of**

Masters of Science in Aeronautics and Astronautics

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FLIGHT TRANSPORTATION LABORATORY**

May 1994

**Copies of the thesis are available through MIT Flight
Transportation Laboratory**

The Problem: Terminal Area Congestion at Major Airports

The arrival rate at a given airport often exceeds the landing capacity rate.

Reasons:

- Air Traffic demand increase.
- Landing capacity rate varies.

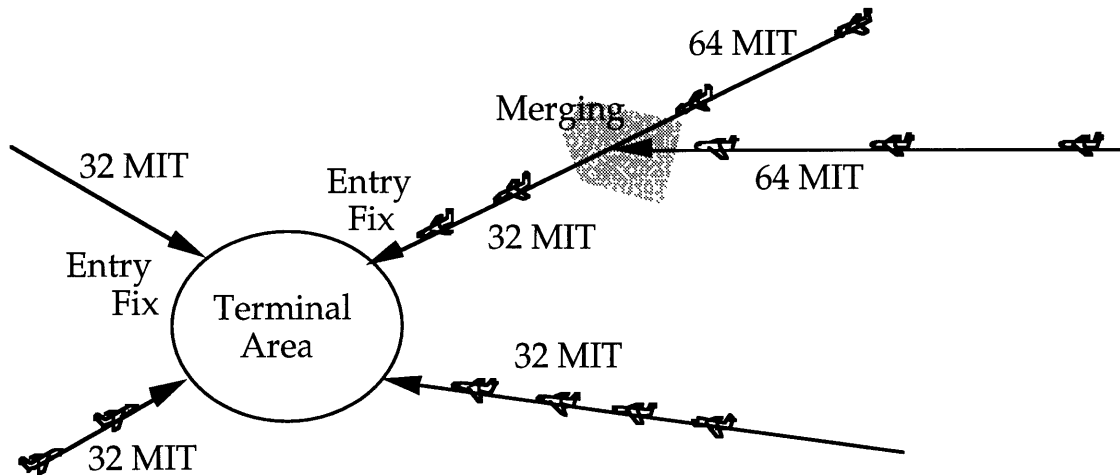
Consequences:

- Increased delays experienced at major airports.
- Rising operating costs.

Some steps taken:

- Specify *tactically* an Airport Acceptance Rate (AAR).
- Dynamic Arrival Flow Management.
- A current approach: Early-Descent/Miles-In-Trail (MIT).

A Current Approach: Early Descent/ Miles-In-Trail (MIT)



Miles in Trail (MIT) for a Terminal Area for
Entry Fix Rates equal to 15 aircraft/hour.

Principle: Depending on AAR, issue Miles-In-Trail constraints along all arrival paths to the Airport.

Inefficiencies:

- Restricts drastically passing.
- Does not efficiently take advantage of the fact that today's jet transport have a range of feasible cruise speeds (from $M = 0.70$ or 460 knots, to $M = 0.84$ or 550 knots).

IIDFC: Integrated Interactive Dynamic Flow Control (I)

Concept

- New concept for a Traffic Flow Management System to control the arrival flow at a single airport.
- Assigns an Entry Slot to all arriving aircraft.
- Computer-generated Traffic Flow Plan, and Traffic Flow Advisories to Traffic Flow Managers.
- based on using current ASD (Aircraft Situation Display)
- Assumes rapid communication of Traffic Advisories

IIDFC: Integrated Interactive Dynamic Flow Control (II)

“Dynamic”

Set of Traffic Flow Management Advisories dynamically updated every T_{update} (e.g. 20 to 30 mins or 1hr.) to account for:

- actual position, cruise speeds and predicted delays of airborne aircraft;
- ground holding, predicted delays of aircraft on the ground;
- *actual* arrival delays and *actual* air holding at the airport;
- cancellations, delays, new flight plan filings;
- revised forecasts of AAR over next few hours.

BUT:

- Traffic Advisories will not need to be issued to every aircraft at every update.
- From the ATC system point of view, IIDFC should also be able to minimize the number of changes in Traffic Advisories.

IIDFC: Integrated Interactive Dynamic Flow Control (III)

“Integrated”

IIDFC integrates all current Traffic Flow Advisories to achieve efficiencies:

- Ground Holding
- Air Holding
- EnRoute Controls (Speed, Top of Descent)

Those advisories are currently worked out separately.

IIDFC: Integrated Interactive Dynamic Flow Control (IV)

“Interactive”

- The set of Traffic Flow Advisories produced by IIDFC can be accepted or modified by Traffic Flow Managers.
 - IIDFC is interactively responsive to various constraints placed dynamically by Flow Managers *and/or* by airline operational control personnel:
 - limit the number of Traffic Flow Advisories issued
 - minimize or eliminate airborne holding at any Entry Fix
 - minimize delays
 - minimize user costs (Fuel costs, time operating costs)
- > Given the constraints, IIDFC gives the best assignment of Traffic Advisories to issue to the fleet proceeding inbound or to aircraft still on the ground at originating airports.

Dynamic Resolution Logic for IIDFC (I)

Goals

If there is **updated information** on current and futur states of the system;

Then, we can quickly calculate a new **Traffic Flow Plan** which **minimizes the “Costs”**. Costs are expressed in terms of delays, holding delays, operating costs, traffic management advisories workload.

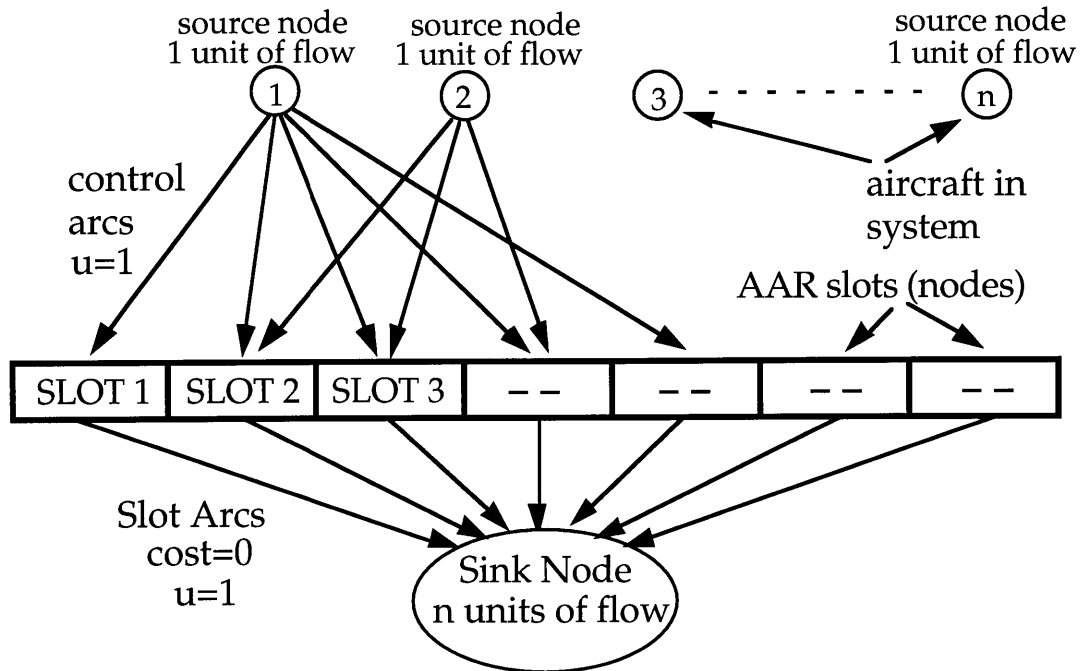
subject to a variety of operational constraints imposed by Traffic Flow Managers and airline operational control personnel.

The Traffic Flow Plan provides:

- 1) new departure times for some aircraft
- 2) new cruising speeds for some aircraft (within their stated ranges)
- 3) planned air hold, landing time for every aircraft which made a request

Dynamic Resolution Logic for IIDFC Model Overview

(II)



Network for Optimal Assignment of Delay

- Optimal Assignment Network
 - Each slot is assigned at most one aircraft.
- Minimum Cost Flow Problem:
 - very fast codes exist to solve it
 - low complexity, tree like structure

Dynamic Resolution Logic for IIDFC (III)

Control Arcs Costs

- **User Cost:**
 - Delay Cost, DC
 - Operating Cost, OC
- **Air Traffic Management Workload Cost:**
 - Traffic Flow Advisory Cost, TFAC
 - Air Holding Delay Cost, HDC

$$\text{Cost} = w_1 \cdot \text{DC} + w_2 \cdot \text{OC} + w_3 \cdot \text{TFAC} + w_4 \cdot \text{HDC}$$

By changing those weights, TFM can change the nature of the solution proposed, and they are always sure that the Traffic Flow Plan generated is the best possible answer to the problem, given the weights.

Dynamic Resolution Logic for IIDFC (IV) Best Flight Profiles

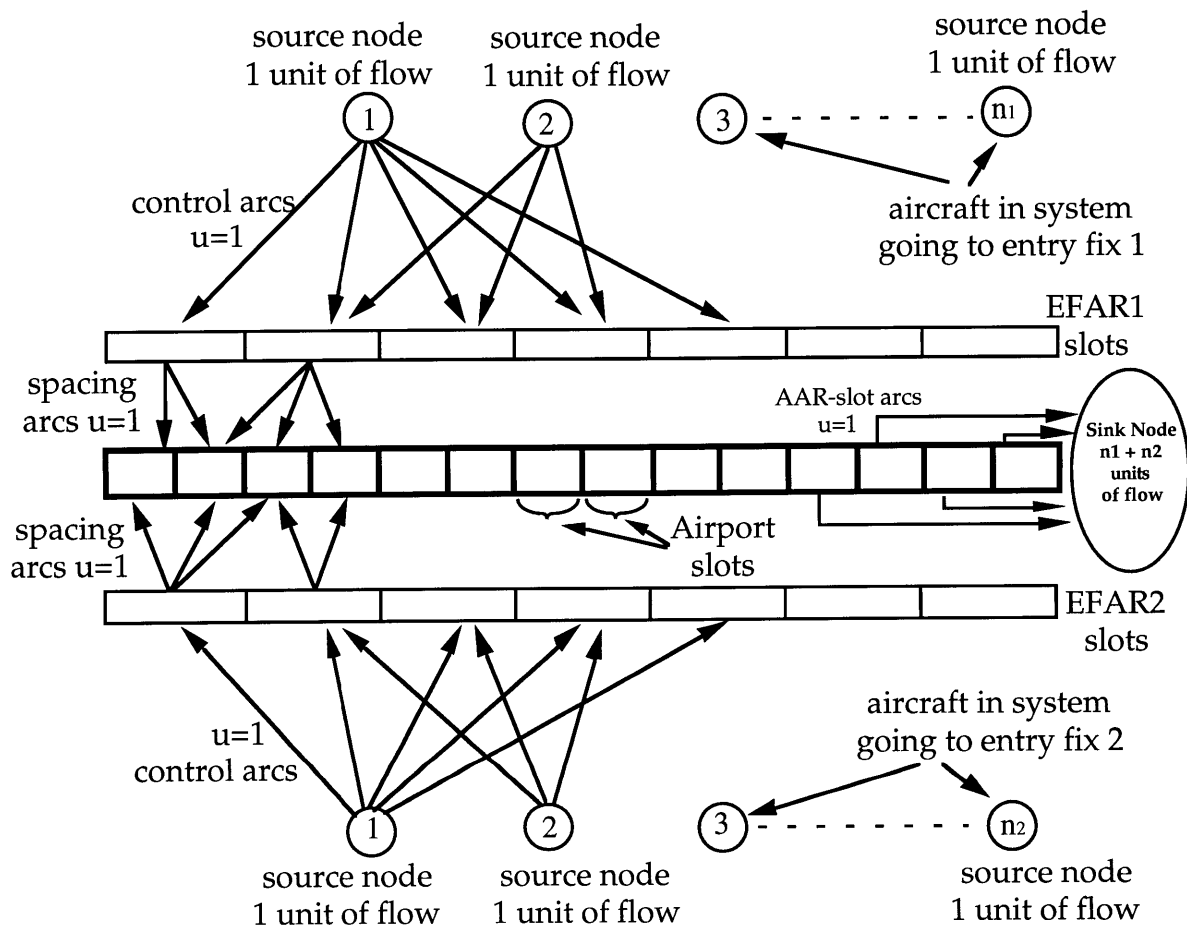
One feasible control arc \leftrightarrow prespecified Best Flight Profile

- Various possible sets of advisories to make a given slot.
- For a given **airborne aircraft** and given slot:
This is done by **using cruise speed advisory as primary control.**
- For an **aircraft on the ground** and a given slot:
Ground Holding is used as primary control.

When an aircraft is assigned a slot (a delay), it is sure that it will also be issued the best set of Traffic Flow Advisories to make that slot.

Extended Network Model

- Case where Air Traffic Flow Managers also specify Entry Fix Acceptance Rates (EFARs) as well as Airport Acceptance Rate.

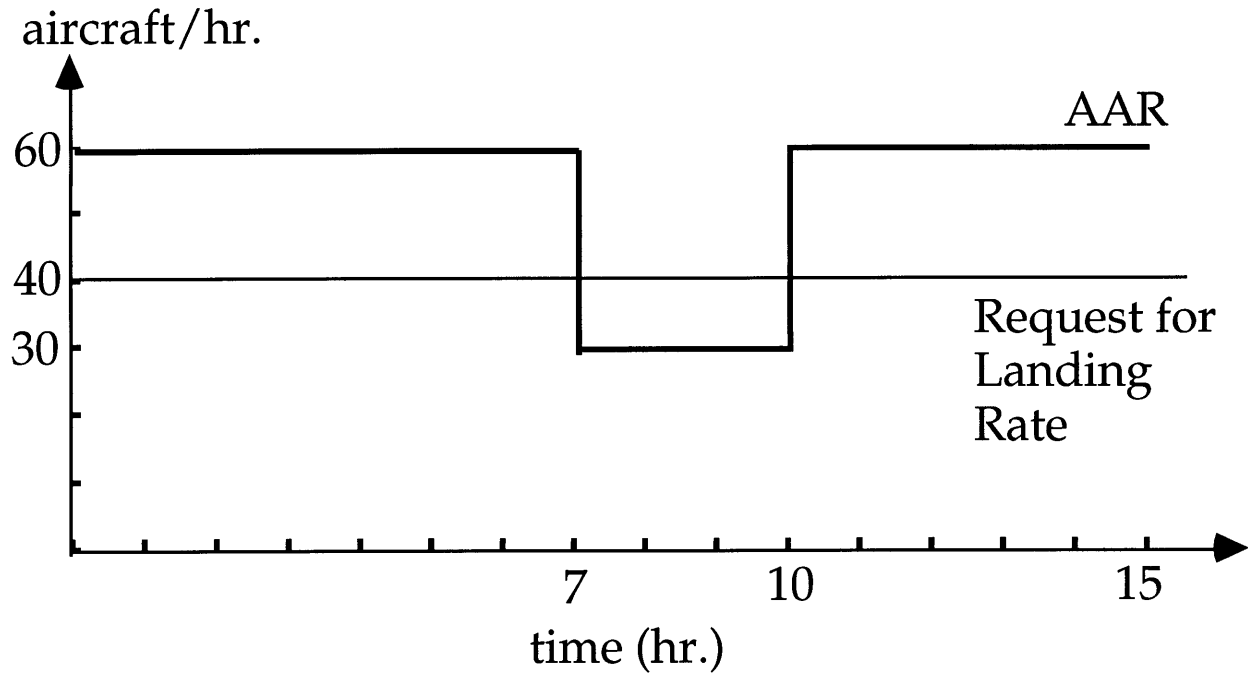


The Traffic Management Simulator

- Ansi - C language (18000 lines of code, 179,508 bites)
-> portability on DOS, UNIX and Macintosh platforms.
Contains a Minimum Cost Flow Algorithm from the MIT Operations Research Center.
- Inputs:
 - *the Airport*: wind forecast, AAR forecast, number of arrival streams, etc.
 - *the Traffic*: Traffic generator for random arrival requests for aircraft of different types (different ranges of cruise speed), from different origins, along different arrival paths, etc.
 - *IIDFC Resolution Logic*: inter-update time period, arcs costs structure and weights, parameters which define the way the network is constructed, etc.
- Dynamic Flow Algorithm exercised every T_{update} (inter-update time period) of simulator time.
- We determine the efficiency achieved by recording the set of commands given to each aircraft, the number of aircraft holding at any time, etc.

Preliminary Testing (I)

- Evaluate the efficiency of IIDFC at handling a capacity deficit at the airport.



- 90% of requests come from aircraft on the ground at intermediate airports located at 400, 600, 800 nm. from the airport under IIDFC.

Minimum flight plan filling time before departure = 45 min.

Commitment to current departure time = 30 min.

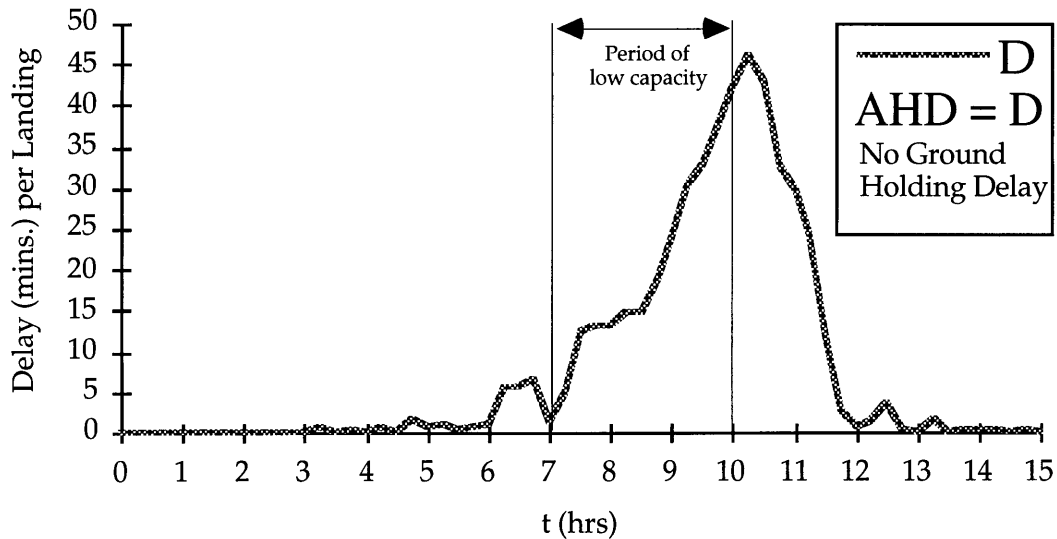
- Speed Ranges (knots):

	min.	nom.	max.
small	400	450	500
large	450	500	550
heavy	500	550	600

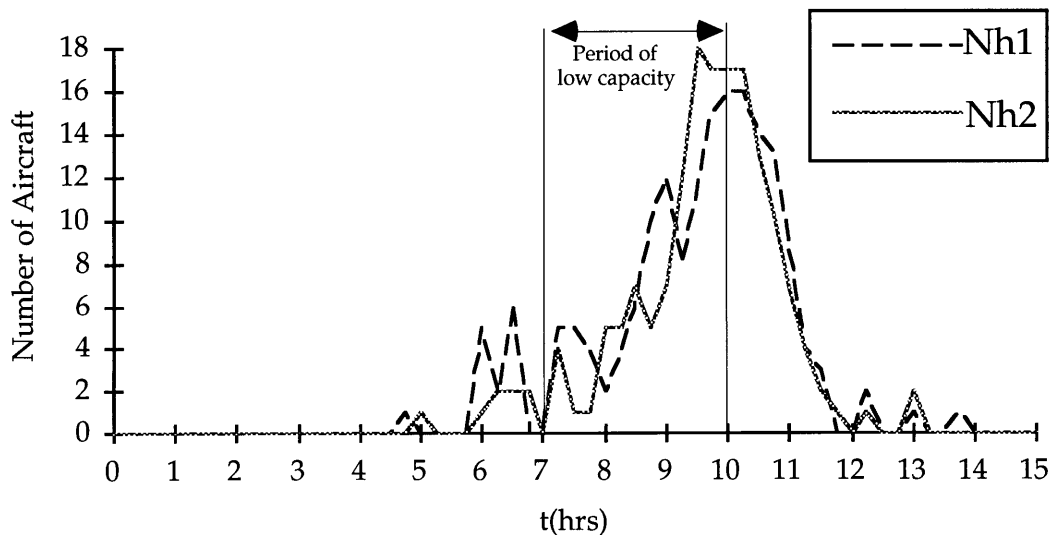
Preliminary Testing Tactical Air Holding -No IIDFC

(II)

Average Delay for Landed Aircraft



Number of Holding Aircraft

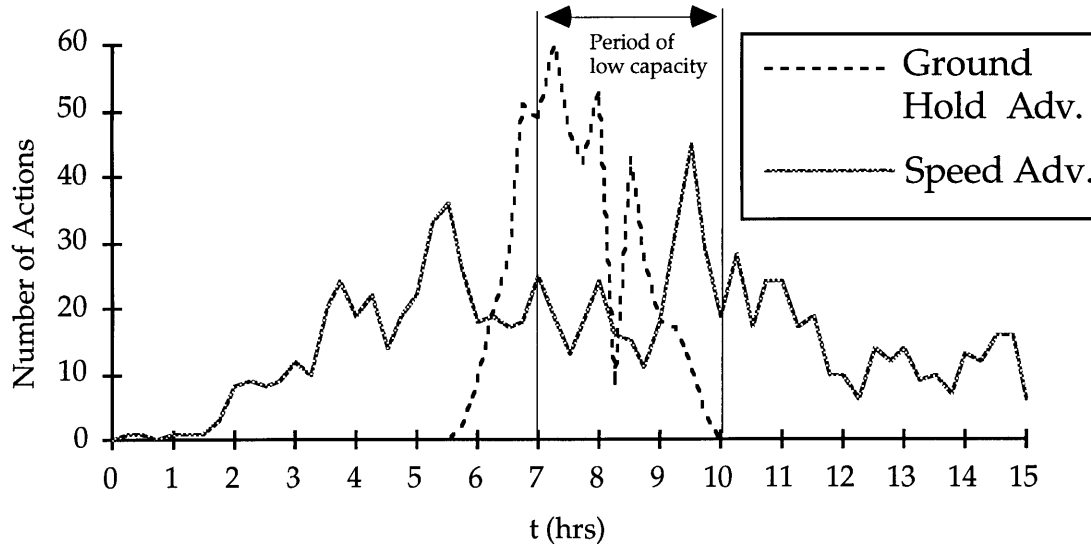


- 480 aircraft have landed, 423 ground-start aircraft.
- Cumulative delay 5233 minutes (10.9 min./aircraft)
= Cumulative Air Holding Delay.

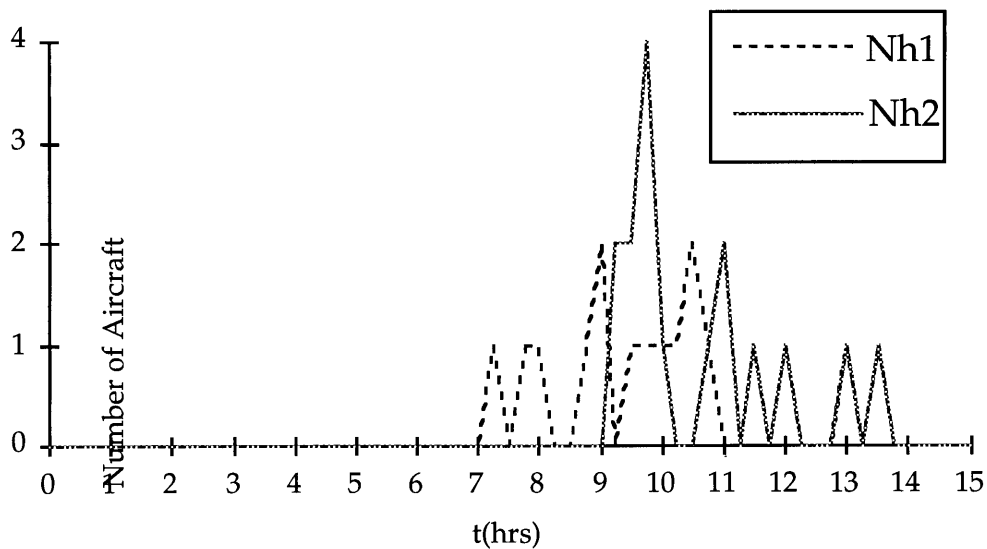
Preliminary Testing (IIa)

IIDFC - Delay (50%), Air Holding Delay (50%)

Traffic Flow Management Advisories vs. Time



Number of Holding Aircraft

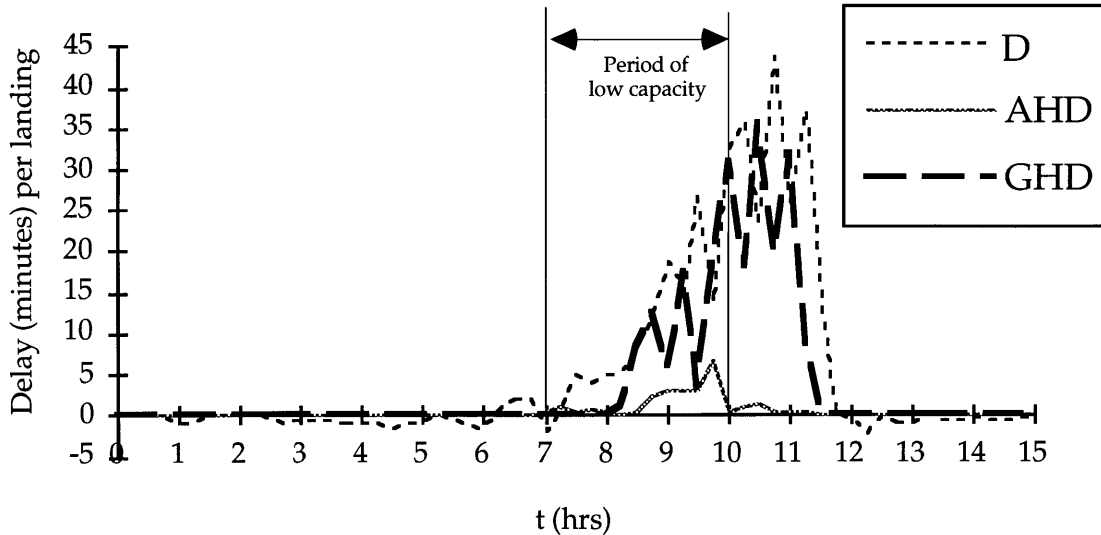


- Maximum number of aircraft in Air Hold is now 5 (as compared to 28 without IIDFC)
Cumulative Air Holding Delay is only 287 min. (vs. 5233 min. without IIDFC) -> reduced by 95 %.
- Up to 140 aircraft in system. Between 1 and 2 changes of cruise speed per aircraft for about 1h30 min. of flying time.

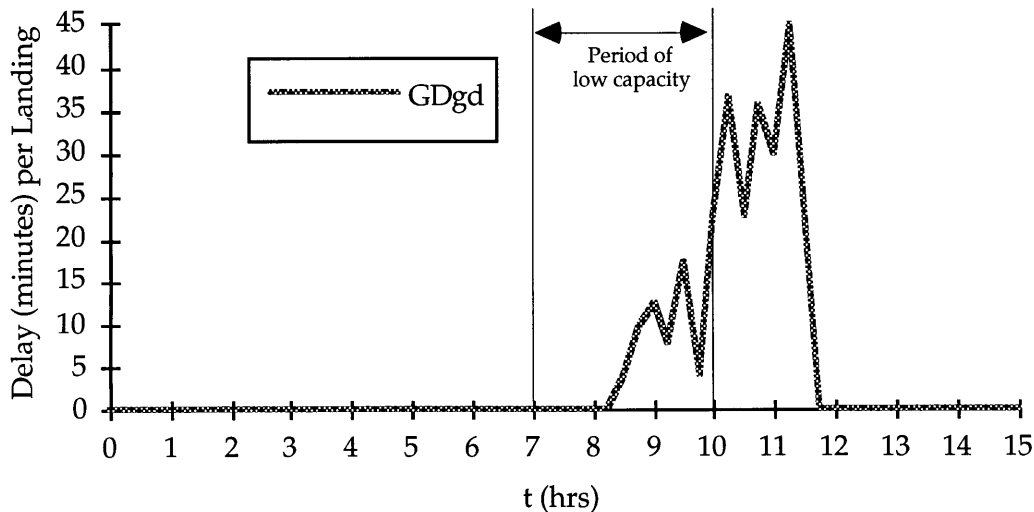
Preliminary Testing (IIb)

IIDFC - Delay (50%), Air Holding Delay (50%)

Average Delay for Landed Aircraft



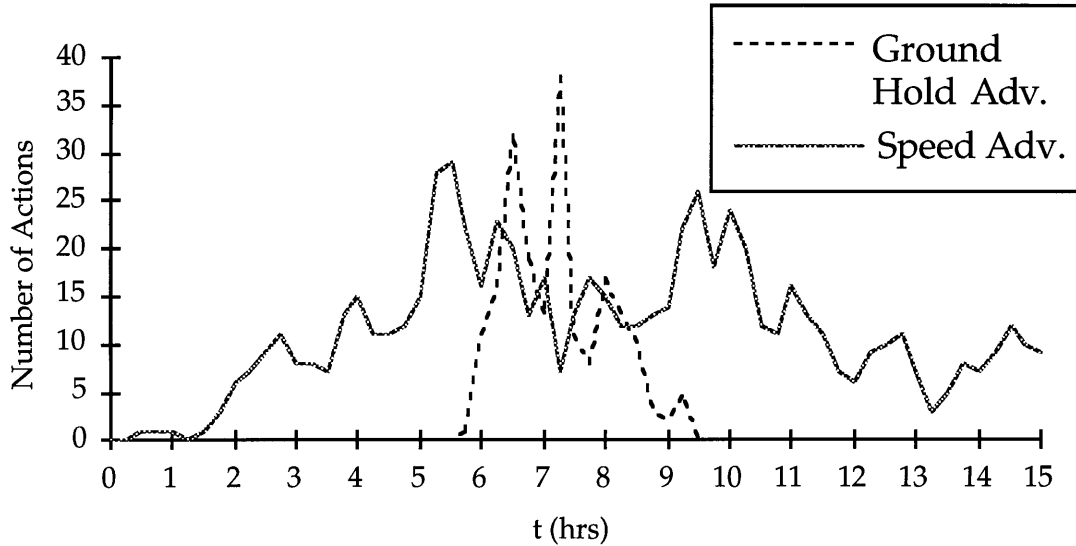
Average Ground Delay per Landed Aircraft which were Ground Held



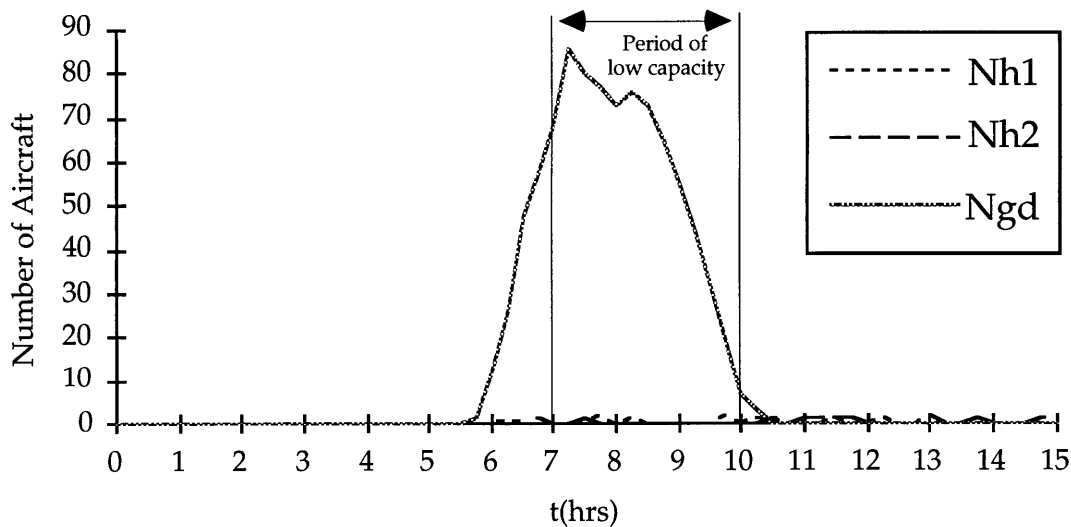
- Ground Held aircraft land after the “capacity deficit” period
- Cumulative delay is 3594 min. (=7.4 mins/aircraft) as compared to 5233 min. (10.9 min./aircraft) -> reduced by 30 %

Preliminary Testing (III) IIDFC -including TFM and User Operating Costs

Traffic Flow Management Advisories vs. Time



Number of Holding Aircraft



- Maximum number of Speed Adv. issued reduced to 29 (vs. 45).
- Maximum number of Ground Hold Adv. reduced to 38 (vs. 56).
- Cumulative Delay increased to 4440 min. (= 9.2 min./aircraft) vs. 3594 min. Still down 15% as compared to "No IIDFC", (55% for air-start, 12% for ground start)

Conclusion

- A new approach for handling Air Traffic Flow Management of arriving aircraft at a congested airport has been presented and investigated.
- Integrated Interactive Dynamic Flow Control, IIDFC, has a great potential to achieve efficiencies in Dynamic Arrival Flow Management at a given airport.
- It is behaving as we expected:
 - it can trade off User Costs and Traffic Flow Management Costs at levels which can be modified at any time during the process.
 - it can account for the evolution of critical Traffic Flow Management parameters in real time (AAR, Actual Holding Delay, etc.).
- Powerful Traffic Management Simulator which allowed us to test various IIDFC Resolution Logics.
- Futures directions:
 - Considerable *experimentation* to be undertaken (sensitivity analysis, response time to actual evolution, robustness to uncertainty, hedging, etc.)
 - *Extensions* of the IIDFC concept (Extended Optimal Model, Category 1, 2, or 3 aircraft, etc.).

The Relationship Between Yield Management and Aircraft Assignment Decisions

-64-

Flight Transportation Laboratory, MIT

By András Farkas

Motivation:

- **Yield Management (YM) systems** set fare class booking limits (BL) given assigned capacity; this affects also the passenger mix
 - **Aircraft assignment (AS) decisions** based on demand forecasts
 - **Today the two optimization processes** work independently:
 - **Demand input for AS is influenced** by the YM decisions
 - **A/C capacities (input for YM)** have influence on the YM decisions
 - **Mutual dependence in the decision process**
 - **Small improvements in the decisions** of the two systems may result in huge revenue (profit) gains for the airlines
-

Objectives:

- Find the interrelationships between the YM and AS processes
- Explore explicitly the influence of YM decisions on AS decisions; and the influence of AS decisions on YM decisions
- Evaluate how the information obtained from one process can be used for better decisions in the other process
- Use the above findings to formulate new models, optimal decision rules, and optimality conditions
- Develop algorithms, heuristics and/or suggest changes in the currently used methods to incorporate the new findings and models of this research

Fleet Assignment Problem

- The **Fleet Assignment Problem** is to match A/C to flight legs such that empty seats are minimized and profits maximized
- *Trade-off:*
Spilled passengers vs. increased costs of large aircraft and empty seats
- *Goal of research:*
Evaluate correctly the expected revenues and costs of assigning a certain aircraft type to a given flight leg

State-of-the-Art in Aircraft Assignment

Mathematical Models

Deterministic Demand:

$$\max \Pi = \sum_l \sum_k [R_l * D_l - N_{l,k} * C_{l,k}]$$

$$s.t. \quad \sum_k MLF_{l,k} * Cap_k * N_{l,k} \geq D_l, \quad \forall l.$$

where: $N_{l,k}$ is the number of flights per day on leg l fleet k ,
and $MLF_{l,k}$ is the maximum load factor for leg l flown by fleet k .

Stochastic Demand:

$$\max \sum_{i \in \text{Leg}} \sum_{f \in \text{Fleet}} (R_{f,i} - C_{f,i}) * X_{f,i} \quad \text{or} \quad \min \sum_{i \in \text{Leg}} \sum_{f \in \text{Fleet}} \text{cost}_{f,i} * X_{f,i}$$

s.t. balance, cover, size, hookup, etc. constraints

- $R_{f,i}$ is the *expected revenue* and $C_{f,i}$ is the cost associated with assigning fleet f to leg i .
 - $\text{cost}_{f,i}$ includes all operating costs plus *spill costs*
 - Demand and revenue potentials (expected revenues and spill costs) are included in these single objective coefficient
 - Without a good estimate of the objective coefficient $\text{cost}_{f,i}$ the results of the A/C assignment models may be sub-optimal
- We need to have precise estimates of the expected revenues or spill costs

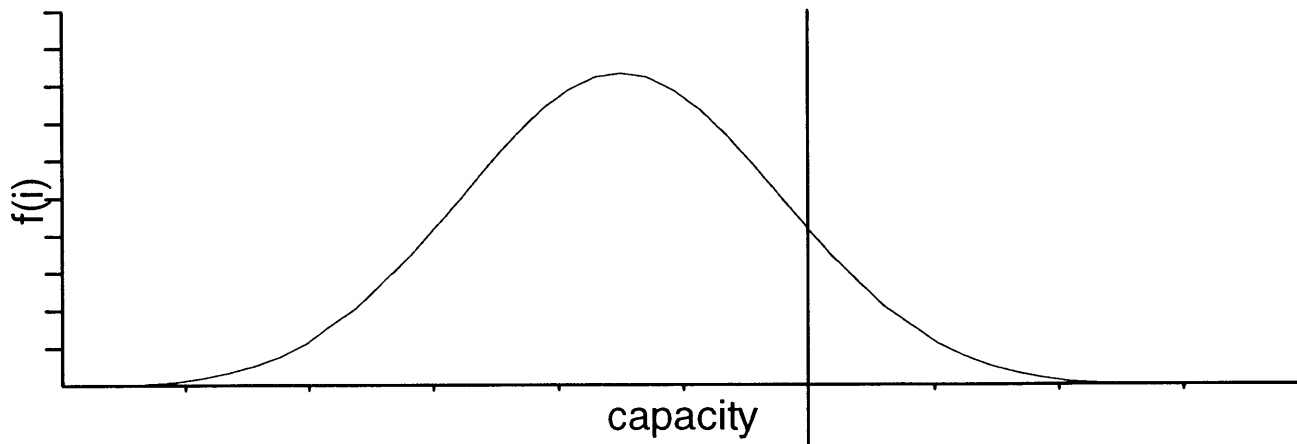
Commonly, total flight leg demand is expressed as a single normal probability function (joint demand curve)

Averaged over all fare classes and over a longer time period (week, month)

Compound curve mean: $\mu = \sum_i \mu_i$, over all booking classes i

standard deviation: $\sigma = \sqrt{\sum_i \sigma_i^2}$, over all booking classes i assuming no correlation

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Revenue Curve Estimation State-of-the-Practice

- Deterministic Demand
 - aggregated by flight leg
 - subject to maximum load factor (e.g. 75%)
- Stochastic Demand
 - aggregated by flight leg
 - unconstrained aggregated demand based on total boardings
 - Expected Load/Spill Estimation (S-curve [Swan])

$$Load = \int_{i=0}^{Cap} i * f(i) di + \int_{i=Cap}^{\infty} Cap * f(i) di$$

$$Spill = \int_{i=Cap}^{\infty} (i - Cap) * f(i) di.$$

- Expected Revenue/Spill Cost Estimation
 - Expected Revenue = Load * "average fare"
 - Spill Cost = Spill * "average spill fare"

- *High level of aggregation -- Aggregation Bias*

Estimating the Expected Revenue Curve, $R(A)$

Determined by:

- Fares (levels and relative ratios)
- Stochastic Demand (forecasted, unconstrained for each fare class)
- Yield Management System and its Optimization Algorithms -- (Nested) Booking Limits, (EMSRb)

$$R(A) = \sum_i R_i = \sum_i \text{Exp_load}_i * \text{fare}_i$$

where A is capacity and i represents the different fare classes.

Exp_load is the expected number of passengers in a given fare class, as a function of booking limits.

Exact formulation - Nested booking limits (Curry):

$$R(A) = R_i(\Pi_{i-1}, A), \text{ and } \Pi_{i-1} \leq A \leq \Pi_i, i = 1, \dots, n$$

where

$$R_i(\Pi_{i-1}, A) = \int_0^{A-\Pi_{i-1}} dr_i p_i(r_i) [f_i r_i + R_{i-1}(\Pi_{i-2}, A - r_i)] +$$

$$[f_i(A - \Pi_{i-1}) + R_{i-1}(\Pi_{i-2}, \Pi_{i-1})] \int_{A-\Pi_{i-1}}^{\infty} dr_i p_i(r_i) ,$$

$$\Pi \equiv 0, R_0 \equiv 0$$

where $p_i(r_i)$ is probability density function of class i request, $R_{i-1}(\Pi_{i-2}, A - r_i)$ is the expected revenue of the $i-1$ classes, Π_i is the protection level for class i , A is the capacity and n is the number of fare classes.

$$\text{Booking Limit : } BL_i = A - \Pi_{i-1}$$

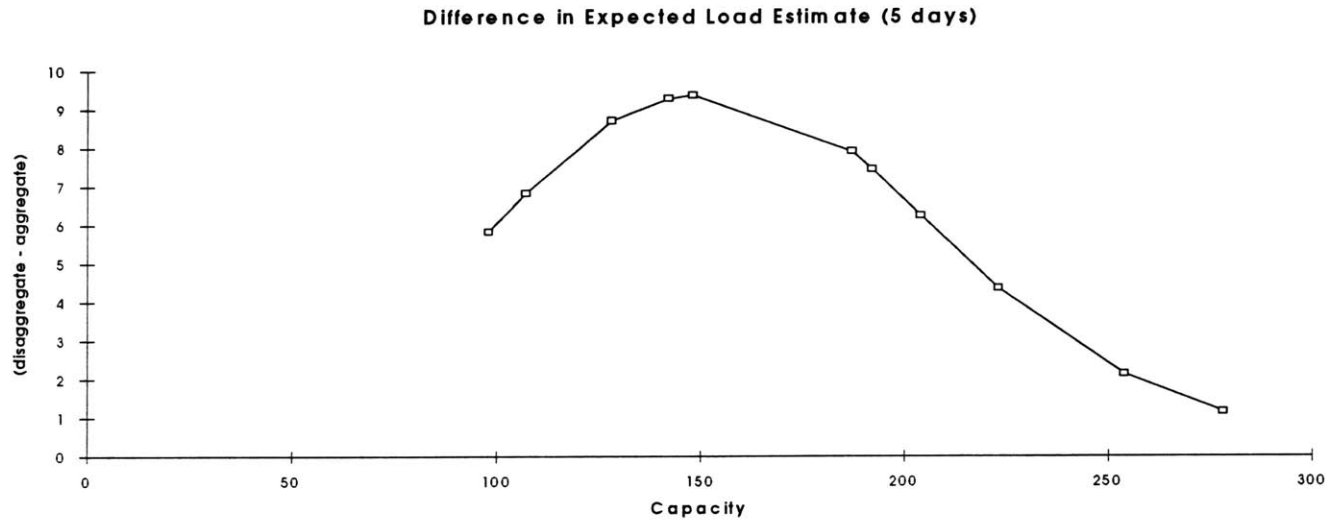
Since BL's appear in the equation we can conclude that **booking limits have a significant influence** on the expected revenues

Two type of aggregation biases in spill estimation

1. Aggregation of fare classes
 - joint demand curve does not hold information about
 - booking patterns
 - fare class distributions
 - total load/spill estimated from a joint normal distribution curve differ from disaggregated simulation results

2. Aggregation of flights over longer time interval (days, weeks)

$$\frac{1}{N} \sum_{i=1}^N E[N_i(\mu_i, \sigma_i^2), Cap] \neq E[N(\bar{\mu}, \bar{\sigma}^2), Cap]$$



Profit Estimates and Ranks

<i>bh=1.5</i>	<i>aggregate</i>		<i>disaggregate</i>	
DC9	\$26787.43	11	\$28678.49	11
B737-200	28747.13	10	30963.08	10
B737-300	33507.59	9	36331.6	9
MD-80	36960.32	8	39968.98	8
B727-200	37321.17	7	40360.92	7
B757-200	42753.55	4	45318.53	2
A310-300	41433.72	6	43851.59	5
B767-200	43698.51	2	45726.5	1
L-11-500	41565.72	5	42982.15	6
B767-300	44244.85	1	44935.6	3
L-11-250	43657.36	3	44031.24	4

Question: What is the "average fare"?

- Simple mean of the fares?
- Weighted average of fares, weighted by the mean demand for each fare class?
- Or more complex?

Issues:

- Demand distributions of each fare class have influence on Booking Limits
- Booking Limits have influence on the passenger mix
- Passenger mix has influence on the "average fare"
- If the Yield Management System works well, then most of the passengers spilled will be lower fare passengers, similarly most of the passengers accommodated will be higher fare passengers

We need to know both the *demand for each fare class* and the *booking limits* given the demand and capacity

Comparison of "average fare" calculations for single flight

(7 fare classes represented by 7 normal distributions)

Approach 1: Expected load is calculated from the joint normal curve
Average fare = mathematical mean of the 7 fares
Rev= Exp_Load*average_fare

Approach 2:Expected load is calculated from the joint normal curve

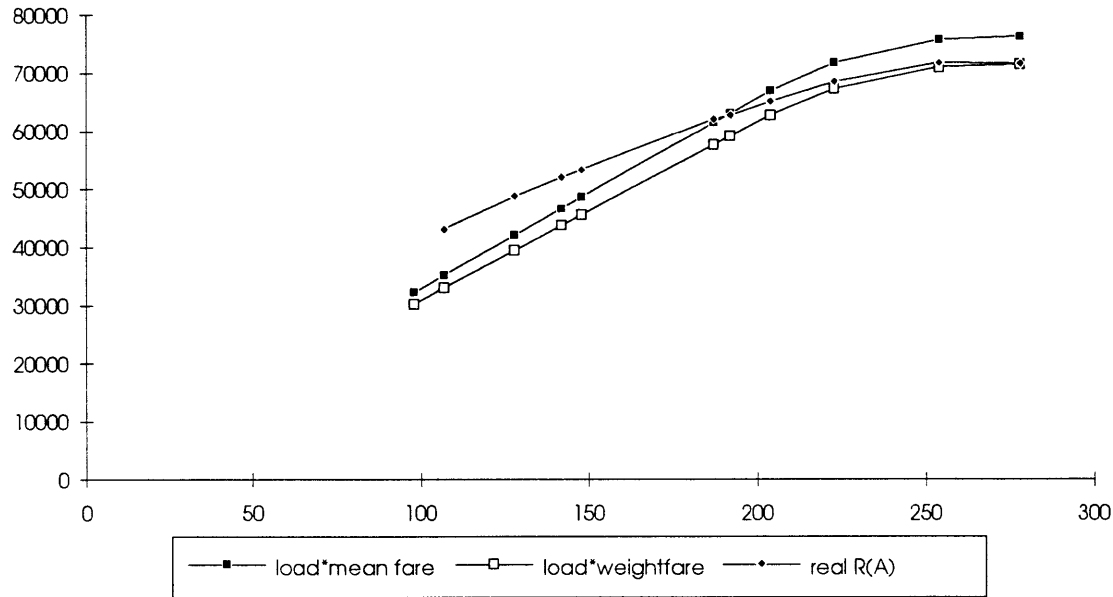
$$average_fare = \frac{\sum(\mu_i * fare_i)}{\sum \mu_i} \text{ (weighted average by means)}$$

$$Rev = Exp_Load * average_fare$$

Approach 3: Calculate Booking Limits -> Calculate Expected Load->

$$\text{-> } Rev = \sum_i Expected_load_i * fare_i$$

Comparison of Expected Revenue Estimates



- Big differences at other than high capacities when no spill occurs
- "Real" $R(A)$ curve is higher at lower capacities, given YM booking limits

Aircraft Assignment Example (Single Leg)

Profit estimates and ranks for Approach 1, 2, and 3.

<i>7 fare classes</i>						
	Approach 1		Approach 2		Approach 3	
DC9	\$21990	12	\$19981	12	\$10202	12
B737-200	23467	11	21274	11	31445	11
B737-300	29425	10	26801	10	36079	10
MD-80	36125	8	33214	7	41480	7
B727-200	35363	9	32329	9	40032	8
B757-200	48774	4	44940	4	49351	3
A310-200	37128	7	33194	8	36790	9
A310-300	43888	6	39954	6	43550	5
B767-200	52758	3	48580	3	50917	2
L-11-500	45993	5	41514	5	42738	6
B767-300	56304	1	51581	1	52340	1
L-11-250	53381	2	48625	2	48730	4

If B763 is infeasible, then choice of L10 would result in \$2187 (=50917-48730) less profit than (second) best choice

Daily Variation in Demand

- Airlines aggregate demand for a flight over a longer time period (e.g., for a week, month or several months)
- Day of week variation in mean total demand
- Day of week variation in fare class demand mix

	MON		TUE		WED		THR		FRI	
Class	mean	sigma	mean	sigma	mean	sigma	mean	sigma	mean	sigma
Y	47.8	15.8	28	13	26	11.2	31	12.8	52	12.6
B	27.9	10.9	16	8	17	11	24	9.4	30	8.9
M	20.4	9.4	15	9.4	16	10	17	8.5	23	6.8
H	22.7	9	13	8	15	9	18	9.6	22.7	15
Q	31	13.3	20	15.2	22	6.6	28	12.5	40	19.8
K	50.2	14.6	50.2	16	35	10	40	14.6	60	15.9

Aggregation of day of week demands

Method 1: One compound distribution is obtained (vertical and horizontal aggregation)

$$\mu_{avg} = \frac{\sum_i \mu_i}{n}, \quad \text{where} \quad \mu_i = \sum_{fareclasses} \mu_f,$$

$$\sigma_{avg} = \sqrt{\frac{\sum_i \sigma_{comp,i}^2}{n}}$$

After obtaining the single average normal distribution, $N(\mu_{avg}, \sigma_{avg})$ the average load is calculated for the different possible aircraft capacities and multiplied by the weighted fare calculated like in previous "Approach 2"

Method 2: Horizontal aggregation: for each fare class f normal distribution is calculated over the n day period :

$$\mu_{avg}^f = \frac{\sum_i \mu_i^f}{n}, \quad \sigma_{avg}^f = \sqrt{\frac{\sum_i \sigma_i^{f2}}{n}} \quad f = 1 \dots m, \quad i = 1 \dots n.$$

From here the data is treated as if it were data for a single flight and previous "Approach 3" is followed

Method 3: For each single day previous "Approach 3" is applied and averaging is done only after evaluating individually the contributions by day of week.

Aircraft Assignment Example (Daily Demand Variation)

*6 fare
classes*

	Method 1		Method 2		Method 3	
DC9	9147	12	12284	12	11323	12
B737-200	9889	11	12724	11	11744	11
B737-300	12075	10	13861	10	13034	10
MD-80	14019	9	15109	6	14133	6
B727-200	14191	8	14998	7	13960	9
B757-200	16910	1	16821	1	15658	3
A310-200	14513	7	14497	9	13465	8
A310-300	15742	4	15726	4	14694	5
B767-200	16706	2	16717	2	15912	1
L-11-500	14598	6	14612	8	14114	7
B767-300	15762	3	15776	3	15716	2
L-11-250	15135	5	15149	5	15165	4

In this case, optimal aircraft and rankings differ between Method 3 and less accurate methods. B757-200 is actually 3rd choice aircraft!

Summary: Aggregating fare class information

- "Approach 1" does not use any YM information => incorrect spill cost estimates
 - historical fare-mix estimates ->
may not be available/not enough observations/not relevant
- "Approach 2" uses limited YM information (mean demand for each fare classes) and the spill cost estimate is closer to the real expected values
- "Approach 3" uses detailed YM information
 - detailed demand forecast
 - booking pattern (time)
 - YM optimization algorithm
 - Expected spills are estimated for each fare class based on calculated booking limits
- The estimation error of the different approaches may result in incorrect aircraft selections

Summary: Aggregating day of week information

- Aggregation bias is significant -- aggregation of non linear functions
-- "average flight" - state-of-the-practice ("Method 1")

$$\frac{1}{N} \sum_{i=1}^N E[N_i(\mu_i, \sigma_i^2), Cap] \neq E[N(\bar{\mu}, \bar{\sigma}^2), Cap]$$

- weighted by fare class demand ("Method 2")
- disaggregate estimation ("Method 3")

- Use disaggregated classification approach to estimate average revenues or spill costs
- Use detailed Yield Management Information

Questions:

Do Approach 3 and Method 3 require much extra effort to produce the required information?

What tools/methods should be used to run the recommended approaches?

- Yield Management Systems have all the required information

- Booking Simulator is a flexible and fast tool to follow Method 3 or Approach 3.
 - easy to implement
 - flexible and relatively fast
 - easy to enhance with more advanced modeling techniques

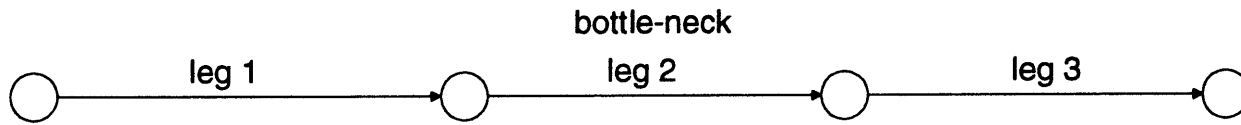
Conclusion:

- Approach 3 and Method 3 require additional computational effort, but these are the correct ways to assess the expected revenue potentials.
- It was shown that the state-of-the-practice approaches are unable to assess correctly the expected revenues and may result in incorrect aircraft selections.
- Incorrect aircraft selection in turn may result in hundreds or even thousands of dollars in unrealized revenues and profits per flight leg.
- Further research is needed to study the problem on the entire network level and to understand the real dynamics between the Yield Management and the Aircraft Assignment Systems

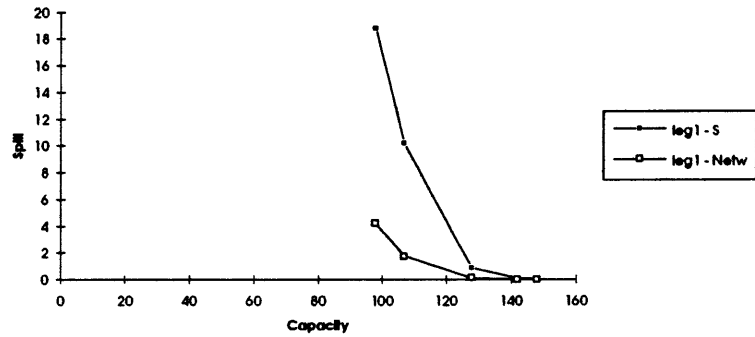
Calculating Spills in Networks

- Network Connectivity
 - Passenger flows link legs together
 - Capacity constraint on a leg has effects on demand of other legs
- Multileg demand is constrained by the minimum through capacity along its path
 - "Bottle Neck" leg modifies demands on other legs
- Leg based fleet assignment approach calculates incorrect spills by assuming unconstrained demand flows
- Leg interdependence also affects the OD-mix of the spilled passengers
 - Fares of different OD's will vary resulting in incorrect spill cost estimates

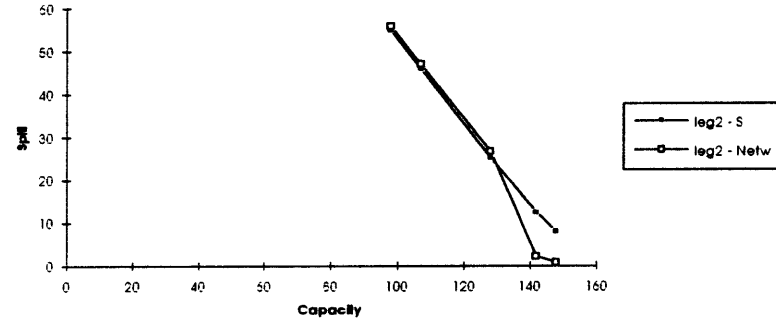
3 Leg Example



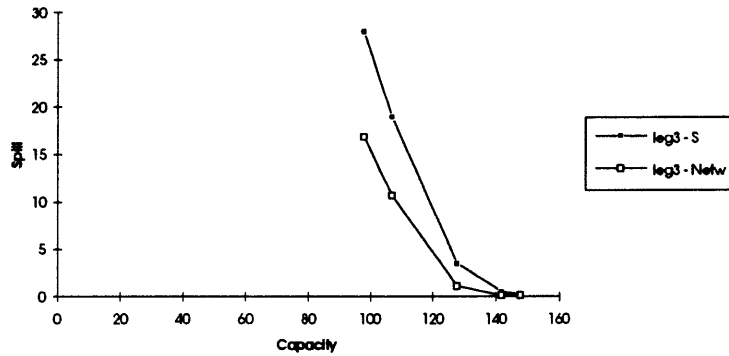
Spill Estimates (Leg 1)



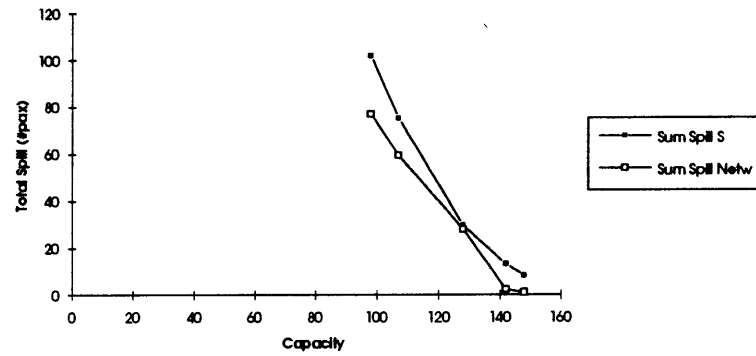
Spill Estimates (Leg 2)



Spill Estimates (Leg 3)



Total Spill Estimates (all legs)



Network Example Conclusions

- An assigned A/C capacity to a flight leg i may have effects on demand not only on leg i but on other flight legs as well
- The realized demand affects estimates of expected revenues or spill costs, and may result in different optimal assignments
- Network leg dependencies must be considered in correct spill estimation
- Network effects should be incorporated in the optimization models:
 - Influence of OD based YM optimization
 - Change of demand due to YM based on assumed A/C assignment

Further Research Directions

- Evaluate different approaches for estimating the objective coefficient on a one leg level
- Evaluate the effects on spill estimates of the network leg dependency
- Evaluate the importance and benefits of the correct spill estimations in aircraft assignments
- Modify currently used leg based optimization models for fleet assignment to incorporate network effects
- Suggest methodologies how correctly available YM information can be used in heuristic fleet assignment models to incorporate network effects

Planes, Trains and Automobiles

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

MIT/Industry Cooperative Research Program
for Air Transportation

April 19, 1994.

Michael D. D. Clarke
Flight Transportation Laboratory
Department of Aeronautics and Astronautics

Background

- Lack of infrastructure to support high speed ground transport systems such as high speed rail (HSR) service.
- Within the Northeast, air travel has become one of the dominant transport modes
- Existing ATC problems could be alleviated by the introduction of improved ground transportation modes, if they could divert a substantial number of air passengers.
- Primary interest of this research project was to consider the potential of future diversion of air passengers to high speed rail

Background

- Ridership is the critical factor in determining the financial feasibility of a high speed ground transport system.
- Forecasting transportation demand focuses on the effects of modal factors such as trip time, cost, and frequency on an individual's choice regarding a particular travel mode.
- Market forecasts ignore total population and income trends, although these play a major role in determining the actual traffic levels
- Existing transportation market is composed of automobile, air, railroad, and bus travel, but automobile and air dominate.

Background

- Attractiveness of high speed rail services is questionable, as the current rail service does not have a significant modal share
- Majority of air passengers are business travelers, who are price insensitive and rely more on air travel because of its convenience and travel time.
- Modal choice of a passenger is influenced by the purpose of the trip
- Most important service characteristics of a transport mode are the travel time and the total travel cost (including the price of ticket for the access and egress to the mode) between the passenger's point of origin and final destination.

Topics to be Addressed

- Existing Air and Rail Service in the Northeast Corridor
- A Review of Market Surveys and Passenger Demographics Data
- Existing Market Conditions: Passenger Traffic
- Forecasting High Speed Rail Ridership

Existing Air Service

- Air Shuttles account for the majority of the airline service offered in the Northeast Corridor
- Since the deregulation act (1978), there has been a consistent increase in the level of regional (commuter) passenger traffic in the Northeast.
- Published one-way unrestricted air fare between the city pair is currently \$135, a substantial increase from the \$60 fares before domestic deregulation
- Significant variation in airfares currently offered in the New York to Boston O/D market

Summary of Air Services in the Northeast Corridor

Market	Boston - New York	Washington - New York ¹
Air Shuttle		
Travel Time (hrs:min)	1:05	1:00
Frequency (daily)	34	31
Fare (one-way)	\$135.00	\$135.00
Scheduled Jet		
Travel Time (hrs:min)	1:15	1:10
Frequency (daily)	36	38
Fare (one-way) ²	\$52.00 - \$158.00	\$64.00 - \$160.00
Regional		
Travel Time (hrs:min)	1:15	1:20
Frequency (daily)	44	84
Fare (one-way)	\$52.00 - \$158.00	\$64.00 - \$160.00

Notes

1. These values are based on the total origin-destination data between the three DC major airports (IAD, DCA, BWI) and NYC five major airports.
2. Fare range for air service depends on restrictions on the ticket purchase

Existing and Future Rail Service

- Conventional rail service between Boston-South Station and New York-Penn Station along a coastal route
- Existence of high-speed rail in the US domestic market has been limited to the New York-Washington segment (225 miles)
- Under the Northeast Corridor Improvement Project, Amtrak has initiated a track modernization program (full electrification)
- Ideal environment for the introduction of high-speed electric rail service between New York and Boston (231 miles)
- Projected Boston-New York trip times ranging from two and half to three hours

Summary of Rail Services in the Northeast Corridor

Market	Boston - New York	Washington - New York
Conventional		
Travel Time (hrs:min)	5:10	4:10
Frequency (daily)	10	15
Fare (one-way)	\$52.00	\$68.00
Express		
Travel Time (hrs:min)	4:00	2:35 1
Frequency (daily)	2	2
Fare (one-way)	\$57.00	\$96.00
Metroliner		
Travel Time (hrs:min)	not available	3:00
Frequency (daily)		17
Fare (one-way)	<i>see Note 2</i>	\$96.00

Notes

1. This service is described as an express Metroliner service in Amtrak's Northeast Timetable.
2. After the completion of the NECIP project, Amtrak plans to introduce Metroliner type rail service between Boston and New York City with similar levels of service (frequency, fare, travel time) to the Washington to New York segment.

Market Surveys and Demographics

- Amtrak Survey 1986

Characteristics of inter-city passengers who travel within the Northeast Corridor (rail, air, automobile). Comprehensive analysis of travel patterns in order to develop a database which would be used for demand model estimation for the region.

- La Guardia Air Shuttle Passenger Survey 1990

Characteristics of Shuttle passengers departing from La Guardia airport. Data was collected over a twelve month period April 1990 through March 1991.

- Massport Logan Airport Ground Access Study 1990

Study of ground access travel patterns of airline passengers departing from Logan airport. Data generated from the database developed from the airport survey.

Total Trip Volumes in the Northeast Corridor based on Survey Data

Source: *AMTRAK Final Report 1989*

A. Point of Origin: Boston

Destination City	Rail	Air	Auto
New York	209,650	1,213,395	2,598,918
Washington DC	27,229	555,152	287,425

B. Point of origin: Washington

Destination City	Rail	Air	Auto
New York	519,531	1,158,777	1,657,336
Boston	27,229	555,152	287,425

Indicated values represent the number of one-way passengers in the origin-destination market.

Summary of Demographic Information Based on Survey Data

Market	Boston - New York		Washington - New York	
Modal Split				
Rail Services (%)	5		15	
Air Services (%)	30		35	
Automobile (%)	65		50	
Modal Preference-Public Service				
Business	Air 97%	Rail 3%	Air 86%	Rail 14%
Non-business	Air 73%	Rail 27%	Air 52%	Rail 48%
Overall (Estimated)	Air 92%	Rail 8%	Air 76%	Rail 24%
Trip Purpose				
Business	79%		70%	
Non-business	21%		30%	

Summary of Market Demographics

- Over the last decade, there has been a gradual reduction in the number of passengers using each public transport mode
- Modal choice of a passenger is influenced primarily by the total travel time and the price of travel.
- Influenced by service characteristics such as the reliability of the scheduled travel time, the convenience of departure times, comfort, on-board and in-terminal amenities, and the perceived safety of the travel mode.
- Percentage of business travellers on existing rail service does not follow the same pattern as that of the air shuttles.

Existing Air Market Conditions: Passenger Traffic

- Number of air shuttle passengers travelling in the corridor between New York and Boston, and New York and Washington has declined from 3.6 million in 1989, to 2.8 million in 1992.
- Total number of air passengers (including regional traffic) in 1992 was 5.02 million, compared to 6.35 million passengers in 1989 [CAB data]
- Decline in air shuttle passenger traffic in the region can be attributed in part to the increase in the number of flights offered by other regularly scheduled air carriers.
- Diversion of air passengers to high speed rail will depend on the existing air travel market.

Existing Air Market Conditions: Passenger Traffic

Boston-New York O/D Market

- Presence of air shuttle service between Boston Logan and New York La Guardia airports accounts for the majority of jet passenger traffic
- In the Boston-Newark sub-market, the number of air passengers has increased significantly as a result of Peoplexpress and Continental
- Presence of a dominant air carrier in the Boston-Newark market has inhibited service by regional carriers
- The lack of adequate airline jet service between Boston and JFK created an ideal environment for the growth of regional service

Washington-New York O/D Market

- Washington area is serviced by three major airports; National DCA, Dulles IAD, Baltimore-Washington, BWI
- Majority of the air passengers travelling between Washington and the New York area fly into La Guardia airport
- Distribution of flights based on the airport of origin in the DC area has changed since 1980, as the level of traffic at the Dulles Airport increased from zero in 1980 to nearly 10% of the total WAS-NYC traffic
- Most of the traffic originating at Dulles airport and Baltimore-Washington International airport were destined for La Guardia
- Significant increase in the number of passengers underscores the importance of diverse airport locations to suit the passenger needs

Summary of Passenger Traffic in the NE Corridor

Year	1980	1988	1992
<i>Air Services</i> ¹			
Boston-New York			
Air Shuttle	1,481,110	2,003,520	1,422,170
Regular Jet	540,840	1,201,380	723,030
Regional	<u>48,644</u>	<u>110,270</u>	<u>259,291</u>
Total	2,070,594	3,315,170	2,404,491
Washington-New York			
Air Shuttle	1,628,040	1,843,670	1,411,350
Regular Jet	455,140	1,178,900	715,410
Regional	<u>13,711</u>	<u>303,060</u>	<u>474,786</u>
Total	2,096,891	3,325,630	2,601,546
<i>Rail Services</i>			
Boston-New York	203,300	714,000	600,000
Washington-New York	2,830,400	1,486,000	1,600,000
Metroliner	1,970,500	n/a	n/a
Conventional	859,900	n/a	n/a

Notes

1. Traffic levels based on ten percent sample data collected by the CAB

Forecasting High Speed Rail Ridership

- Ability to accurately forecast rail ridership in the Northeast Corridor depends on several variables (total population of urban centers, level of employment, average income and the level of ridership on competitive travel modes)
- Proposed HSR service would be an extensive improvement of existing conventional rail service, offering new travel times, fare choices and potentially improved levels of reliability, comfort and convenience.
- All these factors would have an effect on the passenger's choice of travel mode and would have to be incorporated into the ridership forecasts.
- Lack of data on the local point of origin and final point of destination of passengers

Forecasting High Speed Rail Ridership

- Develop more accurate estimates of access and egress times, as well as travel expenses for the total trip.
- Passenger's choice of a particular travel mode is governed by the perceived level of service which has to be factored into the forecast
- Identification of the relevant passenger service variables which influence mode choice, as well as the total travel volume, is important for accurate forecasting.
- Manner in which these variables are incorporated in the demand model is critical to the accuracy of the forecast.
- Ability to identify the structure of competition that will develop among inter-city modes is essential to the forecasting process

Observations and Conclusions

Level of Competition

- Development of transportation modes in the Northeast has been governed by the high level of competition which exists in the market
- Sixty-four percent (64%) of the Air Shuttle passenger at La Guardia Airport originate in Manhattan (80% originating from New York City)
- Fifty percent (50%) of the Air Shuttle passengers at Logan Airport originate in metropolitan Boston, and seventy percent of passengers were destined to the New York City metropolitan area.
- Estimated that only thirty-five percent (35%) of the Air Shuttle passengers travelling between Boston-Logan and New York-La Guardia are city-center to city-center passengers.

Observations and Conclusions

Passenger Traffic

- Significant growth in regional air traffic within the Northeast Corridor, especially between New York City and the Washington DC area
- The growth of regional carriers has affected the level of passenger traffic on the air shuttles, as well as traffic levels on the rail service
- Current regional airfare offerings promotes competition between the two modes of transportation (rail and air)
- The ability of ground transportation modes to compete effectively with air travel has been inhibited by the lack of high speed rail service

Observations and Conclusions

Future Markets

- Completion of the NECIP Improvement Project is intended to allow Amtrak's rail services to compete more effectively with other existing transport modes
- Primary benefit of NECIP will be a significant reduction in rail travel time between Boston-South Station and New York-Penn Station (yet still well above the air travel time)
- Expected HSR travel times are at least twice the existing air travel times, and will not be competitive for the business traveller.

Observations and Conclusions

Forecasted HSR Ridership

- Annual ridership for Amtrak between Boston and New York City market will grow to as much as 2.3 million passengers for a two-and-half hour trip time, compared to the current traffic levels of 600,000 rail passengers per year
- Approximately eighty percent of the new rail passengers will be diverted from air travel, with minimal induced traffic.
- NECIP forecasts are based on several questionable assumptions concerning competing modes of transportation

Observations and Conclusions

Assessment of the Potential for Diversion

- In 1992, there were 2.41 million air passengers (including regional service) travelling in the Boston-New York market, a decrease from 3.315 million passengers in 1988
- It can be estimated that 1.32 million of the new rail passengers will be diverted from air travel to high speed rail based on the forecasted HSR ridership and percent of diversion stated in the NECIP report.
- Air passenger demand for Logan in 2010 (forecasted) will range from 26.51 to 37.92 million passengers assuming existing operational conditions without any ATC improvement or the upgrading of the Northeast Corridor to high speed service

Assessment of the Potential for Diversion

- It was estimated that there will be approximately 4.6 million air passengers travelling from Boston-Logan to the New York city market
- NECIP forecasts calls for a twenty-nine percent (29%) diversion of air passengers to high speed rail in the Boston-New York market
- The justification for this forecast of a large diversion of air passengers is not apparent, since the existing air shuttle travel times of one hour are superior to any projected rail travel times
- Ability of future high speed rail systems in the Northeast Corridor to divert air passengers will depend on several factors, which currently do not play a major role in modal choice.
- Accuracy of the forecasts for high speed rail ridership is therefore questionable for several reasons.

Emerging Competition

- Level of potential diversion of passengers from existing modes is essential to the accuracy of the high speed rail demand forecast.
- Ability to identify the structure of competition that will develop amongst the transport modes is therefore critical to the diversion forecast. This competition has been ignored in NECIP forecasting.
- Emergence of new telecommunication technologies such as video-conferencing could have a substantial impact on future travel market.
- The high percentage of non-discretionary passengers may create an environment for a significant diversion to video-conferencing
- The overall impact of tele-communications on competition amongst the varying transport modes would also be a factor to consider in determining the viability on a new transport mode such as HSR.

Recommendations

- Several issues associated with the diversion question have been considered, and it is the opinion of the investigator, that the anticipated levels of diversion reported by the Department of Transportation are overestimated.
- The ability to accurately predict the level of diversion of air passengers is not currently possible. Overall travel behaviour of existing passengers in the NE Corridor have not been fully considered.
- As a recommendation for future HSR ridership forecasting studies, the author suggests that existing air passengers be surveyed about the proposed high speed rail service, as well as existing transport services. This should enable the forecaster to develop more accurate predictions of rail ridership in the Northeast Corridor, based on revealed and stated preferences of existing passengers.

Operations Research & Computer Science
Developments in Aircraft Scheduling

MIT-Industry Cooperative Research Program
in Air Transportation

May 19, 1994

Dr. Dennis F. X. Mathaisel

Flight Transportation Laboratory
Department of Aeronautics & Astronautics

The Airline Scheduling Process

Airline schedule development is a process which occurs over time, moving through four phases which introduce more detailed data inputs at each phase. It starts with abstract, generic forecasts at the planning phase and moves to specific, very detailed, real time inputs at the execution phase. While it is difficult to isolate these phases, and every airline does them slightly differently, we can identify four phases:

Phase 1 – Planning a Schedule of Services

Phase 2 – Generation of an Operationally Feasible
Schedule

Phase 3 – Assignment of Specific Resources

Phase 4 - Execution Rescheduling

The Airline Scheduling Process

Airline schedule development can be described as a phased process. The inputs change from abstract, generic forecasts to specific, very detailed, real time data where more data becomes available at each phase.

Phase 1 – Planning a Schedule of Services

Phase 2 – Generation of a Operationally Feasible
Schedule

Phase 3 – Assignment of Specific Resources

Phase 4 – Execution Rescheduling

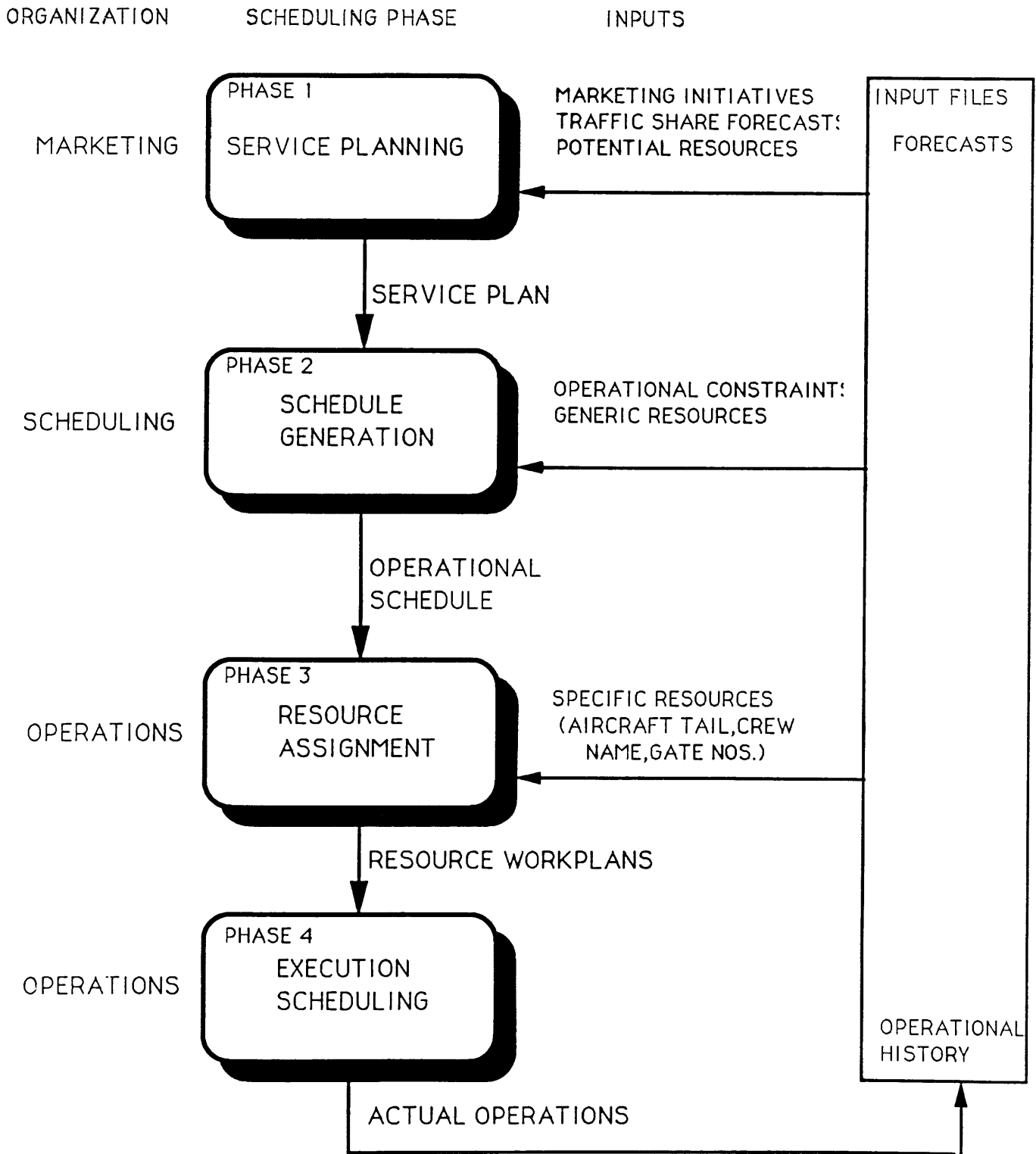
Observations

- The scheduling process is similar, but always slightly different at each airline
- Organizational participants are different at each airline
- The scheduling process changes over time as problems change

Conclusion

It is now possible using the new technology of "Engineering Workstations" to build an integrated, coherent, computerized scheduling system which can be used throughout all these phases and is handled by different organizational entities. It will be adaptive to changing problems and reorganization of the process.

FIG.2- THE TIME PHASED PROCESS OF DEVELOPING A SCHEDULE



Phase 1 – Service Planning (Future Scheduling)

Goal

- determine a basic cyclic (daily or weekly) schedule of services to be flown in air travel markets for the future schedule period

Inputs

1. Forecast of Potentially Available Resources
 - number of available aircraft (by type?)
 - number of available gates
2. Forecast of Market Situations
 - O&D traffic share by fare class
 - competitive service levels
3. Desired Market Initiatives
 - current (or last year's) schedules
 - changes in service

Outputs

1. Service Plan – updated, timed set of services for the basic cycle feasible to be flown by available fleet
 - no aircraft or crew rotations
 - gate loading, but no gate schedule
 - tentative service times
2. System Summary – revenue, costs, activities

Airline Scheduling Process

OR Models for Phase 1 - (Future Scheduling)

A. Fleet Assignment Models

FA-4

LP + Preprocessor + Postprocessor Code

B. REDUCTA

Code in Fortran, C

C. Fleet Planning Models

Cell Model

LP + Preprocessor + Postprocessor Code

OR Models for Phase 1 – (Future Scheduling)

A. Fleet Assignment Models – (FA-1 through FA-7)

- uses large scale, LP technique to find "best" allocation of available fleets to feasible, desirable aircraft routings

Objective

Maximize Operating Income

Given

- O-D market demand shares
- prices, frequency of service, seat availability
- multi-stop, or connecting routings
- limits on available daily fleet hours
- limits on onboard load factors achievable
- limits on Max-Min desired daily market services

Output

Routes to be flown, and frequency by type of aircraft

OR Models for Phase 1 – (Future Scheduling) -- cont.

B. Reducta

- heuristic code in Fortran or C

Objective

Minimize fleet size

Given

- set of services which must be flown
- time window for each service
- minimum turn times

Output

Services flown, and their operating times

C. Fleet Planning Models – Cell

- use aggregate route/market clusters ("cells") over a series of future years given forecasts of availability of new types of aircraft and disposal values
- introduce financial options – borrowing, lease, etc.

Phase 2 – Generation of Operational Schedule (Current Scheduling)

Goal

- given a service plan, create a feasible monthly schedule of operations for resources actually expected to be available

Inputs

- service plan (from marketing)
- expected resources (from flight operations, maintenance)
- aircraft by type
- crews by type
- gates by type
- weekend, holiday service plans
- prior schedule for transition operations
- hubbing constraints

Output

- detailed operational schedule
- rotations for aircraft and crews
- gate schedules
- station personnel requirements
- layovers by aircraft and crew
- modified departure/arrival times
- publication of schedule for OAG, reservations system

Airline Scheduling Process

OR Models for Phase 2 - (Current Scheduling)

- A. Airline Schedule Development: ASD
 - Interactive graphical user interface
 - Librarian
 - Schedule splitting and merging
 - Validation and error checking
 - Rule system
 - Maintenance, crew and airport constraints
 - Printed summary reports
 - Optimization algorithms

- B. Traffic Allocation and Schedule Evaluation:
 - TALLOC
 - Integrated with ASD

- C. Aircraft Routing Models
 - Switch and Save

ASD

- Standalone or client-server architecture
- Multiple users
- Interactive graphics editor
- Unlimited number of aircraft, segments, rotations, stations
- Flexible setup, filtering, sorting, scaling
- Multiple windows
 - Lines of flying
 - Aircraft rotations
 - Station activity
 - Gate assignment
 - Timetable
 - Geographic map view
- Frequency-based and fully-dated schedules

ASD -- cont.

- Rule-based constraint checker
 - Crew requirements
 - Maintenance requirements
 - Operations (ground times, station continuity, curfews, etc.)
- Librarian: merging and splitting schedules
- Interfaces to existing algorithms
- Traffic allocation (TALLOC)
- Automatic flight numbering
- Import and export functions: read and write data files to mainframe
- Interfaces to ORACLE DBMS
- Printed reports
- Runs on any UNIX workstation or PC supporting UNIX

Traffic Allocation and Schedule Evaluation TALLOC

Given

- forecasts of O-D demands for all markets
- schedules for your airline and your competition
- passenger preference factors

Results

- segment analysis
composition of onboard segment traffic
- market analysis
services provided in each market and the traffic carried on each flight

Very detailed evaluation of a schedule in a competitive environment

- simulates passenger booking process
- links scheduling to revenue and capacity management

OR Models for Phase 2 – (Current Scheduling)

Switch and Save – (SWITCH)

Objective

Maximize operating income by switching aircraft types to match capacity with demand

Given

- set of scheduled services for any two fleet types with fixed operating times and known net operating income
- aircraft operating costs

Find

- all possible ways of switching aircraft types and select the fleet assignment with maximum total profit

Note:

For planning purposes it is not necessary to specify the starting location of aircraft. They can be positioned at any station the planner chooses.

OR Models for Phase 2 – (Current Scheduling)

Aircraft Rotation Generation

Objective

Find good set of turns between arrivals and departures at a station

Given

- desire for through service in certain markets
- maintenance operational constraints
- station ramp operational constraints

Output

- rotations or daily lines of flying
- gate occupancies at station
- through services

Note:

Given this output, gate and station resource scheduling in Phase 3 can proceed. Crew scheduling depends to some degree on aircraft rotations. There is no unique solution for aircraft rotations – they will be operated in many different ways due to maintenance and operational deviations.

Phase 3 – Resource Assignment

Goal

- find optimal or good work assignments for specific resources (aircraft by tail, crews by name, gates by number)

Inputs

- operational schedule
- aircraft time, rotations, layovers
- crew rotations and trips
- gate loadings
- station personnel loadings

Outputs

- maintenance schedule of activities
- crew bidlines and assignments (including reserves)
- gate schedule
- station personnel assignments

Phase 4 – Execution Rescheduling

Goal

- execute the operational schedule at least extra cost

Inputs

- operational schedule
- work assignments
- operational deviations
- weather, breakdowns, sickness
- late arrivals
- expected traffic loads
- short term operating costs

Outputs

- modified execution schedule
- cancellations, delays, extra-stops, overfly, etc.
- reassignment of resources

Airline Scheduling Process

OR Models for Phase 4 - (Execution ReScheduling)

Airline Schedule Control: ASC

- Flight following and system operations control
- Real-time graphical user interface
- Embedded icons show the current status

Cancellations

Changes in ETA/ETD

Maintenance

Weather forecasts

Crew information

Passenger loads

Aircraft / airport status

Built-in "flagging" system for warnings

"What-if"

- Standalone or client-server architecture
- Real-time graphical representation of current status
- Multiple users
- Unlimited number of aircraft, segments, rotations, stations

ASC -- cont.

- Flexible setup, filtering, sorting, scaling
- Marketing schedule display to compare planned and actual imbedded icons
- Cancellations, changes in ETA/ETD, overfly, etc.
- Maintenance problems
- Weather forecasts
- Crew information
- Passenger loads
- Interactive graphics editor
- Modify ETAs/ETDs
- Swap equipment
- Cancellations
- Overfly or add additional stop
- Popup menus to edit mainframe transaction commands before transmission
- Popup menus to retrieve aircraft, station, flight information
- Messaging system
- Interactive "what-if": evaluate alternative plans
- Interfaces to existing algorithms
- Import and export functions: read and write data files to mainframe
- Printed reports
- Runs on any UNIX workstation or PC supporting UNIX

The Airline Scheduling Workstation (ASW)

A Computer Tool for Airline Schedulers

1. Desk top Engineering Workstations running UNIX 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 C programming to provide modular code, easily extendable to handle time-varying scheduling constraints, policies, etc., and to reduce programming support.

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 to ensure that the new system will not preclude doing certain schedule sub-processes 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.
- develop modern, transportable, modular, object-oriented software, for automation of sub-processes in scheduling
 - easily extendible
 - easily supported
 - C, C++ language
 - efficient data structures

Development Approach for an ASW

Stage 1 – Introduction of a Manual, Interactive Graphics Scheduling System

- a) Start with Schedule Generation, (i.e. Phase 2 – Current Scheduling)
- b) Provide computer graphic displays of schedule information
 - instantaneously modifiable by mouse, global data base modification
 - selectable screen data -- by fleet, station, time, schedule period
 - save alternate solutions
 - auditable differences
 - memo pad for scheduler
 - keyed to input data, and assumptions used
 - automated search routines, etc. to minimize keyboard and mouse work
- c) 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

Development Approach for an ASW -- cont.

- d) Integrate initial crew, gate, maintenance schedule planning with aircraft schedule planning
 - e.g., rough initial schedules for crews, gates, station personnel
- e) Provide familiar printed reports and graphics for distribution around airline
- f) Provide interface to mainframe data system to maintain current scheduling processes

Development Approach for ASW

Stage 2 – Introduction to Automated Decision Support

(Include Service Planning, Phase 1)

Introduction of Expert Systems, Automated Algorithms

- to assist human schedulers with certain sub-problems
- to eliminate manual effort at certain steps of the 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) automatic aircraft rotation generation (with maintenance constraints)
- b) automatic gate assignment at all stations
- c) automatic fleet assignment, from a set of desirable flights, given revenue, traffic, limited fleet sizes, and aircraft operating costs
- d) best cancellation of flights given breakdowns and spares
- e) minimum fleet size for given services with time windows
- f) least revenue loss when reducing available fleet
- g) optimal switching of flights between types of aircraft
- h) automatic switching for transition to new schedule plan

Development Approach for an ASW

Stage 3 – Move to Real Time, Execution Rescheduling

(or implement in parallel with Phase 1)

- real time bidline and shift rescheduling
- incorporate real time, operational constraints
- aircraft plus crews
- gate rescheduling
- include maintenance and flight operations on ASW

Expected Benefits of an ASW

Stage 1 – Creation of an Interactive Manual Scheduling System

- faster turnaround for scheduling projects
- more thorough study of schedule alternatives
- better handling of the impact of resource constraints
- error-free schedules -- (errors and deficiencies are automatically flagged)
- improvements from integration of small degree of initial crew planning into aircraft scheduling (layover crew problems)
- better utilization of resources
- automated costing of schedules, and profitability, as schedules are generated

Stage 2 – Introduction of Automated Decision Support

- more profitable schedules
- day-of-week customized schedules to minimize cost of obtaining revenue – e.g. patterns which use larger a/c more intensively on SM & F
- better weekend, holiday schedules

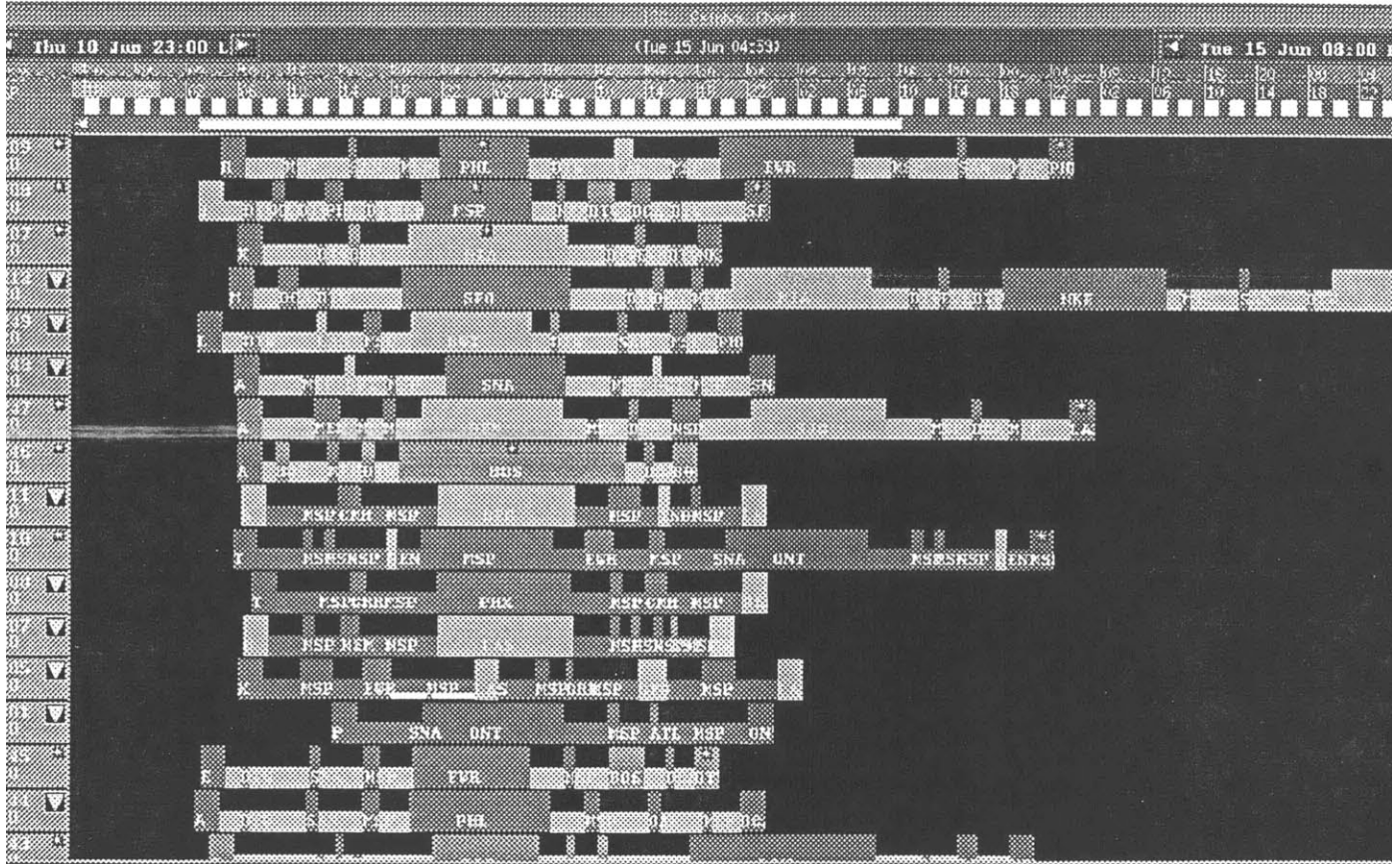
Expected Benefits of ASW -- cont.

Stage 3 – Automated Rescheduling of Real Time Operations

- minimize cost of maintaining schedules
- minimize revenue loss of schedule disruptions

Station	Fleets	Carriers

Stations	Jets	Props	Carriers	TimeTable Org/Dest	Frequencies	Groups
ABE	767	DH7	TB	ABE	<input type="checkbox"/> Monday	All Jets
ABQ	757	SH6	GG	ABC	<input type="checkbox"/> Tuesday	All Props
ACY	72S	BE1	ZV	ACY	<input type="checkbox"/> Wednesday	All Both
AGS	M80	F27	FG	AGS	<input checked="" type="checkbox"/> Thursday	<input type="checkbox"/> Create New Window
AHN	734	J31	JI	AHN	<input type="checkbox"/> Friday	Total Lofs : 2039 Daily Segs : 6287 Total Segs : 13479
ALB	34N	DH8	CC	ALB	<input type="checkbox"/> Saturday	
AND	73L	EMJ	YW	ANL	<input type="checkbox"/> Sunday	
AOO	733	SWM	JN	AOC		
APF	73S	SF3	TH	APF		
ART	732	BEC	JS	ART		
ATL	D93	DHT	UQ	ATL		
AUS	F10	SH3	EN	AUS		
AVL	F24		US	AVL		
AVP	F21			AVP		
AZO				AZC		
BDA				BDA		
BDL				BDL		
BDR				BDR		
BFD				BFD		
BFL				BFL		

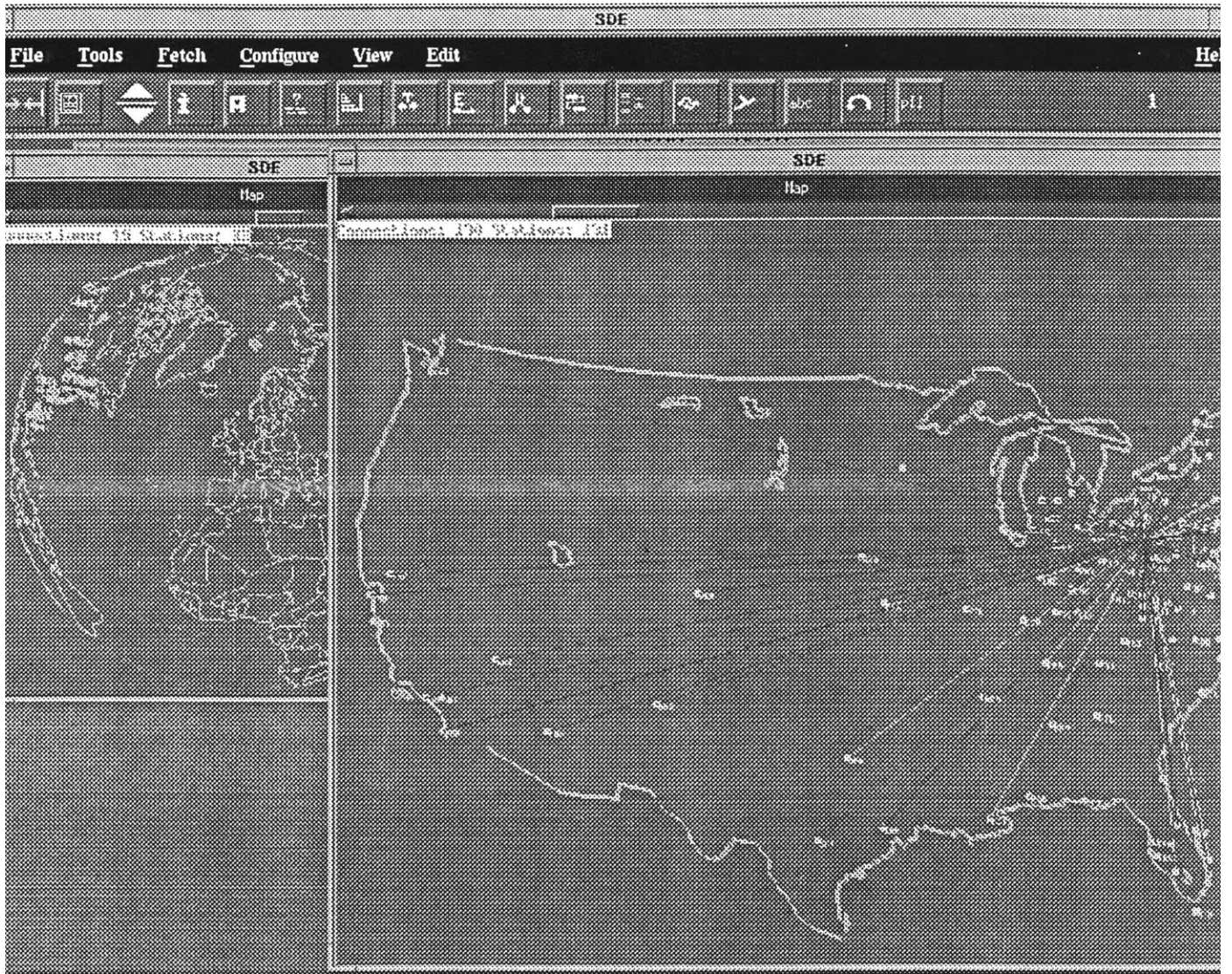


SDF

5765 SH6 PKB 0755 01
58640 SH6 YRG 1145 01
5764 SH6 YRG 1425 01
609 SH6 YRG 0750 01
608 YRG SH6 0500 15
607 YRG SH6 0512 10
601 YRG SH6 0502 20
5829 BE1 CBE 0700 022
644 757 SFD 0714 B2
5853 DHT LBE 0715 71
3982 BE1 JST 0720 051
602 YRG SH6 0700 05
601 YRG SH6 0700 05
12938 N20 ERI 0740 F14
4000 SH6 YRG 0740 05
5752 DHT FRL 0745 72
4000 SH6 YRG 0745 05
3924 DHB H00 0745 075
702 N20 CNH 0746 F11
4599 N20 TOL 0747 F13
2018 N20 GRF 0748 F7
4000 SH6 YRG 0748 05
4000 SH6 YRG 0748 05
3518 DHB SCE 0750 072
4000 SH6 YRG 0750 05
4000 SH6 YRG 0750 05
4000 SH6 YRG 0750 05
4000 SH6 YRG 0750 05
4000 SH6 YRG 0750 05
4000 SH6 YRG 0750 05

01 1805 YRG 55648 SH6
01 1250 YRG 5766 SH6
15 0520 FRL 7500 75
10 0520 FRL 1900 75
B12 0645 DHT 752 757
140 0700 DHT 77 710
753 0700 OPS 401 051
750 0700 DHT 100 051
757 0700 LCO 057 71
100 0700 H00 12100 75
710 0700 FRL 600 71
101 0730 DHT 1070 124
15 0730 BE1 050 71
71 0730 LBE 5769 DHT
022 0730 CKB 5771A BE1
5 0730 SH6 500 71
051 0740 JST 3989 BE1





SDE



Rule checker

Category: Maintenance Information

Category	Rule	Rule Definition
Availability	Rotations	<p>Rule: Percent of fleets/total aircraft RON at MTC stations.</p> <p>Calculate the percent of total aircraft and the percent of the aircraft in each equipment type which are present overnight at designated maintenance bases, and detects when the percent is beyond the desired interval.</p>
Statistics	Main. flow	
Maintenance	Bal. checks	
Crew	LOF's landing	
Facility	LOF Hub	
Operations	No maintenance	
	RON percent	
	Hanger RON	
	Exterior wash	
	RON counts	

Disable Rules Rule Level : ◆ I ◆ II ◆ III

OK Apply Cancel

Interactive Scheduling System

File Edit View Options Tools

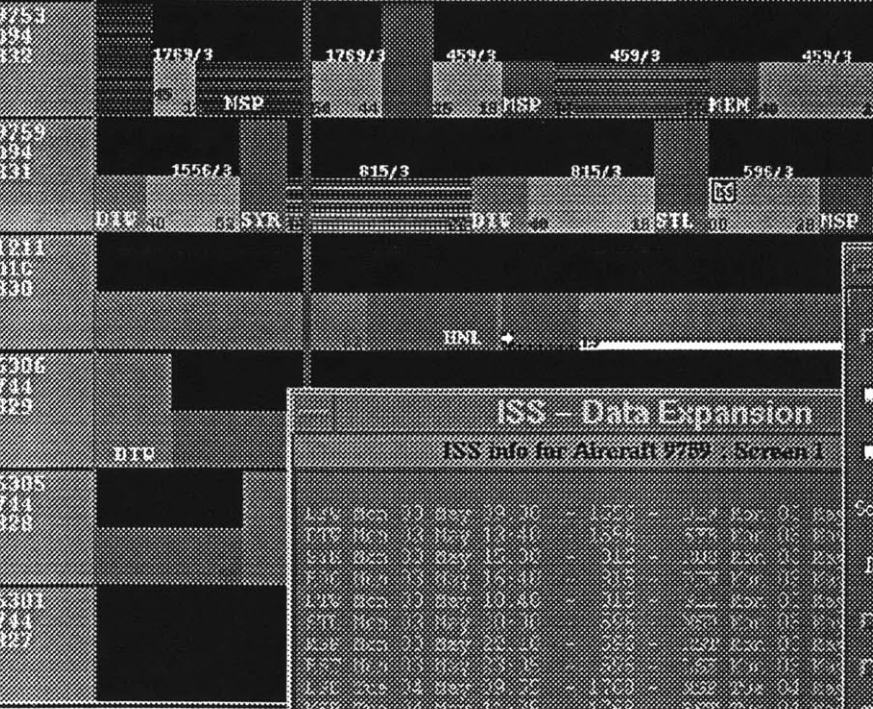


Heart cabinet

ISS - Rainbow Chart

Mon 03 May 17:00 | 596 ← 04:23 14:55 → 1760 MSP (Tue 04 May 06:31) | Tue 04 May 08:00 |

2010 MSP 17 18 19 20 21 22 23 00 01 02 03 04 05 06 07
 MSP 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27



ISS - WorldFlight Command

1769/1769/3
 459/3/459/3/459/3

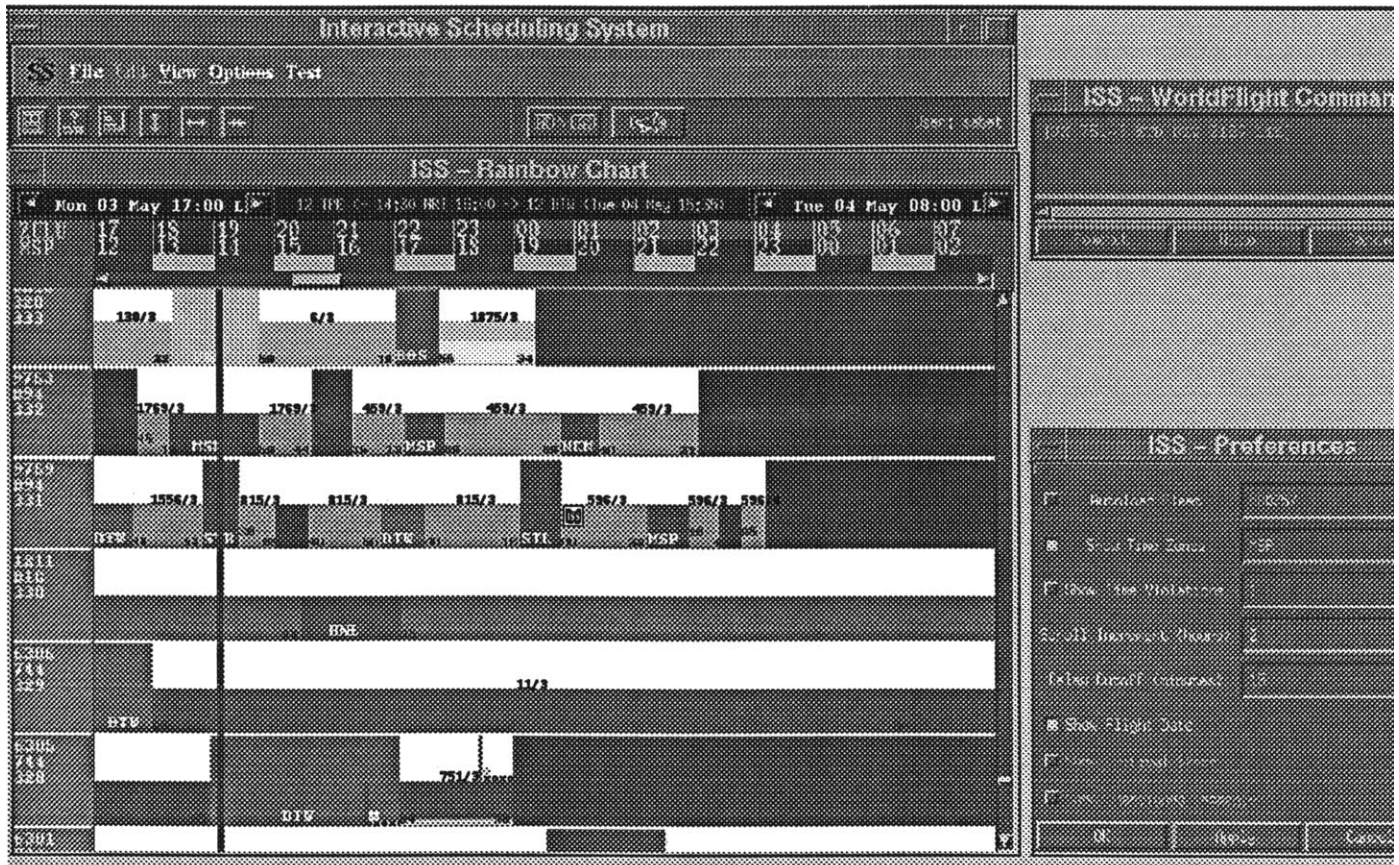
ISS - Preferences

Autocad Fleet: 460757
 Show Time Zones: MSP
 Show Time Violations: 1
 Scroll Increment (hours): 2
 Delay Cutoff (minutes): 15
 Show Flight Info
 Show Historical View
 Show International Segments

ISS - Data Expansion

ISS info for Aircraft 7789 - Screen 1

LAX	Mon	13	May	19:30	-	1755	-	127	Exp	01	Exp
DTW	Mon	13	May	13:40	-	1556	-	578	Exp	05	Exp
LAX	Mon	23	May	15:30	-	312	-	318	Exp	00	Exp
DTW	Mon	23	May	16:40	-	315	-	777	Exp	02	Exp
LAX	Mon	23	May	10:40	-	312	-	222	Exp	01	Exp
DTW	Mon	23	May	10:30	-	356	-	579	Exp	05	Exp
LAX	Mon	23	May	22:30	-	355	-	229	Exp	02	Exp
DTW	Mon	23	May	23:35	-	326	-	152	Exp	05	Exp
LAX	Tue	14	May	19:35	-	1769	-	352	Exp	04	Exp
MSP	Tue	14	May	17:25	-	1769	-	787	Exp	04	Exp
DTW	Tue	14	May	13:42	-	1769	-	352	Exp	04	Exp
MSP	Tue	14	May	18:30	-	1769	-	753	Exp	04	Exp
LAX	Tue	14	May	16:25	-	459	-	222	Exp	04	Exp



Interactive Scheduling System

File Edit View Options Test



ISS-123

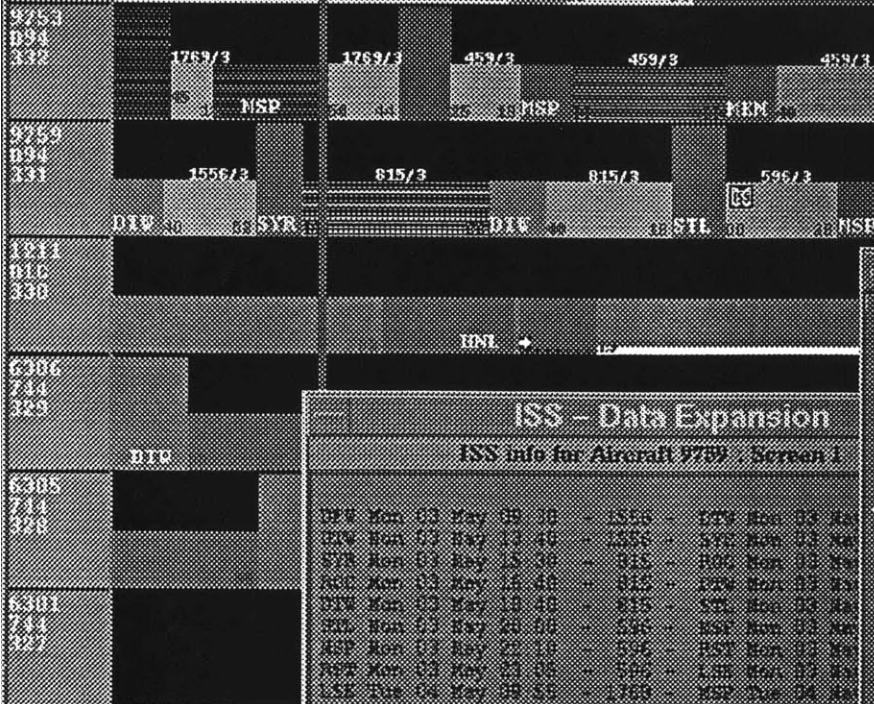


Library Cabinet

ISS - Rainbow Chart

Mon 03 May 17:00 I 596 ← 04:23 14:55 → 1768 MSP (Tue 04 May 06:31) Tue 04 May 08:00 I

ZHLD MSP 17 18 19 20 21 22 23 00 01 02 03 04 05 06 07



ISS - WorldFlight Command

ISS-123/ISS-123
(ISS-123/ISS-123/ISS-123)

Command Mode Cancel

ISS - Data Expansion

ISS info for Aircraft 9753 - Screen 1

ISS	Mon	03	May	08	30	-	ISS	Mon	03	May	08	30
DIA	Mon	03	May	13	40	-	ISS	Mon	03	May	13	40
SYR	Mon	03	May	15	30	-	ISS	Mon	03	May	15	30
DIA	Mon	03	May	15	40	-	ISS	Mon	03	May	15	40
DIA	Mon	03	May	18	40	-	ISS	Mon	03	May	18	40
DIA	Mon	03	May	20	00	-	ISS	Mon	03	May	20	00
DIA	Mon	03	May	22	10	-	ISS	Mon	03	May	22	10
DIA	Mon	03	May	22	30	-	ISS	Mon	03	May	22	30
DIA	Mon	03	May	22	40	-	ISS	Mon	03	May	22	40
DIA	Tue	04	May	09	30	-	ISS	Tue	04	May	09	30
DIA	Tue	04	May	11	20	-	ISS	Tue	04	May	11	20
DIA	Tue	04	May	12	40	-	ISS	Tue	04	May	12	40
DIA	Tue	04	May	14	50	-	ISS	Tue	04	May	14	50
DIA	Tue	04	May	16	00	-	ISS	Tue	04	May	16	00

ISS-123/ISS-123/ISS-123

ISS - Preferences

AutoLoad Fleet: H60757

Show Time Zones: MSP

Show Time Violations: 1

Scroll Increment (hours): 2

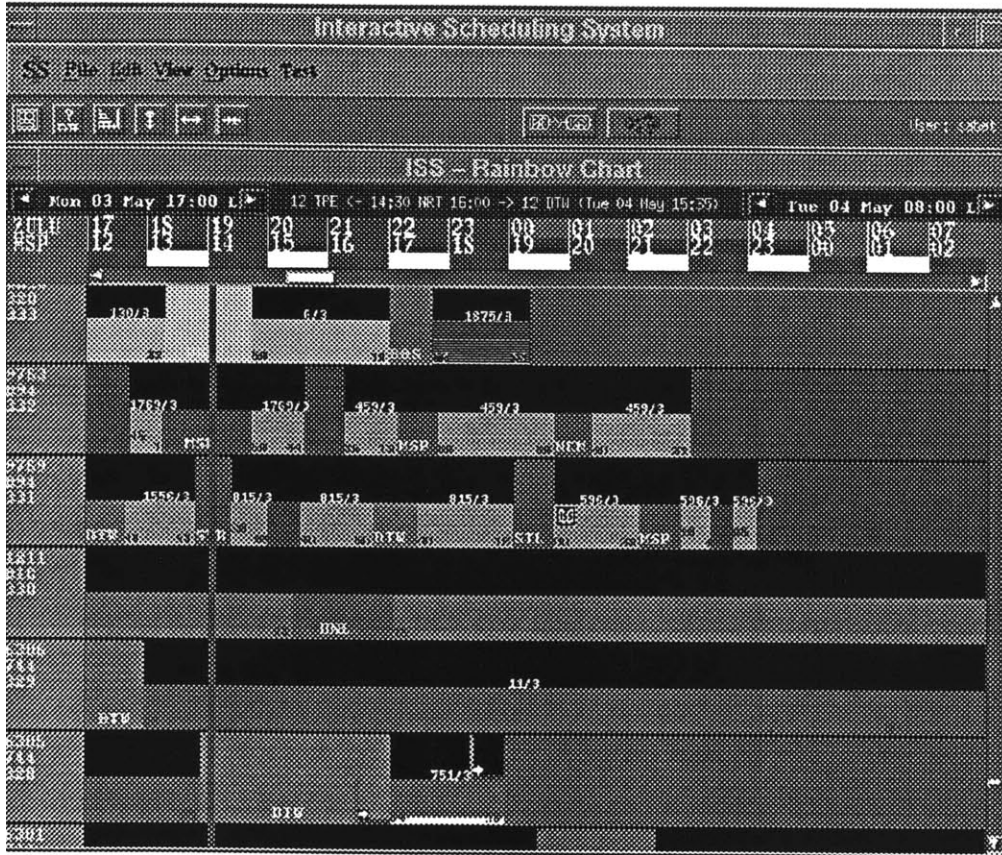
Delay Cutoff (minutes): 15

Show Flight Info

Show Airframe Status

Show Aircraft Legend

OK Apply Cancel



ISS - WorldFlight Command

Use TAB key to move between fields.

Command	Value

ISS - Preferences

<input type="checkbox"/> Reload Files	RESET
<input checked="" type="checkbox"/> Show Time Zones	MSP
<input type="checkbox"/> Show Time Violations	1
Scroll Increment (Hours)	2
Delay (min) of (minutes)	15
<input checked="" type="checkbox"/> Show Flight Date	
<input type="checkbox"/> Use 24-hour clock	
<input type="checkbox"/> Use 12-hour clock	

OK Help Cancel

WorldFlight Transaction

Commands

```
script 'ToggleNoStop' {if(WF 'NSTP  
script 'ModifyTime' {if(WF 'PX 89-
```

Transmit

Success

Failure

Cancel

Summary State-of-the-Art in Computerized Scheduling

Conclusions

1. We cannot create one analytical model which is adequate to describe mathematically the complete airline scheduling problem.
2. We can provide quick, accurate answers to many sub-problems 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.
3. 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.
4. 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 "fully-automatic" scheduling system.
5. The desired approach is 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

Summary
State-of-the-Art in Computerized Scheduling

6. 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.
7. 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.
8. 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 sub-systems.

**MIT/Industry Cooperative Research Program
In Air Transportation**

Annual Meeting

May 19-20, 1994

**"Competitive Behavior Of Airlines
In Multi-Airport Systems"**

By

**Professor Robert W. Simpson
&
Edmund Chen**

PURPOSE OF THE RESEARCH

- **To understand how AIRLINES behave in a competitive multi-airport environment.**

- **To arrive at some systematic HIERARCHICAL STRUCTURE that encapsulates:**
 - (a) the various COMPETITIVE SITUATIONS airlines encounter in multi-airport systems, and**

 - (b) the NORMATIVE BEHAVIOR of airlines under such situations.**

PRELIMINARY REMARKS

The relationship between passengers, airlines, airports:

PASSENGERS* —→ *AIRLINES* —→ *AIRPORTS

- **PASSENGERS:**

- desire the best possible air service

- free to select the air services provided

- **AIRLINES**

- airlines value passengers' patronage of the air services provided

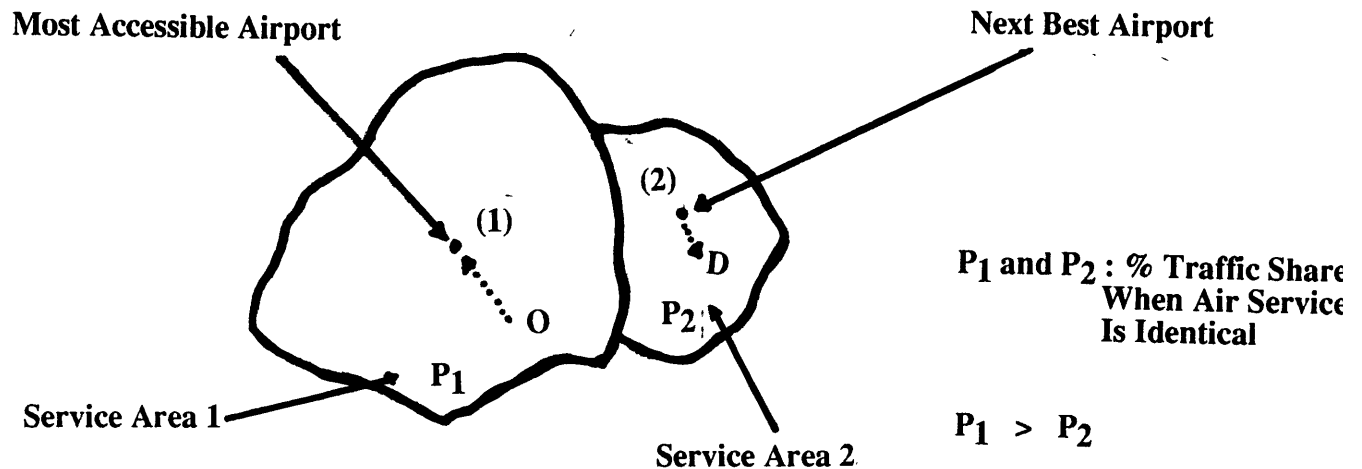
- airlines aim to provide the air services in the most profitable way

- **AIRPORTS**

- provide the facilities that airlines can use

- **Conventional View: Passengers are the users and choose, when possible, which airport to go to.**
- **But AIRLINES are users too; airlines can choose, to the extent possible, which airport to use.**
- **PASSENGERS and AIRLINES jointly determine traffic distribution in multi-airport systems.**
- **Incorporating airlines in the equation means that understanding competitive behavior of airlines is the vital key to the problem.**

DEFINING THE MULTI-AIRPORT SYSTEM (MAS)



A MULTI-AIRPORT SYSTEM WITH IDENTICAL AIR SERVICE FROM BOTH AIRPORTS

- A set of airports serving an urban area.
- *If and only if* the quality of air service were exactly **IDENTICAL** at each airport, a natural "service area" for each airport can be defined within the urban area.
- "Service area" - based on set of minimal cost paths (min. access and egress time) between the passenger's origin or destination and the airport.
- The MAS consists of two airports: the "most accessible" (1), and the "next best" (2).

THE VARIOUS COMPETITIVE SCENARIOS

- **The market structures under which competitive behavior of airlines is analyzed.**
- **The competitive decision dynamics reveal the route planning and resource allocation strategies that airlines employ.**
- **For the analysis, assume:**
 - (a) An incumbent operates at one airport, while challenger initiates services at the other.**
 - (b) A deregulated environment with no barriers to entry or exit.**
- **Interested in the competitive response of the incumbent to the entry of a challenger, and whether some profitable equilibrium is attainable.**
- **Examining game theory scenarios of airline competition.**

CLASSIFICATION OF SCENARIOS

- **S1: MAS - d (non-hub destination)**
- **S2: MAS - HUB - SPOKES**
- **S3: REGIONAL FEEDER - MAS HUB - d**
- **S4: REGIONAL SERVICES- MAS HUB - d**

Each scenario is further divided into two groups:

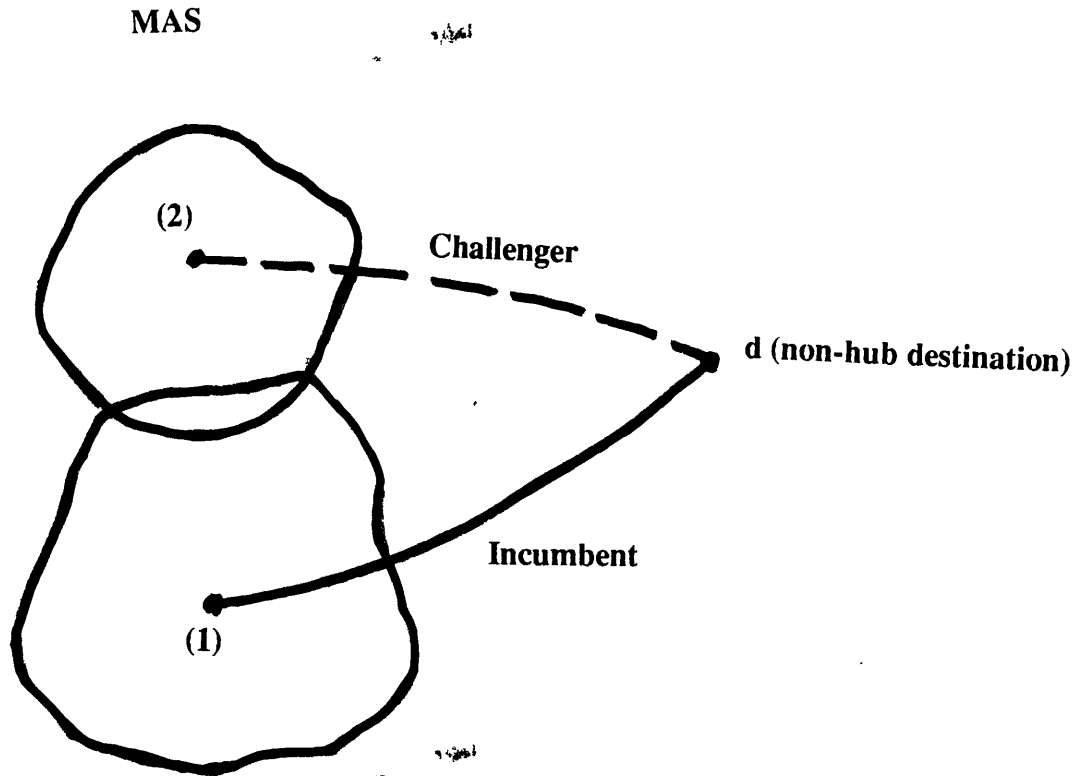
A:

- Incumbent* serving "most accessible" airport (1)
- Challenger* serving "next best" airport (2)

B:

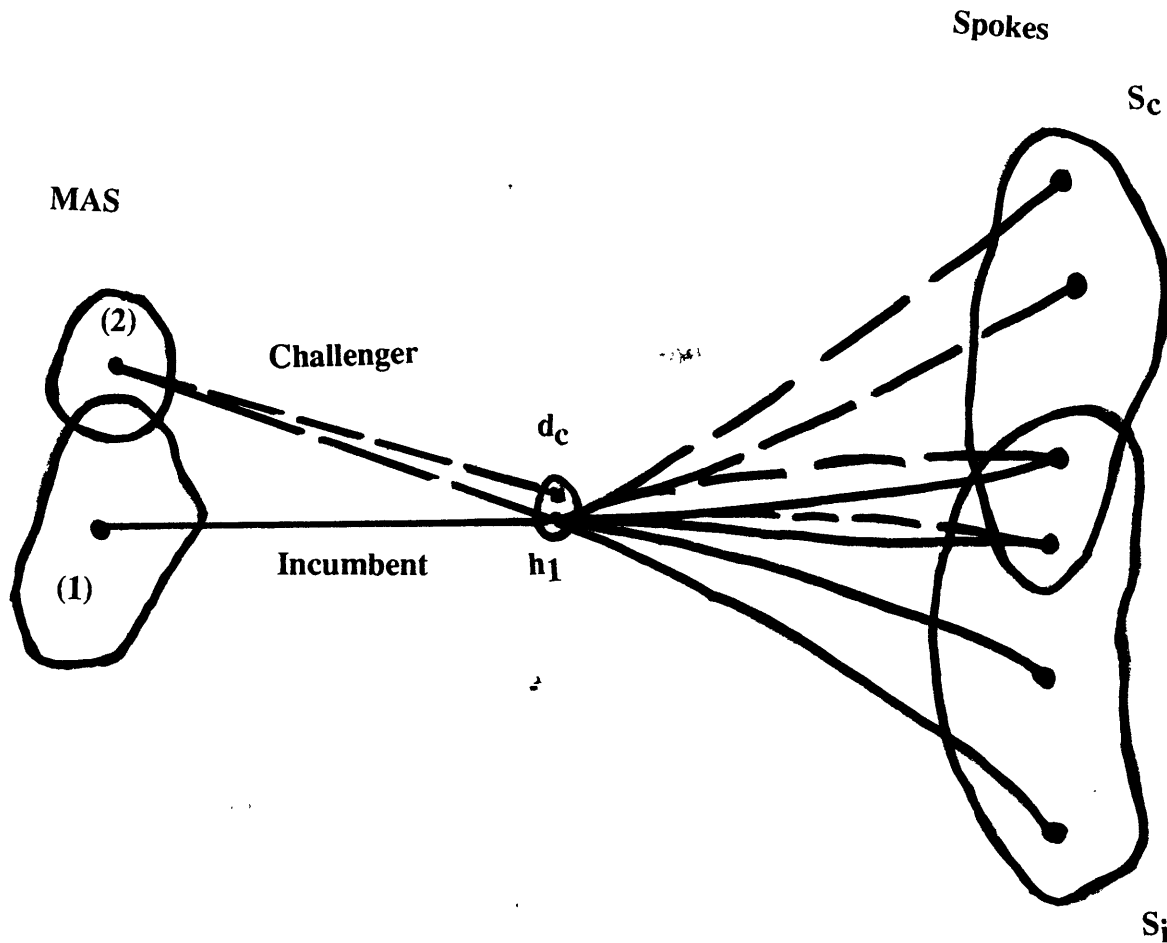
- Incumbent* serving "next best" airport (2)
- Challenger* serving "most accessible airport" (1)

S1A: MAS - d



- **INCUMBENT** operates between (1) and non-hub destination d.
- **CHALLENGER** initiates services between (2) and non-hub destination d.

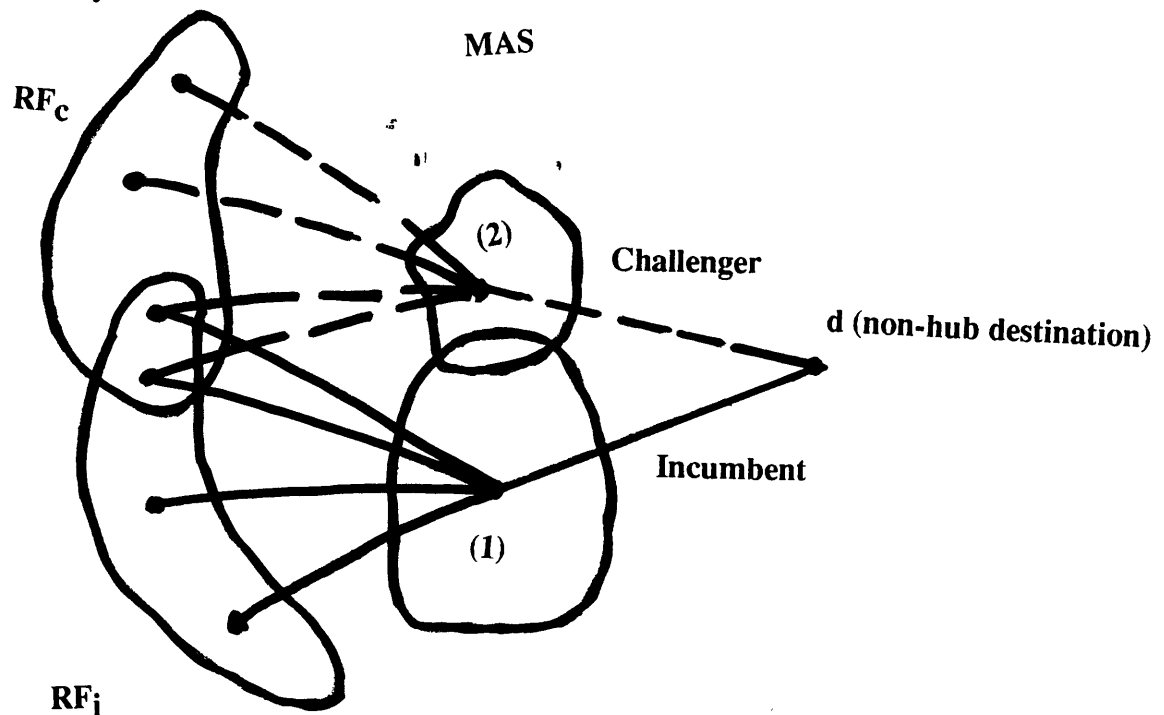
S2A: MAS - HUB - SPOKES



- **INCUMBENT** operates between MAS and hub h_1 , and a set of spoke cities, S_i .
- **CHALLENGER** initiates service
 - (a) between (2) and a non-hub destination d_c , or
 - (b) between (2) and the same hub h_1 , and a set of spoke cities, S_c , part of which overlaps with S_i .

S3A: REGIONAL FEED - MAS HUB - d

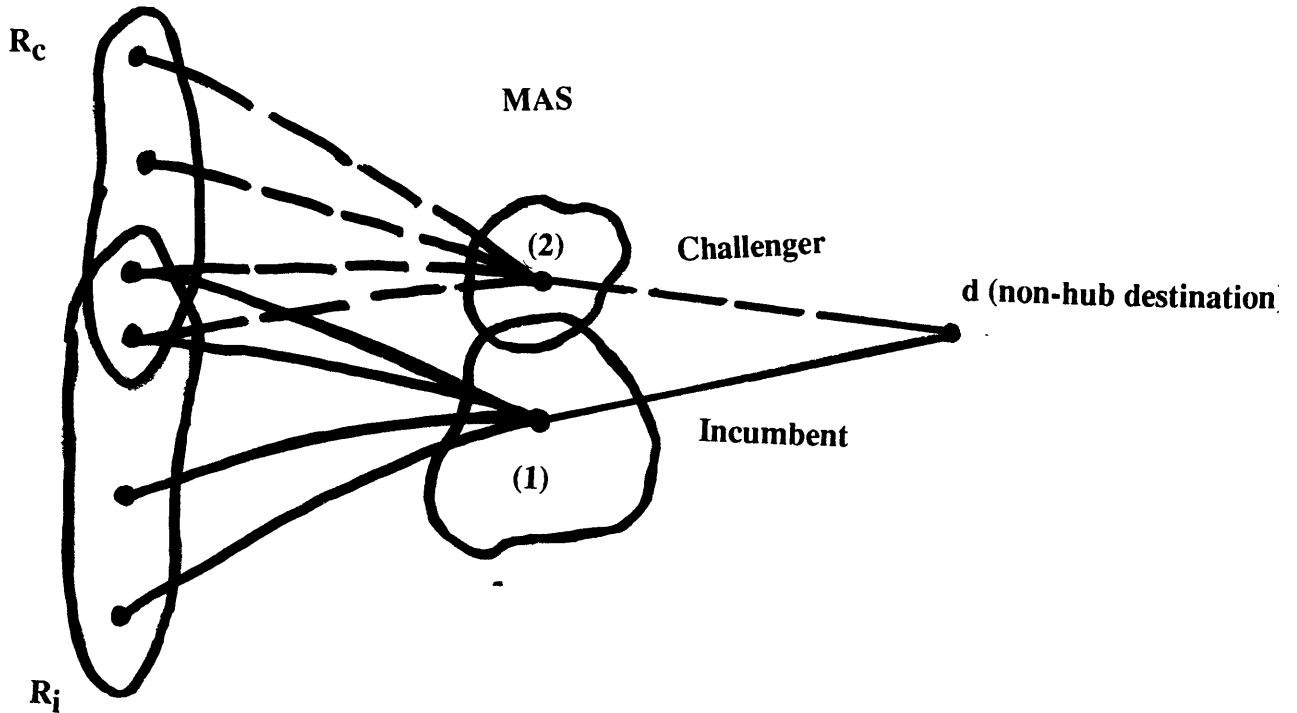
Regional Feeder System



- **INCUMBENT** operates between (1) and a non-hub destination d, and has an affiliated regional/commuter feeder operating between a set of smaller communities and the MAS hub at (1).
- **CHALLENGER** initiates service between (2) and non-hub destination d:
 - (a) without regional feeder.
 - (b) with an affiliated regional feeder operating into and out of the MAS hub at (2).

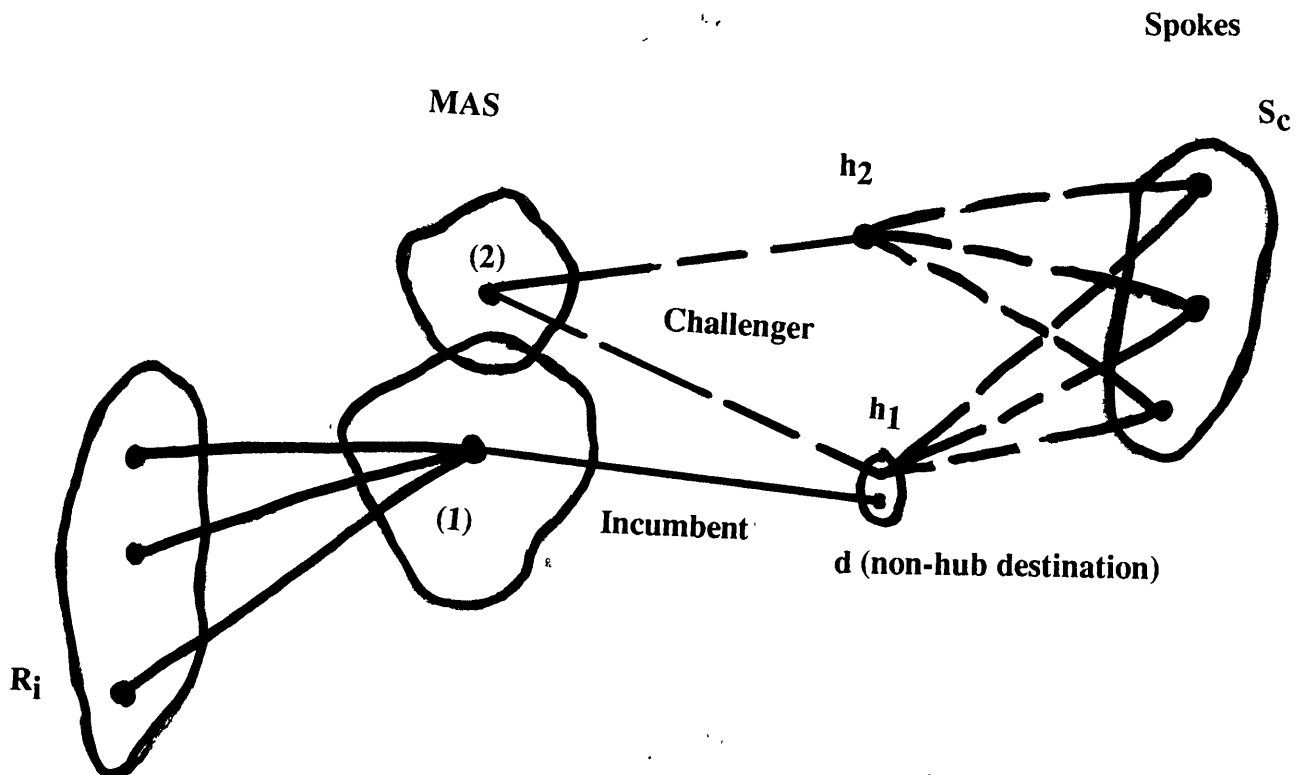
S4A: REGIONAL SERVICE - MAS - d

Regional Services



- **INCUMBENT:**
 - (a) has its own regional service between a set of points R_i and the MAS hub at (1), and operates between (1) and a non-hub destination d .
- **CHALLENGER initiates:**
 - (a) service from (2) to the same non-hub destination d .
 - (b) own regional service between a set of points R_c and MAS hub at (2), and operates between (2) and non-hub destination d .

S4A: REGIONAL SERVICE - MAS HUB - d (Cont'd)



Regional Services

- **CHALLENGER** initiates service:
 - (c) between (2) and hub h_1 , and a set of spoke cities S_c beyond h_1 .
 - (d) between (2) and another hub h_2 , and the same spoke cities of S_c .

MARKETING FACTORS EXAMINED

The following factors are examined in each competitive scenario:

- *Price (Fares)*

- *Cost*
 - high/low cost incumbent/challenger
 - aircraft, ground, passenger operating costs

- *Frequency*
 - incumbent and challenger match frequency?
 - any evidence of saturation frequency?

- *Airline Preference*
 - effect of frequent flyer programs on traffic distribution

POSSIBLE IMPLICATIONS OF RESEARCH

- **Airport Planning And Marketing**

- Enhances predictability of airline operations at multi-airport systems

- Increases awareness of risk in airport investments associated with airlines

- **Airline Planning**

- Reduces level of unpredictability in route planning and resource allocation

- May improve quality of reaction of incumbent to challenger

Analysis of the Impact of Videoconferencing on the Demand for Air Travel

**By Matthias Mette, FTL, M.I.T.
Cambridge, May 20, 1994.**

Agenda:

- ① Introduction to Research Problem**
- ② Objectives of Research**
- ③ Approach / Methodology**
- ④ Preliminary Results and Evaluations**
- ⑤ Areas for Further Research**
- ⑥ Preliminary Conclusions**

Research Problem

- ❑ **Telecommunications/Transportation: Not Only Complementary, But Also Competing**
- ❑ **Productivity of Corporate Travel Is Increasingly Questioned and Subject to A More Critical Assessment**
 - ↪ **Exploring of Alternatives Allowing Personal Contacts Without Expense and Loss of Time of Traveling**
 - ↪ **VIDEOCONFERENCING!!**
- ❑ **Boardroom / Roll-about / PC-Desk-top**
- ❑ **Substitution Potential Widely Recognized, But: Stimulation Must Not Be Neglected (Productivity, Geographic Scope, Customer Contact, ...).**
- ❑ **Videoconferencing May Alter Existing Travel Patterns and Modify Structure of Transportation Demand:
"How We Will Conduct Business Will Change."**

Driving Factors

- Telecommunications Technology Advances**
- Acceptance of New Technology**
 - ↳ **Social, Cultural, Psychological**
- Costs of Travel & High Tech Alternatives**
- Productivity & Time Pressure; Streamlining Organizations**

Objectives of Research

- Identification of Factors Underlying Relationship
Videoconferencing vs. Business Traveling**
 - ↳ **Substitution vs. Stimulation**
- Disaggregated Analysis:**
 - Type of Industry**
 - Departments**
 - Business Purpose**
 - Distances**
 - Regional Aspects: U.S.**
- Scenario Modeling**
- Application to Current Demand Forecasts**
- Extensive & Revealing Picture of the Present State of
Research**
- Identification of Gaps in Knowledge of Research Issue**
- Effective Basis for Future Research**

Approach

- ❑ **Market Statistics & Perspectives in Videoconferencing and Air Transportation (Demand, Cost, Disaggregated by Business Purpose)**
- ❑ **Critical Assessment and Interpretation of Existing Studies and Their Approaches**
 - ➔ **Construction of Coherent Picture of Current State of Art (as far as possible)**
 - ➔ **Reliability of Results**
 - ↳ **Subjectivity**
 - ↳ **Speculative Rather Than Analytical and Empirical**
 - ➔ **Problem: Accessibility to Research**

Approach (Cont'd)

- ❑ **Extensive Survey**
 - ↪ **Telecom./Videoconferencing Managers (~75-80 Companies, Primarily "Fortune 500")**
 - ↪ **Individual Users in Companies**
 - ↪ **Aircraft Manufacturers**
 - ↪ **Airlines**
 - ↪ **Industry Analysts**
- ❑ **Cost-Benefit Modeling**
- ❑ **Application of Video-Travel Impact to Existing Air Travel Forecasts**

Videoconferencing Market

- ❑ **Tremendous Growth:** ^{North America}
Teleconferencing (Worldwide):
 - 1992: +23% in Revenues (Equipment/Services), \$1.75 Billion**
 - 1993: Estimated \$2.3 Billion**
 - 1996/97: Estimated \$5 Billion**

Videoconferencing:

Most Quickly Growing: In 1992: +43% → \$707 Million
Next Years: Estimated Growth of ~40% p.a.

- ❑ **9,500 Videoconferencing Rooms Are Used in the U.S. Daily**
- ❑ **60% of All Systems in U.S.; 75% of "Fortune 500"**
- ❑ **Costs: Roll-About: \$15,000 (Half of 1992 Price)**
PC-Desk-Top: \$2,000; End of 94: ~ \$1,000

Business Travel Market

- ❑ **Since Deregulation: Relative Portion of Business Travel of Total U.S. Airline Travel Has Drastically Decreased:**
52% (1977) → 37% (1992) (ATA, 1993)
1993: Upward Trend: ~40%
- ❑ **Forecast: Business Traveler Portion in 2000: ~25%-30%**
- ❑ **Absolute Terms: Decrease of Business Travel by 13% from 1990 to 1992**
Clear Recovery in 1993/94
- ❑ **Primarily Seen As Factors Underlying These Trends: Gulf War, Recession, and Competition in Leisure Market**
- ❑ **Increasing Price Sensitivity of Business Travelers (Cuts in Travel Budgets); Alternative: Videoconferencing (?)**

Usage of Videoconferencing

- Initial Users: Governmental Agencies & Organizations**
- Today: Besides Large & Medium Size Corporations:
Health Care, Education, Recruiting.**
- Various Usages → Lack of Sufficient Analyses**
- Business Purposes: 85%-90% Intra-Company in U.S.**
- Primarily Executives and Senior Management, But
Increasingly Penetrating into Middle and Lower
Management**
- Lack in Knowledge of Specific Industry and Business Area
Differences in Adoption and Application of Technology**

Barriers and Problems of Acceptance

- Social, Psychological, Cultural**
- Time Zone Differences**
- Accessibility**
- Video-, Audio Performance: Data Transmission Speed and Quality → Development of Nationwide Fiber Optic Network**
- Incompatibility, Interoperability of Systems
→ Improving and Extending Standardization**
- Costs**

Approaches of Existing Studies

- Intuitive Judgement:** **Highly Qualitative, Statistics, Correlation, Travel Purposes, Potential Usage**

- Surveys with Hypothetical Choices:**
 Greater Level of Objectivity, Surveying of Particular Group of Travelers, "Would you...,if...?"

- Field Trials:** **Questionnaire among Users, Characteristics of Use, Cost-Benefits, Personal Experience**

- Modeling Using Survey Data:**
 Behavioral Demand Models, Cost-Benefit Models, Different Time Horizons, Interpretation, Assessment, Projections

Results of Studies

- ❑ **Most Studies See Rather High Substitution Potential (20%-25%)**
 - ➔ **Highest Usefulness for Training, Recruiting, Seminars, Intra-Company Activities**
 - ➔ **Travel Savings Main Justification of Investment Decision**
 - ➔ **Corporations Report 10%-50% Travel Substitution**
- ❑ **Some Studies: Substitution Potential Marginal**
 - ➔ **No Direct Replacement**
 - ➔ **New Meetings, in Past Impossible**
 - ➔ **Change of Travel Patterns**
 - ➔ **More Face-to-Face Interactions**
- ❑ **Stimulation: More Physical Movements, Possible Offsetting or Even Exceeding of Any Substitution Effect**

Limitations

- Highly Speculative & Qualitative**
- Surveys among Travelers with Hypothetical Choices**
- Subjectivity**
- Bias: Focus on Substitution; Neglecting of Stimulation**
- Quantification of Business Travel Savings:
Budget, Frequency → Consideration of Other Underlying
Factors**
- Accessibility to Studies, Particularly Their Methodology**

Own Surveys

- Industry Analysts:** **Aviation: 4%-5% Substitution**
 Teleconferencing: 10%-15% Subst.
- Airlines:** **More Seriously Consideration of Issue;**
 Initiated Research → Consulting Firms;
 Qualitative: Some, But Not Much Substitution;
 Currently: No Impact;
 Highest Potential: North Atlantic, Long-Haul;
 Stimulation in East Europe;
 Reaction of Industry: New Product Attributes.
- Manufacturers:** **Also in Process of Initial Research;**
 Basically Similar Assessment;
 Approach: Surveys, Scenario
 Modeling;
 Reaction of Industry: "Ask Airlines."

Own Surveys (Cont'd)

- Corporate Survey / Individual User Survey**
- Incorporated Aspects:**
 - Corporation**
 - Use of Videoconferencing**
 - Future Plans**
 - Applications**
 - Video vs. Travel**
 - Budget Development and Its Potential Consequences**
 - Impression/Acceptance of Technology**
- User Survey:**
 - Video: Familiarity, Frequency of Use, Purposes**
 - Travel: Frequency, Purposes, Avg. Costs, Changes**
 - Relationship: Experience, Substitution, Stimulation**

Areas for Further Research

- Disaggregated Analysis of Video Applications:
Industry, Department, Bus. Purpose, Vertical Organization**
- Business Travel Breakdown / Composition**
- Cost-Benefit Approaches / Modeling**
- Quantification of Impact on Business Travel (Substitution
vs. Stimulation): Budget, Frequency (?)**
- Response of Airline Industry**

Preliminary Conclusion

- Several Gaps in Knowledge → High Research Potential**
- Too General Approaches; More Disaggregated Analysis Needed**
- Overestimating of Substitution Potential**
- Even Small Substitution (4%-5%) Might Have Severe Economic Effect → Business Travel Segment!**
- Airline Industry Starts to Think about Issue; It Is Time to Develop Strategies for Response**
- No Longer Solely A Future Problem**
 - It Is A Present Problem!!!**

Results (Cont'd)

- ***Telemanagement Resource International (TRI):***
Implementing videoconferencing facilities cuts travel by about 18%.
- ***Arthur D. Little (Logan Airport Study 1993):***
Videoconferencing will substitute for about 12%-16% of U.S.-wide air travel in 2020.
- ***European Economic Research Centre (1983):***
20% to 30% Inter-city travel substitution for the stage of a fully developed telecommunications network.
- ***Arvai Group, Windham, N.H.:***
25% of business air travel could be eliminated by 2010.
- ***Apogee Research / FAA (1994):***
11% of business trips in the U.S. (4% of total U.S. air travel) are substitutable through enhanced telecommunications when network is sufficiently developed and technology fully accepted.