FLIGHT TRANSPORTATION LABORATORY
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PRESENTATIONS FROM THE 1995 MIT/INDUSTRY COOPERATIVE RESEARCH PROGRAM ANNUAL MEETING

MIT

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DFC, DYNAMIC FLOW CONTROL
A NEW APPROACH FOR TRAFFIC FLOW MANAGEMENT

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Overview

- Introduction
- Current Approach : Miles-In-Trails
- DFC, Dynamic Flow Control
- Results
- Future Directions

Introduction

- ***Problem :*** **Most aircraft arriving in a major airport experience unnecessary delays.**

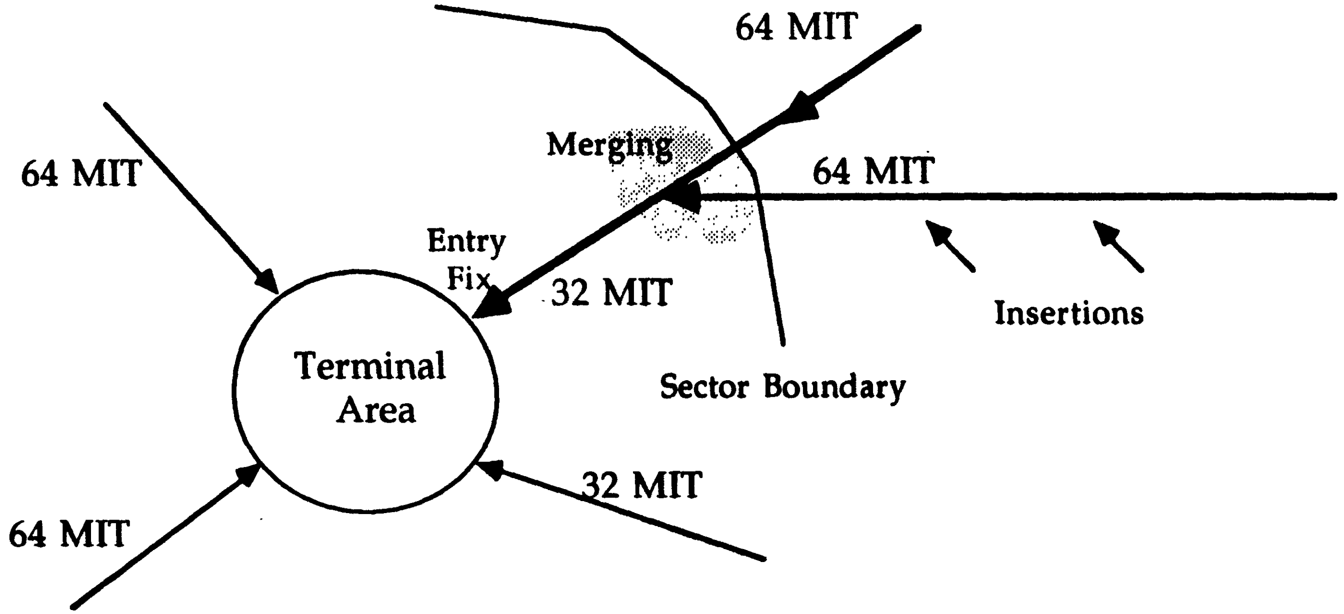
- **Current approach, called Miles-In-Trail, is inefficient.**
  - **It requires a fixed separation distance between subsequent aircraft.**

  Disadvantage: It restricts drastic passing such that it does not efficiently take advantage of the fact that today's jet transports have a range of feasible cruising speeds.

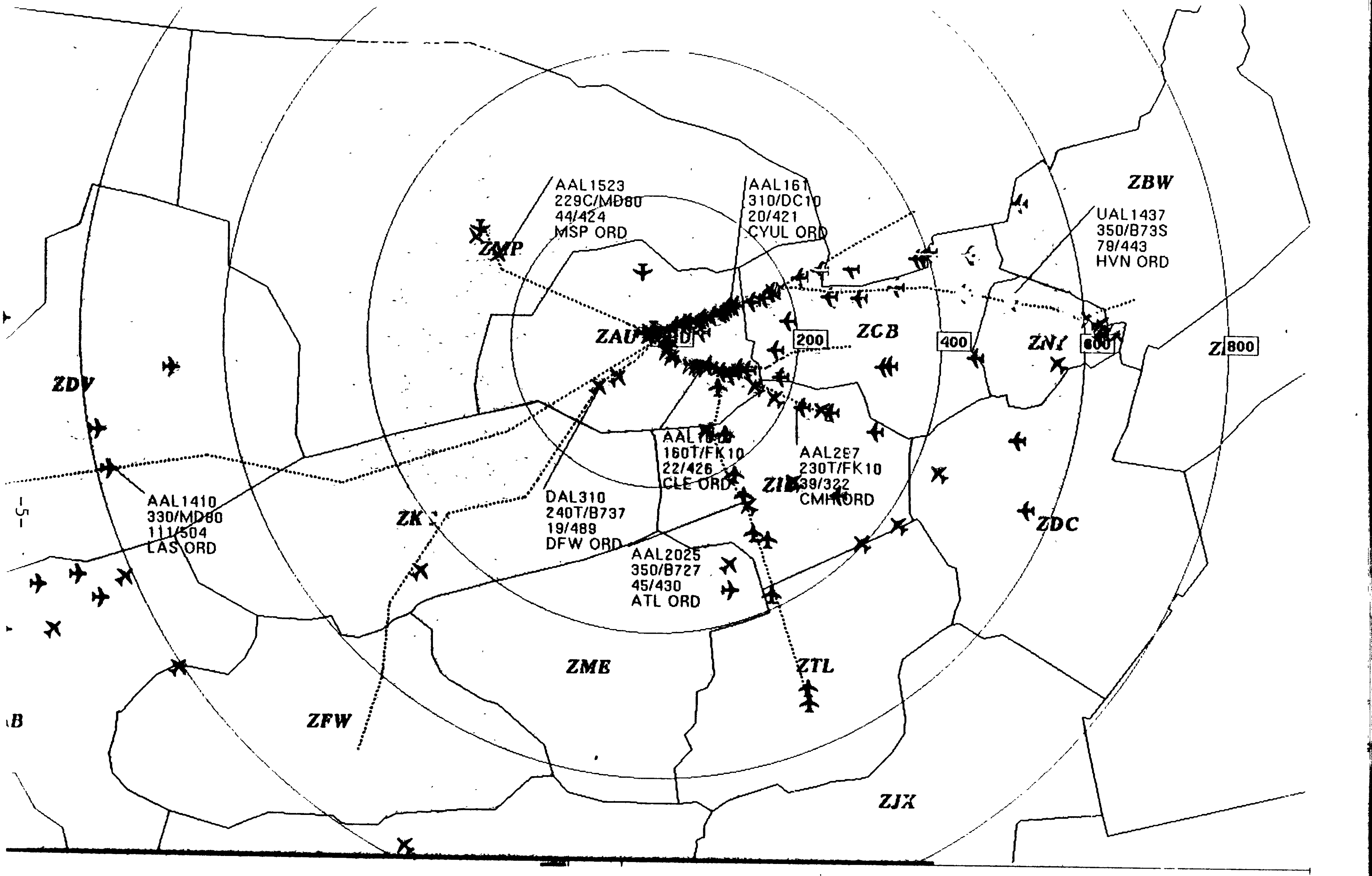
Flow Management Controls

1. MIT - Miles-in-Trail

- depending on the expected time variation of AAR, controllers issue MIT constraints along arrival paths to the airport, and across sectors in different Centers



- eg. if an arrival flow rate of 15 per hour is desired at an Entry Fix, then MIT on the final leg becomes 32 miles if ground speed is 8nm per minute at cruise altitude, and 64 miles if two major arrival airways are merging into the final leg. Controllers are expected to handoff with at least this spacing. Similar values are assigned to the other arrival airways. This fixed assignment is inefficient.


AAL1523
229C/MD80
44/424
MSP ORD
AAL161
310/DC10
20/421
CYUL ORD
UAL1437
350/B73S
79/443
HVN ORD
ZBW
ZMP
ZAU
ORD
200
ZCB
400
ZNY
600
Z
800
ZDV
AAL1410
330/MD80
111/504
LAS ORD
ZKC
DAL310
240T/B737
19/489
DFW ORD
AAL1
160T/FK10
22/426
CLE ORD
ZID
AAL257
230T/FK10
39/322
CMH ORD
ZDC
AAL2025
350/B727
45/430
ATL ORD
ZME
ZTL
ZFW
ZAB
ZJX

Algorithm for Optimal Assignment of Delay

If there is accurate updated information on:

1) current aircraft position and speeds
2) updated forecasts of enroute winds
3) current delays at the airport and forecasted acceptance rates
4) new flight plans and cancellations
5) limitations on air holds at destination

Then, we can quickly calculate a new Traffic Flow Plan (TFP) which minimizes the "Costs" of flow management. Costs are expressed in terms of weighted values of:

1) unnecessary delays,
2) fuel burn,
3) traffic management workload

subject to a variety of operational constraints imposed by the Traffic Flow Manager

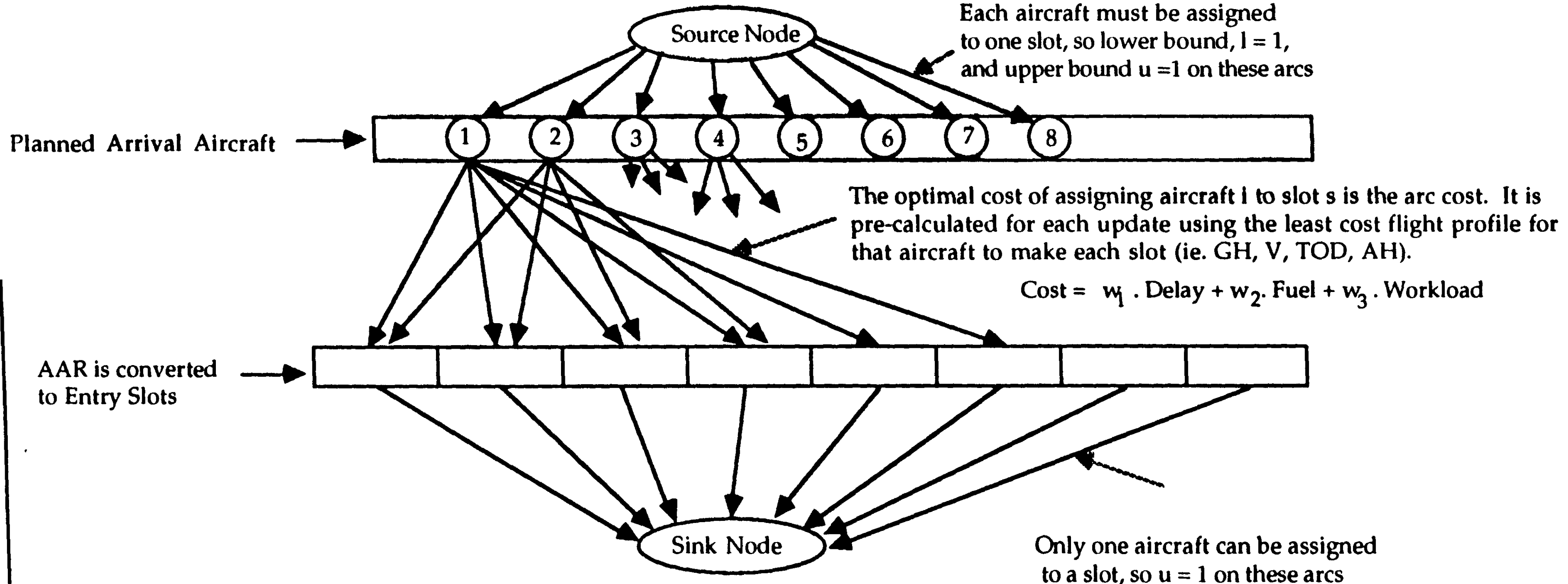
(eg., limited use of airholding, any cruise speed change is greater than .02 M, all speed changes are monotonic, TOD points within a given range)

The Traffic Flow Plan (TFP) provides;

1) new departure times for some aircraft
2) new cruising speeds for some aircraft (within their stated ranges)
3) planned airholds at every Entry Fix (no. of holding aircraft over time)
4) planned TOD points for all arrivals

Algorithm for Optimal Assignment of Delay

- the problem is a simple least cost network flow problem for which many very fast codes exist to solve it in seconds using today's workstations. The network for the problem is given below;



Each aircraft must be assigned to one slot, so lower bound, l = 1, and upper bound u =1 on these arcs

The optimal cost of assigning aircraft i to slot s is the arc cost. It is pre-calculated for each update using the least cost flight profile for that aircraft to make each slot (ie. GH, V, TOD, AH).

Cost = w_1 . Delay + w_2. Fuel + w_3 . Workload

Only one aircraft can be assigned to a slot, so u = 1 on these arcs

- the algorithm assigns an aircraft to each Approach Slot, ie. assigns an ETA at the Entry Fix and the best plan to acheive that ETA is known (ie., departure time, cruise speed, airhold, TOD)

RESEARCH PROGRESS

- we have created a IDFCS simulator in ANSI - C language (1~~2~~8000 lines of code) which contains a Least Cost Network Flow code from the OR Center

- we have a traffic generator for random arrival requests for aircraft of different types, from different origins, along different arrival paths, with varying forecast winds along route, etc. It will provide different rates of arrival over time against forecast variations in AAR.

- at any point in time, all aircraft are either on the ground or in the air proceeding inbound. Feasible traffic advisories can be found for all aircraft in TFP to optimize overall cost.

- the simulator exercises the dynamic flow algorithm every 15 minutes of simulator time

- we record the set of commands (GH, V, TOD, AH) given to each aircraft under different traffic scenarios, and the overall Traffic Management workload

- we determine the efficiency achieved in using the airport's AAR under dynamic changes in AAR (landing rate vs. AAR, and average delays incurred vs. TM workload)

Figure 6-4: Tab of Statistics vs. Time

t	E	Ea	Eg	D	Da	Dg	AHD	AHDa	AHDg	Egd	GDgd	SC	T	N	Nh1	Nh2	Ng	GHA	CSA
0.25	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	7	0	0	5	0	1
0.5	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	21	0	0	18	0	1
0.75	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	28	0	0	25	0	0
1	1	1	0	-0.9	-0.9	0.0	0.0	0.0	0.0	0	0.0	1.0	52.5	35	0	0	32	0	1
1.25	1	1	0	-0.8	-0.8	0.0	0.0	0.0	0.0	0	0.0	1.0	64.7	43	0	0	38	0	1
1.5	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	57	0	0	47	0	1
1.75	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	69	0	0	55	0	3
2	1	1	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0	0.0	96.0	82	0	0	67	0	8
2.25	1	0	1	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0	0.0	107.4	93	0	0	69	0	9
2.5	2	2	0	-0.1	-0.1	0.0	0.0	0.0	0.0	0	0.0	1.0	87.1	97	0	0	72	0	8
2.75	2	1	1	-0.7	-0.6	-0.8	0.0	0.0	0.0	0	0.0	1.0	112.7	111	0	0	78	0	9
3	7	1	6	-0.4	-0.8	-0.3	0.0	0.0	0.1	0	0.0	1.0	136.5	111	0	0	75	0	12
3.25	9	2	7	-0.5	-0.3	-0.6	0.1	0.2	0.1	0	0.0	1.8	132.1	110	0	0	76	0	10
3.5	5	1	4	-0.6	-0.8	-0.6	0.0	0.0	0.0	0	0.0	0.8	142.7	113	0	0	74	0	20
3.75	7	2	5	-0.7	-0.5	-0.8	0.0	0.1	0.0	0	0.0	2.0	139.7	118	0	0	71	0	24
4	7	0	7	-0.9	0.0	-0.9	0.0	0.0	0.0	0	0.0	1.6	183.4	129	0	0	81	0	19
4.25	10	1	9	-0.8	-1.9	-0.7	0.1	0.0	0.1	0	0.0	1.2	160.9	128	0	0	78	0	22
4.5	8	1	7	-1.4	-0.8	-1.5	0.1	0.0	0.1	0	0.0	1.4	148.4	126	0	0	73	0	14
4.75	15	2	13	-0.7	-1.2	-0.7	0.2	0.3	0.2	0	0.0	1.6	162.2	126	0	0	70	0	19
5	12	1	11	-0.8	-0.4	-0.8	0.2	0.1	0.2	0	0.0	2.8	205.2	123	0	0	72	0	22
5.25	4	1	3	0.0	-0.9	0.3	0.1	0.0	0.1	0	0.0	1.0	189.4	124	0	0	58	0	33
5.5	8	1	7	-0.6	0.0	-0.6	0.1	0.0	0.1	0	0.0	1.9	158.2	129	0	0	58	0	36
5.75	11	4	7	-1.1	-0.3	-1.5	0.1	0.3	0.0	0	0.0	1.6	145.8	133	0	0	67	2	26
6	14	2	12	-1.6	-0.6	-1.8	0.3	0.2	0.3	0	0.0	2.1	173.0	127	0	0	70	9	18
6.25	15	4	11	0.9	0.6	1.0	0.2	0.2	0.3	0	0.0	1.8	162.1	128	0	0	72	20	19
6.5	14	0	14	2.1	0.0	2.1	0.2	0.0	0.2	0	0.0	2.7	193.7	127	0	0	77	28	17
6.75	13	2	11	2.0	-0.2	2.4	0.2	0.1	0.2	0	0.0	2.0	184.7	128	0	0	81	51	18
7	15	3	12	-1.9	-1.4	-2.0	0.2	0.2	0.2	0	0.0	1.9	167.5	124	0	0	83	49	25
7.25	7	0	7	0.7	0.0	0.7	0.5	0.0	0.5	0	0.0	1.3	176.1	130	1	0	88	60	19
7.5	8	4	4	5.1	6.4	3.8	1.1	1.7	0.6	0	0.0	1.9	137.8	128	0	0	89	47	13
7.75	7	0	7	4.0	0.0	4.0	0.6	0.0	0.6	0	0.0	2.3	191.6	129	1	0	89	42	18
8	7	0	7	5.1	0.0	5.1	1.0	0.0	1.0	0	0.0	2.0	203.5	129	1	0	86	53	24
8.25	8	0	8	5.4	0.0	5.4	0.4	0.0	0.4	0	0.0	2.9	208.7	133	0	0	91	8	16
8.5	7	0	7	8.0	0.0	8.0	0.3	0.0	0.3	2	3.8	2.1	202.2	133	0	0	90	43	15
8.75	8	0	8	12.2	0.0	12.2	0.4	0.0	0.4	7	9.6	2.0	201.9	133	1	0	91	28	11
9	7	0	7	18.9	0.0	18.9	2.5	0.0	2.5	7	12.6	2.3	202.3	135	2	0	86	18	18
9.25	8	2	6	15.4	7.8	17.9	3.2	1.7	3.7	6	7.8	2.4	155.6	140	0	2	82	17	32
9.5	7	0	7	26.7	0.0	26.7	3.3	0.0	3.3	7	17.4	1.9	204.8	138	1	2	69	11	45
9.75	8	1	7	13.8	12.2	14.0	3.1	1.6	3.3	7	4.0	2.0	180.3	142	1	4	72	4	29
10	7	1	6	32.7	12.6	36.1	6.8	8.4	6.5	6	22.5	1.3	192.8	143	1	1	71	0	19
10.25	14	1	13	35.9	5.8	38.2	0.6	1.2	0.5	12	36.3	1.6	198.9	136	1	0	65	0	28
10.5	15	0	15	23.8	0.0	23.8	1.1	0.0	1.1	12	22.7	2.7	219.3	130	2	0	68	0	17
10.75	15	0	15	43.7	0.0	43.7	1.6	0.0	1.6	15	35.5	2.4	228.3	123	1	1	57	0	24
11	15	2	13	26.0	8.8	28.6	0.5	0.0	0.6	10	29.9	2.5	214.0	115	0	2	55	0	24
11.25	14	0	14	37.4	0.0	37.4	0.5	0.0	0.5	10	44.7	2.4	222.6	110	0	0	55	0	17
11.5	15	1	14	13.2	6.2	13.7	0.5	0.0	0.5	6	21.1	1.9	178.9	101	0	1	57	0	19
11.75	11	0	11	0.1	0.0	0.1	0.3	0.0	0.3	0	0.0	2.0	172.5	98	0	0	59	0	10
12	6	0	6	-0.2	0.0	-0.2	0.0	0.0	0.0	0	0.0	1.0	187.3	104	0	1	60	0	10
12.25	15	1	14	-2.1	-2.6	-2.1	0.3	0.8	0.3	0	0.0	2.3	183.7	97	0	0	57	0	6
12.5	11	1	10	0.3	0.1	0.3	0.2	0.7	0.2	0	0.0	2.1	154.0	91	0	0	53	0	14
12.75	5	0	5	-0.8	0.0	-0.8	0.0	0.0	0.0	0	0.0	1.4	192.6	97	0	0	54	0	12
13	6	2	4	-0.7	-0.7	-0.8	0.0	0.0	0.0	0	0.0	1.2	152.2	100	1	1	56	0	14
13.25	10	0	10	0.5	0.0	0.5	0.4	0.0	0.4	0	0.0	1.2	170.5	97	0	0	55	0	9
13.5	10	3	7	-0.6	-0.3	-0.7	0.2	0.2	0.2	0	0.0	1.3	167.4	95	0	1	55	0	10
13.75	9	1	8	-0.5	-0.3	-0.5	0.1	0.0	0.2	0	0.0	0.8	148.1	93	0	0	52	0	7
14	10	1	9	-0.2	0.3	-0.2	0.2	0.6	0.1	0	0.0	1.5	199.8	89	0	0	52	0	13
14.25	9	1	8	-0.4	-0.9	-0.4	0.1	0.0	0.1	0	0.0	1.1	160.1	90	0	0	49	0	12
14.5	5	1	4	-0.5	0.0	-0.6	0.0	0.0	0.0	0	0.0	1.4	123.8	91	0	0	45	0	16
14.75	8	0	8	-0.3	0.0	-0.3	0.2	0.0	0.2	0	0.0	1.3	189.5	92	0	0	49	0	16
15	6	0	6	-0.6	0.0	-0.6	0.0	0.0	0.0	0	0.0	1.2	175.5	95	0	0	49	0	6
Fleet Sum	480	57	423	3594.0	73.1	3521.0	287.5	27.9	259.3	107	2606.1	884.4						490	939

- Scenario 2 -

Annex

A.1 Scenarios Notations

In this section, we present the data which was obtained from running the simulator under the scenarios described and analyzed in Chapter 4.

For each scenario, we present the statistics which are currently tracked within the simulator in figures entitled *"Tab of Statistics vs. Time"*. Let us explain, for one row -i.e. at a given time t- what they mean:

- *t* is the simulation time in hours.
- *E* is the number of aircraft which *exited* the Entry Fix, that is to say which entered the Terminal Area, between t - 0.25 (i.e. t - 15 minutes) and t.
- *Ea* is the number of "air-start" aircraft which exited the Entry Fix in the same period. An air-start aircraft entered the system while airborne.
- *Eg* is the number of "ground-start" aircraft which exited their Entry Fix between t-0.25 and t. A ground-start aircraft first made its request for arriving at the airport under congestion management as it was flying toward, or when it was already on the ground at an intermediate airport.
- *D* is the delay averaged over all aircraft (in min.) which entered the Terminal Area between t - 15 minutes and t (that is to say averaged over E aircraft). This

delay is the total delay over the originally requested time; i.e. it is the difference between the Actual Exit Time (AET) and the Original Nominal Exit Time (ONET) from the Entry Fix.

- *Da* is the averaged delay (AET - ONET) in minutes over all air-start aircraft (Ea) which entered the Terminal Area between t - 15 minutes and t.
- *Dg* is the averaged delay (AET - ONET) in minutes over all ground-start aircraft (Eg) which entered the Terminal Area between t - 15 minutes and t.
- *AHD* is the Air Holding Delay (in min.) averaged over all aircraft which entered the Terminal Area between t - 15 minutes and t (that is to say averaged over E aircraft). For each aircraft, the holding delay is the difference between the Actual Exit Time (AET) and the Actual Arrival Time (AAT) at the Entry Fix.
- *AHDa* is the averaged holding delay (AET - AAT) in minutes over all air-start aircraft (Ea) which entered the Terminal Area between t - 15 minutes and t.
- *AHDg* is the averaged holding delay (AET - AAT) in minutes over all ground-start aircraft (Eg) which entered the Terminal Area between t - 15 minutes and t.
- *Egd* is the number of ground-start aircraft which were issued a *ground delay* at their originating airport, and which *exited* the Entry Fix of the airport under congestion management between t - 15 minutes and t.
- *GDgd* is the averaged Ground Delay (or ground hold) in minutes that those Egd aircraft endured.
- *SC* is the averaged number of *speed changes* (or speed advisories) that all aircraft which entered the Terminal Area between t - 15 minutes and t were issued during their inbound flight.
- *T* gives an indication of the average time each of the E aircraft spent in the system, air holding not included. It is given in minutes.

- *N* is the number of aircraft in the system at update time t. It gives us an idea of the size of the problem which must be solved by the Dynamic Resolution Logic which is used.
- *Nh1* is the number of aircraft in air hold at Entry Fix 1 at update time t.
- *Nh2* is the number of aircraft in air hold at Entry Fix 2 at update time t.
- *Ng* is the number of aircraft on the ground awaiting takeoff at update time t.
- *Ngd* is the number of aircraft with an issued ground delay at time t (we keep track of Ngd only in Scenario 5).
- *GHA* is the number of Ground Hold Advisories which were issued to the fleet when Tupdate = t. Recall that IIDFC is exercised every 15 minutes in all those scenarios.
- *CSA* is the number of Cruise Speed Advisory which were issued to the fleet at time t.

The last row of the tab "Fleet Sum" gives the sum over time of E, Ea, Eg; the cumulative values (over time) of D, Da, Dg, AHD, AHDa, AHDg; the sum of all Egd; the cumulative value of GDgd (over all Egd aircraft); and the total number of GHA and CSA which were issued during the simulation. Thus, this line is used to give an overall rating on the scenario under consideration..

This tab is followed by several plots:

- *"Traffic Flow Management Advisories vs. Time"* plots show GHA and CSA versus time.
- Plots entitled *"Number of Holding Aircraft"* show the time variation of the number of aircraft in air hold at entry fix 1 (Nh1), Entry Fix 2 (Nh2) and in ground hold (Ngd) versus time.

- *"Average Delay for Landed Aircraft"* plots show the evolution of D, AHD and GHD versus time. GHD is the averaged Ground Hold Delay for all aircraft which landed between t - 15 minutes and t. Thus, it is given by:

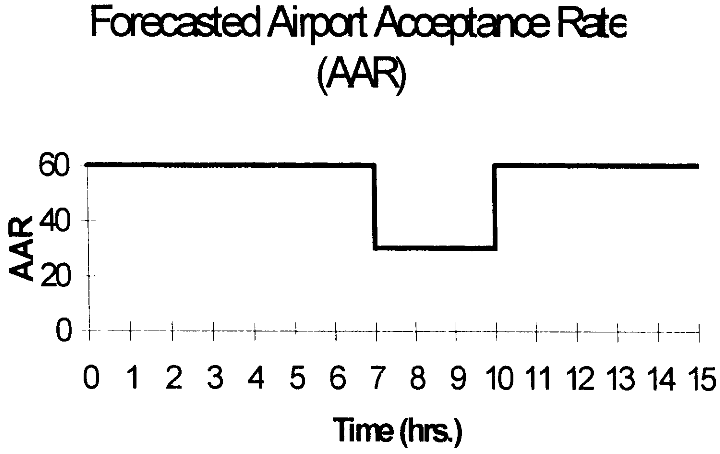
$$\mathrm{GHD} = \frac{\mathrm{Egd} \times \mathrm{GDgd}}{\mathrm{E}}$$

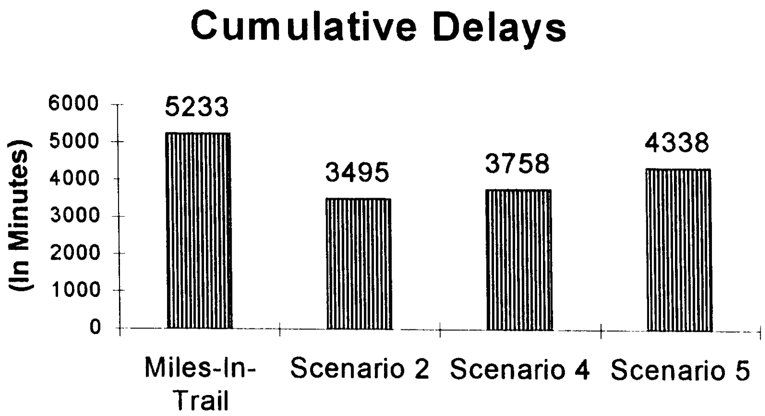
- Plots entitled *"Average Ground Delay of Landed Aircraft which were Ground Held"* show the variation of GDgd versus time.

A.2 Scenario 1 Data and Plots

(See next page)

Research Results



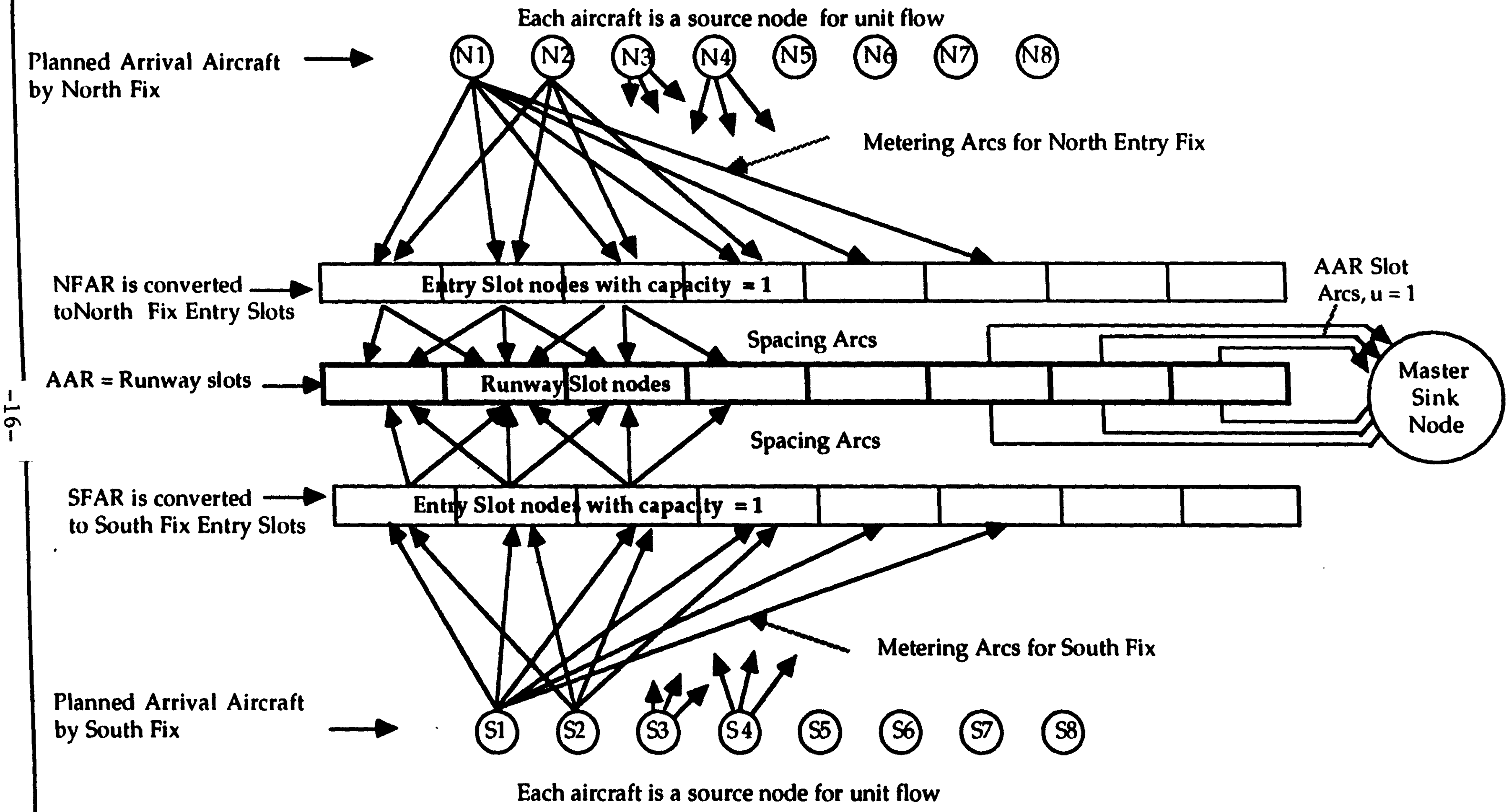


	Scenario 2	4	5
Total Number of Ground Hold Advisories	426	35	202
Total Number of Cruise Speed Advisories	1222	935	934

Future Directions

- **Perform sensitivity analysis**
- **Reduce the number of ground hold advisories**
- **Reduce the number of cruise speed advisories**
- **Restrict speed changes to become monotonous**
- **Develop extensions of DFC concept**

Algorithm for Optimal Assignment of Delay - Entry Fix and Runway Slots



Each aircraft is a source node for unit flow

Planned Arrival Aircraft by North Fix

N1 N2 N3 N4 N5 N6 N7 N8

Metering Arcs for North Entry Fix

NFAR is converted to North Fix Entry Slots

Entry Slot nodes with capacity = 1

AAR Slot Arcs, u = 1

Spacing Arcs

AAR = Runway slots

Runway Slot nodes

Master Sink Node

Spacing Arcs

SFAR is converted to South Fix Entry Slots

Entry Slot nodes with capacity = 1

Metering Arcs for South Fix

Planned Arrival Aircraft by South Fix

S1 S2 S3 S4 S5 S6 S7 S8

Each aircraft is a source node for unit flow

EMSR BID PRICE CONTROL: IMPLEMENTATION AND REVENUE IMPACTS

Professor Peter P. Belobaba
MIT Flight Transportation Laboratory
Cambridge, MA 02139

Presentation to
AGIFORS YIELD MANAGEMENT STUDY GROUP

Washington, DC
May 1, 1995

OUTLINE

1. The O-D Control Problem
2. Obstacles to Network Optimization
3. "Value–Based" Class Control
4. EMSR Bid Price Concept
5. Dynamic EMSR Bid Price Control
6. Implementation in Existing Systems
7. Simulated Revenue Impacts

1. The O–D Control Problem

- Revenue maximization over a network of flight legs requires a combination of two strategies:

  (1) Provide increased availability to high revenue long-haul passengers, regardless of yield

  (2) Prevent high-revenue long-haul passengers from taking seats away from high-yield shorter-haul passengers

- Studies have shown (1) to provide greater network revenue gain than (2), although revenue maximization requires both.

2. Obstacles to Network Optimization

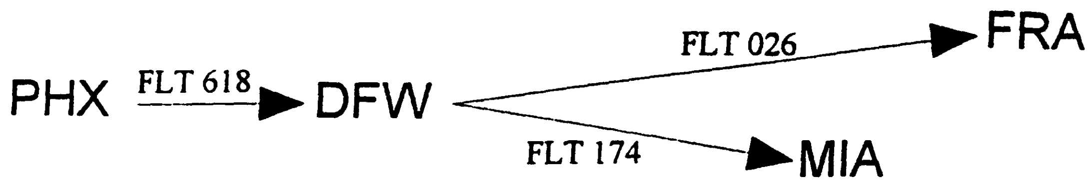
- Practical and theoretical obstacles to "true" network optimization:
  - need to maintain data by itinerary (i) and class (k)
  - difficult to forecast accurately with small (i, k) values
  - LP solutions generate seat "allocations" to each (i, k)
- Several airlines have instead implemented "leg-based" bid price control:
  - data maintained by leg/bucket
  - forecasting and optimization by leg
  - dynamic evaluation of (i, k) revenue values relative to minimum acceptable "bid price"

3. "Value–Based" Bucket Control

- Value-based control concept:
  - Define booking buckets based on revenue value, regardless of itinerary(i) or "fare class" (k).
  - Seat availability for (i, k) depends on corresponding "value bucket" availability.

- Implementation of value-based control:
  - Aggregation of booking data from different (i, k) into "value buckets" with similar revenues.
  - Forecasting and optimization by value bucket on each leg independently.
  - Preference given to highest revenue (i, k), but "greedy" solution.

STRATIFIED BUCKETING BY ODF FARE VALUES



ORIGINAL PUBLISHED FARES/CLASSES

PHX/DFW	
CLASS	FARE (OW)
Y	$520
B	$360
M	$209
V	$139

PHX/FRA (via DFW)	
CLASS	FARE (OW)
Y	$815
B	$605
Q	$470
V	$310

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

RE-FILED FARES BY ODF FARE VALUE

STRATIF. BUCKET	REVENUE RANGE	MAPPING OF O-D MARKETS/CLASSES
Y	700 +	Y PHXFRA Y PHXMIA
B	500-699	B PHXFRA Y PHXDFW
M	330-499	B PHXMIA Q PHXFRA B PHXDFW
Q	200-329	V PHX FRA M PHXMIA Q PHXMIA M PHXDFW
V	0-199	V PHXMIA V PHXDFW

4. EMSR Bid Price Concept

- For any (i, k) on a flight leg, network revenue value is its fare, F_{ik}, minus expected revenue displacement on connecting legs.

- Expected demand and revenue on leg j is summarized by expected marginal revenue function

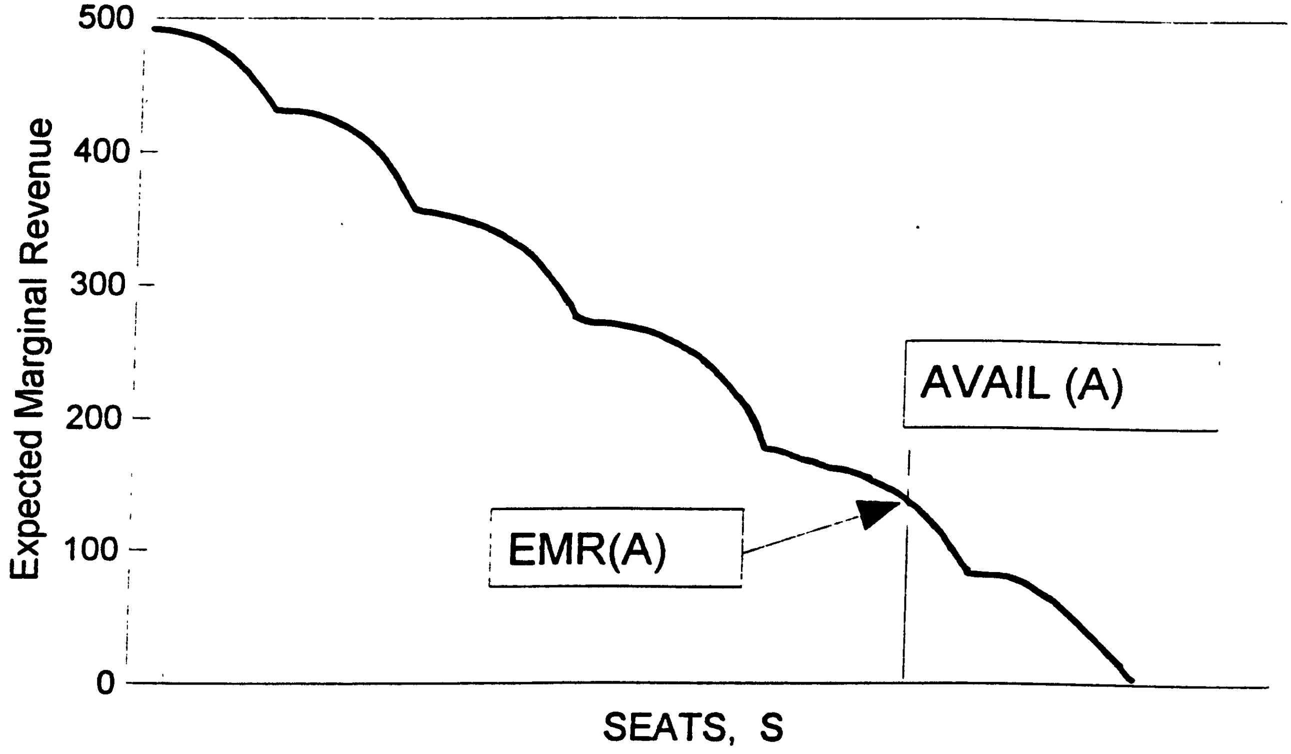
  $$EMR_j(S) = \frac{\delta R}{\delta S}$$

  Value bucket demands and revenue values can be used to derive $EMR_j(S)$.

- Approximation of displacement cost on any leg j is a function of EMR_j (A), where A is remaining available capacity.

Down-Line Displacement Costs

Second Leg of Two-Leg Itinerary



EMSR Bid Price Concept (cont'd)

- EMR_ℓ (S) curve based on non-prorated revenues in value buckets on each leg ℓ.

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

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

where $\overline{P}(A)$ = probability of selling seat A

$\overline{REV}$ = mean revenue of all ODFs on leg

- Network displacement cost on down-line leg j is less than EMR_j (A).

- The displacement cost on leg j can be approximated as:

$$DISP = EMR_j (A) * ODFACTOR$$

where:

$$0 < ODFACTOR < 1.0$$

EMSR Bid Price Concept (cont'd)

- From above, network revenue value of (i, k) on Leg ℓ is approximated by:

  $$N_{ik\ell} = F_{ik} - [EMR_j(A) * ODFACTOR]$$

  where j is a down-line (or up-line) leg of itinerary (i, k)

- Accept a request for itinerary (i, k) if:

  $$N_{ik\ell} \geq EMR_\ell(A)$$

  $$F_{ik} - \left[EMR_j(A) * ODFACTOR\right] \geq EMR_\ell(A)$$

  $$F_{ik} \geq EMR_\ell(A) + EMR_j(A) * ODFACTOR$$

  for all legs ℓ in itinerary (i, k) which involve an upline/downline leg j.

- We are comparing the ODF fare to the minimum acceptable revenue value or "bid price".

5. Dynamic EMSR Bid Price Control

- Seamless CRS availability communication allows (i, k) requests to be evaluated by the selling airline on a real-time basis.

- Simple bid price calculations can be performed at time of request to determine seat availability for (i, k):

  - (i, k) assigned initially to a value bucket

  - when (i, k) request received, calculate:

    $EMR_{\ell}(A) + EMR_{j}(A) * ODFACTOR$

  - seats available to (i, k) if:

    $F_{ik} \geq EMR_{\ell}(A) + EMR_{j}(A) * ODFACTOR$

    on all relevant legs.

- Bid price increases for connecting (i, k) when demand/capacity is high on both legs — preference given to local passengers.

6. Implementation in Existing Systems

- Real-time EMSR bid price control possible in existing YM and CRS environments:
  - leg-based YM system provides updated $EMR_{\ell}(A)$ values based on current forecasts
  - reservations system needs to store F_{ik} tables and appropriate ODFACTOR(s)
- Requires seamless CRS (or control of most bookings):
  - at time of ODF request, compare F_{ik} from market table to calculated minimum EMSR bid price.
  - possible to use maximum class booking limits as "safety net"
- Can be applied to yield-based classes, stratified buckets, or virtual buckets

7. Simulated Revenue Impacts

- Integrated airline yield management optimization/booking simulation routine developed at MIT:
  - actual airline hub scenario (25 legs in, 25 legs out)
  - approx. 600 itineraries; 6 fare types
  - interspersed bookings by class over 15 periods prior to departure
  - 25 iterations of each "connecting complex," at different demand levels.
- We compared the revenue performance of:

(1) Leg-based EMSRb yield-based class control

(2) EMSRb "greedy" control of buckets stratified by total fare value

(3) Dynamic Leg Bid Price Control

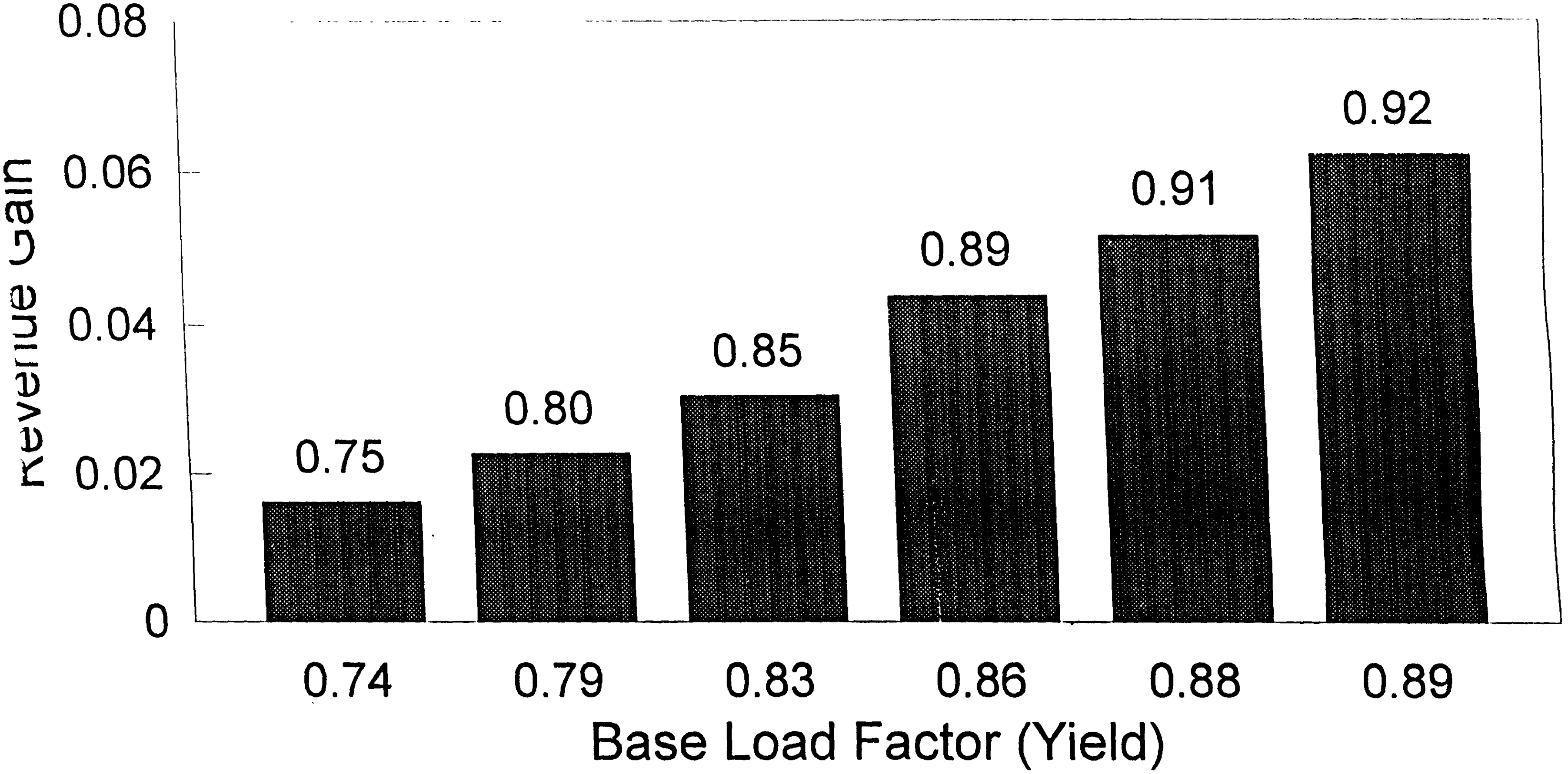
Simulated Revenue Impacts (cont'd)

- Fare stratification with "greedy" algorithm provided 2-4% revenue gains for average HUB load factors of 74-86%:
  - load factors increase because preference given to long-haul passengers
  - higher revenue gains simulated, but at extremely high demands and load factors

- Application of Leg Bid Price method to stratified buckets generated 1-3% in additional revenue gain:
  - average HUB load factors increased further (over stratified bucketing alone)
  - revenue gains consistent across scenarios of 30%, 50% and 70% average local demand by leg

Stratified Bucketing of Fares

Revenue Gain over Yield-Based Classes

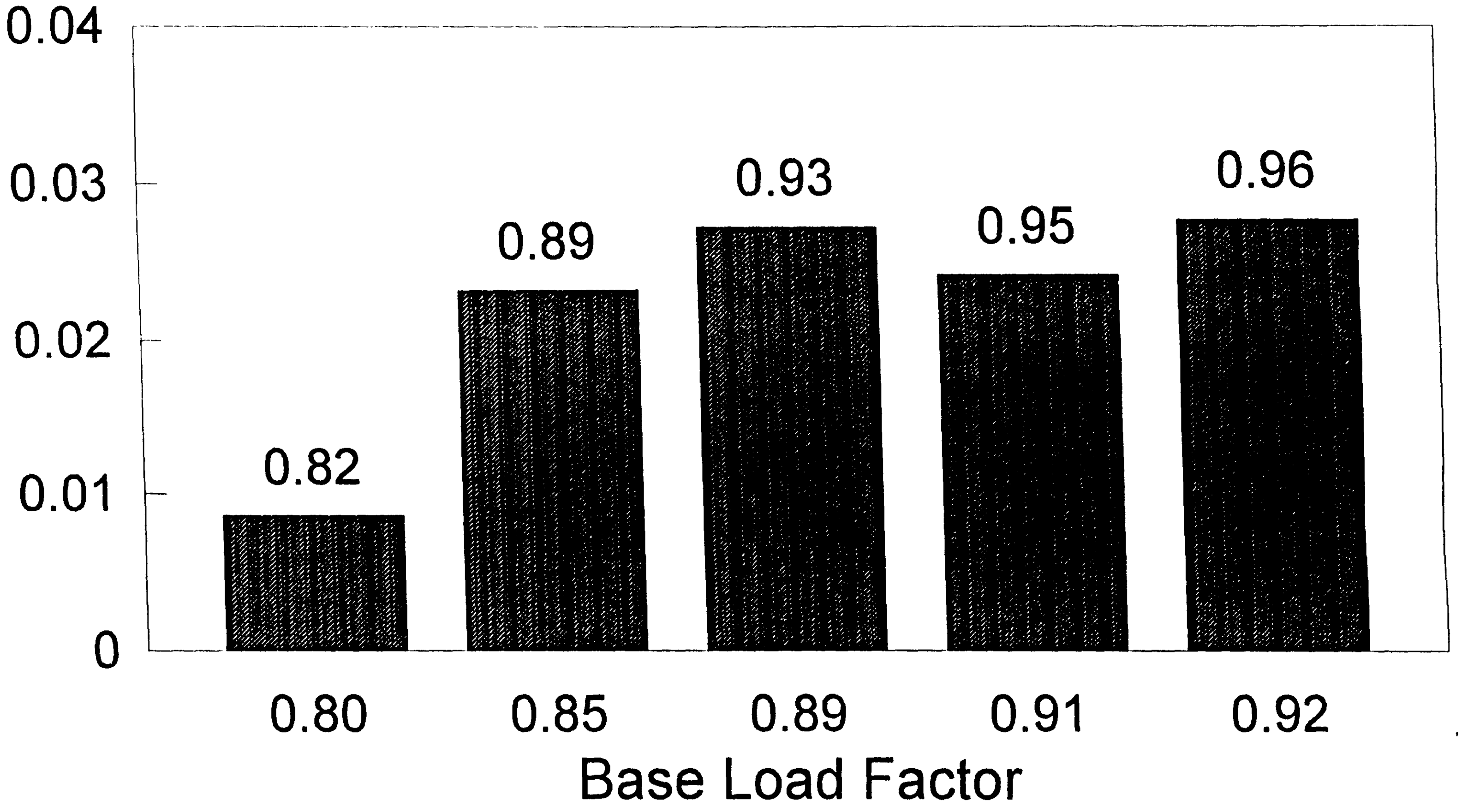


imulated HUB Load Factors
Shown at each Point

▨ 50% Local Demand

Leg Bid Price on Stratified Buckets

Additional Revenue over "Greedy" Algorithm



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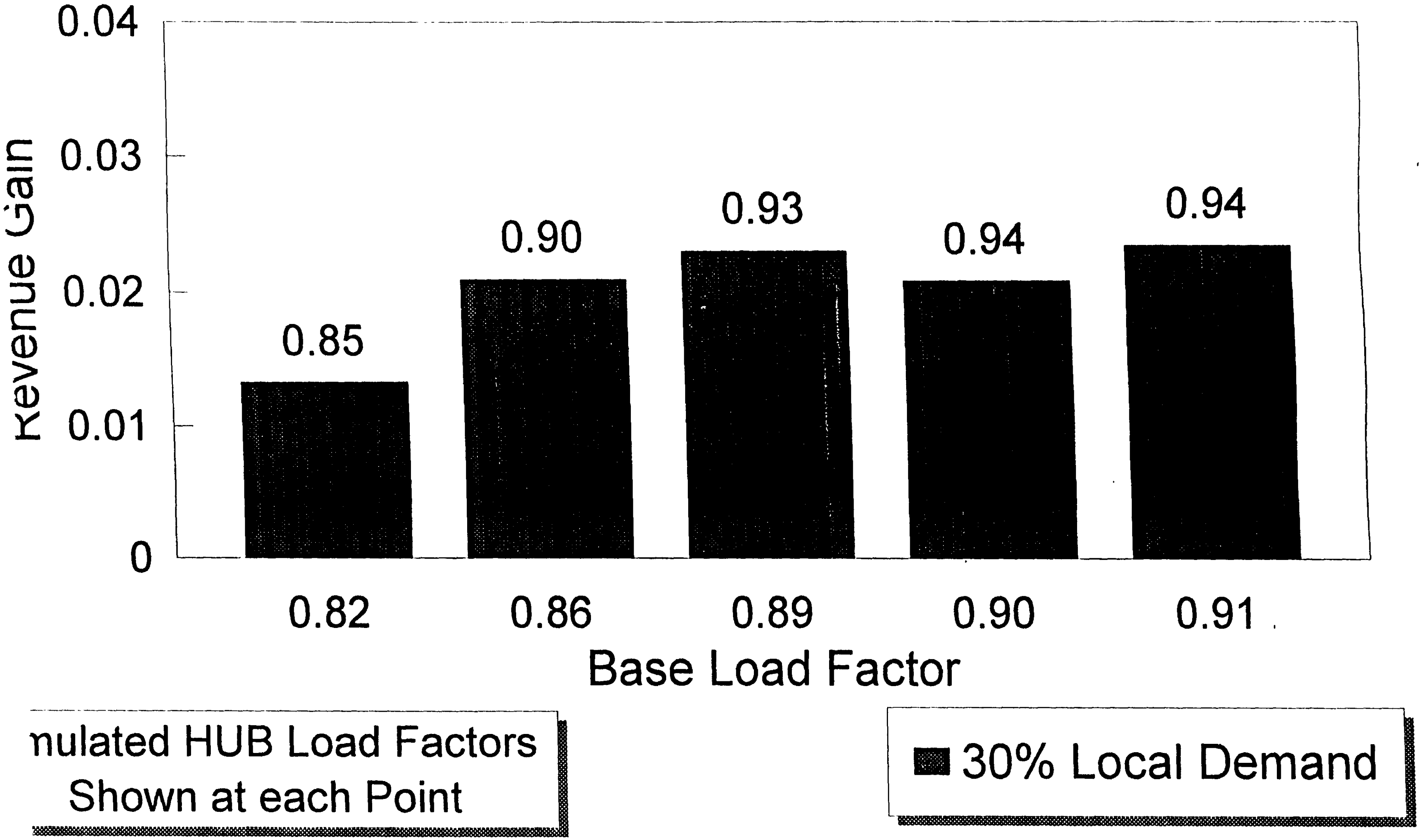
Leg Bid Price on Stratified Buckets

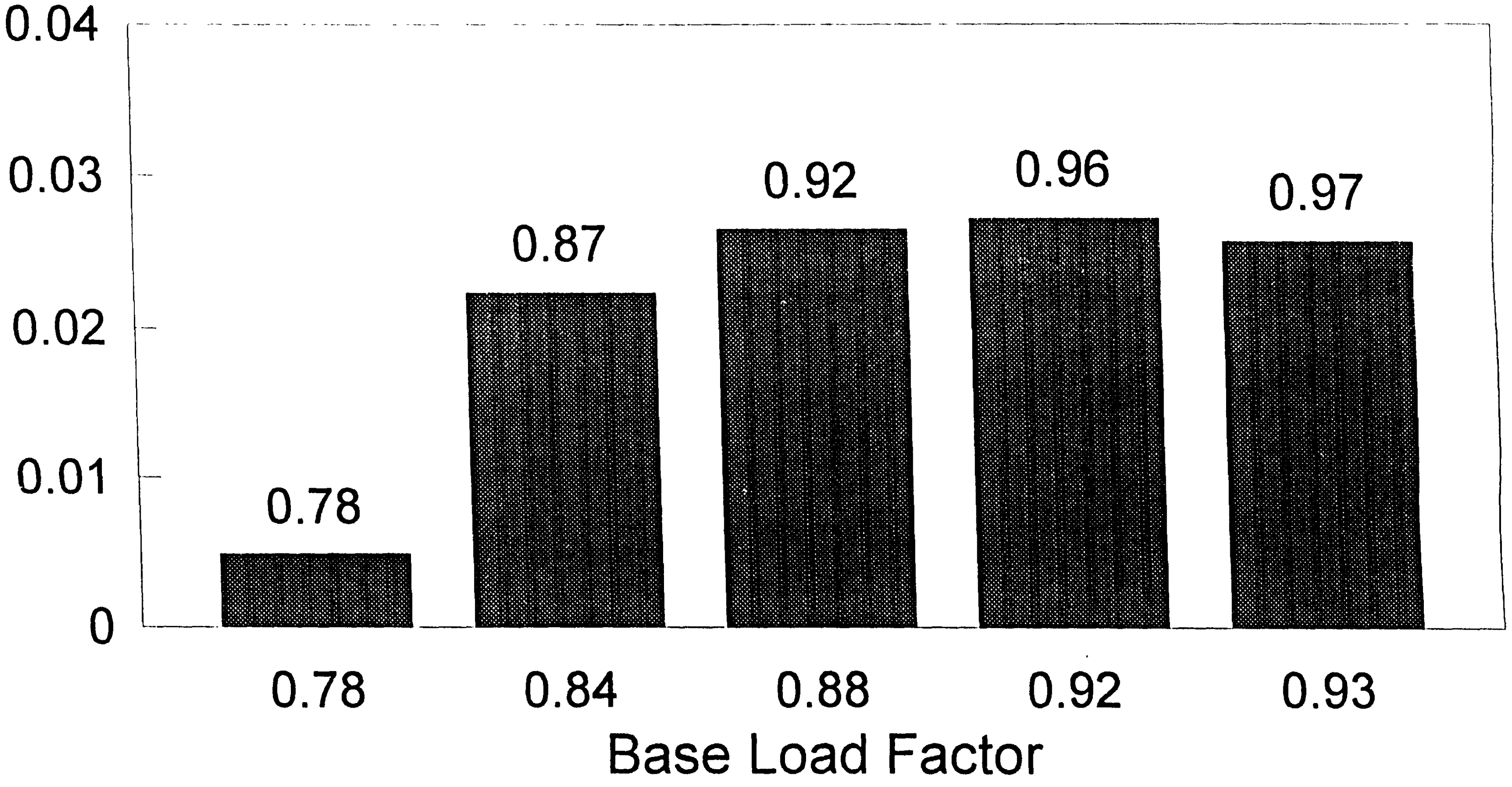
Additional Gain over "Greedy" Algorithm



nulated HUB Load Factors
Shown at each Point

Leg Bid Price on Stratified Buckets

Addditional Gain over "Greedy" Algorithm



imulated HUB Load Factors
Shown at Each Point

▨ 70% Local Demand

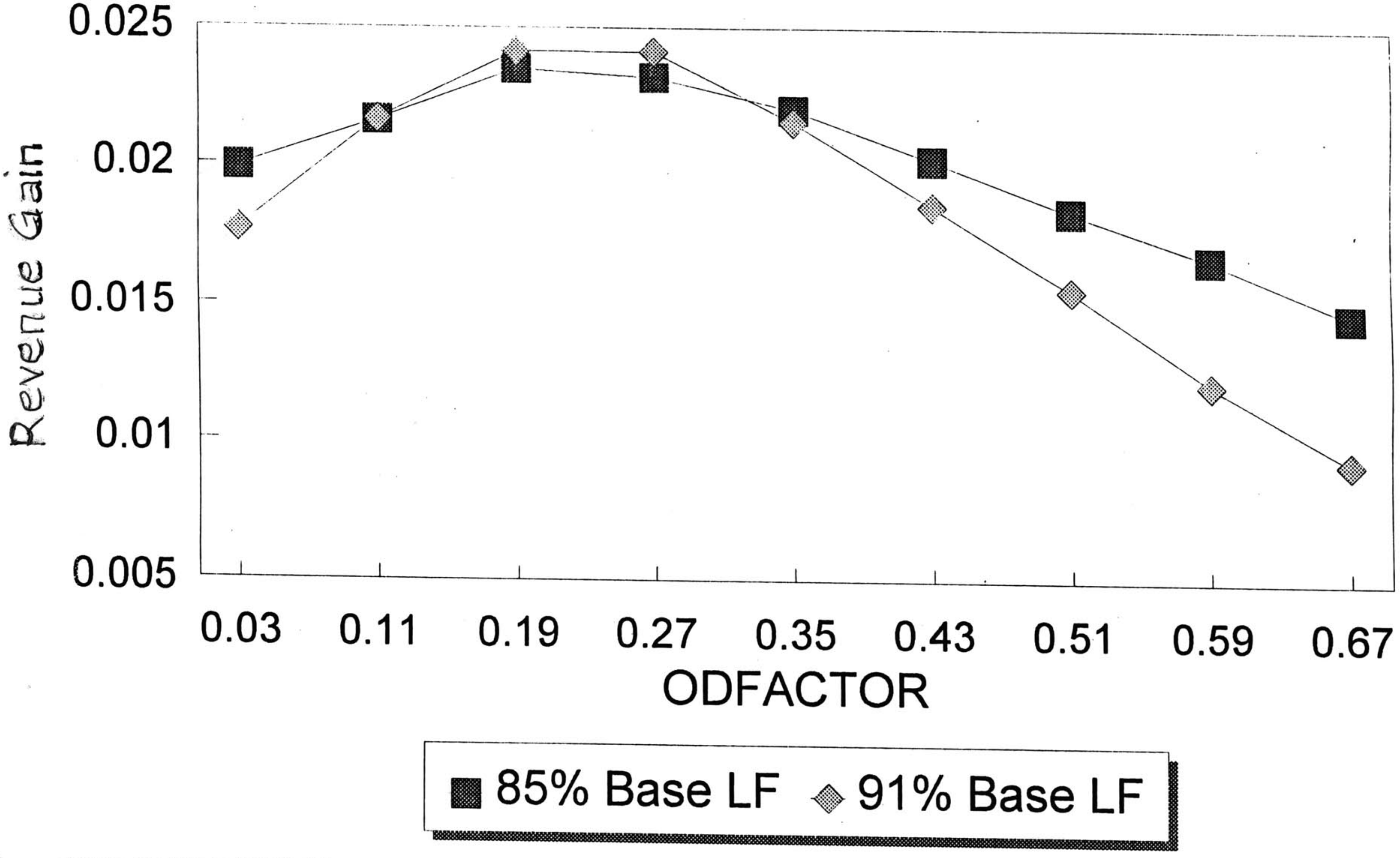
Simulated Revenue Impacts (cont'd)

- Incremental revenue gain of Leg Bid Price is sensitive to proper ODFACTOR value:
  - varies with average proportion of local demand and revenue on HUB network
  - also related to average load factor of HUB network
  - implementation possible with different ODFACTORS by HUB, date, demand level, etc.

- Greatest revenue gains from fare stratification and Leg Bid Price control combined:
  - nonetheless, Leg Bid Price method can be applied to yield-based classes
  - stratified bucketing alone provides an important revenue gain

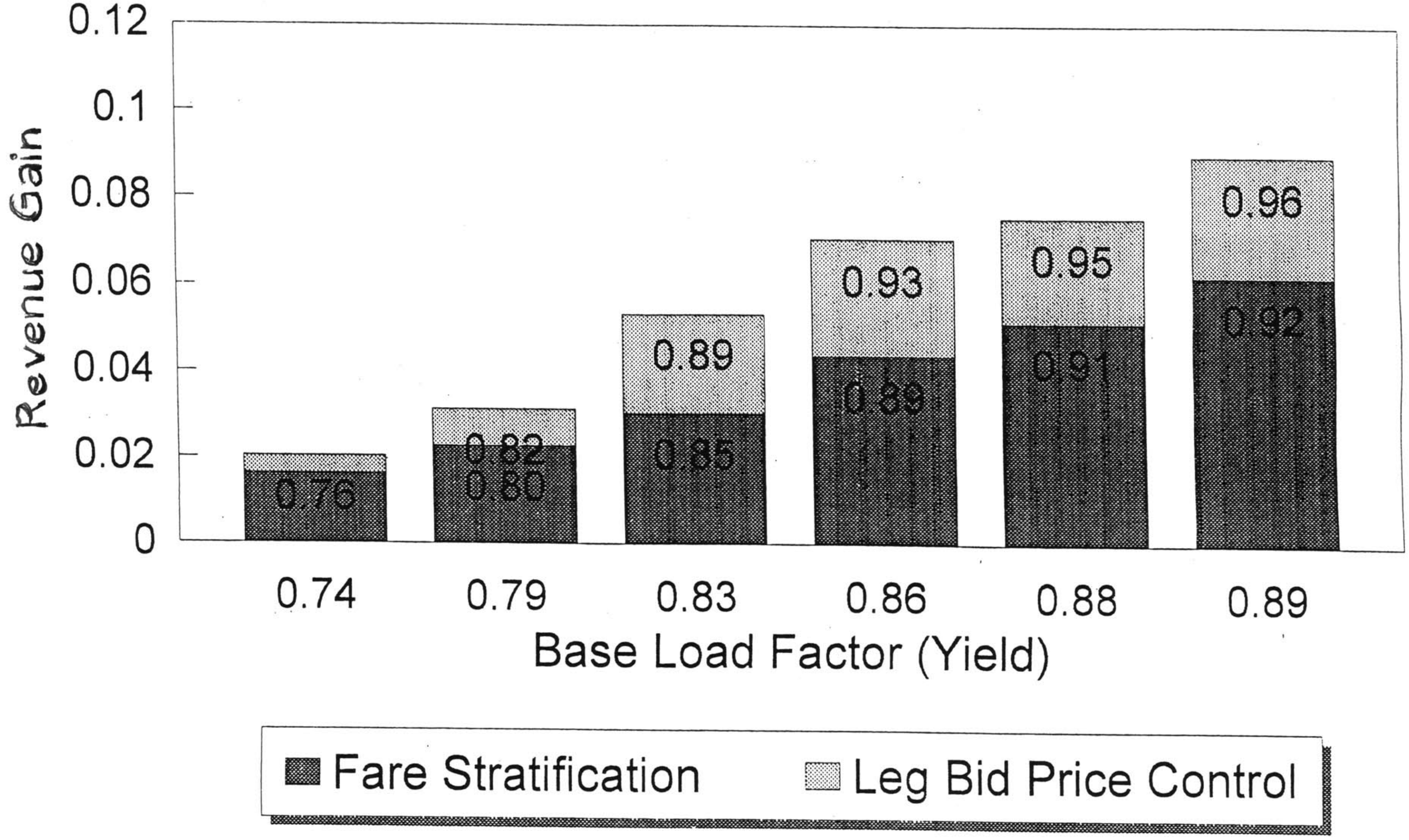
Sensitivity to ODFACTOR

50% Local Demand Scenario



Leg Bid Price on Stratified Buckets

Total Revenue Impact over Yield-Based Classes



Estimating Passenger Flows and Spill in the Presence of Yield Management Systems

Peter P. Belobaba and András Farkas
MIT, Flight Transportation Laboratory

CORS
Calgary, May 23, 1995

OUTLINE

- Motivation
- Estimating Spill for Fleet Assignment
- Use of Yield Management (YM) information in estimating Spill Costs
- Leg-Dependence in Spill Cost estimation
- Analysis of Leg-Dependence effects
- The influence of YM control strategies on Leg-Dependence effects
- Conclusions

Motivation:

- Yield Management (YM) systems set fare class booking limits (BL) given assigned capacity; this affects the passenger mix and total loads.
- Fleet assignment (FA) decisions based on demand forecasts
- Today the two optimization processes work independently:
  - YM decisions influence demand inputs for FA
  - FA decisions (A/C capacities) have influence on the YM decisions

Fleet Assignment Problem

- The **Fleet Assignment Problem** is to match A/C to flight legs such that profits maximized
  - *Trade-off:* Spilled passengers on small aircraft **vs.** increased costs of large aircraft and empty seats

- **Multicommodity Flow IP Models** (Stochastic Demand)

$$\min \sum_{i \in Leg} \sum_{f \in Fleet} \text{cost}_{f,i} * X_{f,i}$$

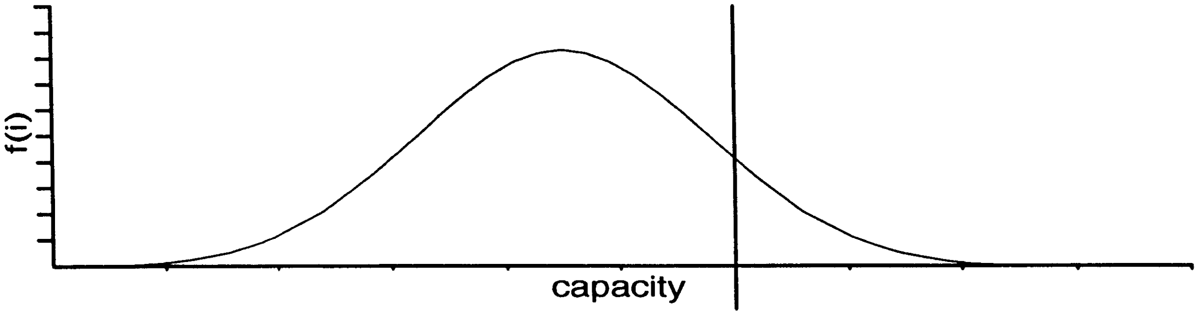
s.t. balance, cover, size, hookup, etc. constraints

  - $\text{cost}_{f,i}$ includes all operating costs plus *spill costs;* $X_{f,i}$ is a binary variable [0,1]
  - Demand and revenue potentials are included in this single objective coefficient

Spill Cost Estimation -- State-of-the-Practice

Total flight leg demand is expressed as a single normal probability function (joint demand curve)

- *Vertical aggregation*: Aggregated over all fare classes of a flight
- Spill Cost = Estimated Spill * "average spill fare"



Estimating Total Spill for a Flight Leg Under YM

Under YM, spill is affected by:

- Demand and booking patterns by fare class
- Fare class booking limits determined by YM system
- The smaller the discount ratio, *d=low fare/high fare*, the more seats will be protected for higher fare classes, and the greater the impact of booking limits on spill.

Aggregation of fare classes (Vertical Aggregation Bias)

- Joint demand curve does not hold information about
  - -- fare class demand distributions
  - -- booking patterns over time
- More accurate spill estimates can be obtained from YM data and booking limits.

Exact formulation for calculating spill for a flight leg

Assuming that lower-valued fare classes book before higher valued fare classes.

Spill, Spill$_C$[0], is given by :

$$Spill_C[S] = \int_{i=0}^{BL_C - S} f_C(i) Spill_{C-1}[i+S]di + \int_{i=BL_C-S}^{\infty} f_C(i)\{i-(BL_C-S)+Spill_{C-1}[BL_C]\}di,$$

$$Spill_0 = 0.$$

$Spill_c$ = expected spilled passengers from fare classes 1 to c;
$f(i)$ = the probability for the number of i fare class c requests;
BL_c = booking limits for class c;
S = number of seats sold for the flight.

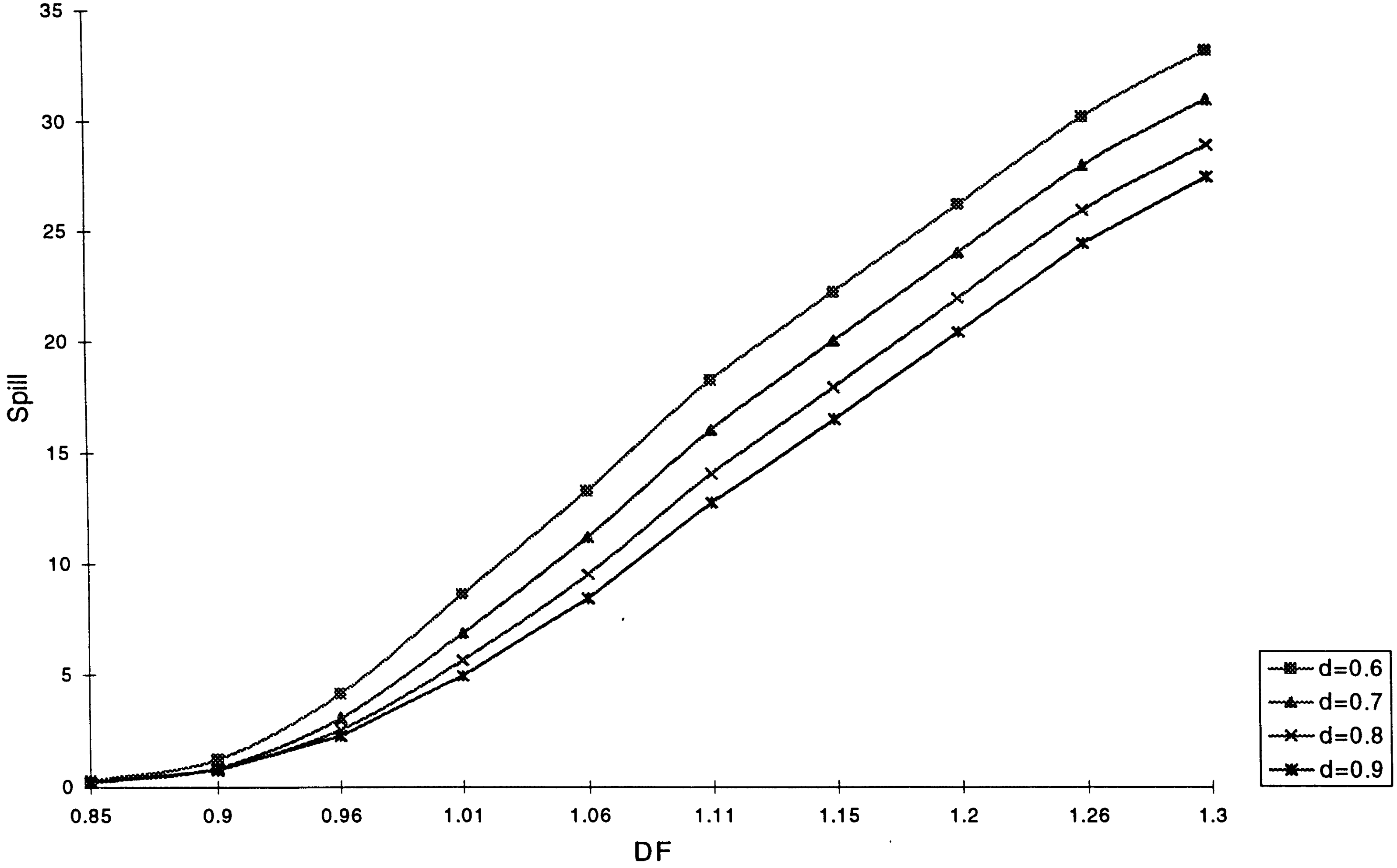
Spill Cost, SC$_c$[0], for the c fare classes is given by:

$$SC_C[S] = \int_{i=0}^{BL_C - S} f_C(i) SC_{C-1}[i+S]di + \int_{i=BL_C-S}^{\infty} f_C(i)\{fare_C * (i-(BL_C-S)) + SC_{C-1}[BL_C]\}di,$$

$$SC_0 = 0.$$

$fare_C$ = fare for fare class c.

Average Spill vs. Discount Ratio (Low Fare/High Fare)



Estimating the "average fare" of spill -- (spill fare)

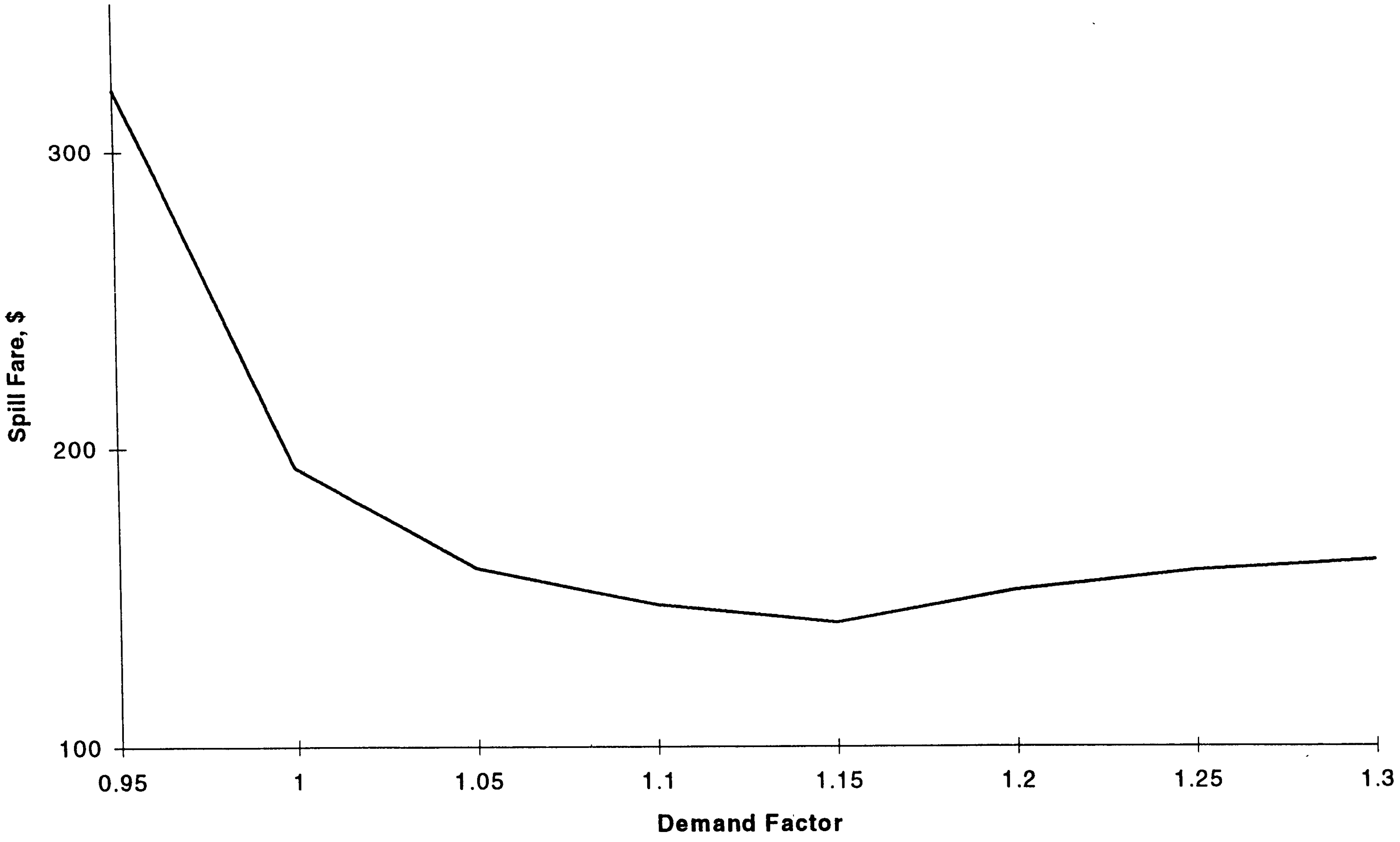
- Simple mean of the fares?
- Weighted average of fares, weighted by the mean demand for each fare class?
- Or more complex?

Issues:

- If the Yield Management System works well, then most of the passengers spilled will be lower fare passengers.

- Spill fare is not constant at different demand factors
  - -- at low spill, most of the fare classes are involved
  - -- at high spill, lower classes are more affected by YM actions.

Average Spill Fare vs. Demand Factor



Comparison of Total Spill Calculations

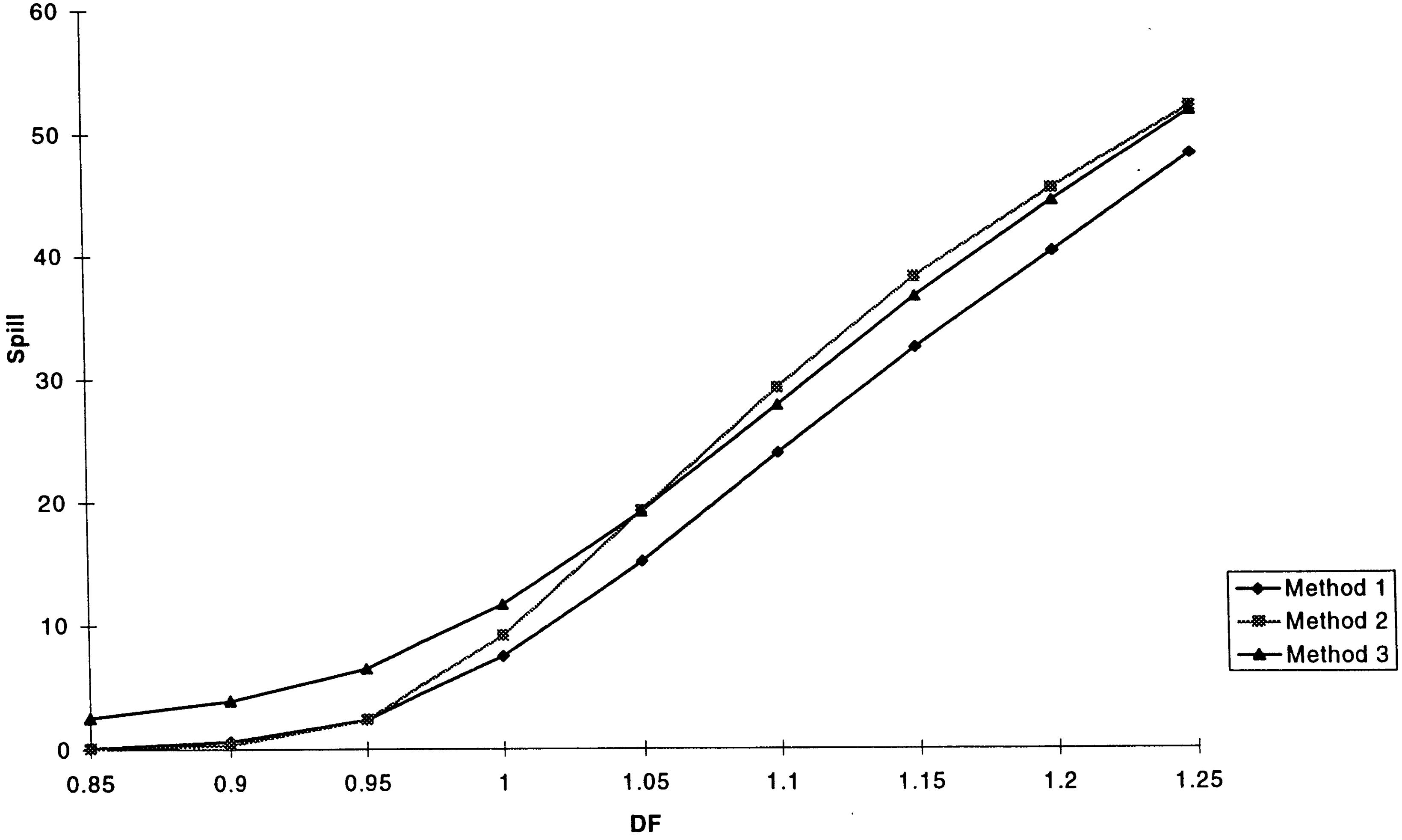
Method 1: Spill is estimated from the joint normal curve using the traditional spill formulas (state-of-the-practice)

Method 2: Spill is calculated assuming lower fare classes book before higher fare classes.

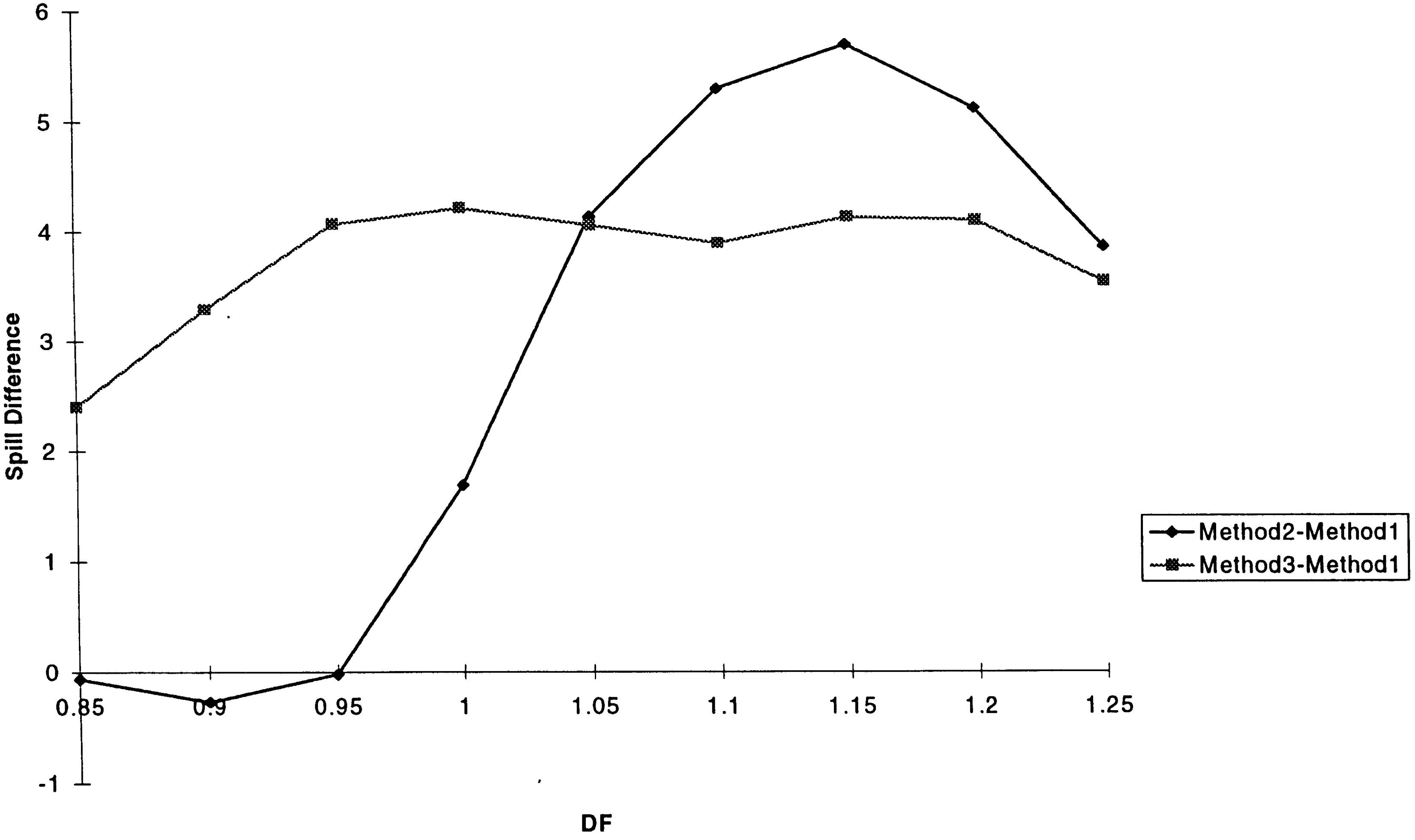
Method 3: Spill is simulated considering fare class booking patterns and booking limits.

Data Example: 7 fare class, business market, single leg, d=0.75...0.88

Average Spill vs. Demand Factor



Differences in Spill Estimates



Summary: Aggregating fare class information

- Spill estimates from the single joint probability function are inaccurate:
  - Joint demand curves do not carry information about fare class demands, relative fares, and booking patterns.
  - Effects of booking limits are not captured.

- Correct spill fares vary with demand factor and cannot be represented by a constant value.

- The estimation biases can differ in direction and magnitude (no systematic bias).

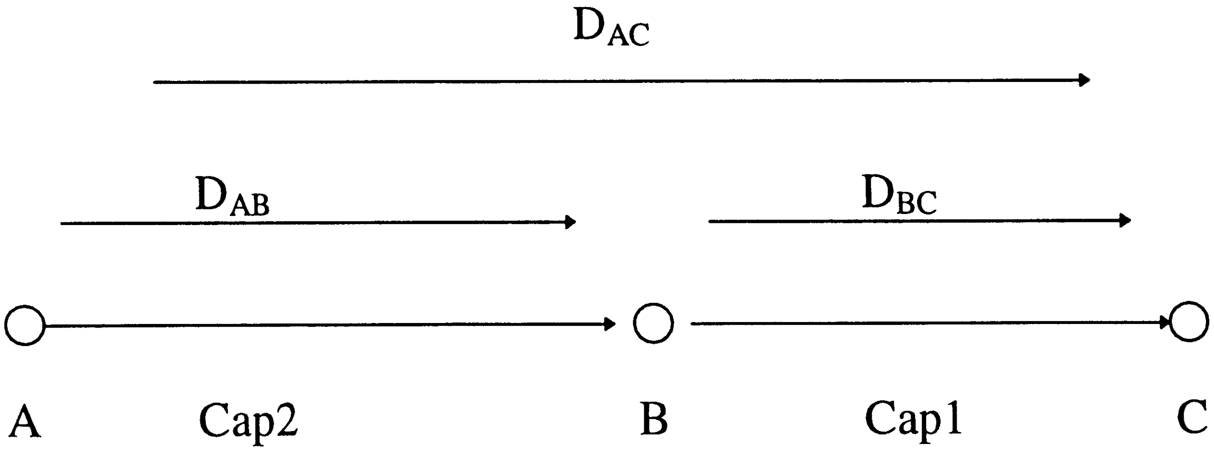
Fundamental dichotomy of Airline Supply and Demand

- Supply Decisions (Fleet Assignment) are made on flight leg basis.
- Demand is generated on an Origin-Destination (OD) basis
- Aircraft flows and passenger flows are different, but overlap on the existing flight leg network.
- Spill should be interpreted and estimated on an OD basis as well, but the problem is that for fleet assignment decisions spill should be leg-based.
  - Still flight legs are the focus.
  - Non-overlapping networks
  - Observed passenger flows and spills on flight legs are only the decomposed projections of the OD passenger flows
  - Different OD Passengers compete for the leg capacities

Calculating Spills in Networks -- Leg-Dependence

- Leg-Dependence
  - -- Passenger flows link legs together
  - -- Capacity constraint on a leg affects the "achievable traffic" on other legs

Unconstrained Demand vs. Achievable Traffic



D_{AC}

D_{AB} D_{BC}

A Cap2 B Cap1 C

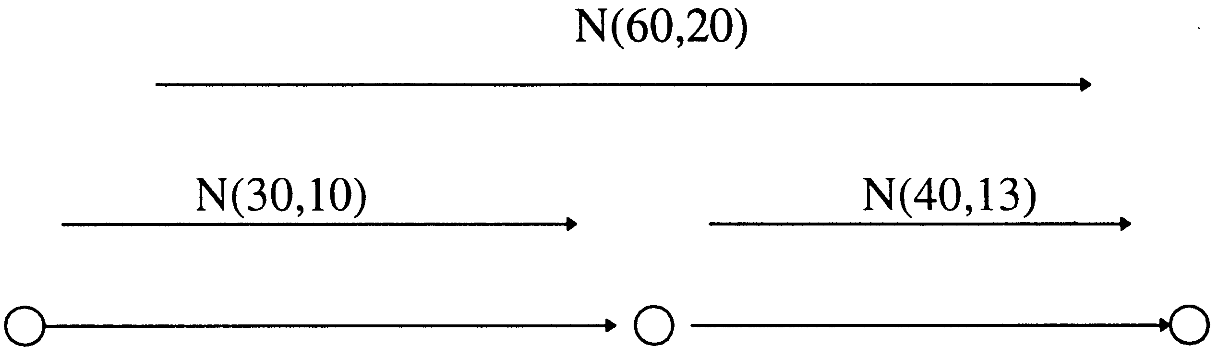
Leg-Dependence Issues

- Leg-dependence occurs when:
  - -- Connecting origin destination (OD) demands are present
  - -- There is spill of connecting passengers due to “censoring effect” of capacity

- Network Connectivity
  - -- Dispersion of Censoring Effects
    - Censoring effect is distributed over many connecting downline legs
  - -- Concentration of Censoring Effects
    - Censoring effects on upline legs concentrate on the connecting leg

- Direction of leg-dependence effect propagation
  - -- Sequence of legs filling up
  - -- Fill Rate: $\overline{P}(Cap) = \int_{i=Cap}^{\infty} f(i)di$
- Boundaries of leg-dependence effect propagation

Example: Leg-Dependence



Cap=100	Cap=100
LegDemand=90	LegDemand=100
Fill Rate = 0.32	Fill Rate = 0.5

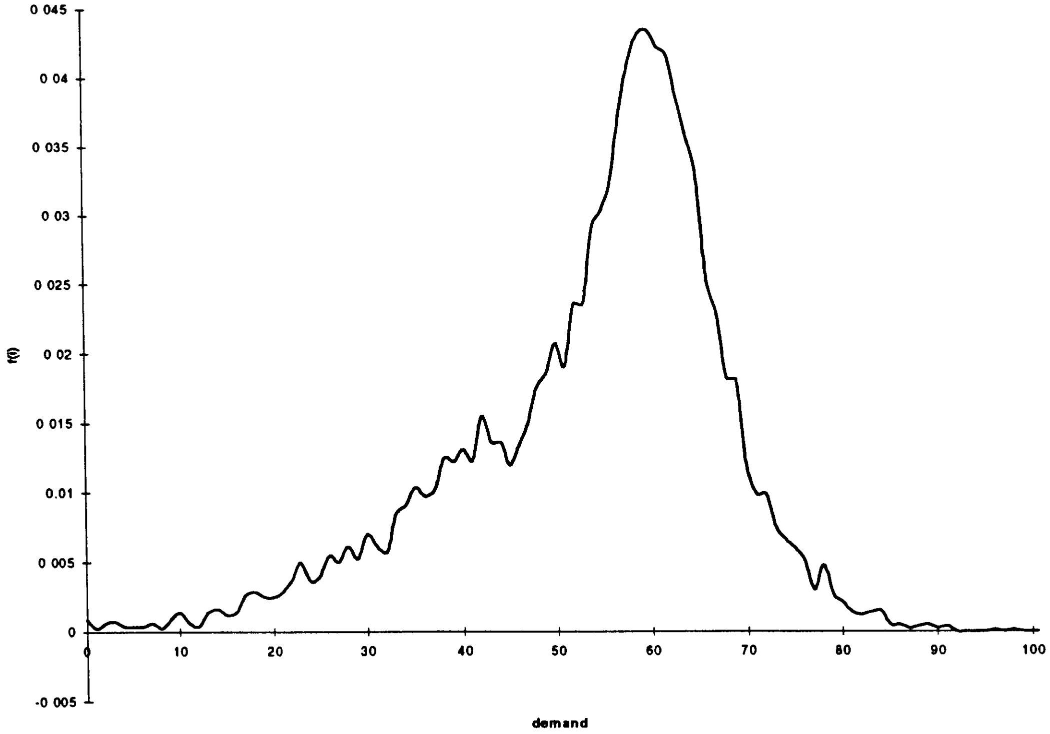
Assumptions:

- -- OD demands are independent and Normally distributed.
- -- OD mix of load and spill is proportional to demands.

Example: Achievable Connecting OD Traffic on Leg 1

Capacity limit on Leg 2 ($Cap_2=100$) censors two OD demand flows proportionally
$w = (loc / loc + conn) * Cap$

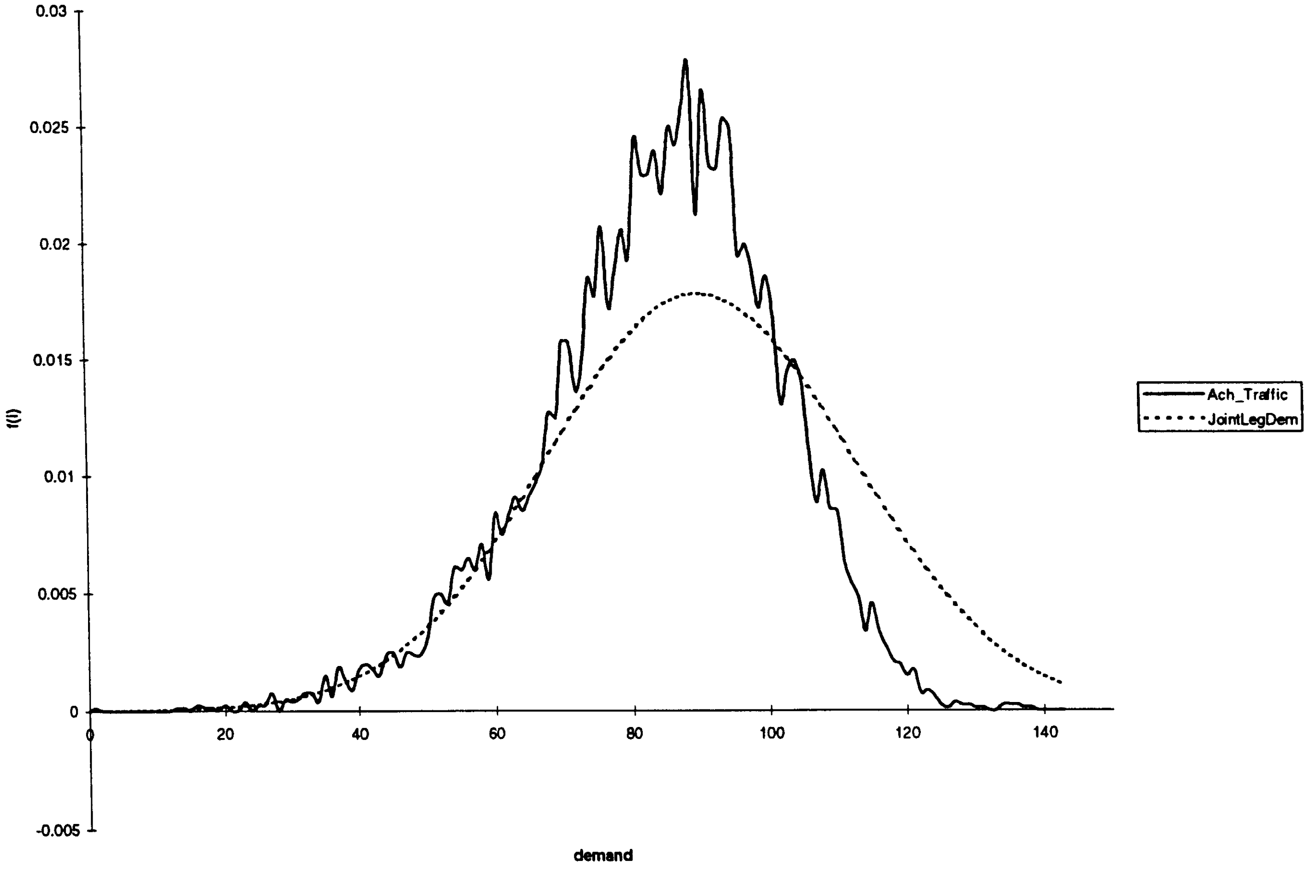
Achievable Traffic pdf



demand

Achievable Traffic (Cap2=100seats) vs. Unconstrained Demand on Leg 1

Convolution Sum of Local Demand on Leg 1 and the Achievable Connecting OD Traffic



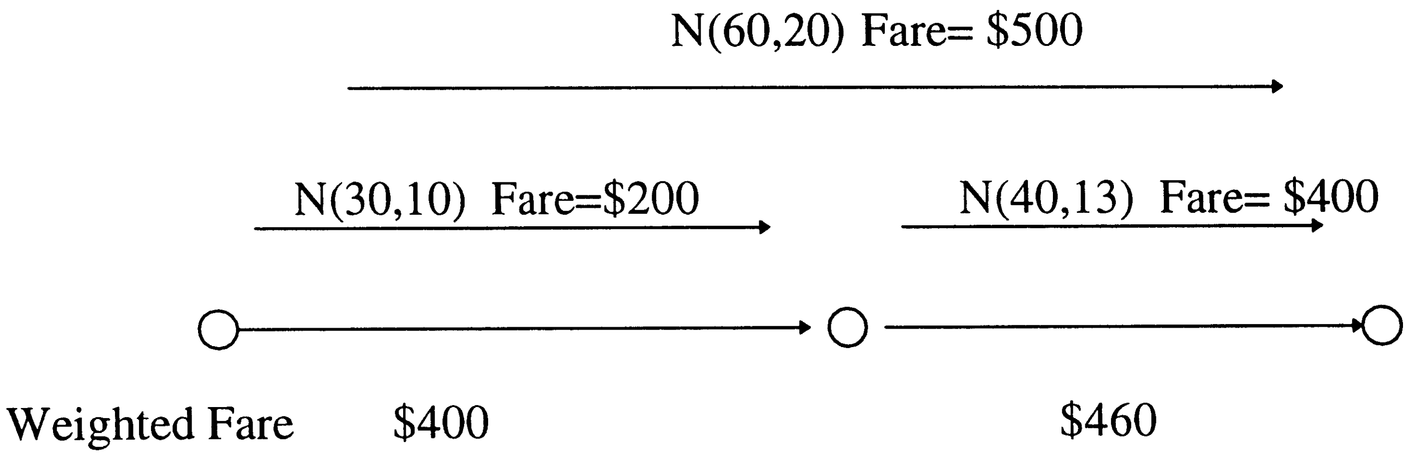
demand

Difference in Spill Estimates

Cap1	**Leg-Dependent Cap2=100**	**Leg-Independ. Traditional Method**	**Difference**
90	4.03	9.07	5.04
95	2.37	6.77	4.4
100	1.27	4.9	3.63

- Traditional leg-independent method over-estimates spill in a leg-dependent network.

OD Mix of Spill is Also Affected



N(60,20) Fare= $500

N(30,10) Fare=$200

N(40,13) Fare= $400

Weighted Fare $400 $460

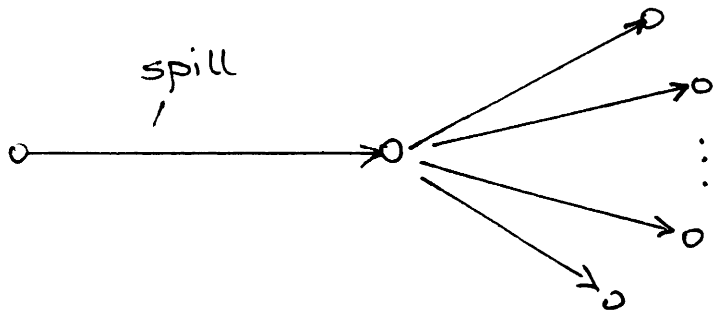
- If passenger demands are censored, then the OD mix of demand is affected
- Consequently, the actual spill fare will be affected as well
  -- Actual spill fare is lower

Network Connectivity

-- Dispersion of Censoring Effects

Censoring effect is distributed over many connecting downline legs

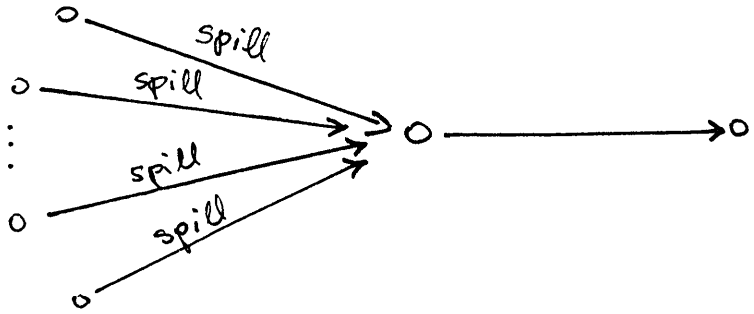
Substantial spill but insignificant leg-dependence effect in the network



-- Concentration of Censoring Effects

Censoring effects on feeding legs concentrate on the fed leg

Small spill on each leg but significant leg-dependence effect in the network



Consequences of Leg-Dependence

- Passenger Spill estimates are affected
  - -- Leg-independent (traditional) spill and fleet assignment approach overestimates spill by assuming unconstrained demand flows.

- Leg interdependence also affects the OD-mix of the spilled passengers
  - -- Fares of different OD's will vary, affecting the average fare of spilled passengers (spill fare)

- Spill Cost estimates are affected by leg interdependence
  - -- Overestimated Spill
  - -- Incorrect Spill fare

Effect of YM Systems on Leg-Dependence

(1) Traditional Fare Class YM System

- Aggregates demand on flight legs into booking classes by fare type (e.g., full fare vs. 14 days advance purchase)

- Leg-based Booking Limits for each booking class

- In Fare Class YM systems connecting and local demands are proportionally spilled -- no OD control over itineraries
  - Leg-dependence is a significant issue in spill and spill cost estimations
  - Fleet Assignment formulations should be reconsidered

Effect of YM Systems on Leg-Dependence

(2) Stratified Bucketing/Virtual Nesting

- Aggregates demand on flight legs into "value classes" according to the OD itinerary total fare.
- Preference given to longer haul connecting OD itineraries
- Local passengers in lower value classes are most likely to be spilled
- Higher revenue connecting OD demands receive greater availability -- limited OD control
  - Since mostly local demand is involved in spill, leg-dependence is not as critical
  - Leg-independent spill cost estimates may be used, but YM impacts are still important
  - Traditional Fleet Assignment formulations might be adequate

Conclusions

- Differences of traditional spill and spill cost estimates from actual are substantial when booking limits and booking patterns are not considered.

- The use of detailed Yield Management information improves the estimates significantly.

- Leg-dependence effects can also significantly influence the estimates of actual spill cost
  - -- leg-independent approaches overestimate actual spill
  - -- leg-independent approaches do not capture the actual OD mix of spill
  - -- incorrect spill fare estimates

- Under different yield management systems, leg-dependence can have different impacts on OD passenger flows.

Further Research

- Analyze the effects of leg-dependence in real airline networks
- Study the effects of different yield management systems on the OD passenger flows and on the leg-dependence problem
- Develop new approaches to efficiently estimate leg-dependent spill costs
- Incorporate leg-dependence into the Fleet Assignment formulations

Schedule Planning and Operations Control

Technologies for Surviving Competition in the Airline Industry

Dr. Dennis F. X. Mathaisel

Flight Transportation Laboratory
Department of Aeronautics & Astronautics
MIT

AGENDA

1. Overview of available models and computer packages for airline schedule planning and airline system operations control
    - 1.1 Strategic
    - 1.2 Tactical
    - 1.3 Operational
2. Systems Development: Approach
    - 2.1 General Strategies
    - 2.2 The Airline Scheduling Workstation (ASW)
    - 2.3 Two Stages of Development
3. Expected Benefits for an ASW
4. Summary and Conclusions

Strategic

- Fleet Planning
- Fleet Assignment
- Network Optimization/Evaluation

Tactical

- Airline Schedule Development
- Timetable Construction
- Traffic Allocation and Network Evaluation
- Aircraft Assignment
- Aircraft Routing
- Aircraft Swapping (Switch and Save)

Operational

- System Operations Control
    - Operations Manager
    - Irregular Operations
    - Crew Management
    - Flight Dispatch
    - Maintenance Recovery
    - Aircraft Situation Display
- Ground Handling and Manpower Planning
- Passenger Services
- Catering

STRATEGIC

Fleet Planning - Cell

- Find optimal (maximum operating income) schedule of aircraft acquisition and retirements over a series of future years
- Use aggregate route/market clusters ("cells")
- Introduce financial parameters and constraints purchase vs. lease options
- Linear Programming techniques

STRATEGIC

Fleet Assignment – FA-4

- Uses large scale LP technique to find "best" allocation of available fleets to feasible, desirable aircraft routings on a network of services
- Maximize Operating Income
- Detailed schedule of departure/arrival times not considered
- Given:
  - O-D market demand function (not fixed)
  - Multi-stop routings
  - Limits on available daily fleet hours
  - Limits on onboard load factors achievable
  - limits on Max-Min desired daily market services
- Results
  - Routes to be flown
  - Frequency by type of aircraft

STRATEGIC

Network Evaluation and Competitive Analysis - TALLOC

- Simulation of an airline's competitive environment at the schedule level of detail
- Given
  - O-D demands
  - Schedules of your airline and your competition
  - Passenger behavior parameters
  - Costs and fares
- Results
  - Composition of onboard segment traffic
  - Market analysis
  - Profitability analysis

TACTICAL

Airline Schedule Development - (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
- Connection Generator (AUTOCONN)
- Automatic flight numbering
- Import and export functions: read and write data files to mainframe
- Interfaces to DBMS
- Printed reports
- Runs on any UNIX workstation or PC supporting UNIX

TACTICAL

Timetable Construction – REDUCTA

- Shifts flights within a specified time window with the objective of increasing the efficiency of the schedule

- Given:
  - Set of services which must be flown
  - Time window for each service
  - Minimum turn times
  - Curfews

- Results:
  - Re-optimized time schedule for the services

TACTICAL

Timetable Construction – INSERT

- Algorithm for building aircraft (or ground vehicle) itineraries based on the demand for service
- Builds routes and schedules through a sequential "insertion" of services into the system
- Structured decision rules
    - Choice of aircraft type
    - Hubbing decision rules
- More useful for charter operations than for scheduled services

TACTICAL

Traffic Allocation and Network 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

Thru - Flight Optimization Module

- Analyzes thru-flight vs. connecting flight possibilities

TACTICAL

Aircraft Assignment

- Optimal assignment of aircraft types to a fixed schedule
- Uses very large scale integer linear programming techniques
- Constraints
  - Minimal set of crew constraints
  - Minimal set of maintenance constraints
- Integration with revenue management systems

TACTICAL

Aircraft Routing - MRS

Objective

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

Given

- Desire for through service in certain markets
- Maintenance operational constraints

Output

- Rotations, daily/weekly lines of flying
- Gate occupancies at station
- Routings to planned maintenance checks

Uses optimal tree-construction techniques, and forward and reverse tree search.

TACTICAL

Switch and Save – SWITCH (David L. Johnson)

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.

OPERATIONAL

System Operations Control

- Operations Manager
- Irregular Operations
- Crew Management
- Flight Dispatch
- Maintenance Recovery
- Aircraft Situation Display

Ground Handling and Manpower Planning

Passenger Services

Catering

OPERATIONAL

System Operations Control – ASC

- Flight following
- 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"
- Client-server architecture
- Multiple users

OPERATIONAL

Systems Operations Control - 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

OPERATIONAL

Resource Allocation and Manpower Planning - RAMPS (ADDAX)

- Assigns agents to ramp services
- Translates real-time operations information into the tasks required for each aircraft's movement
- Management policies and standards programmed into the system
- Includes ramp agent selection criteria and shift break schedules

OPERATIONAL

Passenger Service Agent Allocation System - PSAAS (ADDAX)

- Monitors and assigns passenger service agents to tasks
- Based on real-time flight information, PSAAS matches agents to appropriate jobs throughout the day
- Management policies and standards programmed into the system
- Assignments based on:
  - Job classification
  - Skills
  - Time lapsed since last assignment
  - Travel time to assignments
  - Workload balancing

OPERATIONAL

Catering Allocation Planning Equipment Routing - CAPERS (ADDAX)

- Dispatches catering personnel to tasks
- Translates real-time flight information into the catering tasks required for each aircraft's movement
- Management policies and standards programmed into the system
- Monitors and tracks
    - Job skills for each employee
    - Daily rosters
    - Equipment availability
    - Loading dock schedules

2. Systems Development Approach

2.1 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 transportable, modular, object-oriented code
- Extendible
- Easily supported
- C, C++
- Efficient data structures
- Common graphical user interfaces to all sub-systems
- Common DBMS platforms
- Common hardware platforms

2.2 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 extendible to handle time-varying scheduling constraints, policies, etc., and to reduce programming support.

Two Stages of Development

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

a) Provide computer graphic displays of schedule information

- Instantaneously modifiable by mouse, global data base modification
- Selectable screen data -- by fleet, station, 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

b) Provide instantaneous error flagging (even if error occurs off-screen)

- e.g., insufficient gates, flow imbalance, double crew layover, violation of turnaround or transit times, insufficient aircraft

Stage 1 -- cont.

c) Integrate initial crew, gate, maintenance schedule planning with aircraft schedule planning

  - e.g., rough initial schedules for crews, gates, station personnel)

d) Provide familiar printed reports and graphics for distribution around airline

e) Provide interface to mainframe data system to maintain current scheduling processes

f) Centralize data bases

Two Stages of Development

Stage 2 – Introduction to Automated Decision Support

- Algorithms to assist human schedulers optimize sub-problems
- Eliminate manual effort at certain steps of the process
- Broaden search for optimal or good solutions to scheduling sub-problems
- May introduce large scale optimization algorithms

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

Summary

State-of-the-Art in Computerized Scheduling -- cont.

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.

The Value of Revenue Management in a Competitive Airline Industry

John L. Wilson
Peter P. Belobaba
Flight Transportation Laboratory
Massachusetts Institute of Technology

AGIFORS YM Study Group Meeting
May 2, 1995

Questions

- In competitive setting, how does RM affect...
  - market revenues?
  - total loads and fare class distribution?
- How do carriers with different RM capabilities share these revenue benefits?

Outline of Presentation

- Terminology and simulation approach
- Experiment descriptions and findings for
  - Symmetric two path scenarios for one O-D pair
  - Dominant carrier scenarios for one O-D pair
  - Three-city scenarios
- Conclusions on the importance of competition in evaluation of RM benefits
- Model refinements and extensions

Simulation Terminology

- Sampling unit
  - *observation*: departure day
  - *trial*: series of observations
- Trip components
  - *flight leg*: nonstop departure at specified time
  - *market path*: set of legs comprising OD itinerary

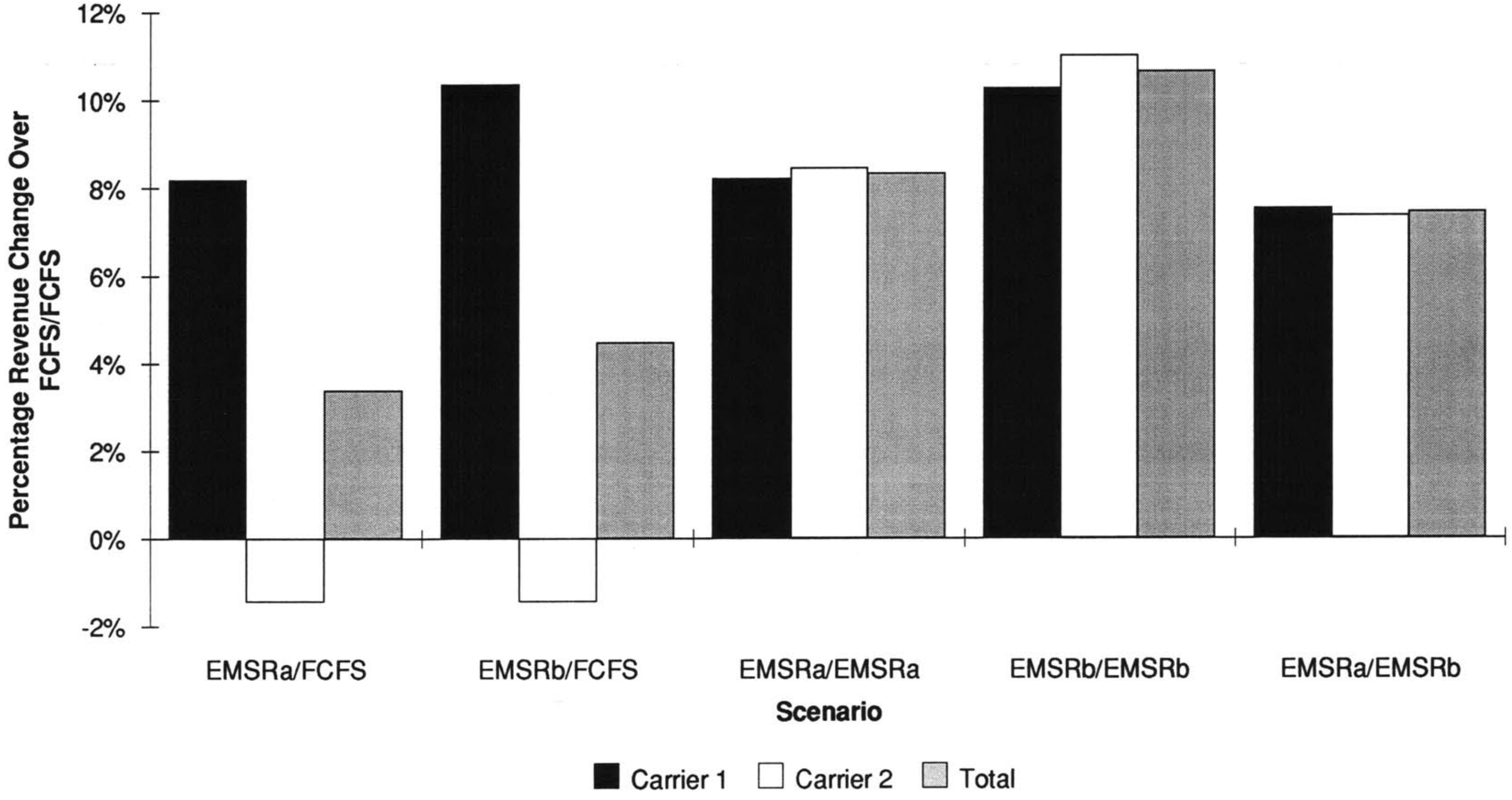
Simulation Approach

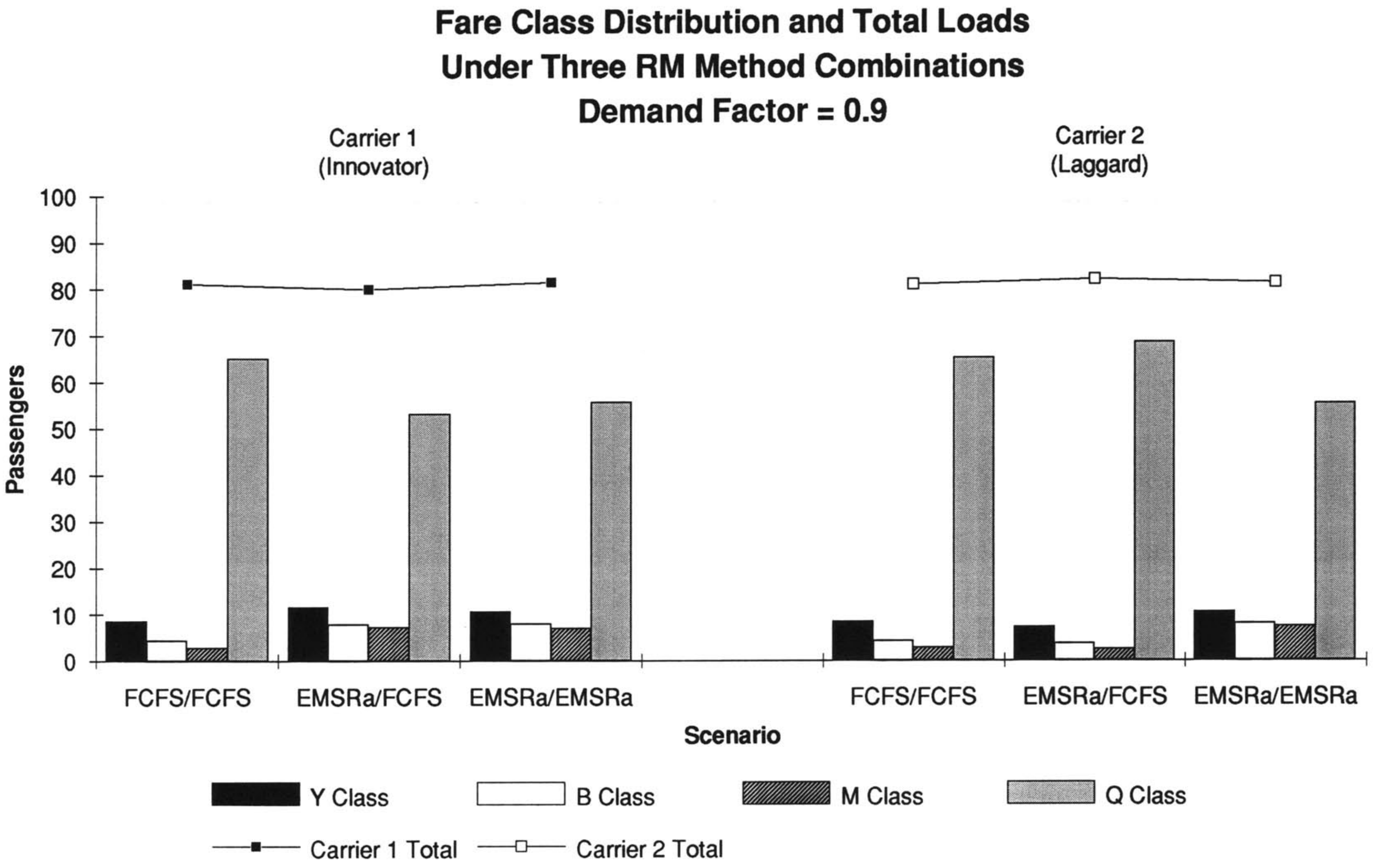
- Forecasting causes correlation of observations within trial
  - self-fulfilling prophecy
  - need for repeated independent trials
- Pax types (2) vs. fare classes (4)
  - specify business & leisure pax type behavior
  - types may not book in “proper” classes

Symmetric Two Path Scenarios: Definition & Dimensions Tested

- Two competitors with one flight each at common departure time
- Unconstrained demand factor: 0.8 to 1.2
- Simple pick-up forecasting model
- Inventory control method combinations
  - First Come First Served (FCFS)
  - Expected Marginal Seat Revenue nested control: EMSRa vs. EMSRb

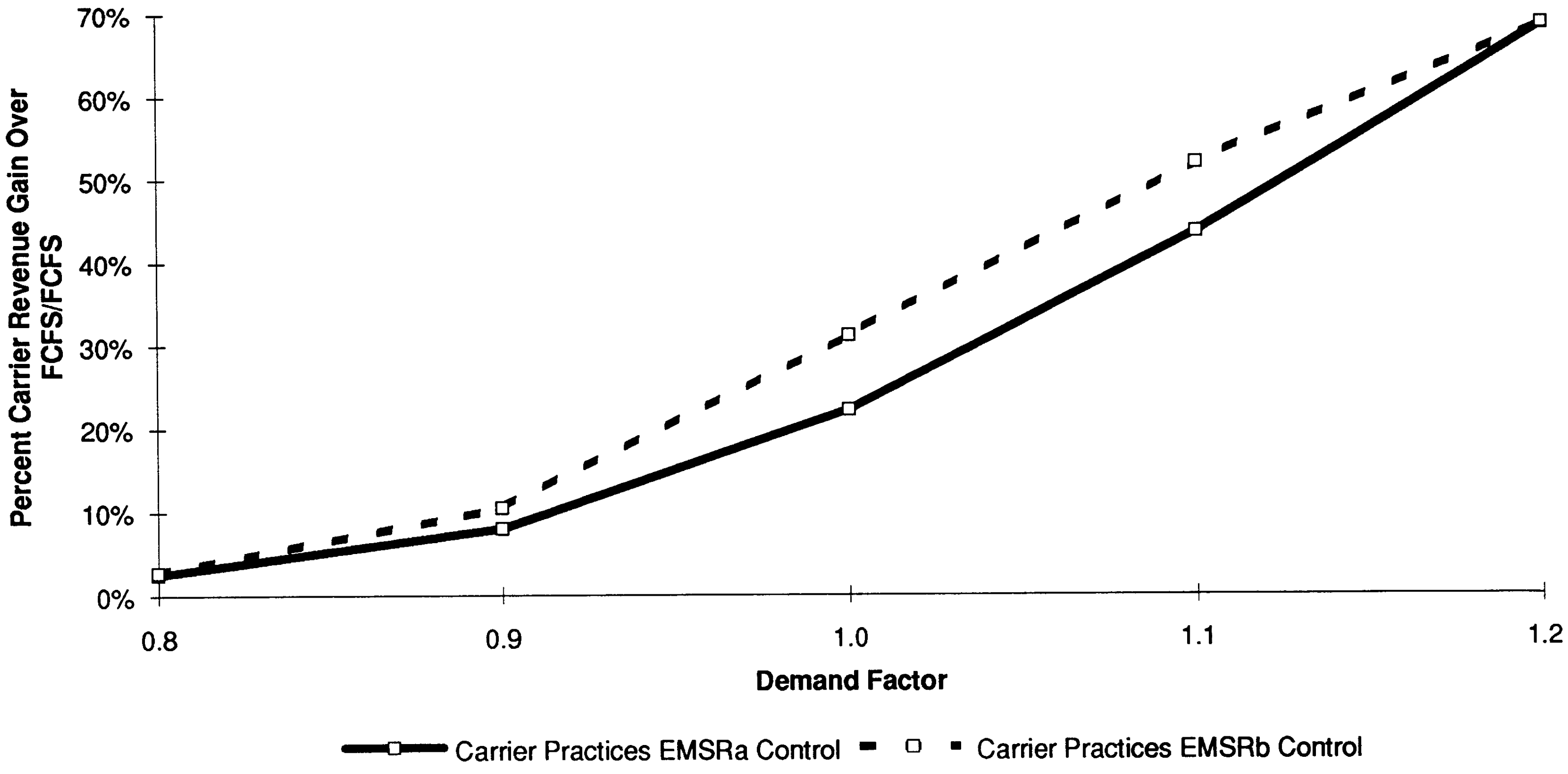
Revenue Impact by Carrier Under all RM Method Combinations
Demand Factor = 0.9





Fare Class Distribution and Total Loads
Under Three RM Method Combinations
Demand Factor = 0.9
Carrier 1
(Innovator)
Carrier 2
(Laggard)
Passengers
100
90
80
70
60
50
40
30
20
10
0
FCFS/FCFS
EMSRa/FCFS
EMSRa/EMSRa
FCFS/FCFS
EMSRa/FCFS
EMSRa/EMSRa
Scenario
Y Class
B Class
M Class
Q Class
Carrier 1 Total
Carrier 2 Total

Carrier Revenue Benefit Achievable Under Each EMSR Variant
When Competitor Maintains FCFS Discipline
Various Demand Factors



Symmetric Two Path Scenarios: Findings

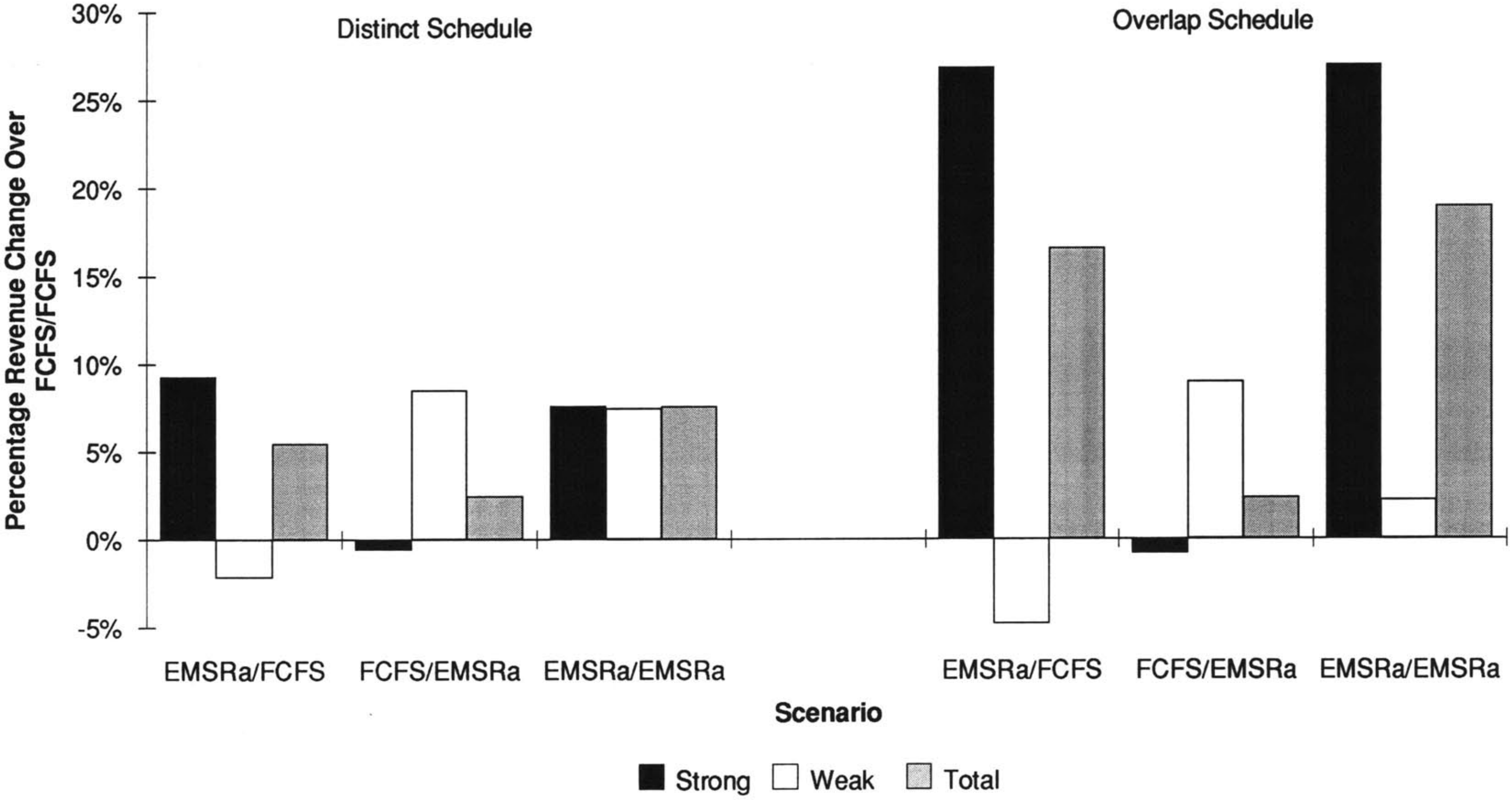
- Evolution from FCFS/FCFS (DF = 0.9)
  - single RM innovator achieves:
    - higher revenue
    - lower load

    } partially at rival's expense
  - after rival acquires RM capability:
    - no change in leader's revenue
    - total traffic balances & shifts toward Y class
- EMSRb marginally outperforms EMSRa

Single Market Dominant Carrier Scenarios: Dimensions Tested

- Degree of frequency superiority: 2 vs. 1
- Schedule separation of weak departure
  - overlap at peak
  - distinct at off peak
- Inventory control method permutations

Per-Flight Revenue Impact by Carrier Dominance (2 vs. 1) & DF = 0.9



Single Market Dominant Carrier Scenarios: Findings

- Both RM method pairing and schedule separation dramatically affect performance
- Dominant carrier benefits from captive market segment
  - if RM disadvantage: limits unit Q class dilution
  - if equal or better RM: redirects leisure pax to weak departure (especially in overlap)

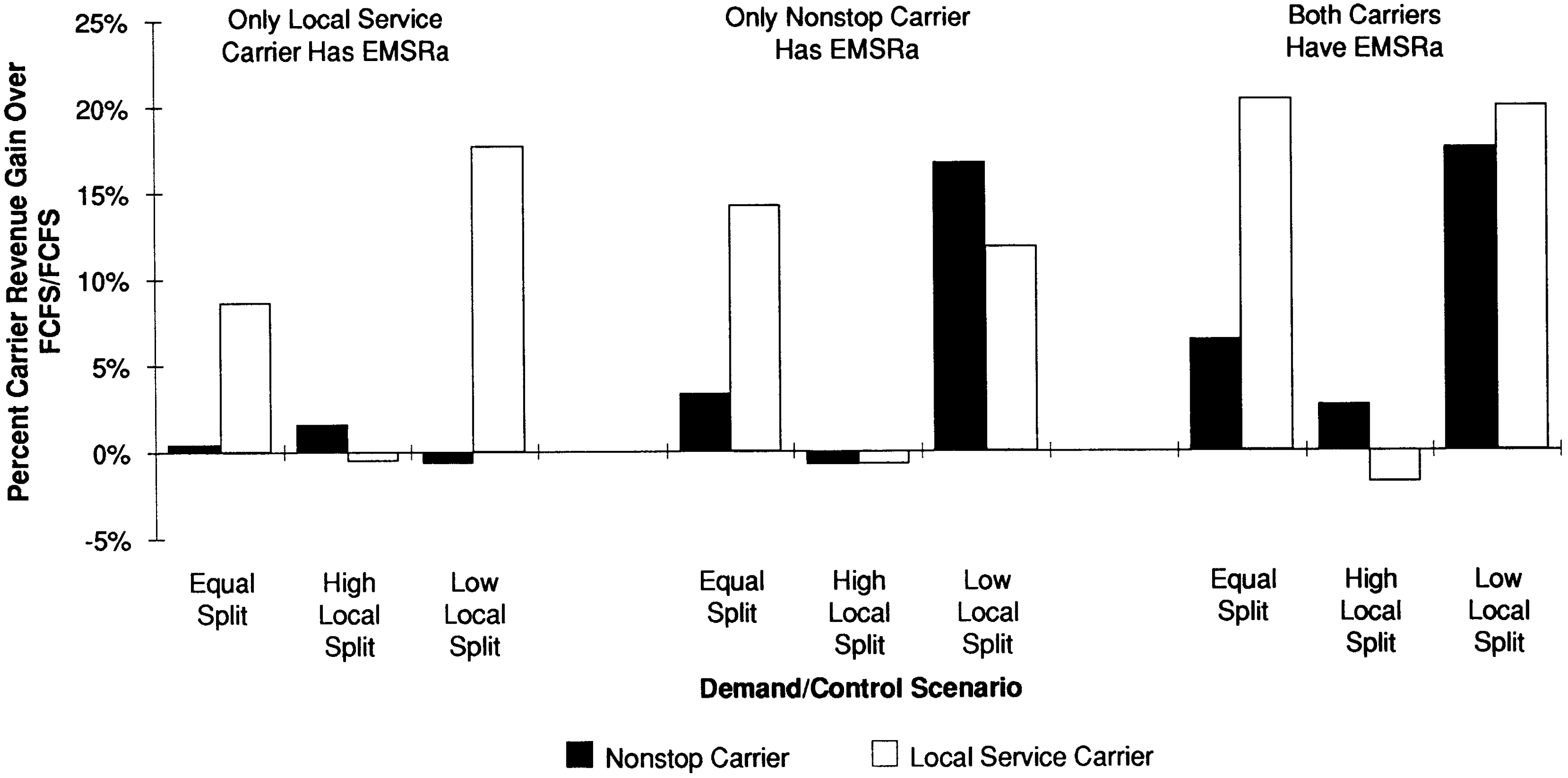
Three-City Scenarios: Motivation

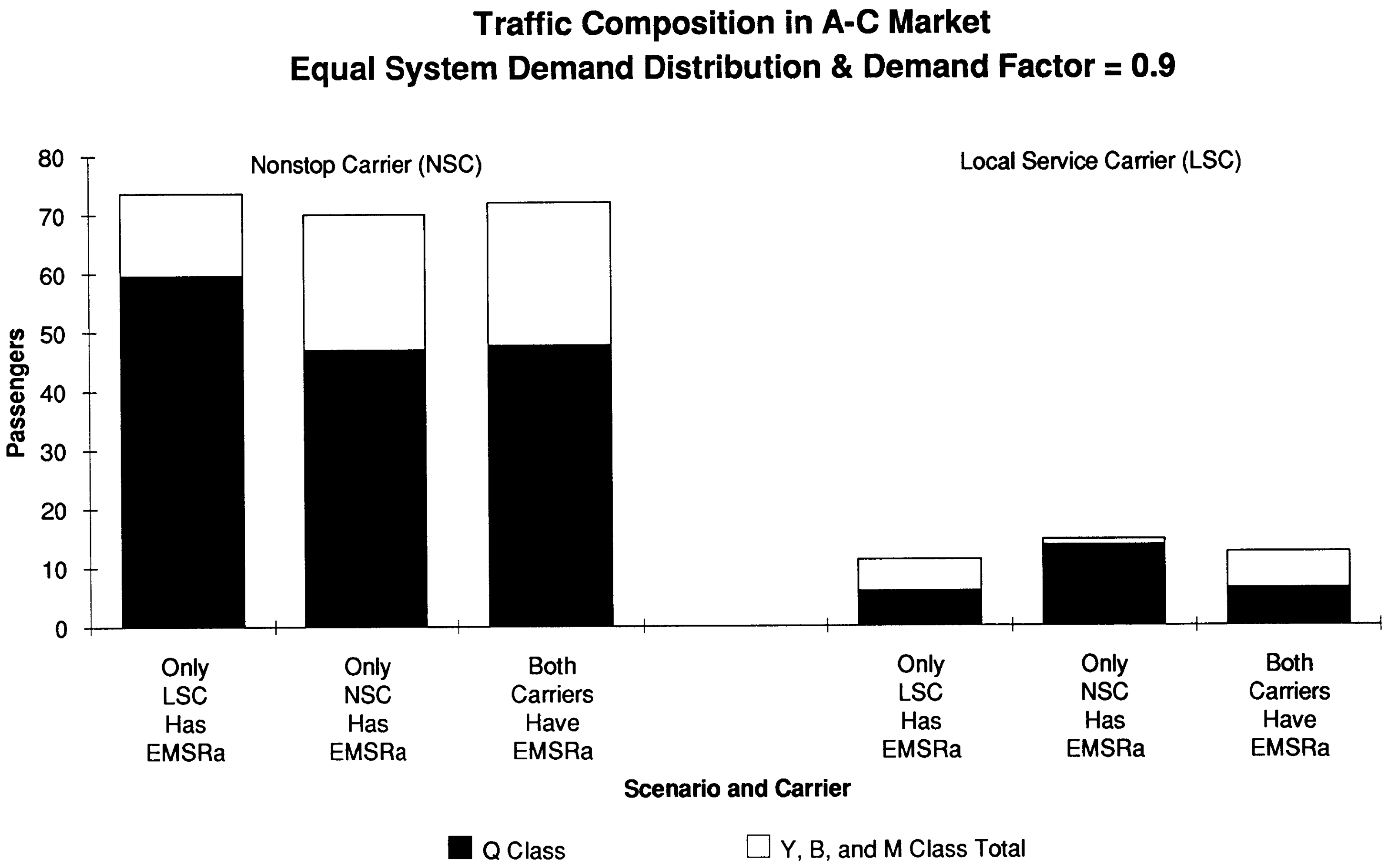
- Direct effects of path quality on pax choice
  - value of time by pax segment captured by Decision Window framework
  - attributed cost for path quality index (intrinsic disutility of connection)
- Multiple paths on a leg allow competition for capacity

Three-City Scenarios: Network and Base Schedules

- Network structure
  - connecting longer haul market: A-C
  - two local (spoke) markets: A-B, B-C
- Carrier 1 offers one A-C nonstop and no local service
- Carrier 2 offers only connecting service in A-C constructed from local service

Carrier Revenues in A-C Market
Under Three Distributions of System Demand
Demand Factor = 0.9




Traffic Composition in A-C Market
Equal System Demand Distribution & Demand Factor = 0.9
Nonstop Carrier (NSC)
Local Service Carrier (LSC)
Passengers
0
10
20
30
40
50
60
70
80
Only LSC Has EMSRa
Only NSC Has EMSRa
Both Carriers Have EMSRa
Only LSC Has EMSRa
Only NSC Has EMSRa
Both Carriers Have EMSRa
Scenario and Carrier
■ Q Class
☐ Y, B, and M Class Total

Three Market Scenarios: Preliminary Findings

- Local service carrier receives larger percentage revenue gains from RM control
- High local demand limits potential benefit of RM for both carriers
- Indirect revenue benefit for local service carrier when nonstop rival introduces control

Conclusions:
RM in Competitive Environment

- Variable "first-mover" advantage
- Non-zero-sum revenue game
- Control pairings decide fate of spilled pax
- Benefits achievable with RM depend on
  - ⇒rival's RM capability
  - – demand, frequency, and network attributes

Research Extensions Under Current Project Plan

- Existing model
  - alternative forecasting systems
  - larger networks
- Enhanced reservation process model: cancellations, overbooking, no-shows
- Assessment of network-based RM methods

Human-Centered Automation of Air Traffic Control Operations in the Terminal Area

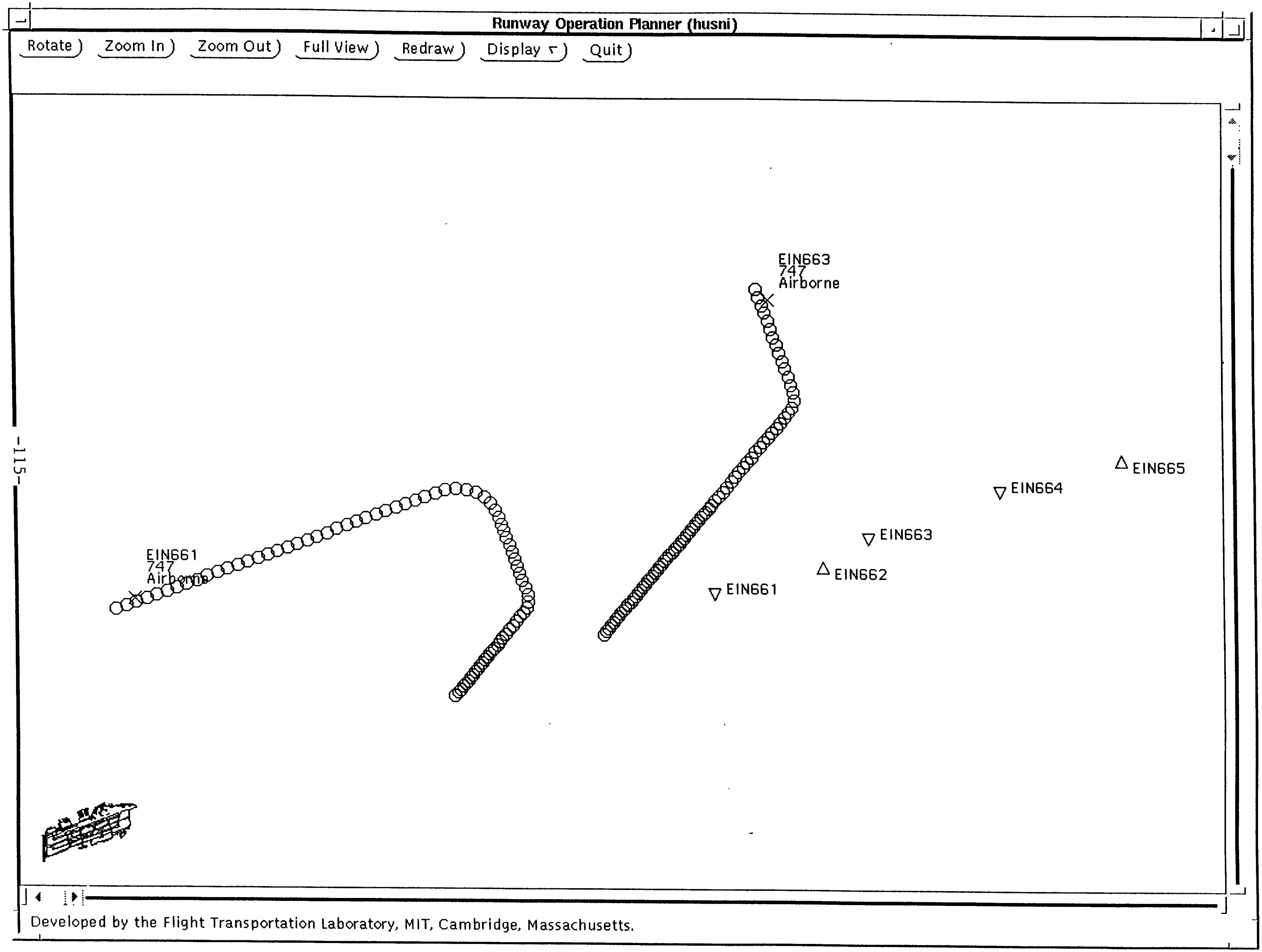
ASLOTS

A Decision Support System to Assist Controllers in the Final Approach and Landing Operations

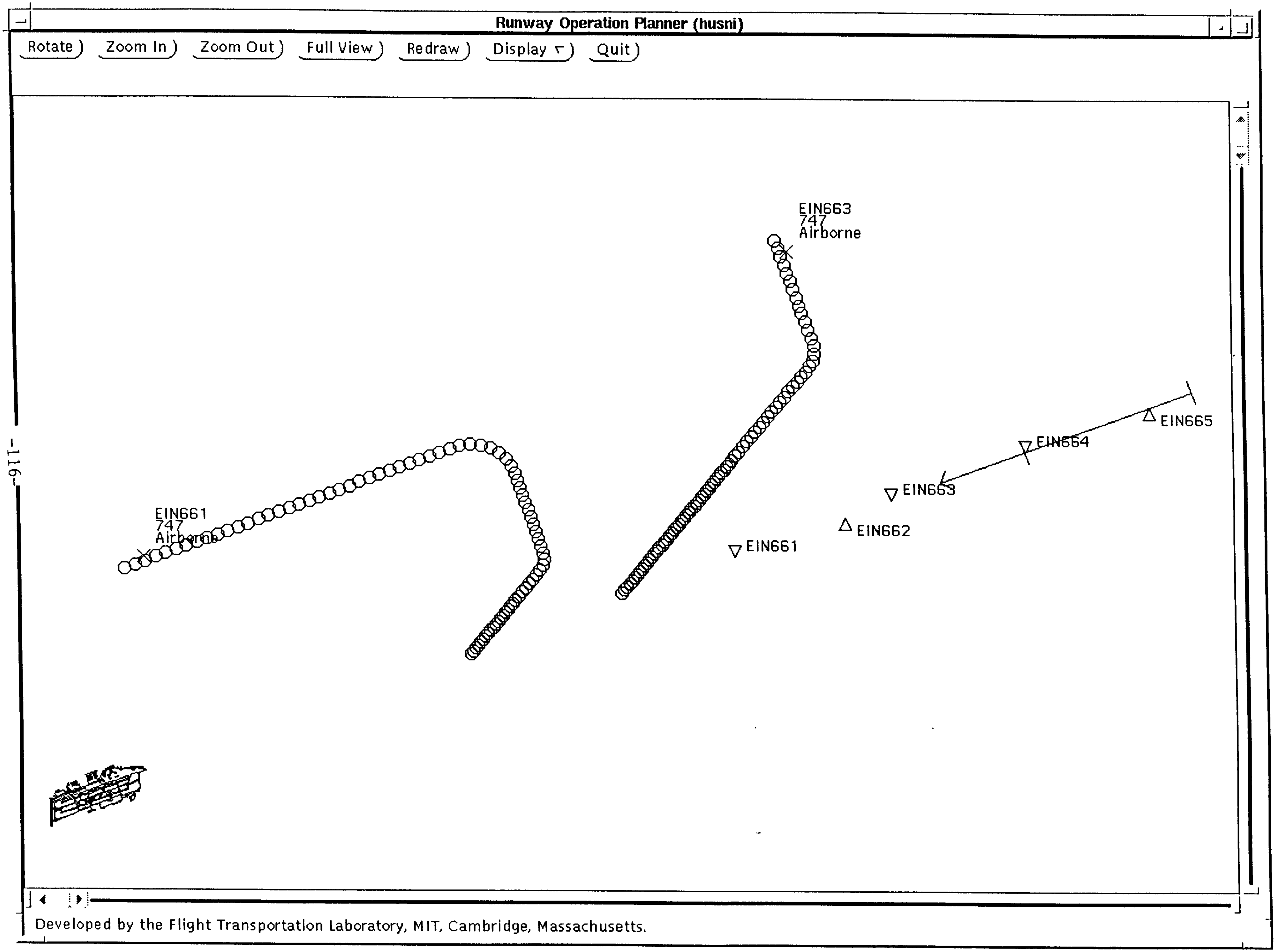
Husni Idris
Flight Transportation Laboratory
MIT

ATC Operations in the Terminal Area:

- Upstream of entry points:
  - Flight management
  - Flow control
- Runway scheduling
- Approach path generation
- Conformance monitoring
- Hazard monitoring



Developed by the Flight Transportation Laboratory, MIT, Cambridge, Massachusetts.

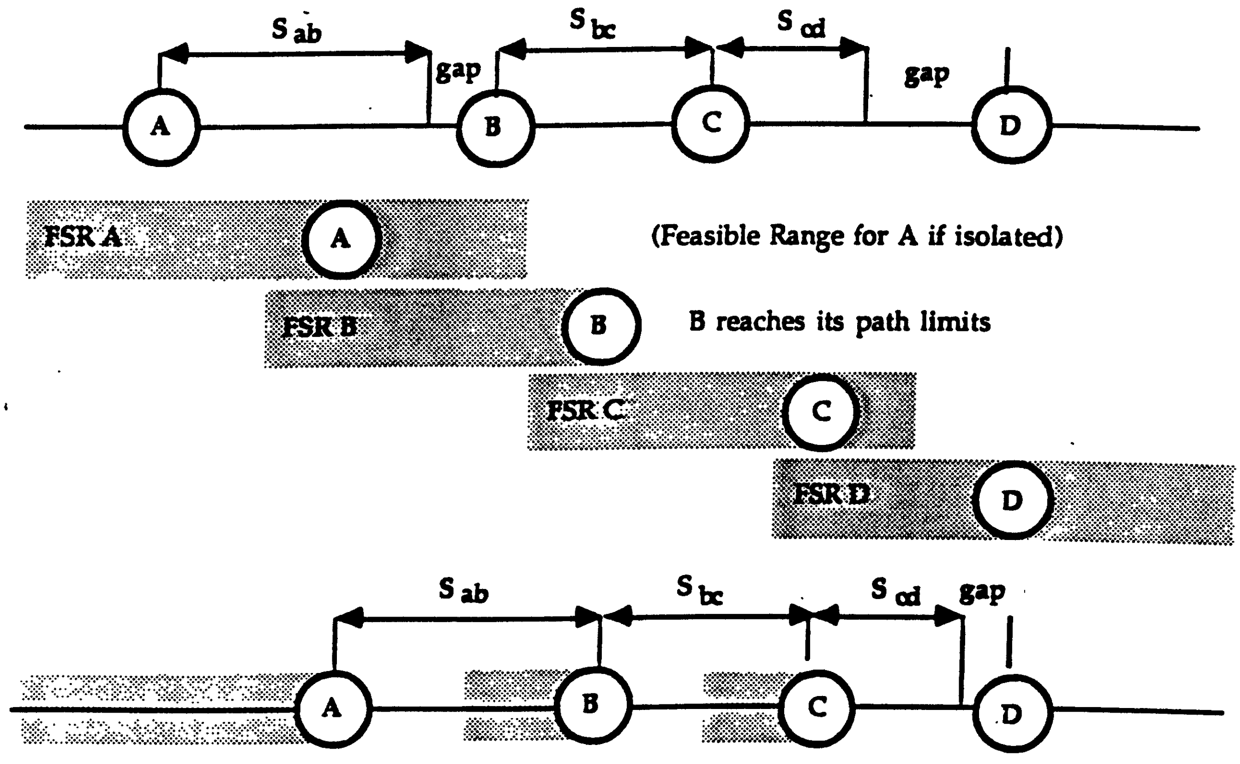


Developed by the Flight Transportation Laboratory, MIT, Cambridge, Massachusetts.

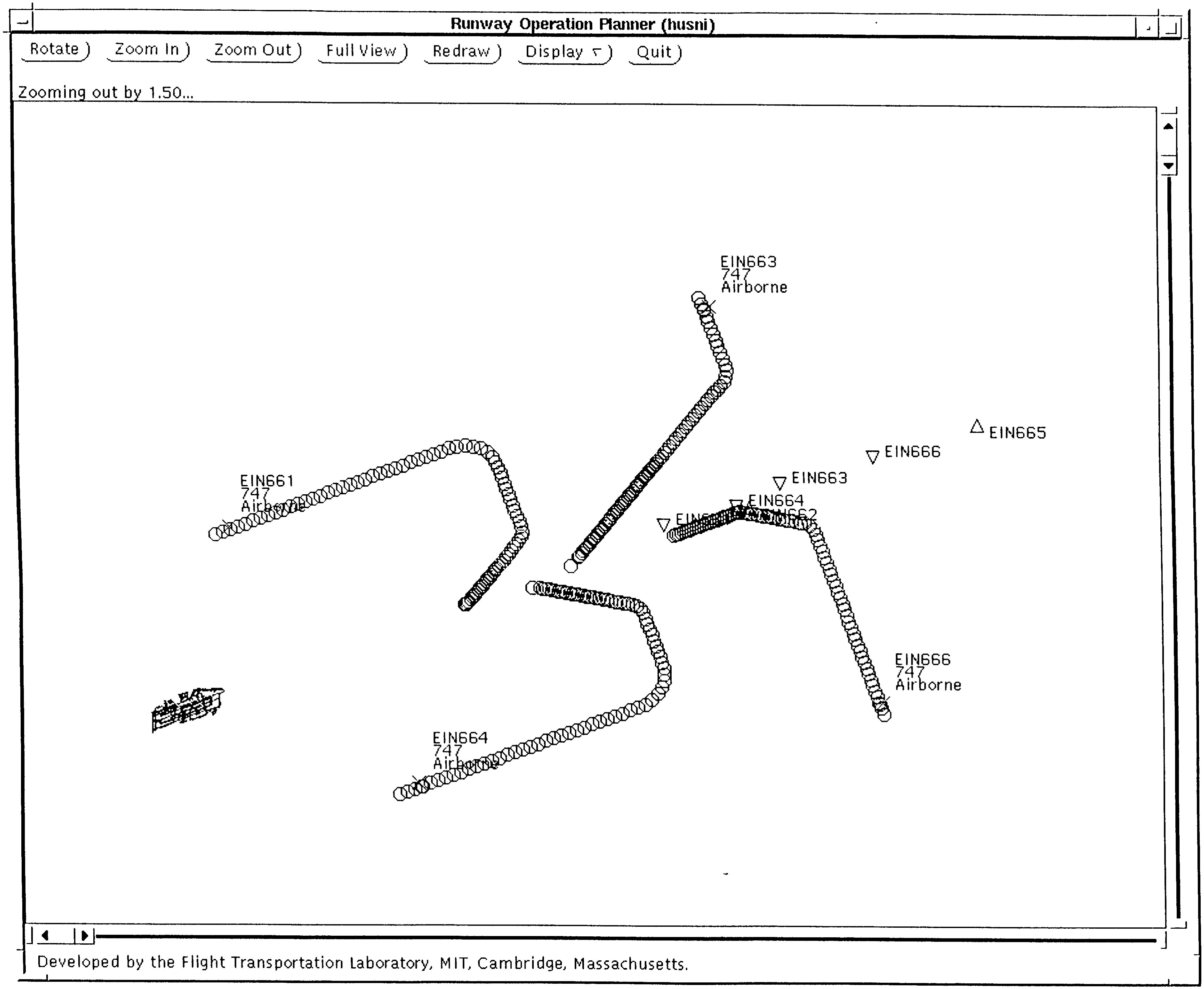
Automatic Rearward Shifting of Slots (ARS)

Example:

> If an attempt is made to shift A rearwards, it cannot reach the limit of its feasible range because it must maintain a separation Sab from B ; and when B reaches the limit of its range, A cannot be moved further and maintain separation from B. As B moves rearward, C is also moved since it is tight in the original spacing, but when B reaches its limit, C stops moving rearward and since there still is excess spacing from D, it turns out that D does not have to be shifted. The shift range shown to the controller will instantly show how far each aircraft can be shifted in any situation so that the complexity of the shifting need not be known.

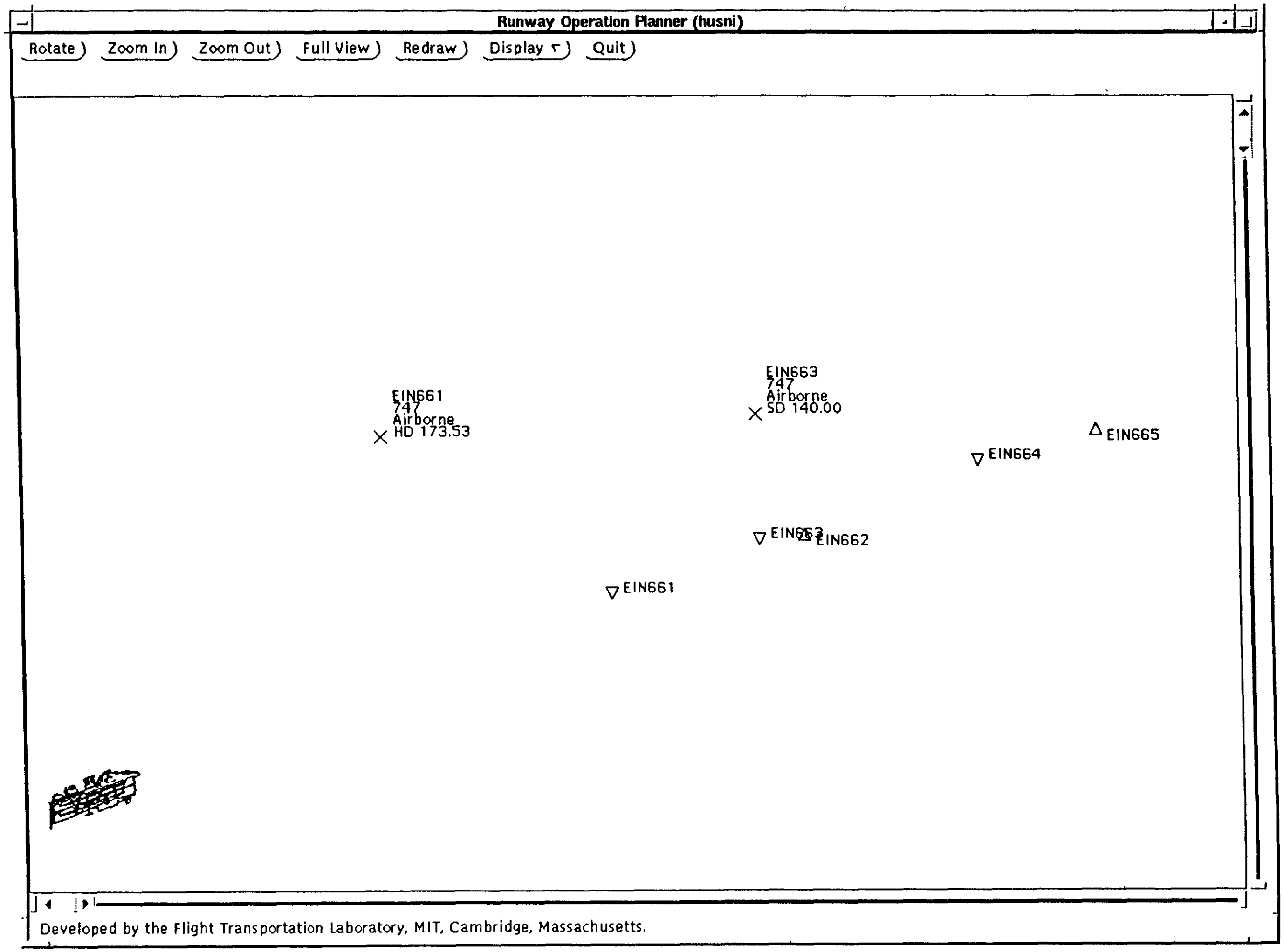


Displayed shift range

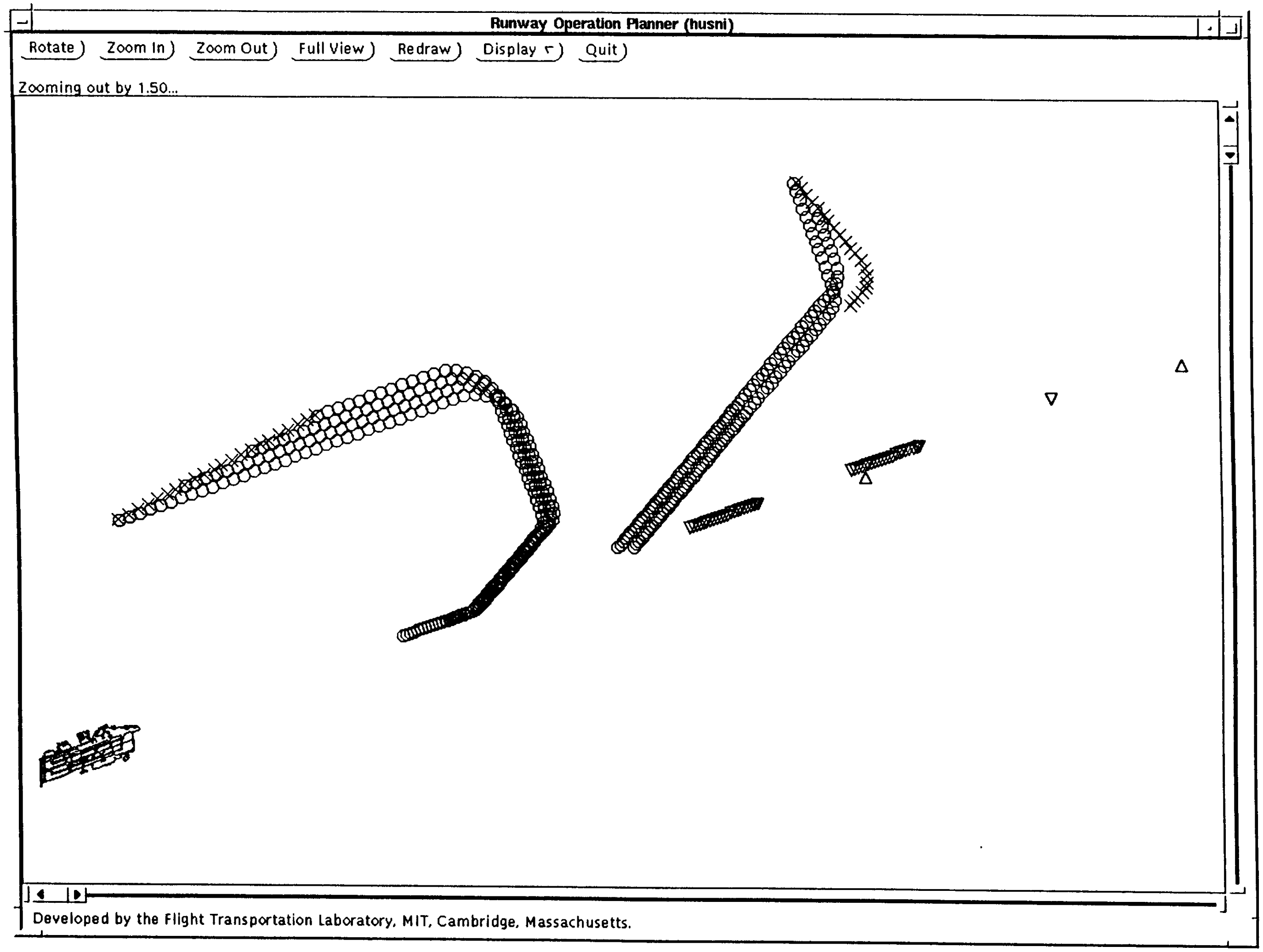


Zooming out by 1.50...

Developed by the Flight Transportation Laboratory, MIT, Cambridge, Massachusetts.



Developed by the Flight Transportation Laboratory, MIT, Cambridge, Massachusetts.



Zooming out by 1.50...

Developed by the Flight Transportation Laboratory, MIT, Cambridge, Massachusetts.

ASLOTS: a human-centered automation system for terminal area operations

- **Runway scheduling:**
  - Manual change of schedule within a limited range: moving the slot markers
  - Manual resequencing of landings: moving the slot markers
  - Manual insertion of takeoffs between landings: using the slot markers
  - Automatic update of the schedule after a manual change: automatic rearward shifting
  - Automatic update of the schedule after a centerline interception error: centerline adaptation
- **Approach path generation:**
  - Automatic assignment of patterns
  - Automatic approach path generation: providing cues for appropriate clearances
  - Manual delivery of clearances following the automatic cues

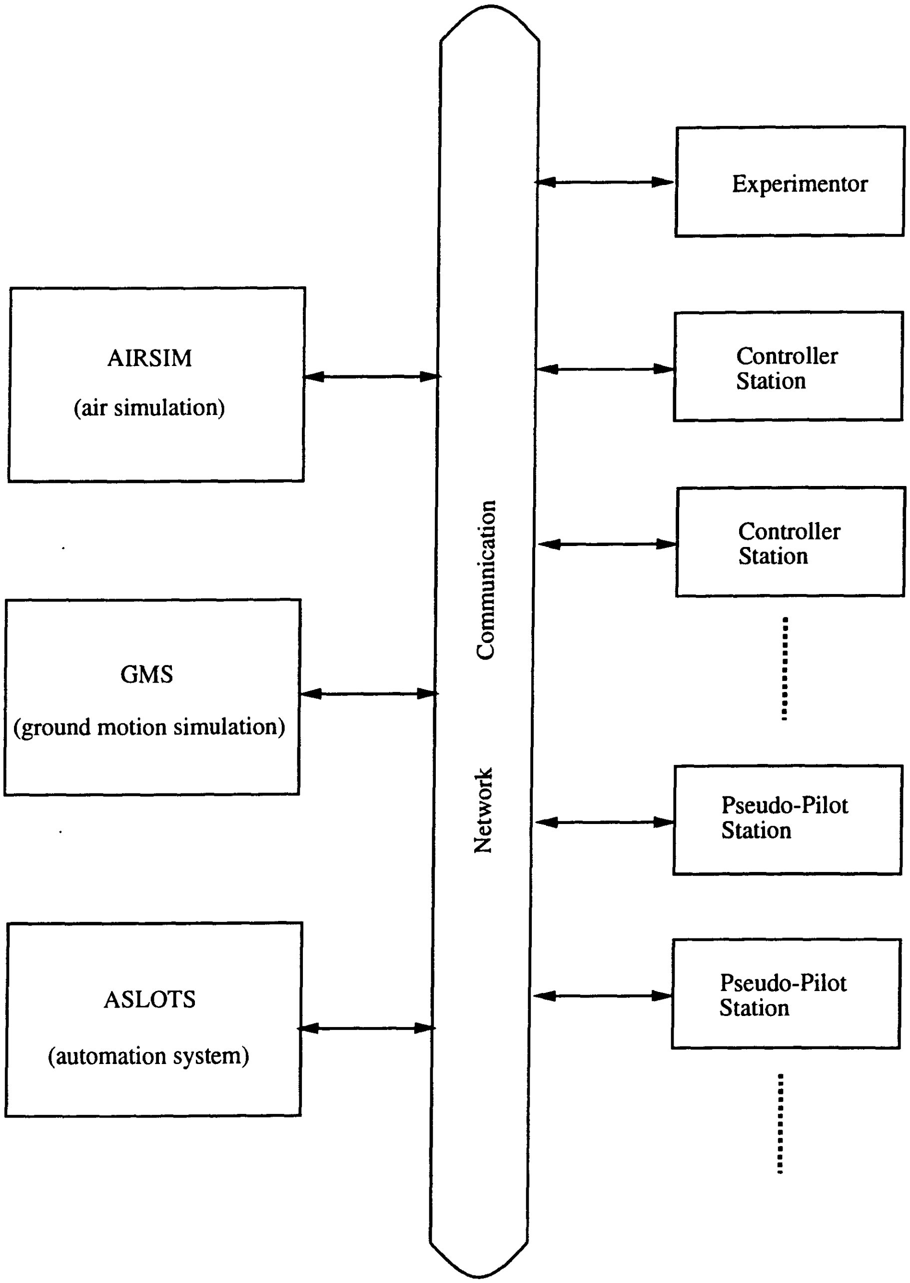
- **Conformance monitoring:**
  - Automatic regeneration of the approach path after a conformance error
  - Automatic regeneration of the approach path after moving the slot marker
- **Hazard monitoring:**
  - Automatic maintenance of the minimum separation between aircraft on the centerline: automatic rearward shifting and centerline adaptation

Level of automation between the human controller and the computer in path generation

Path Generation	Path Choice	Sending Clearances
Human controller generates alternative paths	Human controller chooses path	Human controller sends clearances
Computer generates alternative paths	Human controller chooses path	Human controller sends clearances
Computer generates and selects alternative paths	Human controller chooses path	Human controller sends clearances
Computer generates and advises best paths	Human controller chooses path	Human controller sends clearances
Computer generates and advises best paths	Human controller chooses path	Computer sends clearances if human controller ok
Computer generates alternative paths	Computer chooses path	computer sends clearances, if human controller generates no veto
Computer generates alternative paths	Computer chooses path	computer sends clearances, but must inform human controller
Computer generates alternative paths	Computer chooses path	computer sends clearances, informs human controller if human controller asks
Computer generates alternative paths	Computer chooses path	computer sends clearances, informs human controller if computer agrees
Computer generates alternative paths	Computer chooses path	computer sends clearances

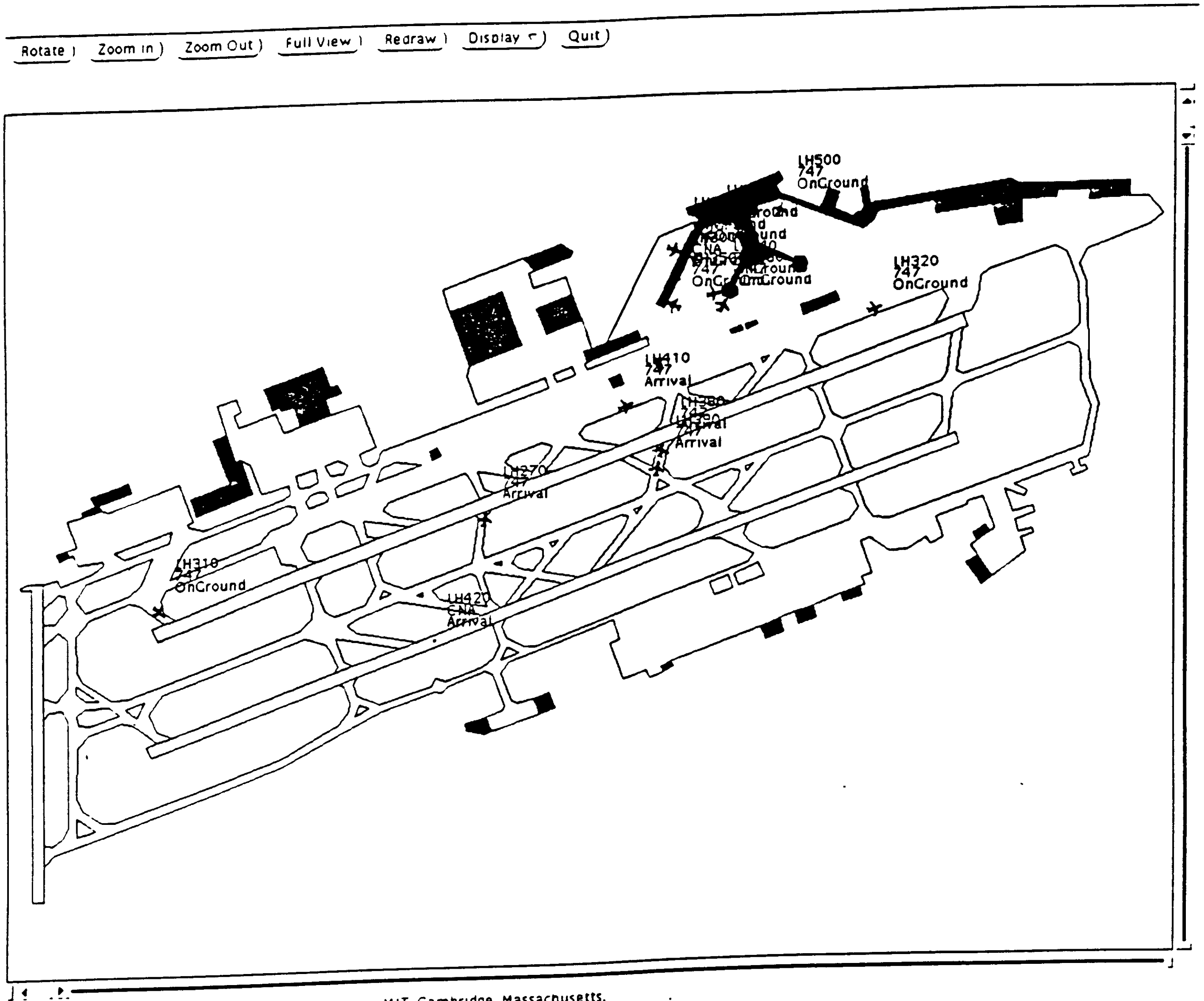
Two main design questions

- Allocation of tasks between the human controller and the ASLOTS automation: Should a task be automated or not?
- Given the tasks to be automated, how should the automation be implemented?


Experimentor
AIRSIM
(air simulation)
Controller Station
Controller Station
Communication
GMS
(ground motion simulation)
Network
Pseudo-Pilot Station
ASLOTS
(automation system)
Pseudo-Pilot Station

Experiment main issues

- The reliability and robustness of the system
- The performance (efficiency) of the system
- The characteristics of the new work responsibilities of the air traffic controller
- The appropriate allocation of tasks between the air traffic controller and the computer under dynamic conditions
- The appropriate design of the graphical interface



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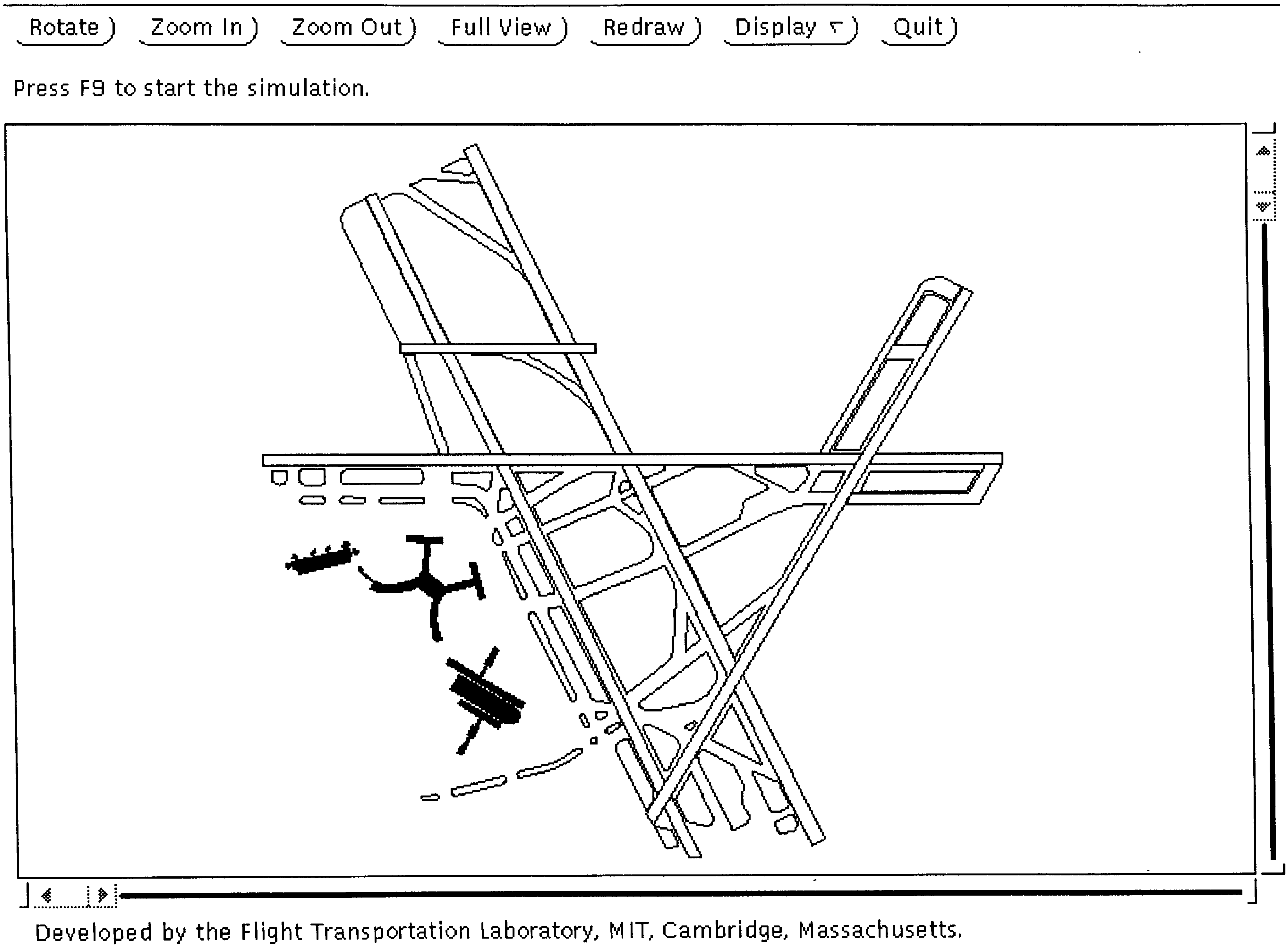


Press F9 to start the simulation.

Developed by the Flight Transportation Laboratory, MIT, Cambridge, Massachusetts.

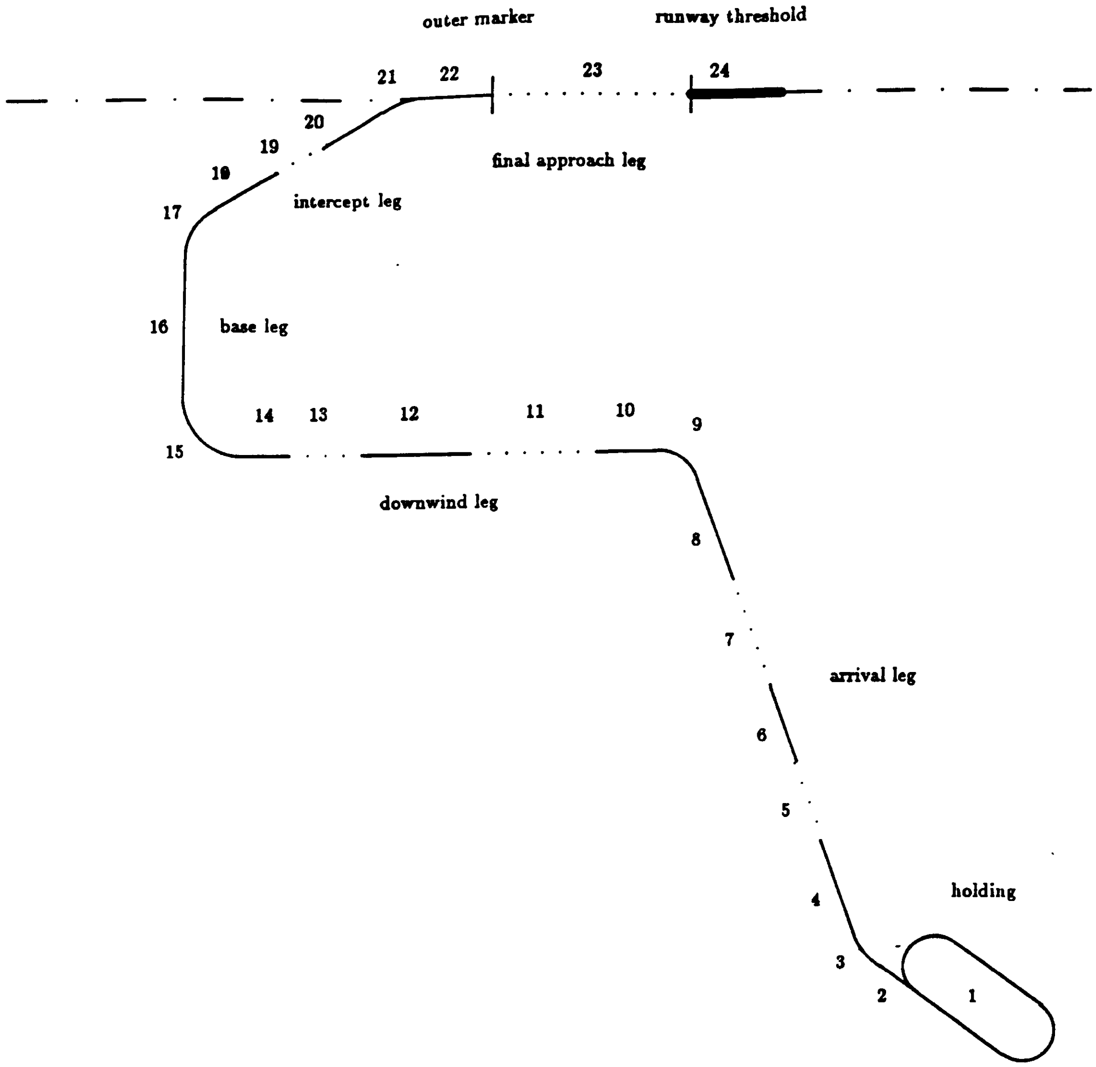


Figure 4.1: “Arrival-Trombone” Pattern

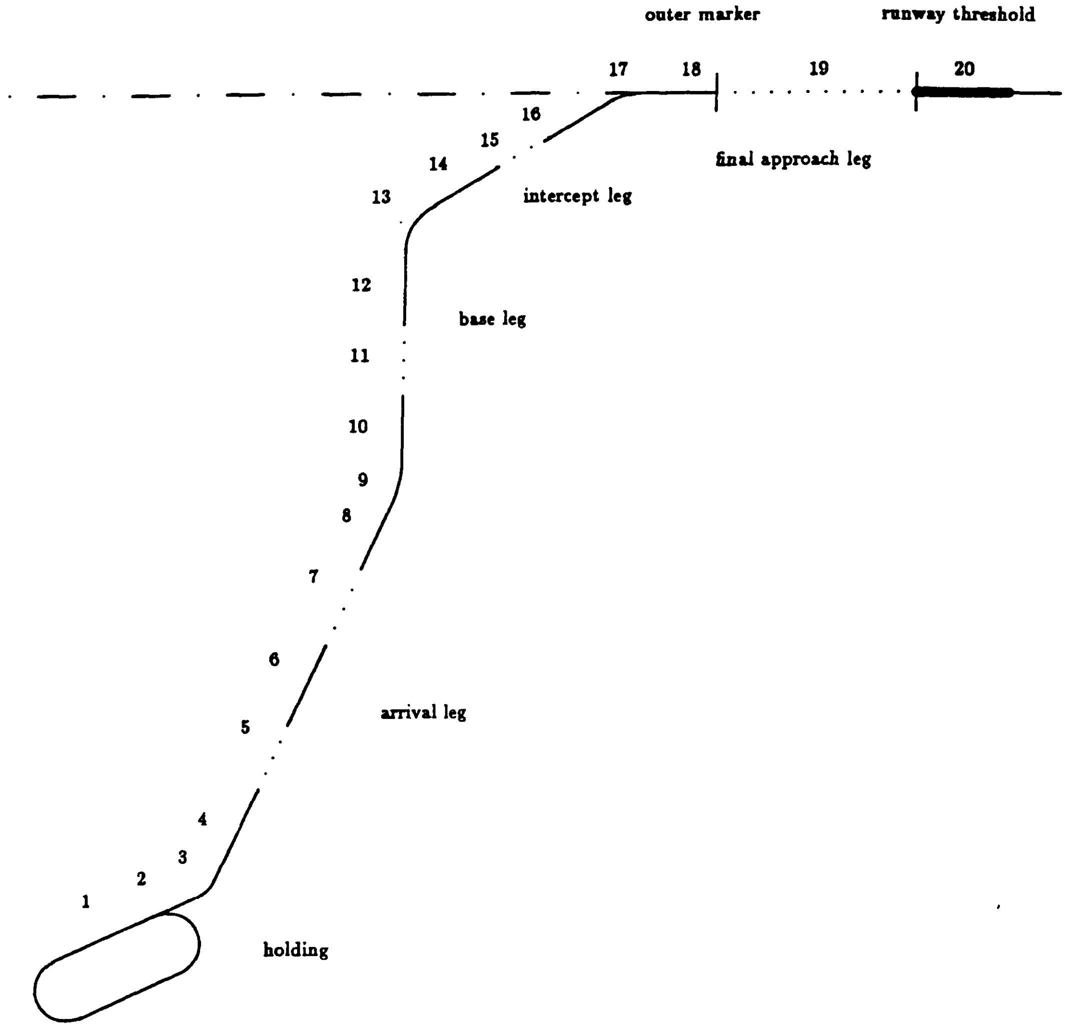


Figure 4.9: "Arrival-Direct-to-Base" Pattern

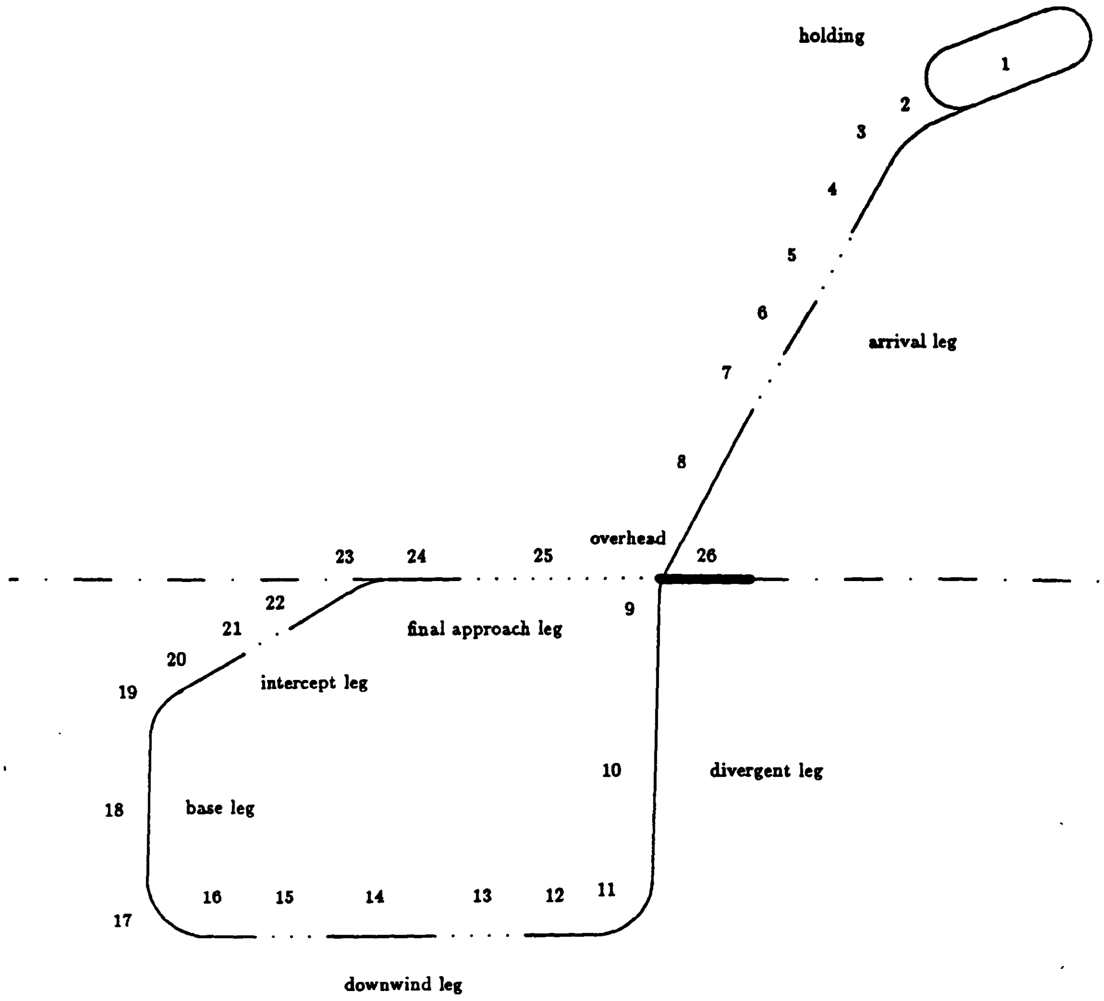


Figure 4.8: "Overhead-Trombone" Pattern

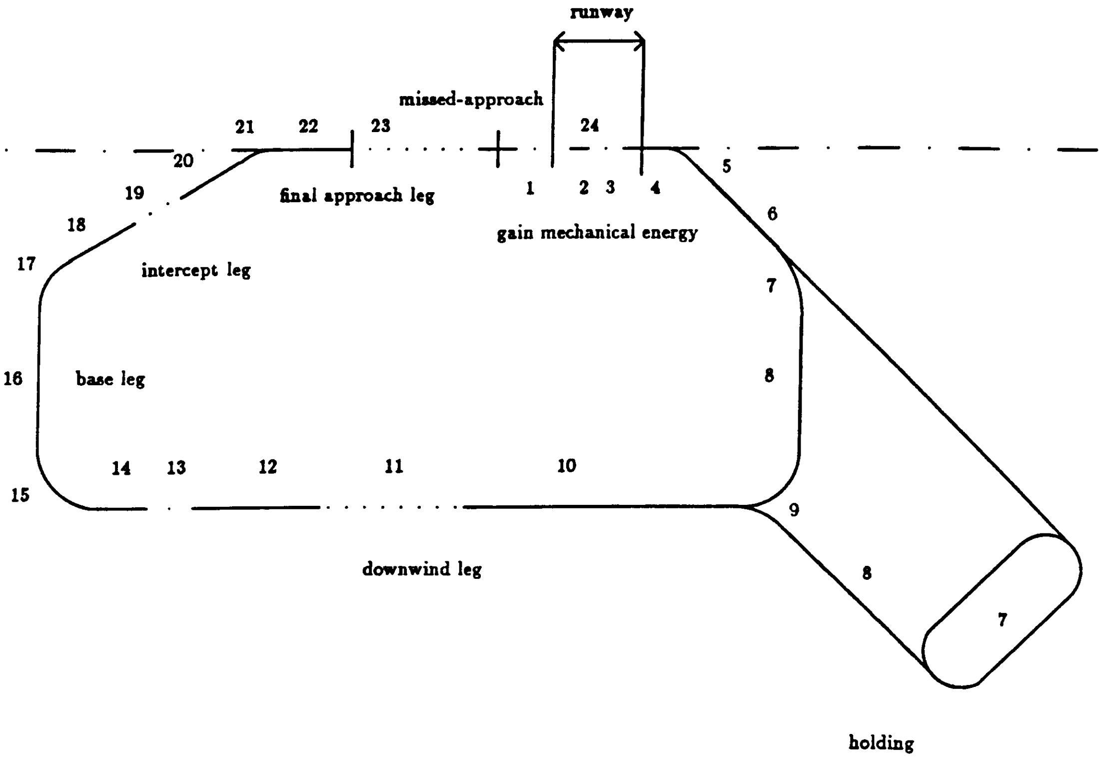


Figure 4.10: "Missed-Approach" Pattern

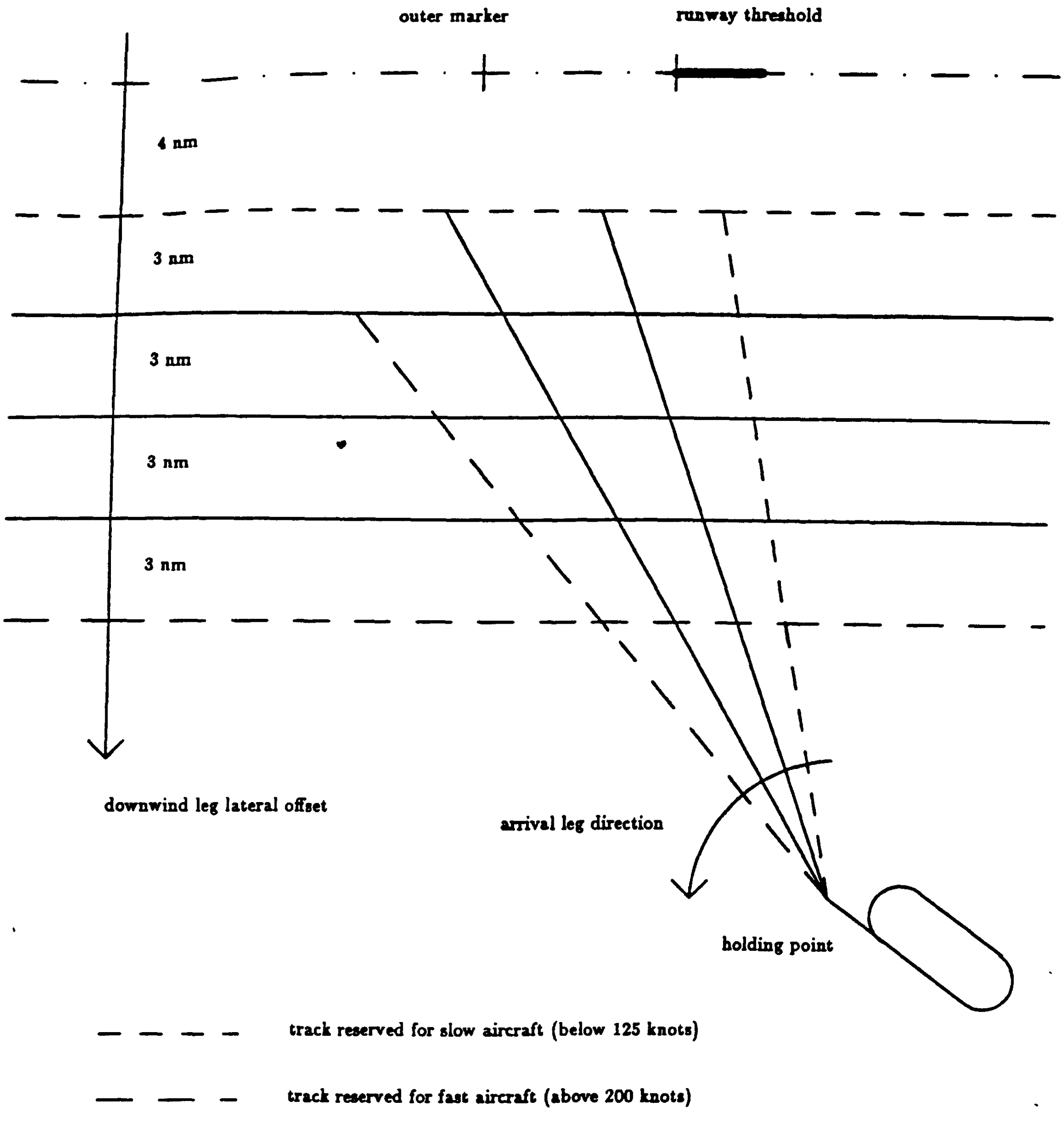


Figure 4.2: Air-space organization

Flexibility as an objective

- Choose the center of the solution set

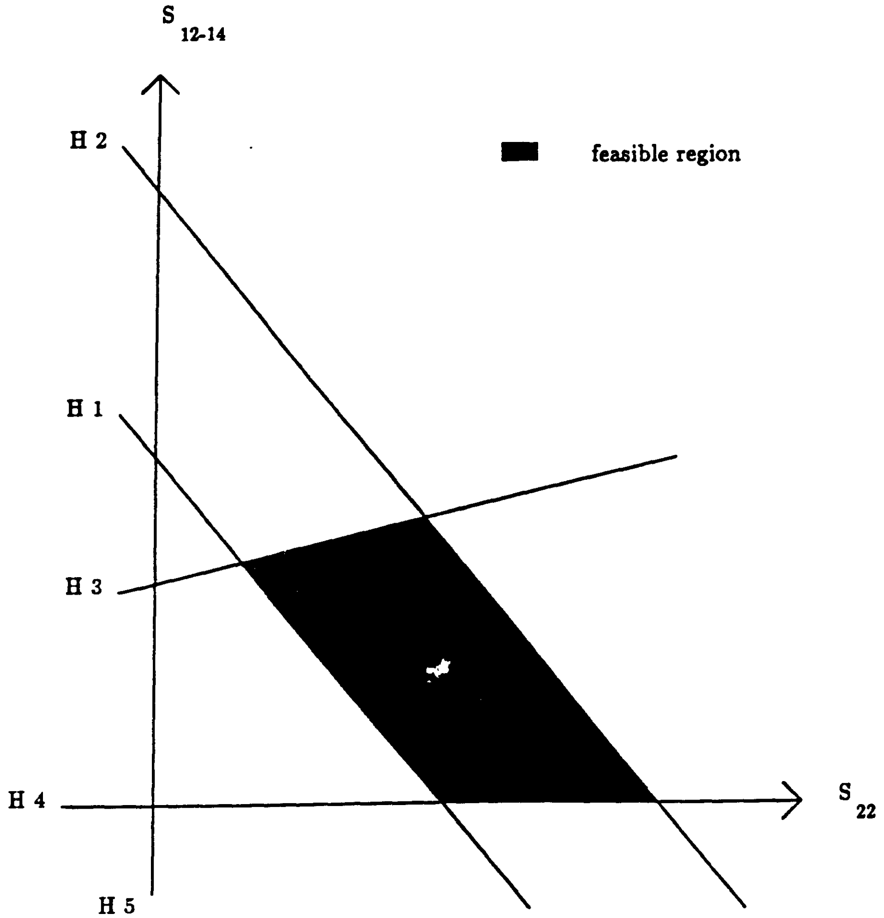
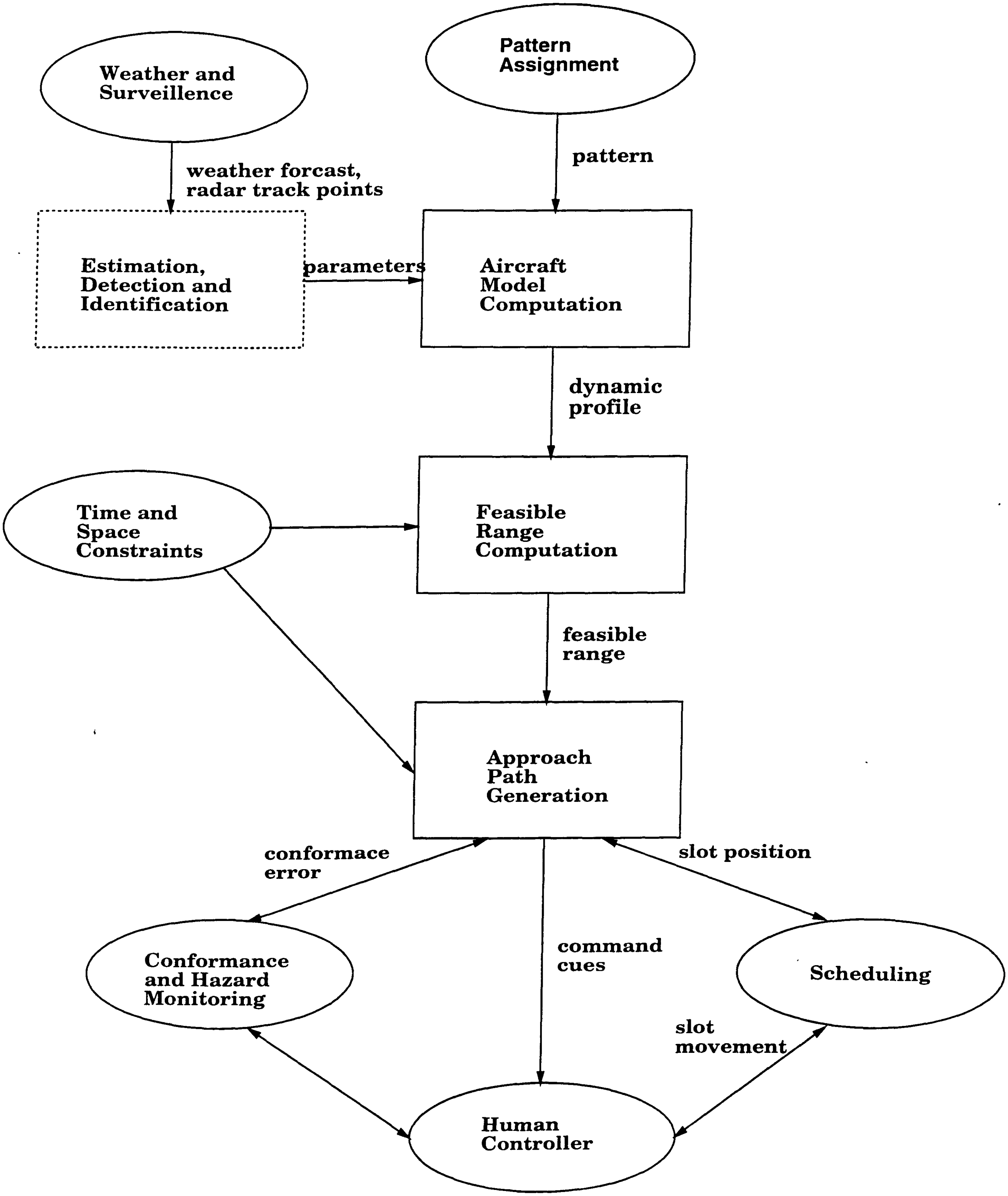


Figure 4.4: Feasible region

ASLOTS' Path Generation

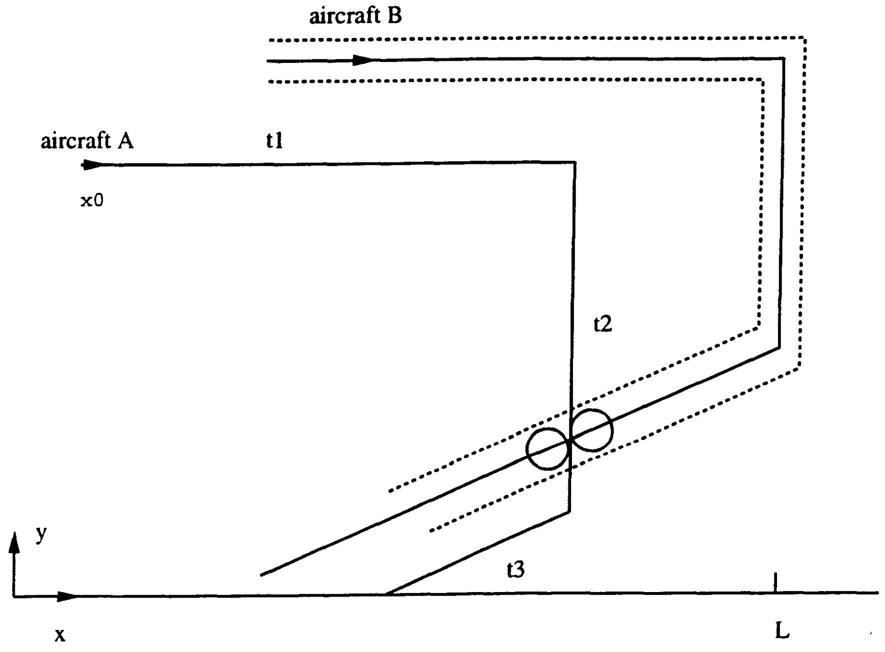


Automation of the conflict avoidance task

- Monitor the conflicts manually, with ASLOTS providing graphical tools such as path previews
- Automated conflict avoidance:
  - Sadoune's generate-and-test scheme
  - Integrate conflict avoidance as constraints in the path generation problem

Conflict avoidance as constraints in the path generation problem

if $t1 < (L - x0)/v$
then either $t1 < c1$ or $t1 > c2$
where $c1$ and $c2$ are constants which depend on the path parameters
if $t1 > (L - x0)/v$
then ...



Efficiency considerations

- Satisficing by using an approximation to the optimal solution
- Reducing the size of the problem by setting the duration of the latest segments to nominal values

Remaining tasks towards running experiments

- Complete the path generation and conflict avoidance automation
- Investigate the runway assignment and scheduling task and implement its automation (as possible)
- Design the graphical interface functions and tools along with the implementation of the main tasks
- Design the experiment(s) (addressing mainly the dynamic automation level issue)
- Perform experiments

FREIGHT MODE CHOICE:
AIR VERSUS OCEAN TRANSPORT

MAY 19, 1995

RAYMOND A. AUSROTAS
FLIGHT TRANSPORTATION LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

LARGE ALL-CARGO AIRCRAFT SYSTEM

(LACAS)

SCOPE OF STUDY

TASK 1.

A. ANALYZE CONTAINER SHIP SYSTEMS

- SYSTEM OPERATION-INTERMODAL ISSUES-TRUCK, RAIL, SHIP
- COSTS OF PROVIDING SERVICE
- PRICE OF SERVICE

B. ANALYZE FREIGHT FLOWS AROUND THE WORLD

- VOLUME OF CARGO
- TYPE OF CARGO CARRIED
- ORIGIN AND DESTINATION OF CARGO

TASK 2.

IDENTIFY POTENTIAL DIVERSION OF CONTAINER FREIGHT TO A LARGE ALL-CARGO AIRCRAFT SYSTEM BY USING LOGISTICS MODEL

- MARKET SHARE ANALYSIS BASED ON VALUE OF CARGO, PERISHABILITY, AND COST OF ORDERING AND PROVIDING TRANSPORTATION SERVICES

FREIGHT MODE CHOICE:

AIR TRANSPORT VERSUS OCEAN TRANSPORT IN THE 1990's

Dale B. Lewis

December 1994

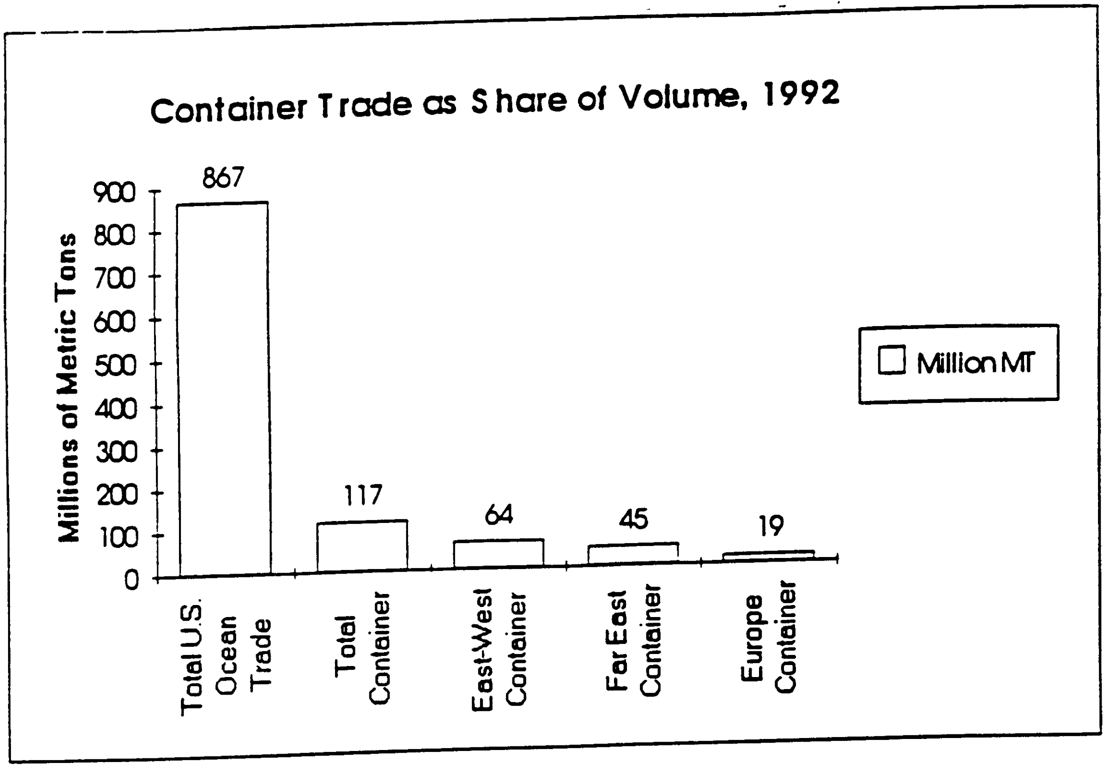
FTL Report 94-9

Flight Transportation Laboratory
Massachusetts Institute of Technology
77 Massachusetts Avenue
Cambridge, MA 02139

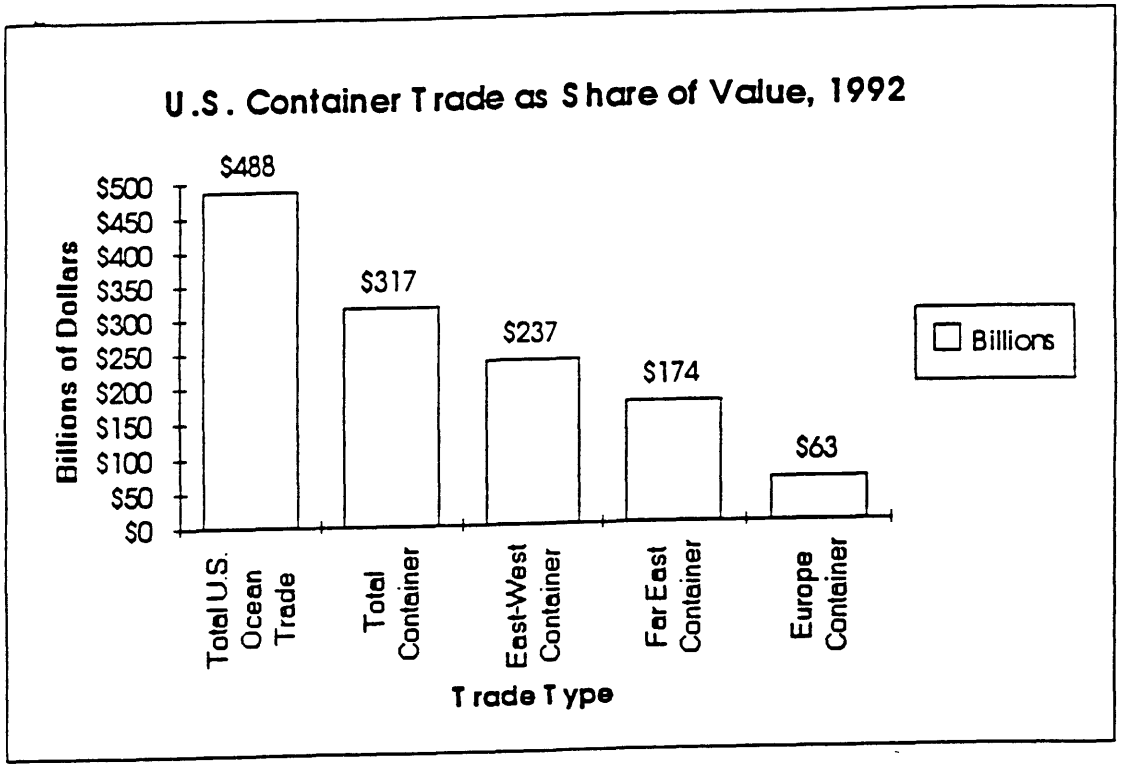
1992 World Trade Comparison - U.S.

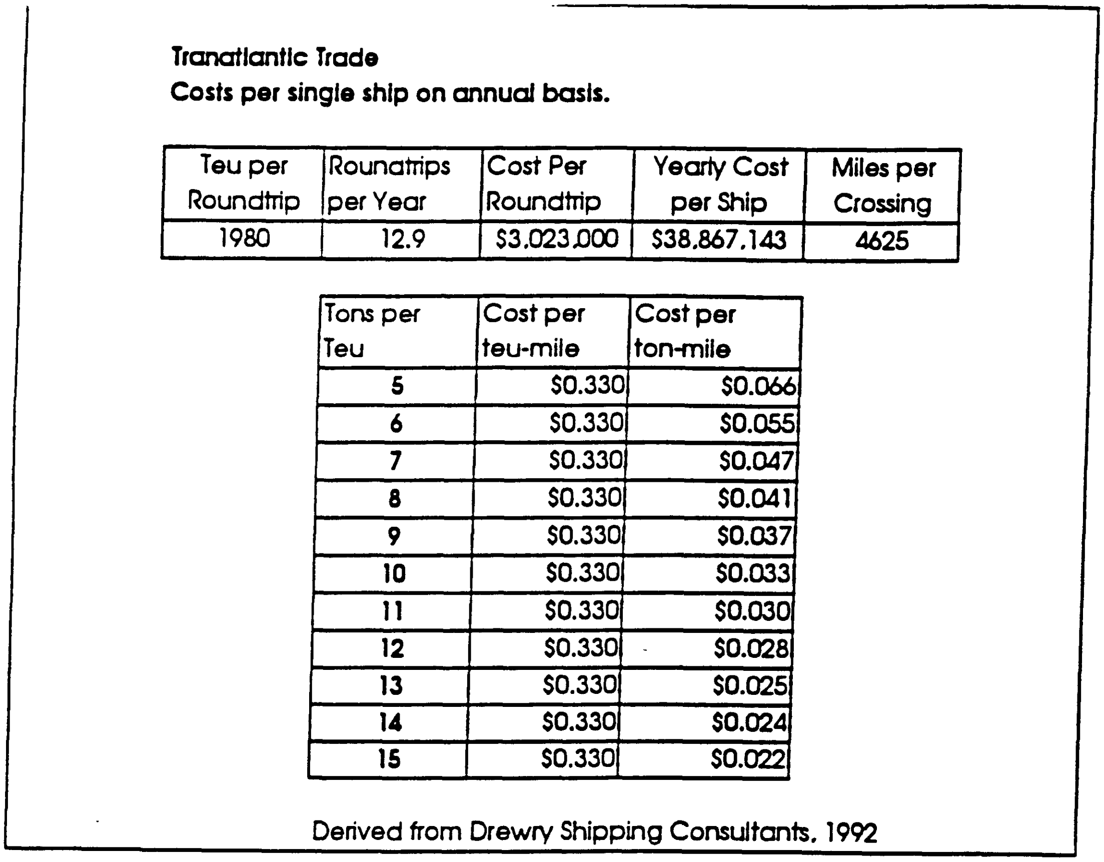
Trade Area	Metric Tons Ocean All Cargo	Metric Tons Ocean Container	Metric Tons Air All Cargo	Air Tons as % of Ocean
World	867,000,000	117,000,000	4,224,045	3.6%
Europe		19,000,000	1,591,589	8.4%
Far East		45,000,000	1,232,549	2.7%
Other		53,000,000	1,399,907	2.6%

Source: MARAD and Office of International Aviation



Container Trade as Share of Volume, 1992


U.S. Container Trade as Share of Value, 1992
Billions of Dollars
$500
$450
$400
$350
$300
$250
$200
$150
$100
$50
$0
$488
$317
$237
$174
$63
Total U.S. Ocean Trade
Total Container
East-West Container
Far East Container
Europe Container
Trade Type
☐ Billions



Tranatlantic Trade
Costs per single ship on annual basis.

Teu per Roundtrip	Rounatrips per Year	Cost Per Roundtrip	Yearly Cost per Ship	Miles per Crossing
1980	12.9	$3,023,000	$38,867,143	4625

Tons per Teu	Cost per teu-mile	Cost per ton-mile
5	$0.330	$0.066
6	$0.330	$0.055
7	$0.330	$0.047
8	$0.330	$0.041
9	$0.330	$0.037
10	$0.330	$0.033
11	$0.330	$0.030
12	$0.330	$0.028
13	$0.330	$0.025
14	$0.330	$0.024
15	$0.330	$0.022

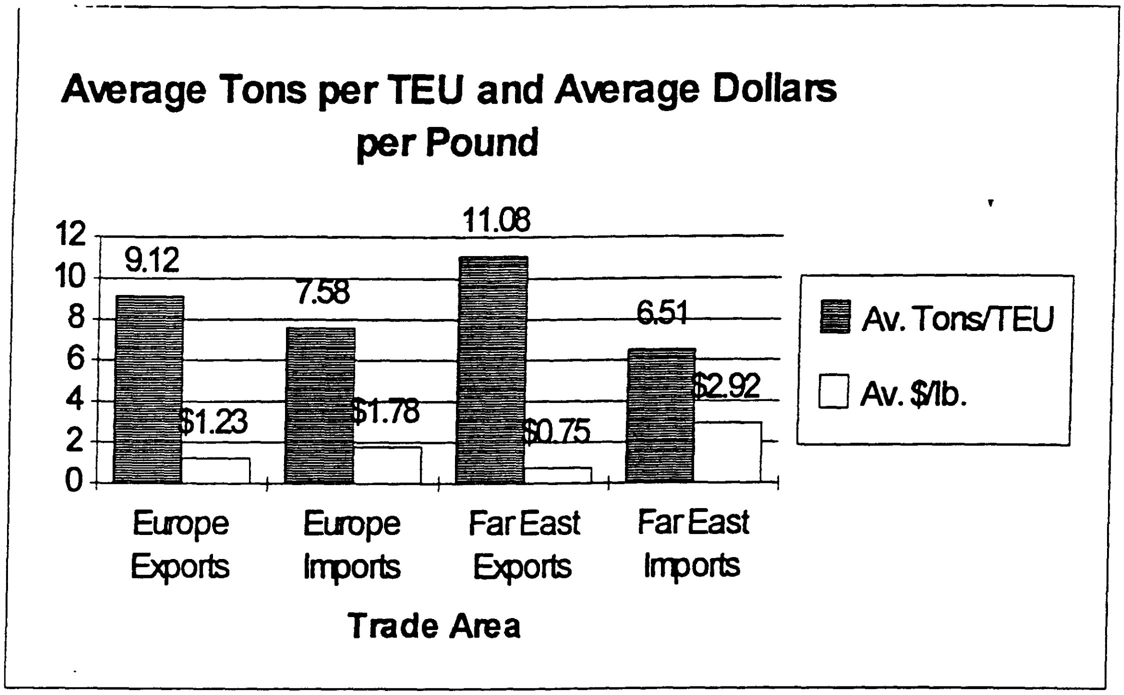
Derived from Drewry Shipping Consultants, 1992

Transpacific Trade
Costs per single ship on annual basis.

Teu per Roundtrip	Roundtrips per Year	Cost Per Roundtrip	Yearly Cost per Ship	Miles per Crossing
4094	8.57	$7,114,000	$60,469,000	8275

Tons per Teu	Cost per teu-mile	Cost per ton-mile
5	$0.208	$0.042
6	$0.208	$0.035
7	$0.208	$0.030
8	$0.208	$0.026
9	$0.208	$0.023
10	$0.208	$0.021
11	$0.208	$0.019
12	$0.208	$0.017
13	$0.208	$0.016
14	$0.208	$0.015
15	$0.208	$0.014

Derived from Drewry Shipping Consultants, 1992


Average Tons per TEU and Average Dollars per Pound
12
10
8
6
4
2
0
9.12
$1.23
7.58
$1.78
11.08
$0.75
6.51
$2.92
Europe Exports
Europe Imports
Far East Exports
Far East Imports
Trade Area
Av. Tons/TEU
Av. $/lb.

Exports by Air and Ocean, Port of New York

(Nonbulk Products)

YEAR 1992	Metric Tons (Thousands)	Dollars (Millions)	Average Value/lb.
Ocean	4,354	$17,739	$1.82
Air Cargo	415	$36,032	$38.76

Source: Port of New York Data

Appendix D-1

1992 Leading Ocean Exports, Port of New York

			Ocean			Air			Cubic Value Density	
									Ocean	Air
U.N. Class	Density Pounds per foot	Commodity	Tons (000s)	Value Dollars (Millions)	Value Dollars per lb.	Tons (000s)	Value Dollars (Millions)	Value Dollars per lb.	Value Dollars per cu.ft.	Value Dollars per cu.ft.
		Leading Ocean Exports								
73	6	Road Motor Vehicles	182	$1,501	$3.70	6	$148	$11.10	$22.20	$66.60
71	33	Machinery General	108	$1,397	$5.80	26	$1,310	$22.50	$191.40	$742.50
57	36	War Material	17	$675	$17.20	2	$272	$66.70	$619.20	$2,401.20
86	27	Photo Supplies	33	$670	$8.90	4	$181	$19.50	$240.30	$526.50
71	20	Office Machinery	21	$635	$13.30	32	$4,899	$68.00	$266.00	$1,360.00
73	17	Scientific Instruments	18	$502	$12.70	17	$2,508	$65.30	$215.90	$1,110.10
71	33	Machinery for Special Ind.	37	$453	$5.50	6	$313	$23.10	$181.50	$762.30
72	21	Electrical Machinery	40	$424	$4.70	15	$3,066	$90.20	$98.70	$1,894.20
73	32	Gas Engines and Diesels	40	$374	$4.20	4	$315	$31.60	$134.40	$1,011.20
73	8	Aircraft and Parts	4	$346	$38.60	10	$2,805	$127.00	$308.80	$1,016.00
71	33	Metal Working Machinery	22	$345	$7.00	4	$229	$26.90	$231.00	$887.70
72	36	Electric Motors and Generators	19	$298	$6.90	12	$1,118	$39.90	$248.40	$1,436.40
89	33	Printed Matter	36	$245	$3.00	18	$602	$23.60	$99.00	$778.80
72	22	Telecommunications Apparatus	9	$239	$11.20	10	$1,659	$71.10	$246.40	$1,564.20
		TOTALS	586	$8,104		166	$19,425			

U.N. =United Nations Standard International Trade Classification Index
Density is drawn from the U.N. table

Appendix D - 2

1992 Leading Air Exports Not on Leading Ocean List, Port of New York

			Ocean			Air			Cubic Value Density Ocean	Cubic Value Density Air
U.N. Class	Density lb / cu.ft	Commodity	Tons (000s)	Value Dollars (Millions)	Value Dollars per lb.	Tons (000s)	Value Dollars (Millions)	Value Dollars per lb.	Value Dollars per cu.ft.	Value Dollars per cu.ft.
		Leading Air Exports								
3	30	Fish and Fish Products	42	$111	$1.20	13	$92	$3.00	$36.00	$90.00
58	13	Plastic Materials	267	$708	$1.20	11	$139	$5.90	$15.60	$76.70
84	18	Clothing	20	$188	$4.20	9	$307	$14.50	$75.60	$261.00
54	21	Pharmaceuticals	16	$201	$5.40	9	$1,572	$80.30	$113.40	$1,686.30
64	20	Paper and Paperboard Mfgs.	40	$99	$1.10	9	$33	$1.70	$22.00	$34.00
65	16	Woven Fabrics (except cotton)	22	$157	$3.10	9	$127	$6.70	$49.60	$107.20
86	20	Sound Recorders	14	$157	$4.90	7	$569	$37.30	$98.00	$746.00
86	20	Electro-Medical Apparatus	2	$102	$18.30	6	$1,350	$76.00	$366.00	$1,520.00
64	32	Paper and Paperboard	100	$159	$0.70	6	$13	$1.00	$22.40	$32.00
73	32	Internal Combustion Engines	10	$185	$8.60	6	$2,373	$189.00	$275.20	$6,048.00
		TOTALS	**533**	**$2,067**		**85**	**$6,575**			

U.N. =United Nations Standard International Trade Classification Index
Density is drawn from the U.N. table

Appendix D-3

1992 Leading Air Exports, Port of New York, Ordered by Dollar Value

U.N. Class	Density lb/cu.ft.		Tons (000s)	Value Dollars (Millions)	Value Dollars per lb.	Cubic Feet (000s)	Pounds (000s)	Cubic Value Density
71	20	Office Machinery	32	$4,899	$68.00	3,584	71,680	$1,360
72	21	Electrical Machinery	15	$3,066	$90.20	1,600	33,600	$1,894
73	8	Aircraft and Parts	10	$2,805	$127.00	2,800	22,400	$1,016
73	17	Scientific Instruments	17	$2,508	$65.30	2,240	38,080	$1,110
73	32	Internal Combustion Engines	6	$2,373	$189.00	420	13,440	$6,048
72	22	Telecommunications Apparatus	10	$1,659	$71.10	1,018	22,400	$1,564
54	21	Pharmaceuticals	9	$1,572	$80.30	960	20,160	$1,686
86	20	Electro-Medical Apparatus	6	$1,350	$76.00	672	13,440	$1,520
71	33	Machinery General	26	$1,310	$22.50	1,765	58,240	$743
72	36	Electric Motors and Generators	12	$1,118	$39.90	747	26,880	$1,436
89	33	Printed Matter	18	$602	$23.60	1,222	40,320	$779
86	20	Sound Recorders	7	$569	$37.30	784	15,680	$746
73	32	Gas Engines and Diesels	4	$315	$31.60	280	8,960	$1,011
71	33	Machinery for Special Ind.	6	$313	$23.10	407	13,440	$762
84	18	Clothing	9	$307	$14.50	1,120	20,160	$261
57	36	War Material	2	$272	$66.70	124	4,480	$2,401
71	33	Metal Working Machinery	4	$229	$26.90	272	8,960	$888
86	27	Photo Supplies	4	$181	$19.50	332	8,960	$527
73	6	Road Motor Vehicles	6	$148	$11.10	2,240	13,440	$67
58	13	Plastic Materials	11	$139	$5.90	1,895	24,640	$77
65	16	Woven Fabrics (except cotton)	9	$127	$6.70	1,260	20,160	$107
3	30	Fish and Fish Products	13	$92	$3.00	971	29,120	$90
64	20	Paper and Paperboard Mfgs.	9	$33	$1.70	1,008	20,160	$34
64	32	Paper and Paperboard	6	$13	$1.00	420	13,440	$32
			251	$26,000		28,141	562,240	

$46.24 per Pound Average

19.98 Pounds per Cubic Feet Average for these commodities

FACTORS THAT CONTRIBUTE TO LOGISTICS COSTS

1) INTEREST CHARGES ON GOODS AWAITING SHIPMENT

2) INTEREST CHARGES ON GOODS IN TRANSIT

3) INTEREST CHARGES ON GOODS HELD AS SAFETY STOCK

4) LOSS, DAMAGE OR DECAY OF GOODS BETWEEN MANUFACTURE AND SALE

5) COSTS OF ORDERING TRANSPORTATION SERVICES

6) COST OF TRANSPORTATION

Appendix E-1

$$\text{Perishable Cost} = \left[(1 - \text{Sal}) * (V * S) * \left(\frac{T}{L}\right)^{d}\right]$$

Perishable Cost = (Per Cent Loss in Value) * (Value of Product Shipped)
* (Per Cent of Shelf Life spent InTransit)

$$\text{Origin Cost} = \left[\left(i * \frac{P}{365}\right) * (V) * \left(\frac{x}{2}\right)\right]$$

Origin Cost = (Interest Rate per Period) * (Value per Container)
* (One Half the Number of Containers per Shipment)

$$\text{InTransit Cost} = \left[(S * V) * \left(i * \frac{P}{365}\right) * \left(\frac{T}{P}\right)\right]$$

InTransit Cost = (Value of Product Shipped) * (Interest Rate per Period)
* (Trip Time in Days / Period Length)

$$\text{SafetyStock Cost} = \left[\left(i * \frac{P}{365}\right) * (V) * (k * \sigma) * \left(\frac{S}{P}\right)\right]$$

Safety Stock Cost = (Interest Rate per Period) * (Value per Container)
* (Protected Time) * (Containers Shipped per Day)

Transport Cost = Quote from Transportation Provider

Logistics Cost = Origin + InTransit + Safety Stock + Perishable Cost + TransportCost

X = Shipment Size in Containers
V = Value per Container
i = Annual Inventory Interest Rate
S = Period Demand in Containers
T = Average Trip Time
L = Shelf Life of Product
σ = Standard Deviation of Trip Time in Days
k = Constant, multiplier for σ
Sal = Salvage Value of Product in Per Cent
P = Demand Period in Days
d = Industry or Commodity - specific decay parameter

Adapted From
C.D. Martland, 1992

Exhibit 7.2

Commodity: Aircraft and Parts

Model Input

$38.60	Value Per Pound
8	Density of Stowage (lb/cu.ft.)
20%	Annual Carrying Charge
365	Demand Period (days)
8960000	Period Demand (lb)
365	Shelf Life (days)
40%	Per Cent Salvage Value
7.0	Air to Ocean Freight Price Ratio
8	Perish/Decay parameter

Container

85%	Container Space Used
20	Container Length (ft)
8	Container Width (ft)
8	Container Height (ft)

Ocean

$1,733	Transport Cost/Container
25	Average Trip Time (days)
1	Std. Dev. of Trip Time (days)
1.7	Std. Deviations for Safety Stock
52	Shipments per Demand Period

Air

$12,131	Transportation Cost/Container
4	Average Trip Time (days)
0.5	Std. Dev. of Trip Time (days)
1.7	Std. Deviations for Safety Stock
104	Shipments per Demand Period

Per Cont.	Air	Ocean	Difference
	$13,347	$7,294	($6,052.46)

Calculated Container Requirement

1,120,000	Cubic ft. Annual Demand
1,088.00	Cubic ft. Used per Container
8,704	Cargo Wght. per Cont. (lb)

1029	Containers Demand in Period
$335,974	Value per Container
$345,856	Period Value of Commodity (000s)

DETAILED MODEL OUTPUT - OCEAN plus RAIL

52	Shipments per Demand Period
19.8	Average Shipment Size
$0	Perishable Cost/Cont.
$646	Origin Inventory/Cont.
$4,602	In-Transit Inventory/Cont.
$313	Safety Stock/Cont.
$1,733	Transportation Cost/Cont

$7,508,999	**Annual Logistics Cost**

Per Container

$5,561	Interest & Perish Costs
$1,733	Transportation Costs
$7,294	**Logistics Cost**

DETAILED MODEL OUTPUT - AIR

104	Shipments per Demand Period
9.9	Average Shipment Size
$0	Perishable Cost/Cont.
$323	Origin Inventory/Cont.
$736	In-Transit Inventory/Cont.
$156	Safety Stock/Cont.
$12,131	Transportation Cost/Cont

$13,739,472	**Annual Logistics Cost**

Per Container

$1,216	Interest & Perish Costs
$12,131	Transportation Costs
$13,347	**Logistics Cost**

Exhibit 7.3

Commodity: Electric Motors and Generators

Model Input

$39.90	Value Per Pound
36	Density of Stowage (lb/cu.ft.)
20%	Annual Carrying Charge
365	Demand Period (days)
42560000	Period Demand (lb)
365	Shelf Life (days)
40%	Per Cent Salvage Value
7.0	Air to Ocean Freight Price Ratio
8	Perish/Decay parameter

Ocean

$1,733	Transport Cost/Container
25	Average Trip Time (days)
1	Std. Dev. of Trip Time (days)
1.7	Std. Deviations for Safety Stock
52	Shipments per Demand Period

Air

$12,131	Transportation Cost/Container
4	Average Trip Time (days)
0.5	Std. Dev. of Trip Time (days)
1.7	Std. Deviations for Safety Stock
104	Shipments per Demand Period

Container

85%	Container Space Used
20	Container Length (ft)
8	Container Width (ft)
8	Container Height (ft)

Per Cont.	**Air**	**Ocean**	**Difference**
	$17,787	$27,602	$9,815.52

Calculated Container Requirement

1,182,222	Cubic ft. Annual Demand
1,088.00	Cubic ft. Used per Container
39,168	Cargo Wght. per Cont. (lb)

1087	Containers Demand in Period
$1,562,803	Value per Container
$1,698,144	Period Value of Commodity (000s)

DETAILED MODEL OUTPUT - OCEAN plus RAIL

52	Shipments per Demand Period
20.9	Average Shipment Size
$0	Perishable Cost/Cont.
$3,005	Origin Inventory/Cont.
$21,408	In-Transit Inventory/Cont.
$1,456	Safety Stock/Cont.
$1,733	Transportation Cost/Cont

$29,992,821	**Annual Logistics Cost**

Per Container

$25,869	Interest & Perish Costs
$1,733	Transportation Costs
$27,602	**Logistics Cost**

DETAILED MODEL OUTPUT - AIR

104	Shipments per Demand Period
10.4	Average Shipment Size
$0	Perishable Cost/Cont.
$1,503	Origin Inventory/Cont.
$3,425	In-Transit Inventory/Cont.
$728	Safety Stock/Cont.
$12,131	Transportation Cost/Cont

$19,327,267	**Annual Logistics Cost**

Per Container

$5,656	Interest & Perish Costs
$12,131	Transportation Costs
$17,787	**Logistics Cost**

Exhibit 7.4

Commodity: Road Motor Vehicles

Model Input

$3.70	Value Per Pound
6	Density of Stowage (lb/cu.ft.)
20%	Annual Carrying Charge
365	Demand Period (days)
407680000	Period Demand (lb)
365	Shelf Life (days)
40%	Per Cent Salvage Value
7.0	Air to Ocean Freight Price Ratio
8	Perish/Decay parameter

Container

85%	Container Space Used
20	Container Length (ft)
8	Container Width (ft)
8	Container Height (ft)

Ocean

$1,733	Transport Cost/Container
25	Average Trip Time (days)
1	Std. Dev. of Trip Time (days)
1.7	Std. Deviations for Safety Stock
52	Shipments per Demand Period

Air

$12,131	Transportation Cost/Container
4	Average Trip Time (days)
0.5	Std. Dev. of Trip Time (days)
1.7	Std. Deviations for Safety Stock
104	Shipments per Demand Period

Per	Air	Ocean	Difference
TEU	$12,218	$2,133	($10,085.59)

Calculated Container Requirement

67,946,667	Cubic ft. Annual Demand
1088	Cubic ft. Used per Container
6,528	Cargo Wght. per Cont. (lb)

62451	Containers Demand in Period
$24,154	Value per Container
$1,508,416	Period Value of Commodity (000s)

DETAILED MODEL OUTPUT - OCEAN plus RAIL

52	Shipments per Demand Period
1201.0	Average Shipment Size
$0	Perishable Cost/Cont.
$46	Origin Inventory/Cont.
$331	In-Transit Inventory/Cont.
$22	Safety Stock/Cont.
$1,733	Transportation Cost/Cont

$133,196,682	**Annual Logistics Cost**

Per Container

$400	Interest & Perish Costs
$1,733	Transportation Costs
$2,133	**Logistics Cost**

DETAILED MODEL OUTPUT - AIR

104	Shipments per Demand Period
600.5	Average Shipment Size
$0	Perishable Cost/Cont.
$23	Origin Inventory/Cont.
$53	In-Transit Inventory/Cont.
$11	Safety Stock/Cont.
$12,131	Transportation Cost/Cont

$763,051,910	**Annual Logistics Cost**

Per Container

$87	Interest & Perish Costs
$12,131	Transportation Costs
$12,218	**Logistics Cost**

Exhibit 7.5

Commodity: Road Motor Vehicles

Model Input

$11.10	Value Per Pound
6	Density of Stowage (lb/cu.ft.)
20%	Annual Carrying Charge
365	Demand Period (days)
13440000	Period Demand (lb)
365	Shelf Life (days)
40%	Per Cent Salvage Value
7.0	Air to Ocean Freight Price Ratio
6	Perish/Decay parameter

Ocean

$1,733	Transport Cost/Container
25	Average Trip Time (days)
1	Std. Dev. of Trip Time (days)
1.7	Std. Deviations for Safety Stock
52	Shipments per Demand Period

Air

$12,131	Transportation Cost/Container
4	Average Trip Time (days)
0.5	Std. Dev. of Trip Time (days)
1.7	Std. Deviations for Safety Stock
104	Shipments per Demand Period

Container

85%	Container Space Used
20	Container Length (ft)
8	Container Width (ft)
8	Container Height (ft)

Per	Air	Ocean	Difference
TEU	$12,393	$2,932	($9,460.78)

Calculated Container Requirement

2,240,000	Cubic ft. Annual Demand
1088	Cubic ft. Used per Container
6,528	Cargo Wght. per Cont. (lb)

2059	Containers Demand in Period
$72,461	Value per Container
$149,184	Period Value of Commodity (000s)

DETAILED MODEL OUTPUT - OCEAN plus RAIL

52	Shipments per Demand Period
39.6	Average Shipment Size
$0	Perishable Cost/Cont.
$139	Origin Inventory/Cont.
$993	In-Transit Inventory/Cont.
$67	Safety Stock/Cont.
$1,733	Transportation Cost/Cont

$6,037,425	**Annual Logistics Cost**

Per Container

$1,199	Interest & Perish Costs
$1,733	Transportation Costs
$2,932	**Logistics Cost**

DETAILED MODEL OUTPUT - AIR

104	Shipments per Demand Period
19.8	Average Shipment Size
$0	Perishable Cost/Cont.
$70	Origin Inventory/Cont.
$159	In-Transit Inventory/Cont.
$34	Safety Stock/Cont.
$12,131	Transportation Cost/Cont

$25,515,496	**Annual Logistics Cost**

Per Container

$262	Interest & Perish Costs
$12,131	Transportation Costs
$12,393	**Logistics Cost**

Exhibit 7.6

Commodity: Clothing

Model Input

$14.50	Value Per Pound
18	Density of Stowage (lb/cu.ft.)
20%	Annual Carrying Charge
365	Demand Period (days)
20160000	Period Demand (lb)
90	Shelf Life (days)
40%	Per Cent Salvage Value
7.0	Air to Ocean Freight Price Ratio
1	Perish/Decay parameter

Ocean

$1,733	Transport Cost/Container
25	Average Trip Time (days)
1	Std. Dev. of Trip Time (days)
1.7	Std. Deviations for Safety Stock
52	Shipments per Demand Period

Air

$12,131	Transportation Cost/Container
4	Average Trip Time (days)
0.5	Std. Dev. of Trip Time (days)
1.7	Std. Deviations for Safety Stock
104	Shipments per Demand Period

Container

85%	Container Space Used
20	Container Length (ft)
8	Container Width (ft)
8	Container Height (ft)

Per	Air	Ocean	Difference
TEU	$20,731	$53,762	$33,030.40

Calculated Container Requirement

1,120,000	Cubic ft. Annual Demand
1088	Cubic ft. Used per Container
19,584	Cargo Wght. per Cont. (lb)

1029	Containers Demand in Period
$283,968	Value per Container
$292,320	Period Value of Commodity (000s)

DETAILED MODEL OUTPUT - OCEAN plus RAIL

52	Shipments per Demand Period
19.8	Average Shipment Size
$47,328	Perishable Cost/Cont.
$546	Origin Inventory/Cont.
$3,890	In-Transit Inventory/Cont.
$265	Safety Stock/Cont.
$1,733	Transportation Cost/Cont

$55,342,806	**Annual Logistics Cost**

Per Container

$52,029	Interest & Perish Costs
$1,733	Transportation Costs
$53,762	**Logistics Cost**

DETAILED MODEL OUTPUT - AIR

104	Shipments per Demand Period
9.9	Average Shipment Size
$7,572	Perishable Cost/Cont.
$273	Origin Inventory/Cont.
$622	In-Transit Inventory/Cont.
$132	Safety Stock/Cont.
$12,131	Transportation Cost/Cont

$21,340,921	**Annual Logistics Cost**

Per Container

$8,600	Interest & Perish Costs
$12,131	Transportation Costs
$20,731	**Logistics Cost**

EXAMPLES OF MAXIMUM AIR TRANSPORT COSTS (FOR VALUES OF $10/LB. @ CURRENT LB/CU FT) SUPPORTED BY REDUCED INVENTORY COSTS

	OCEAN COST	AIR PREMIUM	COST/TEU TOTAL	CURRENT AIR COST
FAR EAST EXPORT	$1,700	$2,400	$4,100	$12,000
FAR EAST IMPORT	$1,700	$1,700	$4,400	$12,000
EUROPE EXPORT	$1,400	$2,200	$3,600	$ 9,800
EUROPE IMPORT	$1,400	$1,600	$3,000	$ 9,800

Cubic Value Densities for 1992 Containerized Trade

Far East	Export	Import
Space Used	1088	1088
Tons/Teu	9.3	10.2
Lb/cu.ft.	17	19

Europe	Export	Import
Space Used	1088	1088
Tons/Teu	11.9	7.58
Lb/cu.ft.	22	13.93

Value	C.V.D.	C.V.D.
$5	$85	$94
$10	$170	$188
$15	$255	$281
$20	$341	$375
$25	$426	$469
$30	$512	$562

Value	C.V.D.	C.V.D.
$5	$109	$69
$10	$219	$138
$15	$328	$207
$20	$438	$275
$25	$547	$344
$30	$656	$414

Derived from unpublished MARAD sample data for 1992.

ADDITIONAL ADVANTAGES OF AIR FREIGHT
(NOT QUANTIFIED BY LOGISTICS MODEL)

1. LATER PRODUCTION OF GOODS BASED ON MORE ACCURATE DEMAND FORECAST (SPEED OF AIR TRANSPORT LEADS TO REDUCED COSTS FOR OBSOLETE/UNSALEABLE PRODUCTS)

2. REDUCTION IN DIRECT WAREHOUSING COST AS VOLUME BETWEEN SHIPMENTS DECLINES (DUE TO INCREASED TRANSPORTATION SERVICE FREQUENCY; POSSIBLE CONSOLIDATION OF INVENTORY AT CENTRAL LOCATION

3. USE FOR EMERGENCY SHIPMENTS

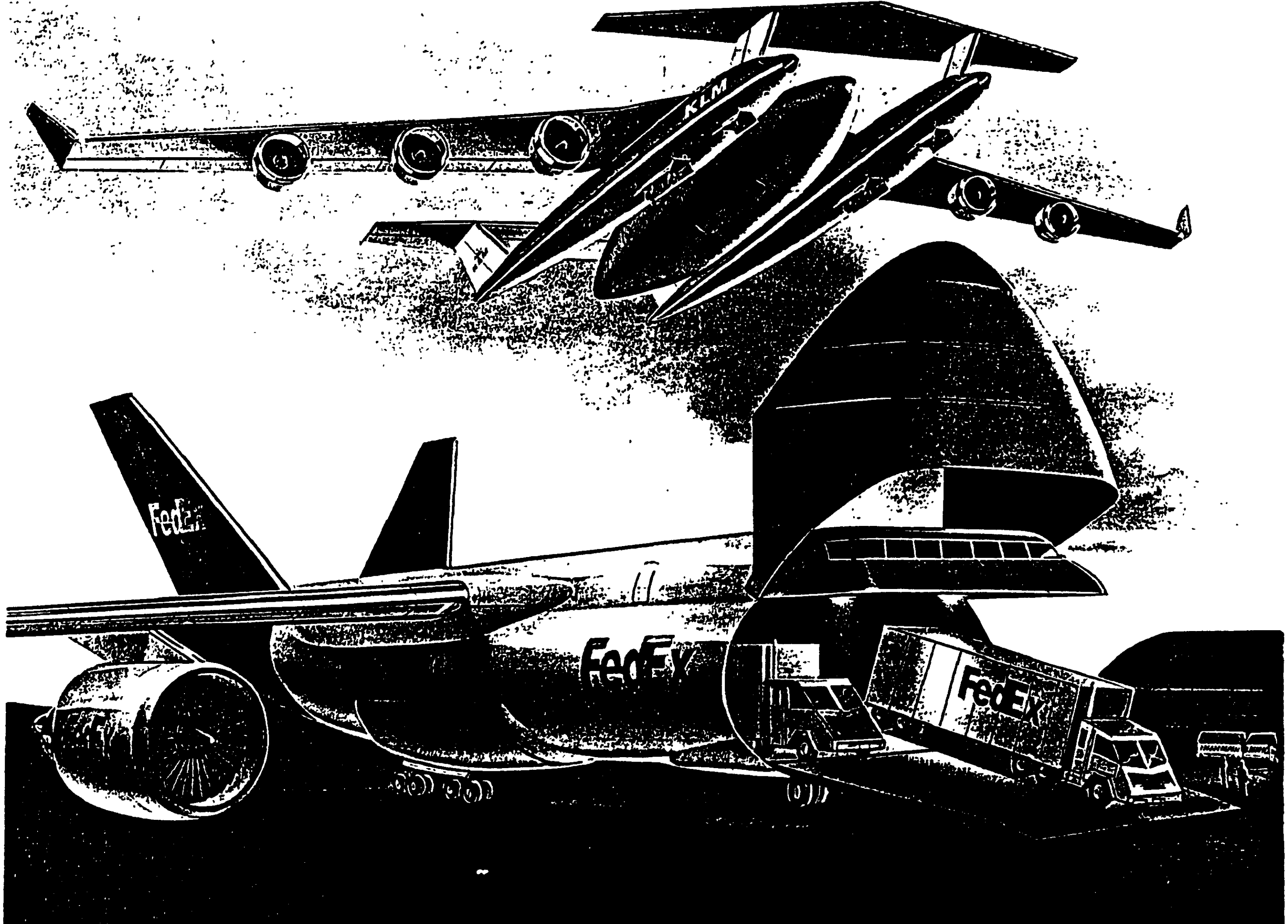
4. UNKNOWN LATENT DEMAND DUE TO:
    1) NEW MARKETS BEING DEVELOPED (I.E. CUT FLOWERS, FRESH FISH
    2) REDUCED AIR TRANSPORTATION COSTS

COVER STORY

TITANS OF TRANSPORT

A new generation of oversize cargo planes—container ships with wings—promises to fast-forward the freight business.

BY GREGORY T. POPE, Science/Technology Editor; PM Illustration by Craig Attebery



• March 19, 2015. Welcome to America's newest port. The thriving complex was once an abandoned military base. Today it pulses to the rhythm of import and export. Here, tractor-trailers stream off a freeway spur that feeds the port's material-handling zone. There, great robotic gantries hoist containers from the trucks and swing them into their next mode of transportation. Elsewhere, the big rigs themselves wheel right into gaping cargo holds, while others, brightly splashed with Asian and Cyrillic markings, rumble out.

The activity recalls the bustle of Amsterdam or New Orleans. But the ocean lies a thousand miles away. This port sprawls in the nation's heartland—it's an airport dedicated to freight. Those cargo holds yawn not from ships but from monster planes that touch down, discharge containers, load up, check out, refuel and roar off again to destinations abroad.

Could such a vision—the freight business lifted from the seas to the skies—come to pass? Transportation researchers are preparing for that possibility. After

MIT Cooperative Program in Education and Research with PT Garuda Indonesia/University of Indonesia

FTL Annual Coop Meetings
Cambridge, MA
Friday May 19, 1995

Michael Clarke
Research Assistant

Presentation Outline

- Introduction
- Flight Transportation Laboratory Involvement in Educational Program
- Airline Operations Control System (AOCS)
- Revenue/Market Share Forecasting Study

Airline Operations Control System (AOCS)

Primary Objective

- Evaluation of the current operations control system and organizational structures at Garuda
- Create a cost-effective plan for implementing an improved AOCS system at the airline

Activities

- Review all data sources and operational information systems currently in use
- Analysis of current AOCS, identifying needs for improved analysis or systems, organizational structures, additional data sources
- Comprehensive review of the daily operations of the carrier, and divisions with the company directly related to operational issues

Forecasting Traffic at Garuda Indonesia

Revenue/Market Share Forecasting Study

PT Garuda Indonesia Corporate Planning

MIT Flight Transportation Laboratory

March 16, 1995

Primary Objective

- Determine methodology to generate robust models for forecasting demand, traffic, and revenue in a given origin-destination market

Activities

- Review and analyze all data sources currently available at GA for traffic and revenue
- Explore external data sources which could make further data available
- Given current and prospective data, create and test alternative forecasting models for a given market. Example : Tokyo - Jakarta

Recommendations

Based on observations of the bureau of corporate planning at PT Garuda Indonesia, the following recommendations for improved work efficiency have been determined. Corporate planning should:

- Obtain data on the carrier's passnger traffic directly from station managers and establishment managers via the commercial department, instead of relying on external sources such as the airport authorities.
- Improve data collection and storage procedures, in order to reduce unnecessary work repetition.
- Develop a better working relationship with the information systems, reservation control, and commercial departments of the company.
- Establish a computer cluster/terminal dedicated to passenger traffic analysis and forecasting.