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

MAY 1995

Robert W. Simpson
Fabien Fedida
Gary K. Wong

Flight Transportation Laboratory, MIT
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.
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;

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

- we have created a IDFCS simulator in ANSI - C language (12000 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)
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 $t$.
- $E_a$ 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.
- $E_g$ 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 $T_{update} = t$. 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:
\[ GHD = \frac{\text{Egd} \times \text{GDgd}}{E} \]

• 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

Forecasted Airport Acceptance Rate (AAR)

Cumulative Delays

<table>
<thead>
<tr>
<th>Miles-In-Trail</th>
<th>Scenario 2</th>
<th>Scenario 4</th>
<th>Scenario 5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5233</td>
<td>3495</td>
<td>3758</td>
</tr>
</tbody>
</table>

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

NFAR is converted to North Fix Entry Slots

AAR = Runway slots

SFAR is converted to South Fix Entry Slots

Planned Arrival Aircraft by South Fix

Entry Slot nodes with capacity = 1

Runway Slot nodes

Spacing Arcs

Spacing Arcs

Metering Arcs for North Entry Fix

Metering Arcs for South Fix

AAR Slot Arcs, \( u = 1 \)

Master Sink Node
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

<table>
<thead>
<tr>
<th>PHX/DFW</th>
<th>PHX/FRA (via DFW)</th>
<th>PHX/MIA (via DFW)</th>
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</thead>
<tbody>
<tr>
<td>CLASS</td>
<td>FARE (OW)</td>
<td>CLASS</td>
</tr>
<tr>
<td>Y</td>
<td>$520</td>
<td>Y</td>
</tr>
<tr>
<td>B</td>
<td>$360</td>
<td>B</td>
</tr>
<tr>
<td>M</td>
<td>$209</td>
<td>Q</td>
</tr>
<tr>
<td>V</td>
<td>$139</td>
<td>V</td>
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</table>

RE-FILED FARES BY ODF FARE VALUE

<table>
<thead>
<tr>
<th>STRATIF. BUCKET</th>
<th>REVENUE RANGE</th>
<th>MAPPING OF O-D MARKETS/CLASSES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y</td>
<td>700 +</td>
<td>Y PHXFRA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Y PHXDFW</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Y PHXMIA</td>
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<tr>
<td>B</td>
<td>500-699</td>
<td>B PHXFRA</td>
</tr>
<tr>
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<td></td>
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<tr>
<td></td>
<td></td>
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<tr>
<td>M</td>
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<tr>
<td></td>
<td></td>
<td>V PHXDFW</td>
</tr>
</tbody>
</table>
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

$$\text{EMR}_j(S) = \frac{\delta R}{\delta S}$$

Value bucket demands and revenue values can be used to derive $\text{EMR}_j(S)$.

- Approximation of displacement cost on any leg $j$ is a function of $\text{EMR}_j(A)$, where $A$ is remaining available capacity.
Down-Line Displacement Costs
Second Leg of Two-Leg Itinerary

Expected Marginal Revenue

AVAIL (A)

EMR(A)

SEATS, S
EMSR Bid Price Concept (cont'd)

- EMRₜ (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:

\[ \text{EMR}(A) = \bar{P}(A) \times \bar{REV} \]

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

\( \bar{REV} \) = mean revenue of all ODFs on leg

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

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

\[ \text{DISP} = \text{EMR}_j (A) \times \text{ODFACTOR} \]

where:

\[ 0 < \text{ODFACTOR} < 1.0 \]
EMSR Bid Price Concept (cont'd)

• From above, network revenue value of \((i, k)\) on Leg \(\ell\) is approximated by:

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

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

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

\[
N_{ik\ell} \geq EMR_\ell(A)
\]

\[
F_{ik} - [EMR_j(A) \times ODFACTOR] \geq EMR_\ell(A)
\]

\[
F_{ik} \geq EMR_\ell(A) + EMR_j(A) \times ODFACTOR
\]

for all legs \(\ell\) 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:

    \[ EMR_\ell (A) + EMR_j (A) \times \text{ODFACTOR} \]

  
  - seats available to (i, k) if:

    \[ F_{ik} \geq EMR_\ell (A) + EMR_j (A) \times \text{ODFACTOR} \]

  
  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 $EMR_l(A)$ 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

Simulated HUB Load Factors Shown at each Point

50% Local Demand
Leg Bid Price on Stratified Buckets

Additional Revenue over "Greedy" Algorithm

- 0.89
- 0.04
- 0.03
- 0.02
- 0.01

nulated HUB Load Factors Shown at each Point

Base Load Factor

- 0.82
- 0.89
- 0.93
- 0.95
- 0.96

0.80 0.85 0.89 0.91 0.92

50% Local Demand
Leg Bid Price on Stratified Buckets
Additional Gain over "Greedy" Algorithm

- Revenue Gain
- Base Load Factor
- 30% Local Demand

nulated HUB Load Factors Shown at each Point
Leg Bid Price on Stratified Buckets

Additional Gain over "Greedy" Algorithm

HUB Load Factors Shown at Each Point

Base Load Factor

- 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

Revenue Gain

ODFACTOR

■ 85% Base LF  ◇ 91% Base LF
Leg Bid Price on Stratified Buckets

Total Revenue Impact over Yield-Based Classes

Revenue Gain

Base Load Factor (Yield)

0.74 0.79 0.83 0.86 0.88 0.89

Fare Stratification  Leg Bid Price Control
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)
  \[
  \min \sum_{i \in \text{Leg}} \sum_{f \in \text{Fleet}} \text{cost}_{f,i} \times x_{f,i}
  \]
  \[
  \text{s.t. balance, cover, size, hookup, etc. constraints}
  \]
  - 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"

![Graph showing a normal distribution with capacity on the x-axis and f(t) on the y-axis.](image)
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, $d=\text{low fare}/\text{high fare}$, 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, Spillc[0]**, is given by:

\[
Spill_c[S] = \int_{0}^{BL_c-S} f_c(i)Spill_{c-1}[i+S]di + \int_{BL_c-S}^{\infty} f_c(i)\{i-(BL_c-S)+Spill_{c-1}[BL_c]\}di,
\]

\[
Spill_0 = 0.
\]

- \(Spill_c\) = 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, SCc[0]**, for the c fare classes is given by:

\[
SC_c[S] = \int_{0}^{BL_c-S} f_c(i)SC_{c-1}[i+S]di + \int_{BL_c-S}^{\infty} f_c(i)\{fare_c*(i-(BL_c-S))+SC_{c-1}[BL_c]\}di,
\]

\[
SC_0 = 0.
\]

\(fare_c\) = 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

![Graph showing the relationship between average spill fare and demand factor.](image-url)
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

- Method 1
- Method 2
- Method 3

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

Slide 11
Differences in Spill Estimates

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

\[ D_{AC} \]

\[ D_{AB} \quad \rightarrow \quad D_{BC} \]

A \quad \text{Cap2} \quad \rightarrow \quad B \quad \text{Cap1} \quad \rightarrow \quad 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: \( \bar{P}(\text{Cap}) = \int_{i=\text{Cap}}^{\infty} f(i) di \)

- Boundaries of leg-dependence effect propagation
Example: Leg-Dependence

\[ N(60,20) \rightarrow N(30,10) \rightarrow N(40,13) \]

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
\[ w = (\text{loc} / \text{loc} + \text{conn}) \times \text{Cap} \]
Achievable Traffic (Cap2=100seats) vs. Unconstrained Demand on Leg 1

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

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

Slide 19
Difference in Spill Estimates

<table>
<thead>
<tr>
<th>Cap1</th>
<th>Leg-Dependent Cap2=100</th>
<th>Leg-Independ. Traditional Method</th>
<th>Difference</th>
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</thead>
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<tr>
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<td>95</td>
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<td>6.77</td>
<td>4.4</td>
</tr>
<tr>
<td>100</td>
<td>1.27</td>
<td>4.9</td>
<td>3.63</td>
</tr>
</tbody>
</table>

- 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

- 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
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

[Bar chart showing percentage revenue change over FCFS for different scenarios: EMSR\text{a}/FCFS, EMSR\text{b}/FCFS, EMSR\text{a}/EMSR\text{a}, EMSR\text{b}/EMSR\text{b}, EMSR\text{a}/EMSR\text{b}]

- Carrier 1
- Carrier 2
- Total
Fare Class Distribution and Total Loads
Under Three RM Method Combinations
Demand Factor = 0.9

Carrier 1
(Innovator)

Carrier 2
(Laggard)

Scenario

FCFS/FCFS  EMSRa/FCFS  EMSRa/EMSRa

Y Class
B Class
M Class
Q Class

Passengers

0 10 20 30 40 50 60 70 80 90 100

Scenario

FCFS/FCFS  EMSRa/FCFS  EMSRa/EMSRa

Carrier 1 Total  Carrier 2 Total
Carrier Revenue Benefit Achievable Under Each EMSR Variant
When Competitor Maintains FCFS Discipline
Various Demand Factors

- Carrier Practices EMSRa Control
- Carrier Practices EMSRb Control

Demand Factor

Percent Carrier Revenue Gain Over FCFS/FCFS
Symmetric Two Path Scenarios: Findings

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

![Graph showing per-flight revenue impact by carrier dominance and scheduling. The graph compares distinct and overlap schedules, with scenarios categorized as weak, strong, and total. The Y-axis represents percentage change over FCFS/FCFS, ranging from -5% to 30%. The X-axis lists scheduling scenarios: EMSRa/FCFS, FCFS/EMSRa, EMSRa/EMSRa, EMSRa/FCFS, FCFS/EMSRa, EMSRa/EMSRa. The graph highlights the revenue impact for different scenarios and carrier dominance strengths.]
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

![Bar chart showing carrier revenues under different scenarios.]

- Only Local Service Carrier Has EMSRa
- Only Nonstop Carrier Has EMSRa
- Both Carriers Have EMSRa

Demand/Control Scenario:
- Equal Split
- High Local Split
- Low Local Split

Percent Carrier Revenue Gain Over FCFS/FCFS
- 25%
- 20%
- 15%
- 10%
- 5%
- 0%
- -5%

- Nonstop Carrier
- Local Service Carrier
Traffic Composition in A-C Market
Equal System Demand Distribution & Demand Factor = 0.9

Nonstop Carrier (NSC)

Local Service Carrier (LSC)

Scenario and Carrier

- Only LSC Has EMSRa
- Only NSC Has EMSRa
- Both Carriers Have EMSRa

Bars represent:
- 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 $S_{ab}$ 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.
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

<table>
<thead>
<tr>
<th>Path Generation</th>
<th>Path Choice</th>
<th>Sending Clearances</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human controller generates alternative</td>
<td>Human controller chooses path</td>
<td>Human controller sends clearances</td>
</tr>
<tr>
<td>paths</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Computer generates alternative paths</td>
<td>Human controller chooses path</td>
<td>Human controller sends clearances</td>
</tr>
<tr>
<td>Computer generates and selects alternative paths</td>
<td>Human controller chooses path</td>
<td>Human controller sends clearances</td>
</tr>
<tr>
<td>Computer generates and advises best</td>
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</tr>
<tr>
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<td></td>
<td></td>
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<tr>
<td>Computer generates and advises best</td>
<td>Human controller chooses path</td>
<td>Computer sends clearances if human</td>
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<tr>
<td>paths</td>
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<tr>
<td>Computer generates alternative paths</td>
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<td>controller generates no veto</td>
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<td>Computer generates alternative paths</td>
<td>Computer chooses path</td>
<td>computer sends clearances, but must</td>
</tr>
<tr>
<td></td>
<td></td>
<td>inform human controller</td>
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<tr>
<td>Computer generates alternative paths</td>
<td>Computer chooses path</td>
<td>computer sends clearances, informs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>human controller if human controller</td>
</tr>
<tr>
<td>Computer generates alternative paths</td>
<td>Computer chooses path</td>
<td>asks</td>
</tr>
<tr>
<td></td>
<td></td>
<td>computer sends clearances, informs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>human controller if computer agrees</td>
</tr>
<tr>
<td>Computer generates alternative paths</td>
<td>Computer chooses path</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Computer generates alternative paths</td>
<td>Computer chooses path</td>
<td></td>
</tr>
<tr>
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<td></td>
</tr>
<tr>
<td>Computer generates alternative paths</td>
<td>Computer chooses path</td>
<td></td>
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<tr>
<td>Computer generates alternative paths</td>
<td>Computer chooses path</td>
<td></td>
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<tr>
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<tr>
<td>Computer generates alternative paths</td>
<td>Computer chooses path</td>
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</tr>
<tr>
<td>Computer generates alternative paths</td>
<td>Computer chooses path</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Computer generates alternative paths</td>
<td>Computer chooses path</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Computer generates alternative paths</td>
<td>Computer chooses path</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
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</tr>
<tr>
<td>Computer generates alternative paths</td>
<td>Computer chooses path</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Computer generates alternative paths</td>
<td>Computer chooses path</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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?
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
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

Weather and Surveillance

Estimation, Detection and Identification

Pattern Assignment

Aircraft Model Computation

Feasible Range Computation

Approach Path Generation

Conformance and Hazard Monitoring

Scheduling

Human Controller

Command cues

Slot position

Slot movement

Conformace error

Dynamic profile

Pattern

Parameters

Weather forecast, radar track points
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 $t_1 < (L - x_0)/v$
then either $t_1 < c_1$ or $t_1 > c_2$
where $c_1$ and $c_2$ are constants which depend on the path parameters
if $t_1 > (L - x_0)/v$
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
<table>
<thead>
<tr>
<th>Trade Area</th>
<th>Metric Tons All Cargo</th>
<th>Metric Tons Ocean Container</th>
<th>Metric Tons Air All Cargo</th>
<th>Air Tons as % of Ocean</th>
</tr>
</thead>
<tbody>
<tr>
<td>World</td>
<td>867,000,000</td>
<td>117,000,000</td>
<td>4,224,045</td>
<td>3.6%</td>
</tr>
<tr>
<td>Europe</td>
<td></td>
<td>19,000,000</td>
<td>1,591,589</td>
<td>8.4%</td>
</tr>
<tr>
<td>Far East</td>
<td></td>
<td>45,000,000</td>
<td>1,232,549</td>
<td>2.7%</td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td>53,000,000</td>
<td>1,399,907</td>
<td>2.6%</td>
</tr>
</tbody>
</table>

Source: MARAD and Office of International Aviation
Container Trade as Share of Volume, 1992

- Total U.S. Ocean Trade: 867
- Total Container: 117
- East-West Container: 64
- Far East Container: 45
- Europe Container: 19

Millions of Metric Tons

Million MT

-144-
U.S. Container Trade as Share of Value, 1992

Billions of Dollars

- Total U.S. Ocean Trade: $488
- Total Container: $317
- East-West Container: $237
- Far East Container: $174
- Europe Container: $63
### Tranatlantic Trade

Costs per single ship on annual basis.

<table>
<thead>
<tr>
<th>Teu per Roundtrip per Year</th>
<th>Cost Per Roundtrip</th>
<th>Yearly Cost per Ship</th>
<th>Miles per Crossing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980</td>
<td>$3,023,000</td>
<td>$38,867,143</td>
<td>4625</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tons per Teu</th>
<th>Cost per teu-mile</th>
<th>Cost per ton-mile</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>$0.330</td>
<td>$0.066</td>
</tr>
<tr>
<td>6</td>
<td>$0.330</td>
<td>$0.055</td>
</tr>
<tr>
<td>7</td>
<td>$0.330</td>
<td>$0.047</td>
</tr>
<tr>
<td>8</td>
<td>$0.330</td>
<td>$0.041</td>
</tr>
<tr>
<td>9</td>
<td>$0.330</td>
<td>$0.037</td>
</tr>
<tr>
<td>10</td>
<td>$0.330</td>
<td>$0.033</td>
</tr>
<tr>
<td>11</td>
<td>$0.330</td>
<td>$0.030</td>
</tr>
<tr>
<td>12</td>
<td>$0.330</td>
<td>$0.028</td>
</tr>
<tr>
<td>13</td>
<td>$0.330</td>
<td>$0.025</td>
</tr>
<tr>
<td>14</td>
<td>$0.330</td>
<td>$0.024</td>
</tr>
<tr>
<td>15</td>
<td>$0.330</td>
<td>$0.022</td>
</tr>
</tbody>
</table>

Derived from Drewry Shipping Consultants, 1992
Transpacific Trade
Costs per single ship on annual basis.

<table>
<thead>
<tr>
<th>Teu per Roundtrip</th>
<th>Roundtrips per Year</th>
<th>Cost Per Roundtrip</th>
<th>Yearly Cost per Ship</th>
<th>Miles per Crossing</th>
</tr>
</thead>
<tbody>
<tr>
<td>4094</td>
<td>8.57</td>
<td>$7,114,000</td>
<td>$60,469,000</td>
<td>8275</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tons per Teu</th>
<th>Cost per teu-mile</th>
<th>Cost per ton-mile</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>$0.208</td>
<td>$0.042</td>
</tr>
<tr>
<td>6</td>
<td>$0.208</td>
<td>$0.035</td>
</tr>
<tr>
<td>7</td>
<td>$0.208</td>
<td>$0.030</td>
</tr>
<tr>
<td>8</td>
<td>$0.208</td>
<td>$0.026</td>
</tr>
<tr>
<td>9</td>
<td>$0.208</td>
<td>$0.023</td>
</tr>
<tr>
<td>10</td>
<td>$0.208</td>
<td>$0.021</td>
</tr>
<tr>
<td>11</td>
<td>$0.208</td>
<td>$0.019</td>
</tr>
<tr>
<td>12</td>
<td>$0.208</td>
<td>$0.017</td>
</tr>
<tr>
<td>13</td>
<td>$0.208</td>
<td>$0.016</td>
</tr>
<tr>
<td>14</td>
<td>$0.208</td>
<td>$0.015</td>
</tr>
<tr>
<td>15</td>
<td>$0.208</td>
<td>$0.014</td>
</tr>
</tbody>
</table>

Derived from Drewry Shipping Consultants, 1992
Average Tons per TEU and Average Dollars per Pound

<table>
<thead>
<tr>
<th>Trade Area</th>
<th>Av. Tons/TEU</th>
<th>Av. $/lb.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Europe Exports</td>
<td>9.12</td>
<td>$1.23</td>
</tr>
<tr>
<td>Europe Imports</td>
<td>7.58</td>
<td>$1.78</td>
</tr>
<tr>
<td>Far East Exports</td>
<td>11.08</td>
<td>$0.75</td>
</tr>
<tr>
<td>Far East Imports</td>
<td>6.51</td>
<td>$2.92</td>
</tr>
</tbody>
</table>
## Exports by Air and Ocean, Port of New York
(Nonbulk Products)

<table>
<thead>
<tr>
<th>YEAR 1992</th>
<th>Metric Tons (Thousands)</th>
<th>Dollars (Millions)</th>
<th>Average Value/lb.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ocean</td>
<td>4,354</td>
<td>$17,739</td>
<td>$1.82</td>
</tr>
<tr>
<td>Air Cargo</td>
<td>415</td>
<td>$36,032</td>
<td>$38.76</td>
</tr>
</tbody>
</table>

Source: Port of New York Data
# Appendix D-1
1992 Leading Ocean Exports, Port of New York

| U.N. Class | Density Pounds per foot | Commodity               | Ocean Tons (000s) | Ocean Value Dollars (Millions) | Ocean Value Dollars per lb. | Air Tons (000s) | Air Value Dollars (Millions) | Air Value Dollars per lb. | Cubic Value Density
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>73</td>
<td>6</td>
<td>Road Motor Vehicles</td>
<td>182</td>
<td>$1,501</td>
<td>$3.70</td>
<td>6</td>
<td>$148</td>
<td>$11.10</td>
<td>$22.20</td>
</tr>
<tr>
<td>71</td>
<td>33</td>
<td>Machinery General</td>
<td>108</td>
<td>$1,397</td>
<td>$5.80</td>
<td>26</td>
<td>$1,310</td>
<td>$22.50</td>
<td>$219.10</td>
</tr>
<tr>
<td>57</td>
<td>36</td>
<td>War Material</td>
<td>17</td>
<td>$675</td>
<td>$17.20</td>
<td>2</td>
<td>$272</td>
<td>$66.70</td>
<td>$619.20</td>
</tr>
<tr>
<td>86</td>
<td>27</td>
<td>Photo Supplies</td>
<td>33</td>
<td>$670</td>
<td>$8.90</td>
<td>4</td>
<td>$181</td>
<td>$19.50</td>
<td>$240.30</td>
</tr>
<tr>
<td>71</td>
<td>20</td>
<td>Office Machinery</td>
<td>21</td>
<td>$635</td>
<td>$13.30</td>
<td>32</td>
<td>$4,899</td>
<td>$68.00</td>
<td>$266.00</td>
</tr>
<tr>
<td>73</td>
<td>17</td>
<td>Scientific Instruments</td>
<td>18</td>
<td>$502</td>
<td>$12.70</td>
<td>17</td>
<td>$2,508</td>
<td>$65.30</td>
<td>$215.90</td>
</tr>
<tr>
<td>71</td>
<td>33</td>
<td>Machinery for Special Ind.</td>
<td>37</td>
<td>$453</td>
<td>$5.50</td>
<td>6</td>
<td>$313</td>
<td>$23.10</td>
<td>$181.50</td>
</tr>
<tr>
<td>72</td>
<td>21</td>
<td>Electrical Machinery</td>
<td>40</td>
<td>$424</td>
<td>$4.70</td>
<td>15</td>
<td>$3,066</td>
<td>$90.20</td>
<td>$98.70</td>
</tr>
<tr>
<td>73</td>
<td>32</td>
<td>Gas Engines and Diesels</td>
<td>40</td>
<td>$374</td>
<td>$4.20</td>
<td>4</td>
<td>$315</td>
<td>$31.60</td>
<td>$134.40</td>
</tr>
<tr>
<td>73</td>
<td>8</td>
<td>Aircraft and Parts</td>
<td>4</td>
<td>$346</td>
<td>$38.60</td>
<td>10</td>
<td>$2,805</td>
<td>$127.00</td>
<td>$308.80</td>
</tr>
<tr>
<td>71</td>
<td>33</td>
<td>Metal Working Machinery</td>
<td>22</td>
<td>$345</td>
<td>$7.00</td>
<td>4</td>
<td>$229</td>
<td>$26.90</td>
<td>$231.00</td>
</tr>
<tr>
<td>72</td>
<td>36</td>
<td>Electric Motors and Generators</td>
<td>19</td>
<td>$298</td>
<td>$6.90</td>
<td>12</td>
<td>$1,118</td>
<td>$39.90</td>
<td>$248.40</td>
</tr>
<tr>
<td>89</td>
<td>33</td>
<td>Printed Matter</td>
<td>36</td>
<td>$245</td>
<td>$3.00</td>
<td>18</td>
<td>$602</td>
<td>$23.60</td>
<td>$99.00</td>
</tr>
<tr>
<td>72</td>
<td>22</td>
<td>Telecommunications Apparatus</td>
<td>9</td>
<td>$239</td>
<td>$11.20</td>
<td>10</td>
<td>$1,659</td>
<td>$71.10</td>
<td>$246.40</td>
</tr>
<tr>
<td><strong>TOTALS</strong></td>
<td></td>
<td></td>
<td><strong>586</strong></td>
<td><strong>$8,104</strong></td>
<td></td>
<td><strong>166</strong></td>
<td><strong>$19,425</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**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

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

**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

<table>
<thead>
<tr>
<th>U.N. Class</th>
<th>Density lb/cu.ft.</th>
<th>U.N. Number</th>
<th>Tons (000s)</th>
<th>Value Dollars (Millions)</th>
<th>Value Dollars per lb.</th>
<th>Cubic Feet (000s)</th>
<th>Pounds (000s)</th>
<th>Cubic Value Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>71</td>
<td>20</td>
<td>Office Machinery</td>
<td>32</td>
<td>$4,899</td>
<td>$68.00</td>
<td>3,584</td>
<td>71,680</td>
<td>$1,360</td>
</tr>
<tr>
<td>72</td>
<td>21</td>
<td>Electrical Machinery</td>
<td>15</td>
<td>$3,066</td>
<td>$90.20</td>
<td>1,600</td>
<td>33,600</td>
<td>$1,894</td>
</tr>
<tr>
<td>73</td>
<td>8</td>
<td>Aircraft and Parts</td>
<td>10</td>
<td>$2,805</td>
<td>$127.00</td>
<td>2,800</td>
<td>22,400</td>
<td>$1,016</td>
</tr>
<tr>
<td>73</td>
<td>17</td>
<td>Scientific Instruments</td>
<td>17</td>
<td>$2,508</td>
<td>$65.30</td>
<td>2,240</td>
<td>38,080</td>
<td>$1,110</td>
</tr>
<tr>
<td>73</td>
<td>32</td>
<td>Internal Combustion Engines</td>
<td>6</td>
<td>$2,373</td>
<td>$189.00</td>
<td>420</td>
<td>13,440</td>
<td>$6,048</td>
</tr>
<tr>
<td>72</td>
<td>22</td>
<td>Telecommunications Apparatus</td>
<td>10</td>
<td>$1,659</td>
<td>$71.10</td>
<td>1,018</td>
<td>22,400</td>
<td>$1,564</td>
</tr>
<tr>
<td>54</td>
<td>21</td>
<td>Pharmaceuticals</td>
<td>9</td>
<td>$1,572</td>
<td>$80.30</td>
<td>960</td>
<td>20,160</td>
<td>$1,685</td>
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<tr>
<td>86</td>
<td>20</td>
<td>Electro-Medical Apparatus</td>
<td>6</td>
<td>$1,350</td>
<td>$76.00</td>
<td>672</td>
<td>13,440</td>
<td>$1,520</td>
</tr>
<tr>
<td>71</td>
<td>33</td>
<td>Machinery General</td>
<td>26</td>
<td>$1,310</td>
<td>$22.50</td>
<td>1,765</td>
<td>58,240</td>
<td>$743</td>
</tr>
<tr>
<td>72</td>
<td>36</td>
<td>Electric Motors and Generators</td>
<td>12</td>
<td>$1,118</td>
<td>$39.90</td>
<td>747</td>
<td>26,880</td>
<td>$1,436</td>
</tr>
<tr>
<td>89</td>
<td>33</td>
<td>Printed Matter</td>
<td>18</td>
<td>$602</td>
<td>$23.60</td>
<td>1,222</td>
<td>40,320</td>
<td>$779</td>
</tr>
<tr>
<td>86</td>
<td>20</td>
<td>Sound Recorders</td>
<td>7</td>
<td>$569</td>
<td>$37.30</td>
<td>784</td>
<td>15,680</td>
<td>$746</td>
</tr>
<tr>
<td>73</td>
<td>32</td>
<td>Gas Engines and Diesels</td>
<td>4</td>
<td>$315</td>
<td>$31.60</td>
<td>280</td>
<td>8,960</td>
<td>$1,011</td>
</tr>
<tr>
<td>71</td>
<td>33</td>
<td>Machinery for Special Ind.</td>
<td>6</td>
<td>$313</td>
<td>$23.10</td>
<td>407</td>
<td>13,440</td>
<td>$762</td>
</tr>
<tr>
<td>84</td>
<td>18</td>
<td>Clothing</td>
<td>9</td>
<td>$307</td>
<td>$14.50</td>
<td>1,120</td>
<td>20,160</td>
<td>$251</td>
</tr>
<tr>
<td>57</td>
<td>36</td>
<td>War Material</td>
<td>2</td>
<td>$272</td>
<td>$66.70</td>
<td>124</td>
<td>4,480</td>
<td>$2,401</td>
</tr>
<tr>
<td>71</td>
<td>33</td>
<td>Metal Working Machinery</td>
<td>4</td>
<td>$229</td>
<td>$26.90</td>
<td>272</td>
<td>8,960</td>
<td>$888</td>
</tr>
<tr>
<td>86</td>
<td>27</td>
<td>Photo Supplies</td>
<td>4</td>
<td>$181</td>
<td>$19.50</td>
<td>332</td>
<td>8,960</td>
<td>$527</td>
</tr>
<tr>
<td>73</td>
<td>6</td>
<td>Road Motor Vehicles</td>
<td>6</td>
<td>$148</td>
<td>$11.10</td>
<td>2,240</td>
<td>13,440</td>
<td>$67</td>
</tr>
<tr>
<td>58</td>
<td>13</td>
<td>Plastic Materials</td>
<td>11</td>
<td>$139</td>
<td>$5.90</td>
<td>1,895</td>
<td>24,640</td>
<td>$77</td>
</tr>
<tr>
<td>65</td>
<td>16</td>
<td>Woven Fabrics (except cotton)</td>
<td>9</td>
<td>$127</td>
<td>$6.70</td>
<td>1,260</td>
<td>20,160</td>
<td>$107</td>
</tr>
<tr>
<td>3</td>
<td>30</td>
<td>Fish and Fish Products</td>
<td>13</td>
<td>$92</td>
<td>$3.00</td>
<td>971</td>
<td>29,120</td>
<td>$90</td>
</tr>
<tr>
<td>64</td>
<td>20</td>
<td>Paper and Paperboard Mfgs.</td>
<td>9</td>
<td>$33</td>
<td>$1.70</td>
<td>1,008</td>
<td>20,160</td>
<td>$34</td>
</tr>
<tr>
<td>64</td>
<td>32</td>
<td>Paper and Paperboard</td>
<td>6</td>
<td>$13</td>
<td>$1.00</td>
<td>420</td>
<td>13,440</td>
<td>$32</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$46.24 per Pound Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>19.98 Pounds per Cubic Feet Average for these commodities</td>
</tr>
</tbody>
</table>
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

Perishable Cost = \left[(1 - Sal) \cdot (V \cdot S) \cdot \left(\frac{T}{L}\right)^a\right]

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

Origin Cost = \left[(i \cdot \frac{P}{365}) \cdot (V) \cdot \left(\frac{X}{2}\right)\right]

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

InTransit Cost = \left[(S \cdot V) \cdot \left(i \cdot \frac{P}{365}\right) \cdot \left(\frac{L}{P}\right)\right]

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

Safety Stock Cost = \left[(i \cdot \frac{P}{365}) \cdot (V) \cdot (k \cdot \sigma) \cdot \left(\frac{S}{P}\right)\right]

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

Transport Cost = Quote from Transportation Provider

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

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
\sigma = Standard Deviation of Trip Time in Days
k = Constant, multiplier for \sigma
Sal = Salvage Value of Product in Per Cent
P = Demand Period in Days
Adapted From C.D. Martland, 1992

d = Industry or Commodity - specific decay parameter
Exhibit 7.2
Commodity: Aircraft and Parts

Model Input

<table>
<thead>
<tr>
<th><strong>Model Input</strong></th>
<th><strong>Ocean</strong></th>
<th><strong>Air</strong></th>
<th><strong>Difference</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Value Per Pound</td>
<td>$38.60</td>
<td>$13,347</td>
<td>$7,294</td>
</tr>
<tr>
<td>Density of Stowage (lb/cu ft.)</td>
<td>8</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>20% Annual Carrying Charge</td>
<td>365</td>
<td>365</td>
<td>0</td>
</tr>
<tr>
<td>Demand Period (days)</td>
<td>365</td>
<td>365</td>
<td>0</td>
</tr>
<tr>
<td>Period Demand (lb)</td>
<td>8,988,000</td>
<td>8,988,000</td>
<td>0</td>
</tr>
<tr>
<td>Shelf Life (days)</td>
<td>40%</td>
<td>40%</td>
<td>0</td>
</tr>
<tr>
<td>Per Cent Salvage Value</td>
<td>7.0</td>
<td>7.0</td>
<td>0</td>
</tr>
<tr>
<td>Air to Ocean Freight Price Ratio</td>
<td>8</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Perish/Decay parameter</td>
<td>8</td>
<td>8</td>
<td>0</td>
</tr>
</tbody>
</table>

### Container

<table>
<thead>
<tr>
<th><strong>Container</strong></th>
<th><strong>Ocean</strong></th>
<th><strong>Air</strong></th>
<th><strong>Difference</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>85% Container Space Used</td>
<td>$12,131</td>
<td>$12,131</td>
<td>0</td>
</tr>
<tr>
<td>20 Container Length (ft)</td>
<td>$4,602</td>
<td>$4,602</td>
<td>0</td>
</tr>
<tr>
<td>8 Container Width (ft)</td>
<td>$313</td>
<td>$313</td>
<td>0</td>
</tr>
<tr>
<td>8 Container Height (ft)</td>
<td>$1,733</td>
<td>$1,733</td>
<td>0</td>
</tr>
</tbody>
</table>

### Calculated Container Requirement

| **Cubic ft. Annual Demand** | 1,120,000 | 1,088,000 |
| **Cubic ft. Used per Container** | 1,029 |
| **Cargo Wght. per Cont. (lb)** | 8,704 |

### DETAILED MODEL OUTPUT - OCEAN plus RAIL

| **52** Shipments per Demand Period | **$7,508,999** Annual Logistics Cost Per Container |
| **19.8** Average Shipment Size | **$5,561** Interest & Perish Costs |
| **$646** Origin Inventory/Cont. | **$1,733** Transportation Costs |
| **$4,602** In-Transit Inventory/Cont. | **$7,294** Logistics Cost |
| **$313** Safety Stock/Cont. | **$1,733** Transportation Cost/Cont |

### DETAILED MODEL OUTPUT - AIR

| **104** Shipments per Demand Period | **$13,739,472** Annual Logistics Cost Per Container |
| **9.9** Average Shipment Size | **$1,216** Interest & Perish Costs |
| **$323** Origin Inventory/Cont. | **$12,131** Transportation Costs |
| **$736** In-Transit Inventory/Cont. | **$13,347** Logistics Cost |
| **$156** Safety Stock/Cont. | **$12,131** Transportation Cost/Cont |

---

-155-
## Exhibit 7.3
**Commodity: Electric Motors and Generators**

### Model Input

<table>
<thead>
<tr>
<th>Model Input</th>
<th>Ocean</th>
<th>Air</th>
<th>Container</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>$39.90</strong></td>
<td>Value Per Pound</td>
<td><strong>$12,131</strong></td>
<td>Transportation Cost/Container</td>
</tr>
<tr>
<td><strong>36</strong></td>
<td>Density of Stowage (lb/cu.ft.)</td>
<td><strong>4</strong></td>
<td>Average Trip Time (days)</td>
</tr>
<tr>
<td><strong>20%</strong></td>
<td>Annual Carrying Charge</td>
<td><strong>0.5</strong></td>
<td>Std. Dev. of Trip Time (days)</td>
</tr>
<tr>
<td><strong>365</strong></td>
<td>Demand Period (days)</td>
<td><strong>1.7</strong></td>
<td>Std. Deviations for Safety Stock</td>
</tr>
<tr>
<td><strong>4256000</strong></td>
<td>Period Demand (lb)</td>
<td><strong>52</strong></td>
<td>Shipments per Demand Period</td>
</tr>
<tr>
<td><strong>365</strong></td>
<td>Shelf Life (days)</td>
<td><strong>$1,733</strong></td>
<td>Transport Cost/Container</td>
</tr>
<tr>
<td><strong>40%</strong></td>
<td>Per Cent Salvage Value</td>
<td><strong>1,733</strong></td>
<td>Average Trip Time (days)</td>
</tr>
<tr>
<td><strong>7.0</strong></td>
<td>Air to Ocean Freight Price Ratio</td>
<td><strong>1,733</strong></td>
<td>Average Trip Time (days)</td>
</tr>
<tr>
<td><strong>8</strong></td>
<td>Perish/Decay parameter</td>
<td><strong>1,733</strong></td>
<td>Average Trip Time (days)</td>
</tr>
</tbody>
</table>

### Calculated Container Requirement

<table>
<thead>
<tr>
<th>Calculated Container Requirement</th>
<th>Air</th>
<th>Ocean</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1,182,227</strong></td>
<td>Cubic ft. Annual Demand</td>
<td><strong>1087</strong></td>
<td>Containers Demand in Period</td>
</tr>
<tr>
<td><strong>1,086,000</strong></td>
<td>Cubic ft. Used per Container</td>
<td><strong>1,562,803</strong></td>
<td>Value per Container</td>
</tr>
<tr>
<td><strong>39,168</strong></td>
<td>Cargo Wght. per Cont. (lb)</td>
<td><strong>1,699,144</strong></td>
<td>Period Value of Commodity (000s)</td>
</tr>
</tbody>
</table>

### Detailed Model Output - Ocean plus Rail

<table>
<thead>
<tr>
<th>Detailed Model Output - Ocean plus Rail</th>
<th>Air</th>
<th>Ocean</th>
<th>Container</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>52</strong></td>
<td>Shipments per Demand Period</td>
<td><strong>$29,992,821</strong></td>
<td>Annual Logistics Cost</td>
</tr>
<tr>
<td><strong>20.9</strong></td>
<td>Average Shipment Size</td>
<td></td>
<td>Per Container</td>
</tr>
<tr>
<td><strong>$3,005</strong></td>
<td>Perishable Cost/Cont.</td>
<td><strong>$25,869</strong></td>
<td>Interest &amp; Perish Costs</td>
</tr>
<tr>
<td><strong>$21,408</strong></td>
<td>In-Transit Inventory/Cont.</td>
<td><strong>$1,733</strong></td>
<td>Transportation Costs</td>
</tr>
<tr>
<td><strong>$1,456</strong></td>
<td>Safety Stock/Cont.</td>
<td><strong>$27,602</strong></td>
<td>Logistics Cost</td>
</tr>
<tr>
<td><strong>$1,733</strong></td>
<td>Transportation Cost/Cont.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Detailed Model Output - Air

<table>
<thead>
<tr>
<th>Detailed Model Output - Air</th>
<th>Air</th>
<th>Ocean</th>
<th>Container</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>104</strong></td>
<td>Shipments per Demand Period</td>
<td><strong>$19,327,267</strong></td>
<td>Annual Logistics Cost</td>
</tr>
<tr>
<td><strong>10.4</strong></td>
<td>Average Shipment Size</td>
<td></td>
<td>Per Container</td>
</tr>
<tr>
<td><strong>$1,503</strong></td>
<td>Perishable Cost/Cont.</td>
<td><strong>$5,656</strong></td>
<td>Interest &amp; Perish Costs</td>
</tr>
<tr>
<td><strong>$3,425</strong></td>
<td>Origin Inventory/Cont.</td>
<td><strong>$12,131</strong></td>
<td>Transportation Costs</td>
</tr>
<tr>
<td><strong>$7,268</strong></td>
<td>In-Transit Inventory/Cont.</td>
<td><strong>$17,787</strong></td>
<td>Logistics Cost</td>
</tr>
<tr>
<td><strong>$12,131</strong></td>
<td>Transportation Cost/Cont.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Exhibit 7.4

**Commodity: Road Motor Vehicles**

<table>
<thead>
<tr>
<th>Model Input</th>
<th>Ocean</th>
<th>Air</th>
</tr>
</thead>
<tbody>
<tr>
<td>$3.70 Value Per Pound</td>
<td>$1,733 Transport Cost/Container</td>
<td>$12,131 Transportation Cost/Container</td>
</tr>
<tr>
<td>6 Density of Stowage (lb/cu.ft.)</td>
<td>25 Average Trip Time (days)</td>
<td>4 Average Trip Time (days)</td>
</tr>
<tr>
<td>20% Annual Carrying Charge</td>
<td>1 Std. Dev. of Trip Time (days)</td>
<td>0.5 Std. Dev. of Trip Time (days)</td>
</tr>
<tr>
<td>365 Demand Period (days)</td>
<td>1.7 Std. Deviations for Safety Stock</td>
<td>1.7 Std. Deviations for Safety Stock</td>
</tr>
<tr>
<td>407680000 Period Demand (lb)</td>
<td>52 Shipments per Demand Period</td>
<td>104 Shipments per Demand Period</td>
</tr>
<tr>
<td>40% Per Cent Salvage Value</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.0 Air to Ocean Freight Price Ratio</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 Perish/Decay parameter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Container</td>
<td></td>
<td></td>
</tr>
<tr>
<td>85% Container Space Used</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 Container Length (ft)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 Container Width (ft)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 Container Height (ft)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Per</th>
<th>Air</th>
<th>Ocean</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEU</td>
<td>$12.218</td>
<td>$2.133</td>
<td>($10.085.59)</td>
</tr>
</tbody>
</table>

**Calculated Container Requirement**

- 67,946,667 Cubic ft. Annual Demand
- 1061 Cubic ft. Used per Container
- 6,528 Cargo Wght. per Cont. (lb)

- 62,451 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
- 50 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
- $1,733 Transportation Costs
- $2,133 Logistics Cost

**DETAILED MODEL OUTPUT - AIR**

- 104 Shipments per Demand Period
- 600.5 Average Shipment Size
- 50 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
- $12,131 Transportation Costs
- $12,218 Logistics Cost
### Exhibit 7.5

**Commodity:** Road Motor Vehicles

#### Model Input

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

**Ocean**

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

**Air**

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

#### Container

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

#### Per | Air | Ocean | Difference

| TEU | $12,393 | $2,932 | ($9,460.78) |

### Calculated Container Requirement

- 2,240,000 Cubic ft. Annual Demand
- 1068 Cubic ft. Used per Container
- 6,528 Cargo Wght. per Cont. (lb)

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

### DETAILED MODEL OUTPUT - OCEAN plus RAIL

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

**Annual Logistics Cost**

| $6,037,425 |

**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
- 50 Perishable Cost/Cont.
- $70 Origin Inventory/Cont.
- $159 In-Transit Inventory/Cont.
- $34 Safety Stock/Cont.
- $12,131 Transportation Cost/Cont

**Annual Logistics Cost**

| $25,515,496 |

**Per Container**

| $262 Interest & Perish Costs |
| $12,131 Transportation Costs |
| $12,393 Logistics Cost |
### Exhibit 7.6

**Commodity: Clothing**

#### Model Input

<table>
<thead>
<tr>
<th>Model Input</th>
<th>Ocean</th>
<th>Air</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value Per Pound</td>
<td>$14.50</td>
<td>$12,131</td>
</tr>
<tr>
<td>Density of Stowage (lb/cu.ft.)</td>
<td>18</td>
<td>85%</td>
</tr>
<tr>
<td>Annual Carrying Charge</td>
<td>20%</td>
<td>20%</td>
</tr>
<tr>
<td>Demand Period (days)</td>
<td>365</td>
<td>45</td>
</tr>
<tr>
<td>Period Demand (lb)</td>
<td>20160000</td>
<td>20160000</td>
</tr>
<tr>
<td>Shelf Life (days)</td>
<td>90</td>
<td>50</td>
</tr>
<tr>
<td>Per Cent Salvage Value</td>
<td>40%</td>
<td>40%</td>
</tr>
<tr>
<td>Air to Ocean Freight Price Ratio</td>
<td>7.0</td>
<td>7.0</td>
</tr>
</tbody>
</table>

#### Container

<table>
<thead>
<tr>
<th>Container</th>
<th>Ocean</th>
<th>Air</th>
</tr>
</thead>
<tbody>
<tr>
<td>Container Space Used</td>
<td>85%</td>
<td>85%</td>
</tr>
<tr>
<td>Container Length (ft)</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Container Width (ft)</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Container Height (ft)</td>
<td>8</td>
<td>8</td>
</tr>
</tbody>
</table>

#### Calculated Container Requirement

<table>
<thead>
<tr>
<th>Calculated Container Requirement</th>
<th>Ocean</th>
<th>Air</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cubic ft. Annual Demand</td>
<td>1,120,000</td>
<td>1,120,000</td>
</tr>
<tr>
<td>Cubic ft. Used per Container</td>
<td>1086</td>
<td>1086</td>
</tr>
<tr>
<td>Cargo Wght. per Cont. (lb)</td>
<td>19,584</td>
<td>19,584</td>
</tr>
</tbody>
</table>

#### Detailed Model Output - Ocean plus Rail

<table>
<thead>
<tr>
<th>Detailed Model Output - Ocean plus Rail</th>
<th>Ocean</th>
<th>Air</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shipments per Demand Period</td>
<td>52</td>
<td>104</td>
</tr>
<tr>
<td>Average Shipment Size</td>
<td>19.8</td>
<td>9.0</td>
</tr>
<tr>
<td>Perishable Cost/Cont.</td>
<td>$47,328</td>
<td>$7,572</td>
</tr>
<tr>
<td>Origin Inventory/Cont.</td>
<td>$546</td>
<td>$273</td>
</tr>
<tr>
<td>In-Transit Inventory/Cont.</td>
<td>$3,890</td>
<td>$622</td>
</tr>
<tr>
<td>Safety Stock/Cont.</td>
<td>$265</td>
<td>$132</td>
</tr>
<tr>
<td>Transportation Cost/Cont</td>
<td>$1,733</td>
<td>$12,131</td>
</tr>
<tr>
<td>Annual Logistics Cost</td>
<td>$55,342,800</td>
<td>$21,340,921</td>
</tr>
</tbody>
</table>

#### Detailed Model Output - Air

<table>
<thead>
<tr>
<th>Detailed Model Output - Air</th>
<th>Ocean</th>
<th>Air</th>
</tr>
</thead>
<tbody>
<tr>
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<tr>
<td>Annual Logistics Cost</td>
<td>$55,342,800</td>
<td>$21,340,921</td>
</tr>
</tbody>
</table>
EXAMPLES OF MAXIMUM AIR TRANSPORT COSTS
(FOR VALUES OF $10/LB. @ CURRENT LB/CU FT)
SUPPORTED BY REDUCED INVENTORY COSTS

<table>
<thead>
<tr>
<th></th>
<th>OCEAN COST</th>
<th>AIR PREMIUM</th>
<th>COST/TEU TOTAL</th>
<th>CURRENT AIR COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>FAR EAST EXPORT</td>
<td>$1,700</td>
<td>$2,400</td>
<td>$4,100</td>
<td>$12,000</td>
</tr>
<tr>
<td>FAR EAST IMPORT</td>
<td>$1,700</td>
<td>$1,700</td>
<td>$4,400</td>
<td>$12,000</td>
</tr>
<tr>
<td>EUROPE EXPORT</td>
<td>$1,400</td>
<td>$2,200</td>
<td>$3,600</td>
<td>$9,800</td>
</tr>
<tr>
<td>EUROPE IMPORT</td>
<td>$1,400</td>
<td>$1,600</td>
<td>$3,000</td>
<td>$9,800</td>
</tr>
</tbody>
</table>

Cubic Value Densities for 1992 Containerized Trade

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
<th>C.V.D.</th>
<th>C.V.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Far East Export</td>
<td>$5</td>
<td>$85</td>
<td>$94</td>
</tr>
<tr>
<td></td>
<td>$10</td>
<td>$170</td>
<td>$188</td>
</tr>
<tr>
<td></td>
<td>$15</td>
<td>$255</td>
<td>$281</td>
</tr>
<tr>
<td></td>
<td>$20</td>
<td>$341</td>
<td>$375</td>
</tr>
<tr>
<td></td>
<td>$25</td>
<td>$426</td>
<td>$469</td>
</tr>
<tr>
<td></td>
<td>$30</td>
<td>$512</td>
<td>$562</td>
</tr>
<tr>
<td>Import</td>
<td>$5</td>
<td>$109</td>
<td>$69</td>
</tr>
<tr>
<td></td>
<td>$10</td>
<td>$219</td>
<td>$138</td>
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<tr>
<td></td>
<td>$15</td>
<td>$328</td>
<td>$207</td>
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<tr>
<td></td>
<td>$20</td>
<td>$438</td>
<td>$275</td>
</tr>
<tr>
<td></td>
<td>$25</td>
<td>$547</td>
<td>$344</td>
</tr>
<tr>
<td></td>
<td>$30</td>
<td>$656</td>
<td>$414</td>
</tr>
</tbody>
</table>

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
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 passenger 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.