FLIGHT TRANSPORTATION LABORATORY
REPORT R 91-4

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

Belobaba, Williamson, et al.

May 1991

MIT

DEPARTMENT
OF
AERONAUTICS
&
ASTRONAUTICS

FLIGHT TRANSPORTATION
LABORATORY
Cambridge, Mass. 02139

FTL REPORT R 91-4

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O-D / SEGMENT SEAT INVENTORY CONTROL:

Modeling and Implementation Issues

Professor Peter P. Belobaba
MIT Flight Transportation Laboratory

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

PASSENGER ITINERARY CONTROL

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

- Passenger Itinerary Control concepts can be applied through:

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

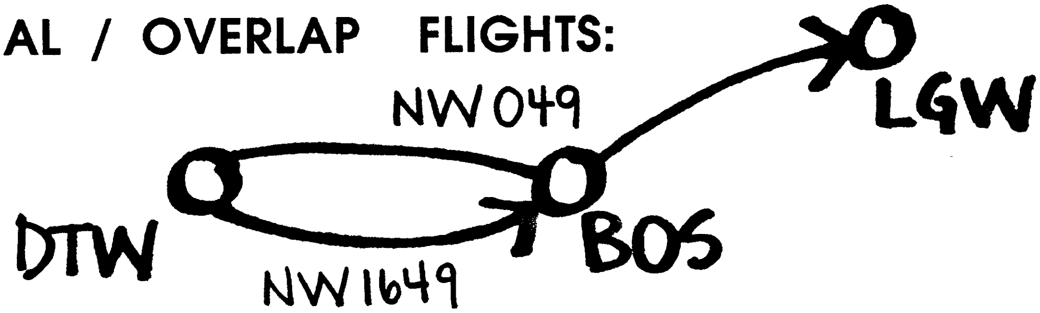
  POINT OF SALE CONTROL: Seat availability is differentiated between points of sale due to currency or net revenue differences.

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

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

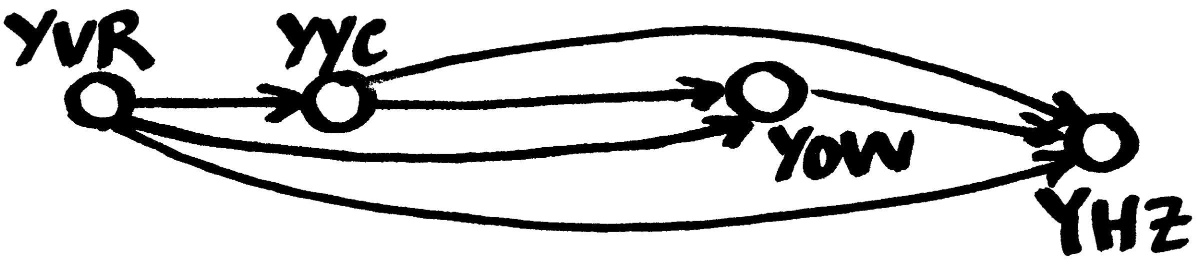
PASSENGER ITINERARY CONTROL

DUAL / OVERLAP FLIGHTS:

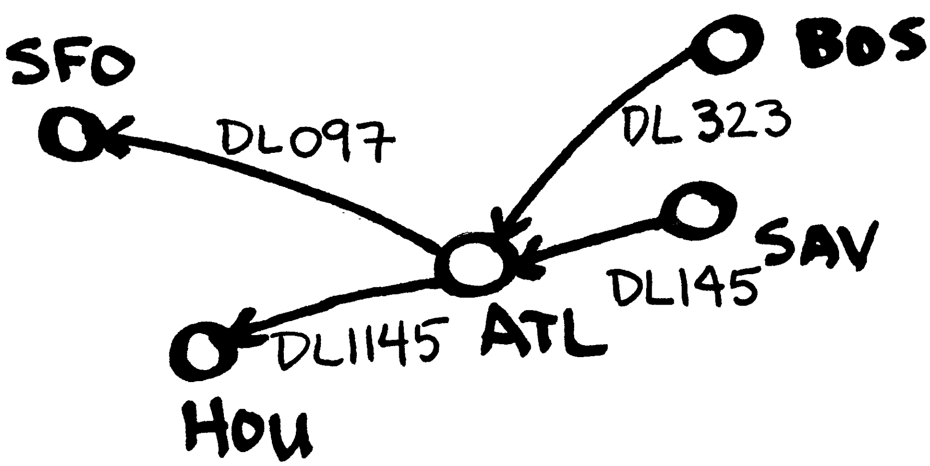


POINT OF SALE: KL 015

SEGMENT CONTROL: AC113



CONNECTING O-D CONTROL:



NETWORK OPTIMIZATION APPROACHES

- Traditional O.R. approach to dealing with itinerary control is to perform a joint optimization over the entire network of flight legs defined by the problem.

- Network formulations and/or mathematical programming approaches are used to find the optimal allocation of seats to each origin-destination itinerary and fare type (ODF) on each flight leg:

  -- requires demand forecasts and fare values for each ODF

  -- problem representation can be deterministic or probabilistic

  -- solution ensures balanced ODF allocations across flight legs

  -- ODF allocations are "optimal" given assumed mathematical formulation of problem

- Implementation of these "optimal" network ODF seat allocations as ODF booking limits, however, can have substantial negative revenue impacts.

  -- use of partitioned or discrete booking limits lowers expected revenue relative to nested limits

  -- negative revenue impact becomes larger with more ODF allocations

  -- dynamic simulations show that use of "optimal" partitioned segment/class limits on a 3-leg flight can result in revenue reductions of 1% to 2% relative to simple leg/booking class control

- The optimal solution to an assumed mathematical formulation does not maximize revenues when implemented this way.

NESTING OF NETWORK OPTIMAL SOLUTIONS

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

- Network ODF allocations for each O-D/segment are nested into a shared inventory of seats, in order of normal nested booking classes

    -- each ODF allocation is treated as a fare class "protection level" within the O-D/segment "nest"

    -- each flight leg still has a discrete allocation of seats for each segment/O-D itinerary

    -- simply summing discrete allocations gives sub-optimal nested booking limits within each O-D/segment nest

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

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

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

- Published by Curry in Transportation Science (1990)

  -- approach jointly finds optimal allocation to each "O-D nest" <u>and</u> nested limits on each booking class within the nest

  -- optimal solution to the formulated problem

  -- still a <u>discrete</u> allocation of seats to each segment/O-D (i.e., "O-D nest")

- Both approaches above can have positive revenue impacts compared to leg/booking class control <u>provided that</u> number of discrete O-D nests does not become large

- Otherwise, <u>negative</u> revenue impacts can result when implemented as a control methodology

3. Nesting of ODF Allocations on Shadow Prices

- Described in Williamson's (1988) MIT Master's thesis

  -- optimal ODF allocations are ranked and nested in order of shadow price values derived from the optimization algorithms

  -- the shadow price of an ODF allocation is the amount by which total expected network revenue will increase (or decrease) if one additional seat is allocated to that ODF

  -- on each flight leg, ODFs with highest shadow prices values receive greatest availability -- ODF allocations are treated as "protection levels" for nesting purposes

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

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

- Implementation into control structure possible through <u>virtual inventory classes</u> defined by shadow price ranges

- Nesting of optimal ODF allocations on current shadow prices results in theoretically <u>sub-optimal</u> booking limits for different ODFs

- Yet, a large number of dynamic booking simulations of this approach as a control methodology show consistent and substantial revenue improvement over leg/booking class control

4. Network "Bid-Price" Approaches

- Developed at MIT: Simpson (1989) and Williamson (1990)

  -- network optimization can also produce shadow prices on the capacity constraint associated with each flight leg, or "bid prices"

  -- Bid Price Control of seat inventories simply requires a comparison of the fare of the requested ODF itinerary and the <u>sum of the bid prices</u> involved in the itinerary.

  -- Implementation requires frequent (real-time?) updating of network bid prices to overcome absence of booking limit controls

- Bid Price Approach is a sub-optimal control application of optimal network solution, which overcomes negative impacts of discrete ODF allocations through "implicit nesting" of availability through bid price evaluation decision.

SUMMARY -- NETWORK OPTIMIZATION APPROACHES

- Network optimization approaches produce optimal ODF seat allocations over a network of flights:

  -- require ODF demand forecasts and fares

  -- generate partitioned ODF allocations that must be "nested" in sub-optimal ways to have positive revenue impacts

- Truly <u>optimal</u> solution for <u>control</u> of ODF itineraries over a network requires an approach that

  -- accounts for nesting of ODFs explicitly

  -- allows "desirability" of ODFs to change as demand materializes

  -- recognizes dynamic nature of future booking process

  -- overcomes "small number" problems of forecasting ODF demands

CONCLUSIONS

- Network optimization methods produce an optimal solution to an assumed mathematical formulation of the O-D/segment control problem

- Implementation of optimal solutions in actual reservations control structures can lead to negative revenue impacts if done incorrectly

- Nesting of optimal network ODF allocations for control purposes is a sub-optimal solution, although some nesting approaches consistently produce better revenue impacts than others

- No one has formulated, let alone "solved" the dynamic, nested ODF network seat inventory control problem

APPLICATION OF NETWORK SOLUTIONS TO O-D SEAT INVENTORY CONTROL

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Flight Transportation Laboratory
Massachusetts Institute of Technology

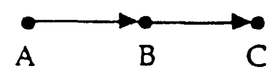
Presented to

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

Introduction

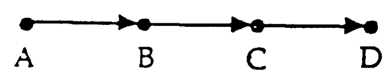
Reviewing network seat inventory control techniques and applying them to three different multi-leg examples, using real airline data:

1) 2 Leg Flight



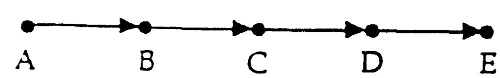
4 Fare Classes
3 OD Pairs
12 ODF Combinations

2) 3 Leg Flight



4 Fare Classes
6 OD Pairs
24 ODF Combinations

3) 4 Leg Flight



4 Fare Classes
10 OD Pairs
40 ODF Combinations

Network Solutions
Nested on Shadow Prices

- Network formulation used to find seat allocations for each ODF over an entire network of flights.

- Distinct allocations are nested according to the shadow price of each ODF.

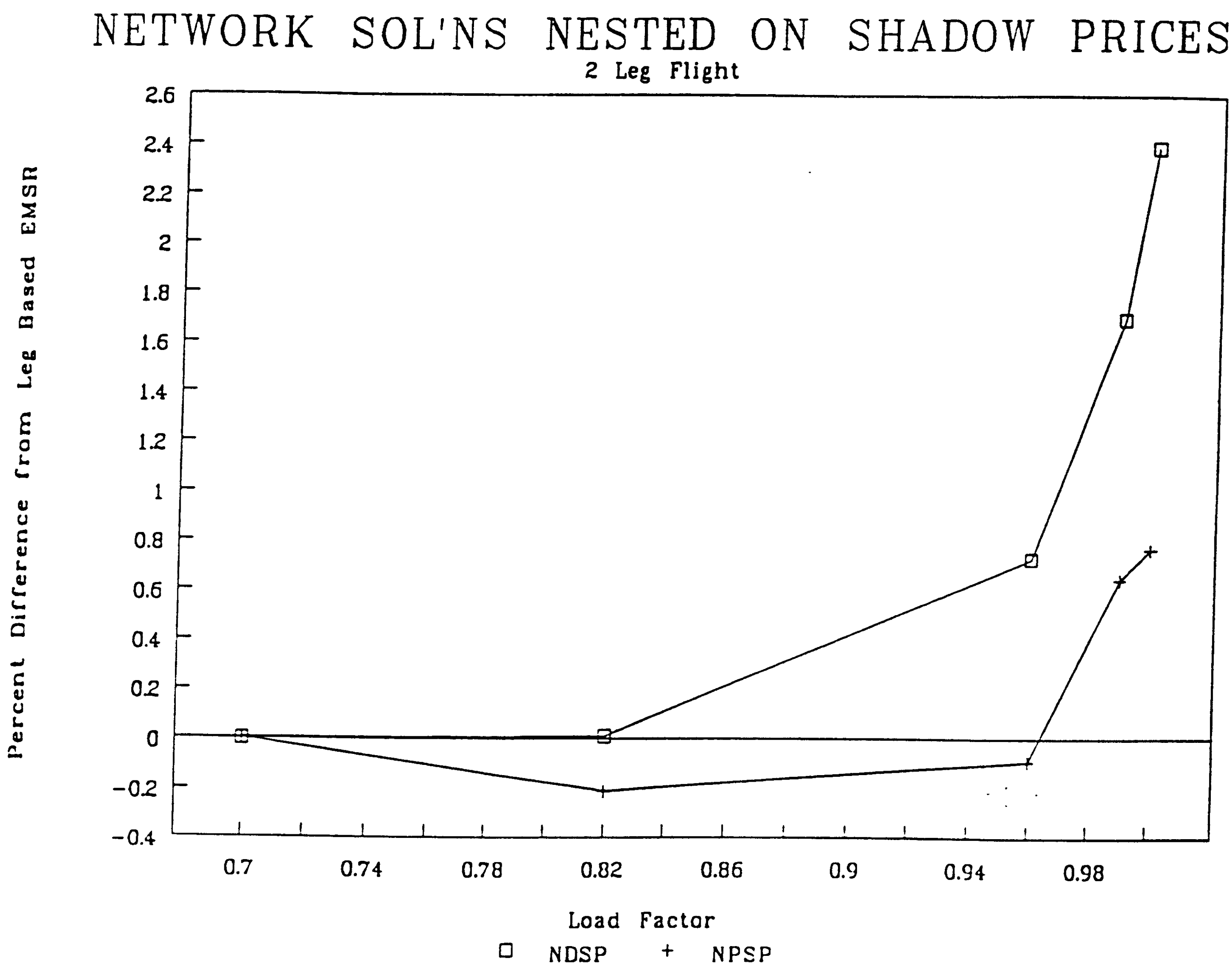
- Shadow Price: The amount the optimal system revenue value would change if one more seat was made available to the given ODF.

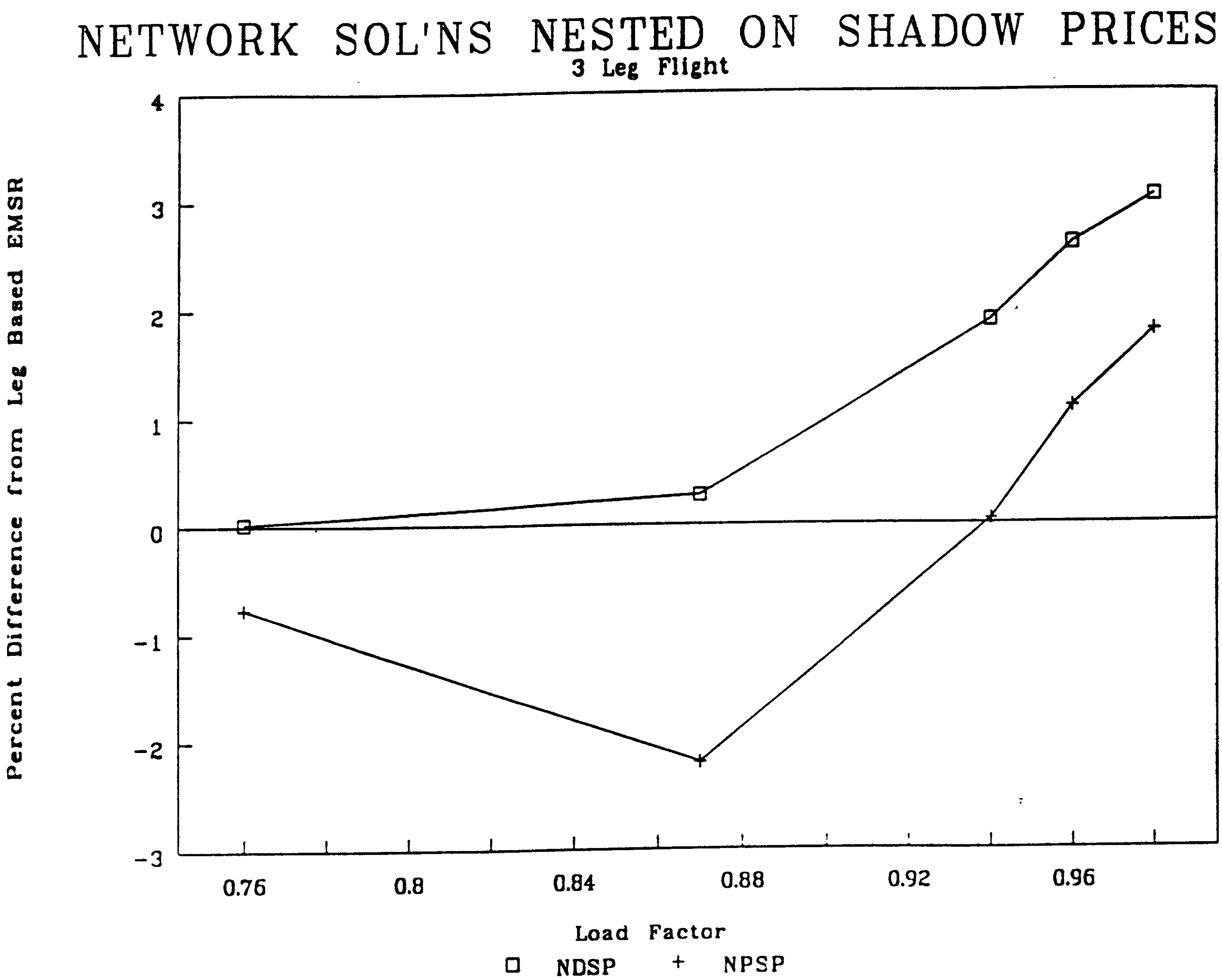
Nested Deterministic by Shadow Prices

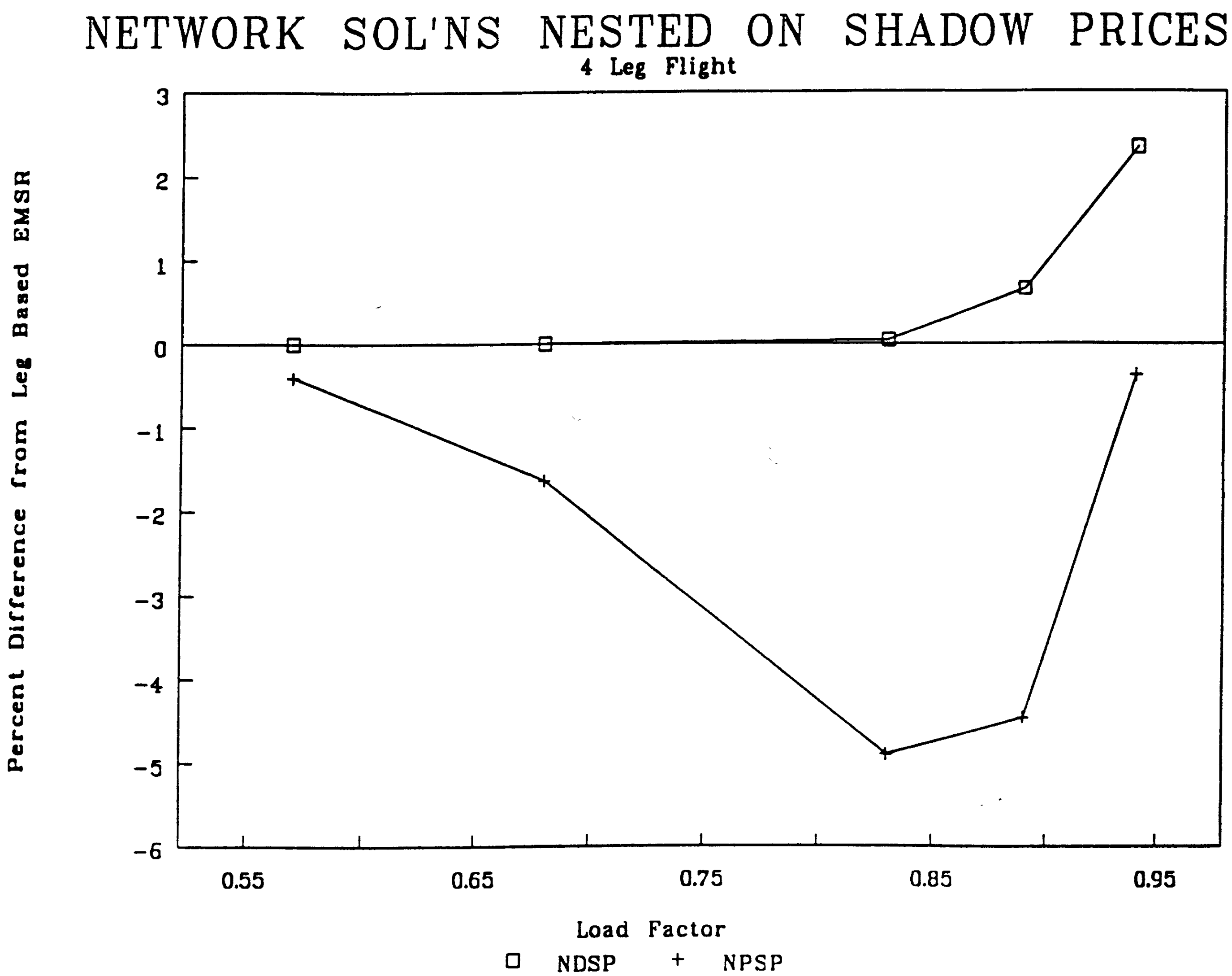
3 Leg Example

Leg BC - Capacity=90

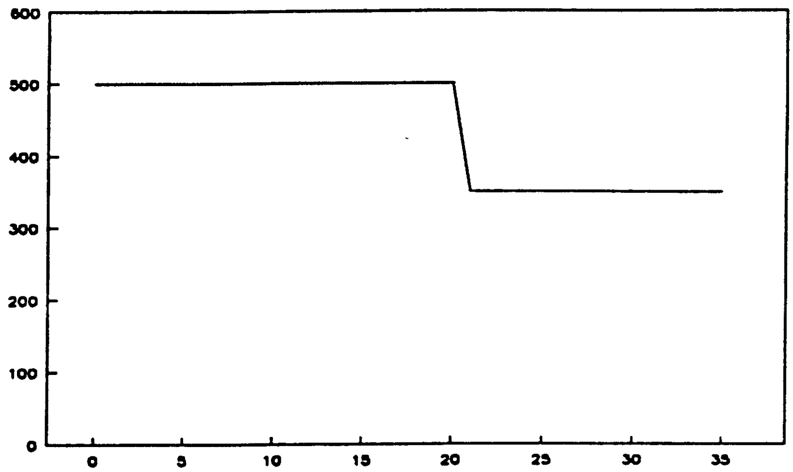
ODF	Seats Allocated	Fare	Shadow Price	Booking Limit
ACY	2	519	322	90
BCY	10	440	243	88
ADY	3	582	216	78
ACM	1	344	147	75
BCM	22	315	118	74
BDY	6	440	74	52
ACB	4	262	65	46
ACQ	14	231	34	42
BCB	12	223	26	28
ADM	1	379	13	16
BCQ	15	197	0	15
BDM	0	307	-59	0
ADB	0	302	-64	0
ADQ	0	269	-97	0
BDB	0	221	-145	0
BDQ	0	199	-167	0


NETWORK SOL'NS NESTED ON SHADOW PRICES
2 Leg Flight
Percent Difference from Leg Based EMSR
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
0.7
0.74
0.78
0.82
0.86
0.9
0.94
0.98
Load Factor
NDSP
NPSP

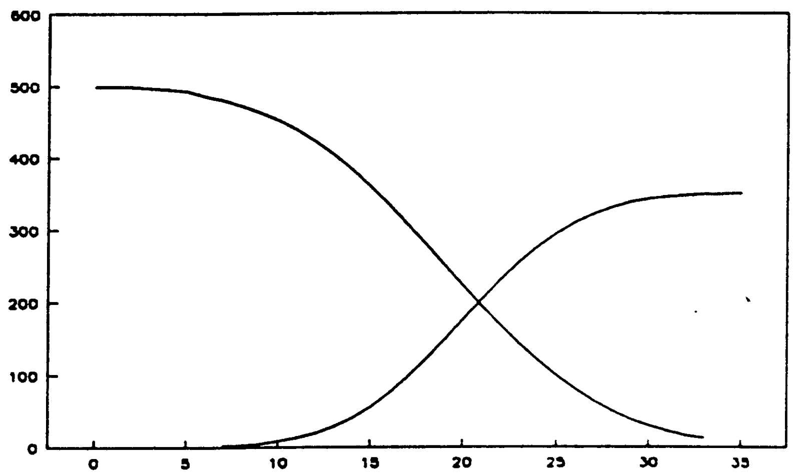

NETWORK SOL'NS NESTED ON SHADOW PRICES
3 Leg Flight
Percent Difference from Leg Based EMSR
4
3
2
1
0
-1
-2
-3
0.76
0.8
0.84
0.88
0.92
0.96
Load Factor
NDSP
+ NPSP


NETWORK SOL'NS NESTED ON SHADOW PRICES
4 Leg Flight
Percent Difference from Leg Based EMSR
3
2
1
0
-1
-2
-3
-4
-5
-6
0.55
0.65
0.75
0.85
0.95
Load Factor
NDSP
NPSP

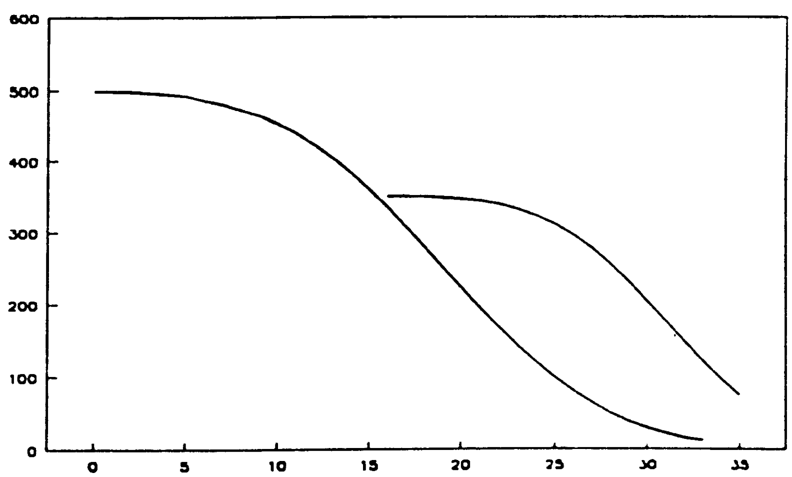
DISTINCT DETERMINISTIC APPROACH



DISTINCT PROBABILISTIC APPROACH



EMSR APPROACH



EXAMPLE

Single Leg, 4 Fare Classes

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

ALLOCATIONS

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

BOOKING LIMITS

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

Initial Allocations

3 Leg Example
AB Leg - Capacity=75

Distinct Deterministic

	Y	M	B	Q
AB	25	3	7	26
AC	2	1	4	4
AD	3	0	0	0

Distinct Probabilistic

	Y	M	B	Q
AB	28	5	10	26
AC	3	0	1	0
AD	2	0	0	0

Difference in Allocations
(Prob - Deter)

	Y	M	B	Q
AB	3	2	3	0
AC	1	-1	-3	-4
AD	-1	0	0	0

Comparison of Allocations Over 15 Revisions

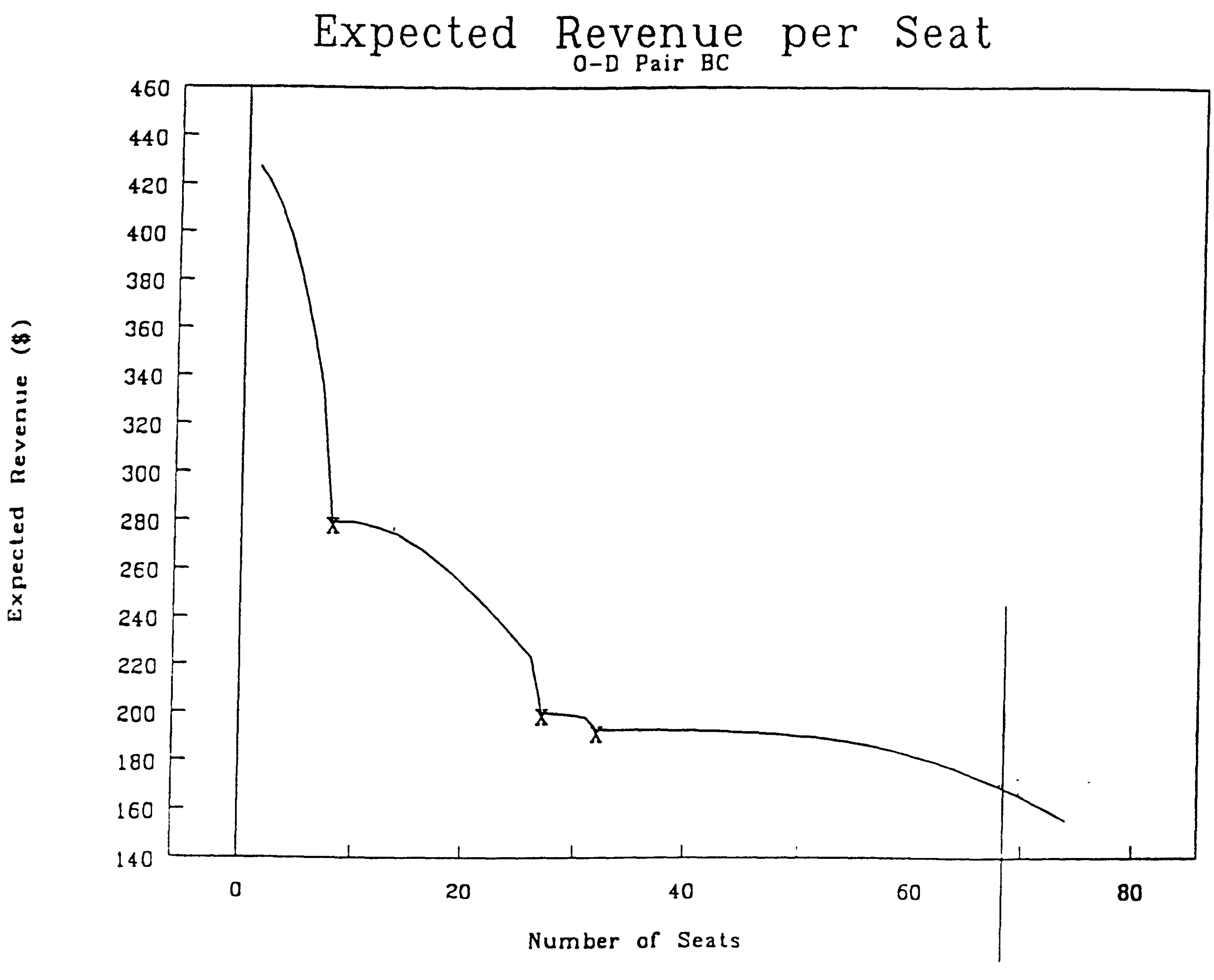
	Mean	Deter Alloc	Prob Alloc
AB Y	25.2	25	28
	25.1	25	28
	24.8	25	28
	24.0	24	28
	22.8	23	28
	22.0	22	26
	20.4	20	26
	19.3	19	26
	16.9	17	25
	15.6	16	23
	12.3	12	21
	9.2	9	19
	8.6	9	18
	5.9	6	15
	2.6	3	11

Partially Nested versus Fully Nested

Partially Nested (Curry):

- Determine discrete allocations for each OD, based on expected revenue from nested fare classes.

- Determine fare class booking limits within each OD allocation.

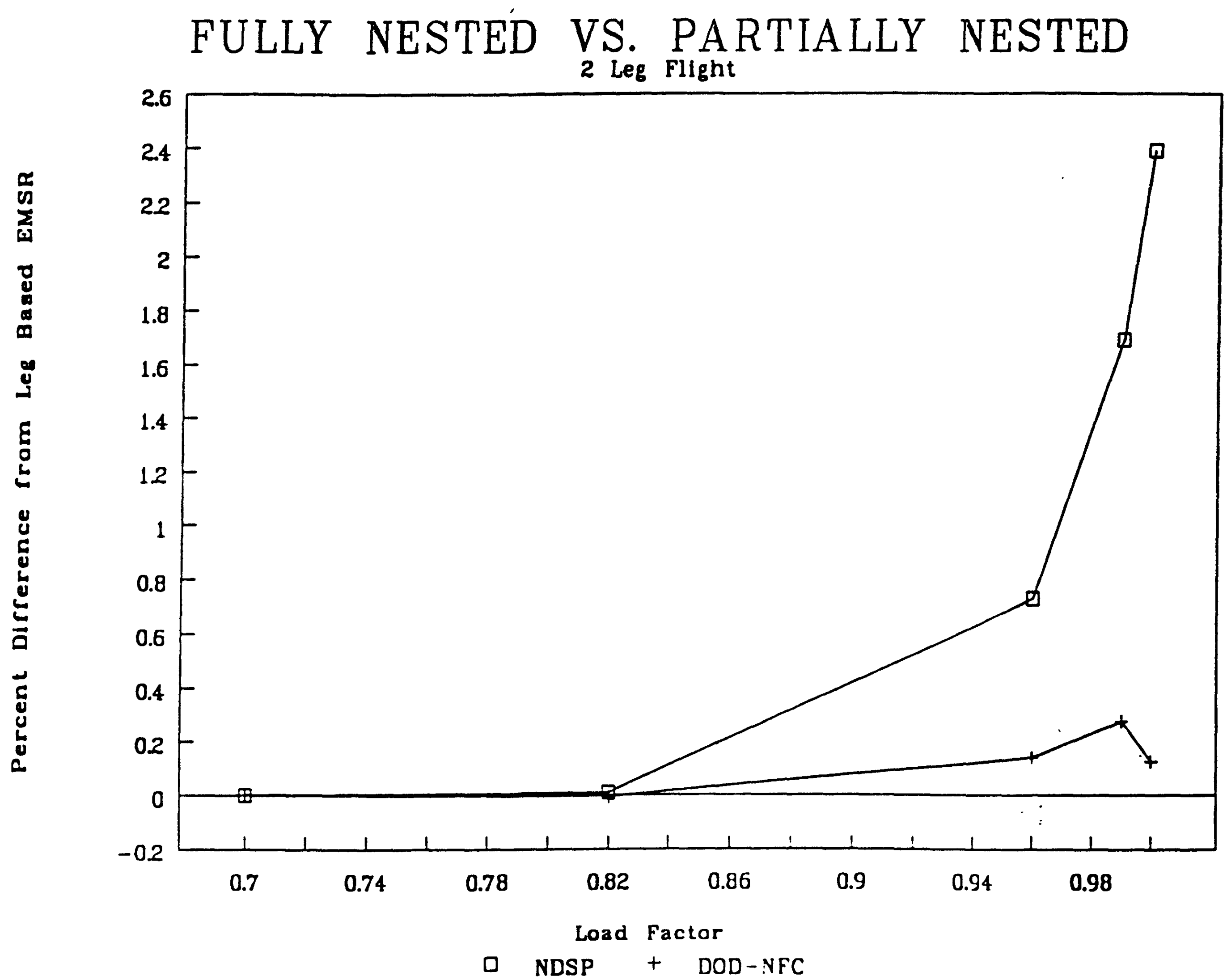

Expected Revenue per Seat
O-D Pair BC
Expected Revenue ($)
460
440
420
400
380
360
340
320
300
280
260
240
220
200
180
160
140
0
20
40
60
80
Number of Seats

Fully Nested versus Partially Nested

3 Leg Example

Leg BC - Capacity=75

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


FULLY NESTED VS. PARTIALLY NESTED
2 Leg Flight
Percent Difference from Leg Based EMSR
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
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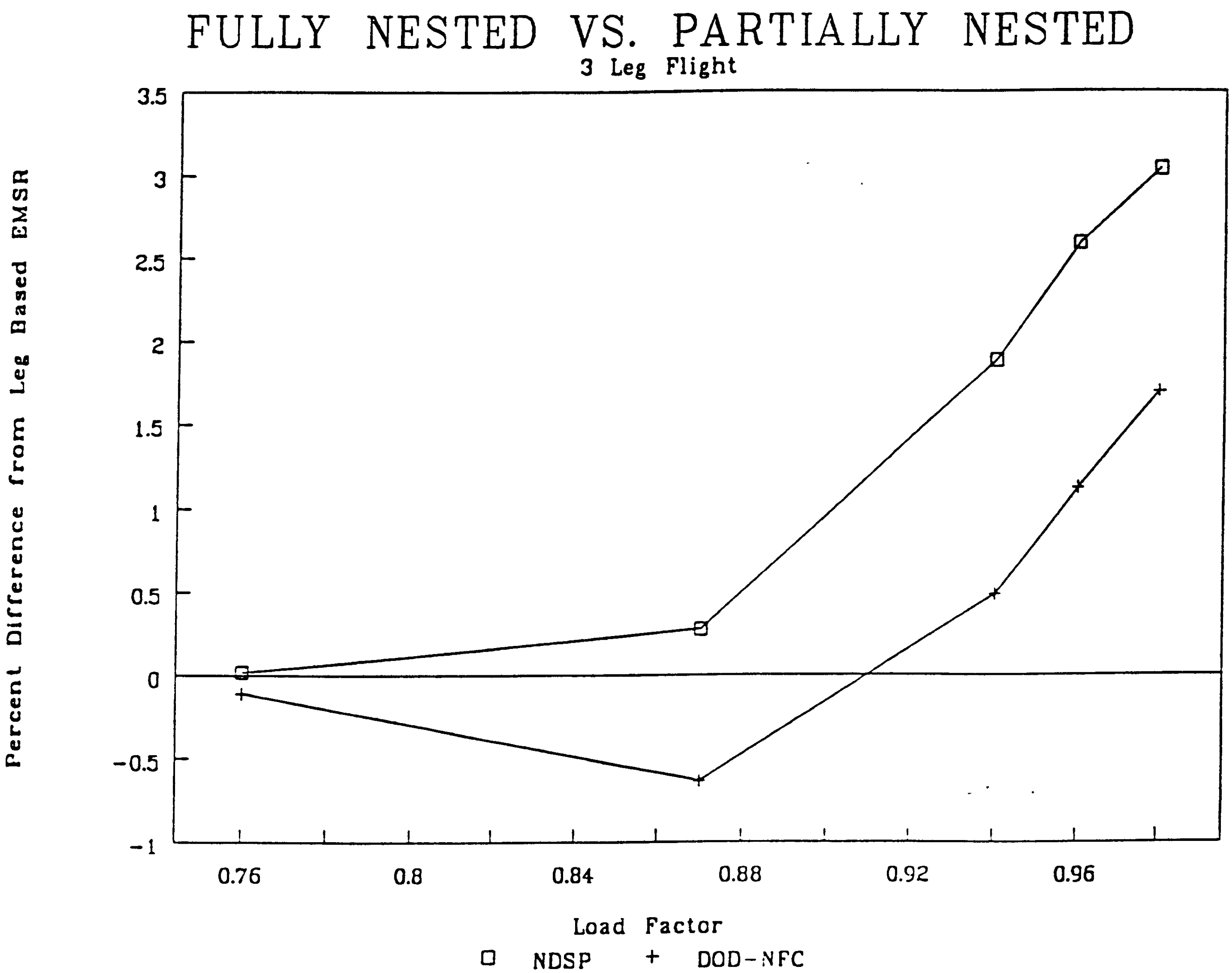
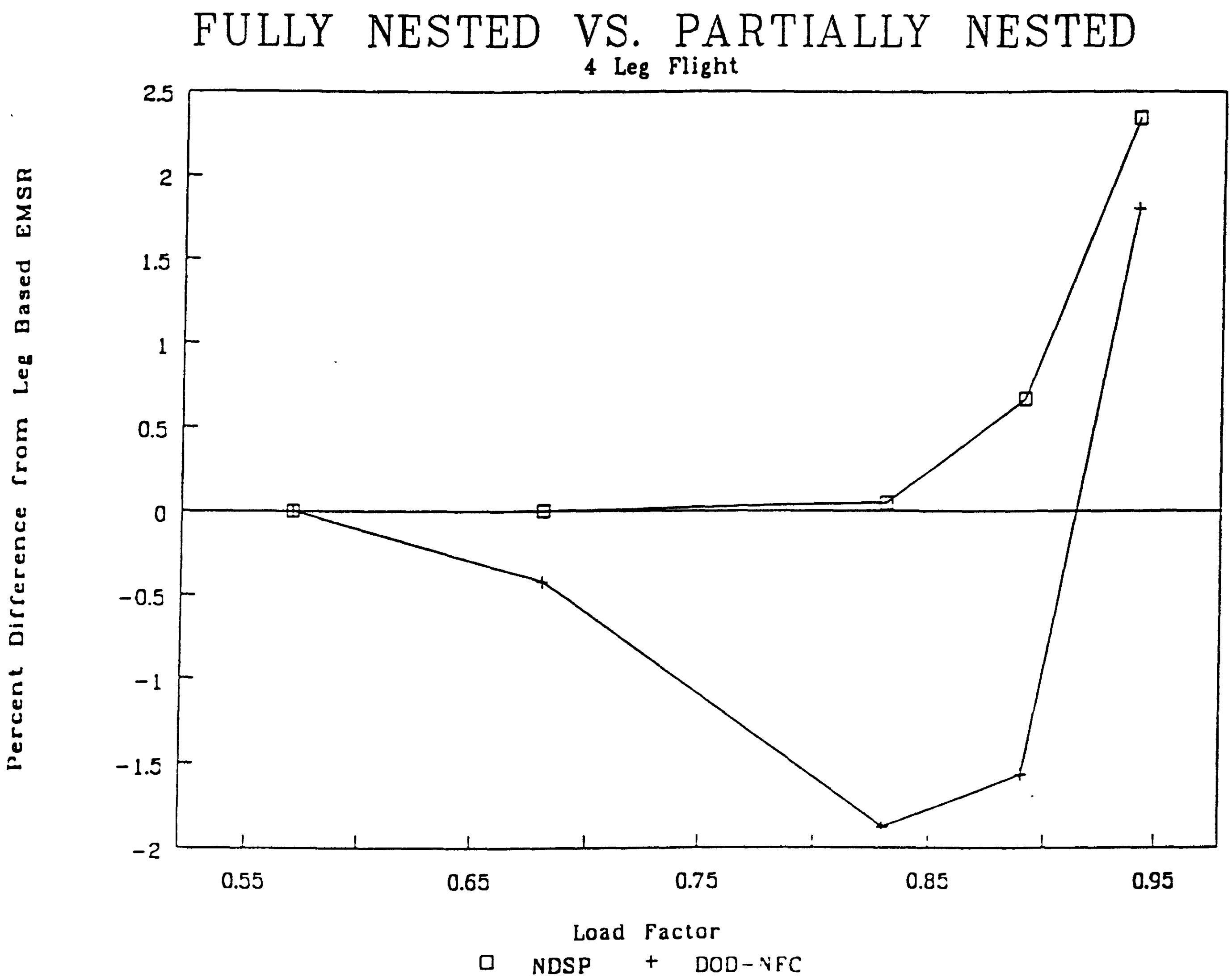
0.7
0.74
0.78
0.82
0.86
0.9
0.94
0.98
Load Factor
NDSP
DOD-NFC


FULLY NESTED VS. PARTIALLY NESTED
3 Leg Flight
Percent Difference from Leg Based EMSR
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0.76
0.8
0.84
0.88
0.92
0.96
Load Factor
NDSP
DOD-NFC


FULLY NESTED VS. PARTIALLY NESTED
4 Leg Flight
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
Percent Difference from Leg Based EMSR
0.55
0.65
0.75
0.85
0.95
Load Factor
NDSP
DOD-NFC

Bid Price

- Bid Price is a Shadow Price for the capacity constraints.

- Obtained from the same network formulations.

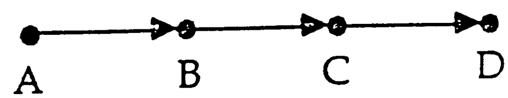
- The marginal value of the last seat of a given flight leg.

- Bid Prices establish a "cutoff" value for each flight leg, on which decisions can be made whether to accept or reject a given O-D/fare class request.

- For a single leg itinerary, a fare class is open for bookings if the corresponding fare is greater than the bid price, or shadow price, for the leg.

- For a multi-leg itinerary, fares must be greater than the sum of the bid prices from the respective flight legs.

3 Leg Example
Capacity=75

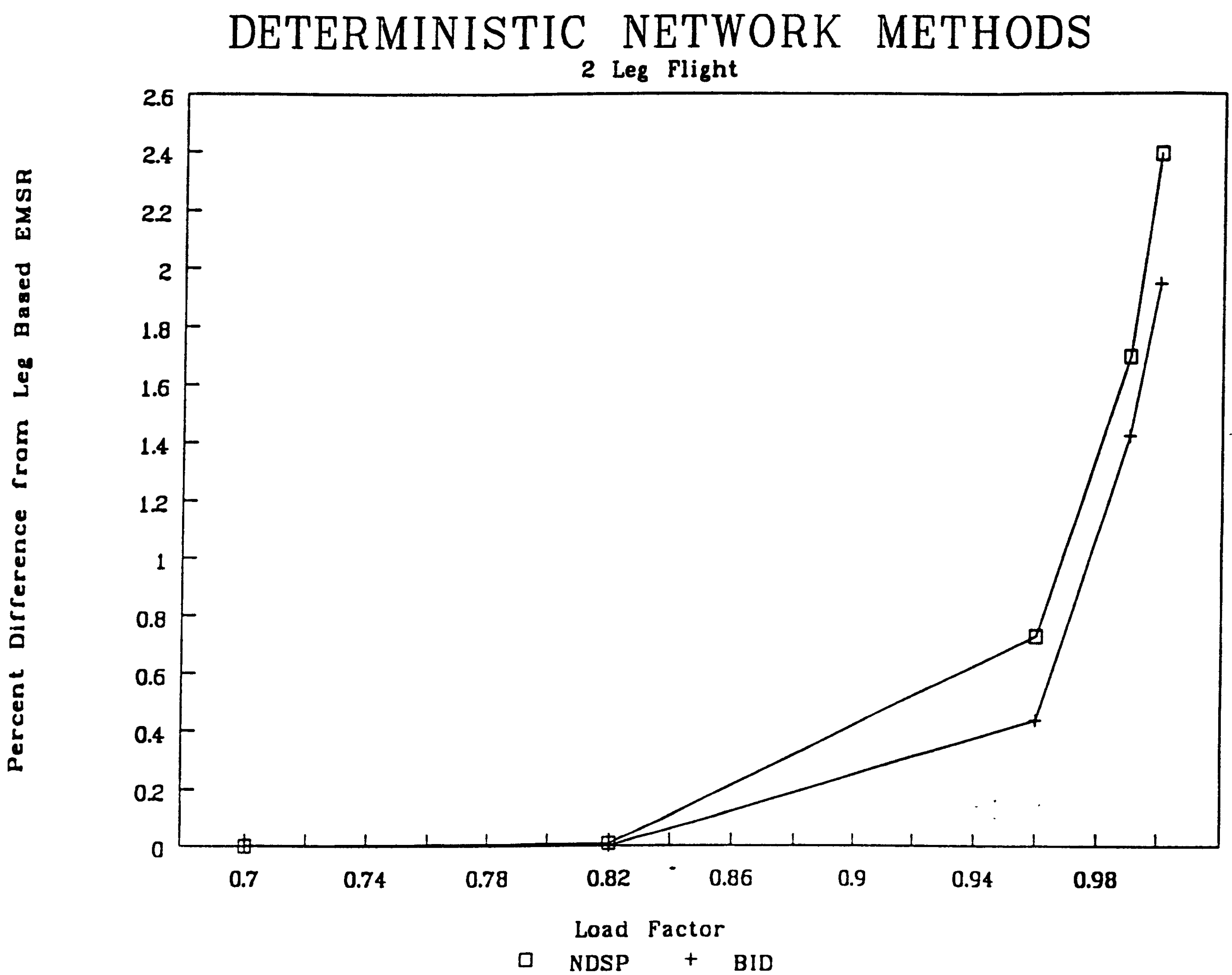


A-B	34
B-C	197
C-D	169

BC:	197
Y	440
M	315
B	223
Q	197

AC:	231
Y	519
M	344
B	262
Q	231

AD:	400
Y	582
M	379
B	302
Q	269


DETERMINISTIC NETWORK METHODS
2 Leg Flight
Percent Difference from Leg Based EMSR
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
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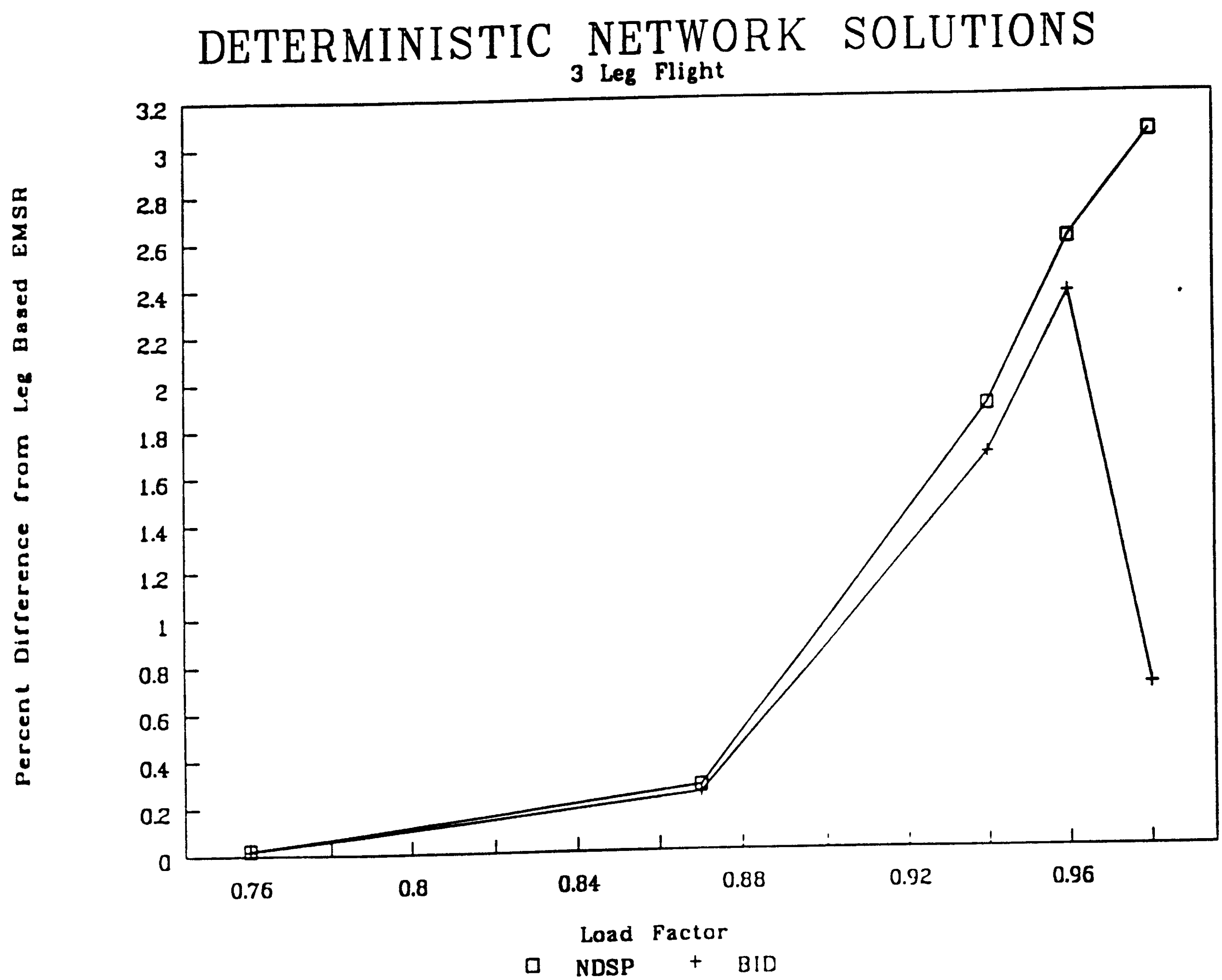
0.7
0.74
0.78
0.82
0.86
0.9
0.94
0.98
Load Factor
NDSP
BID


DETERMINISTIC NETWORK SOLUTIONS
3 Leg Flight
Percent Difference from Leg Based EMSR
3.2
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
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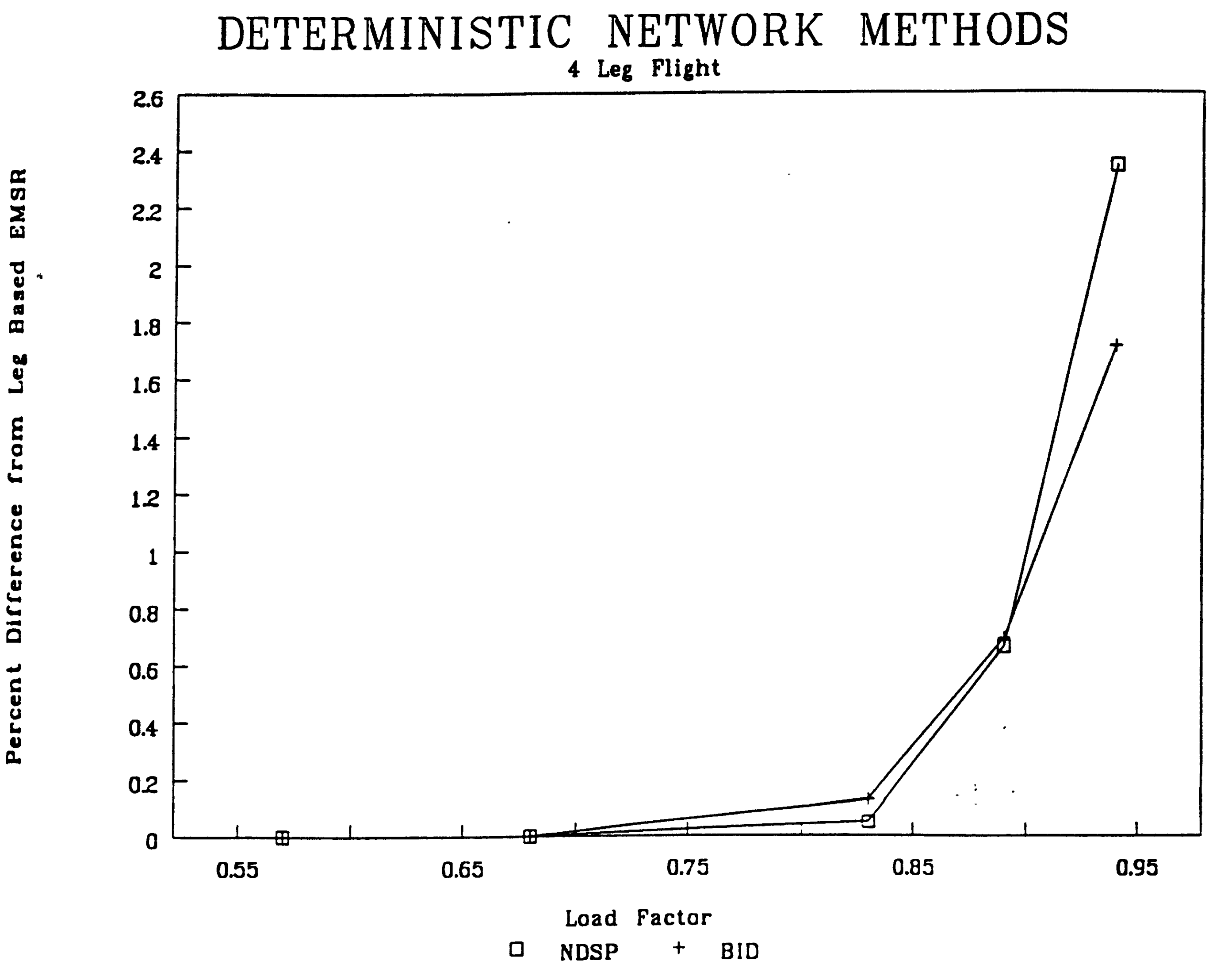
0.92
0.96
Load Factor
NDSP
BID


DETERMINISTIC NETWORK METHODS
4 Leg Flight
Percent Difference from Leg Based EMSR
2.6
2.4
2.2
2
1.8
1.6
1.4
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1
0.8
0.6
0.4
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0.55
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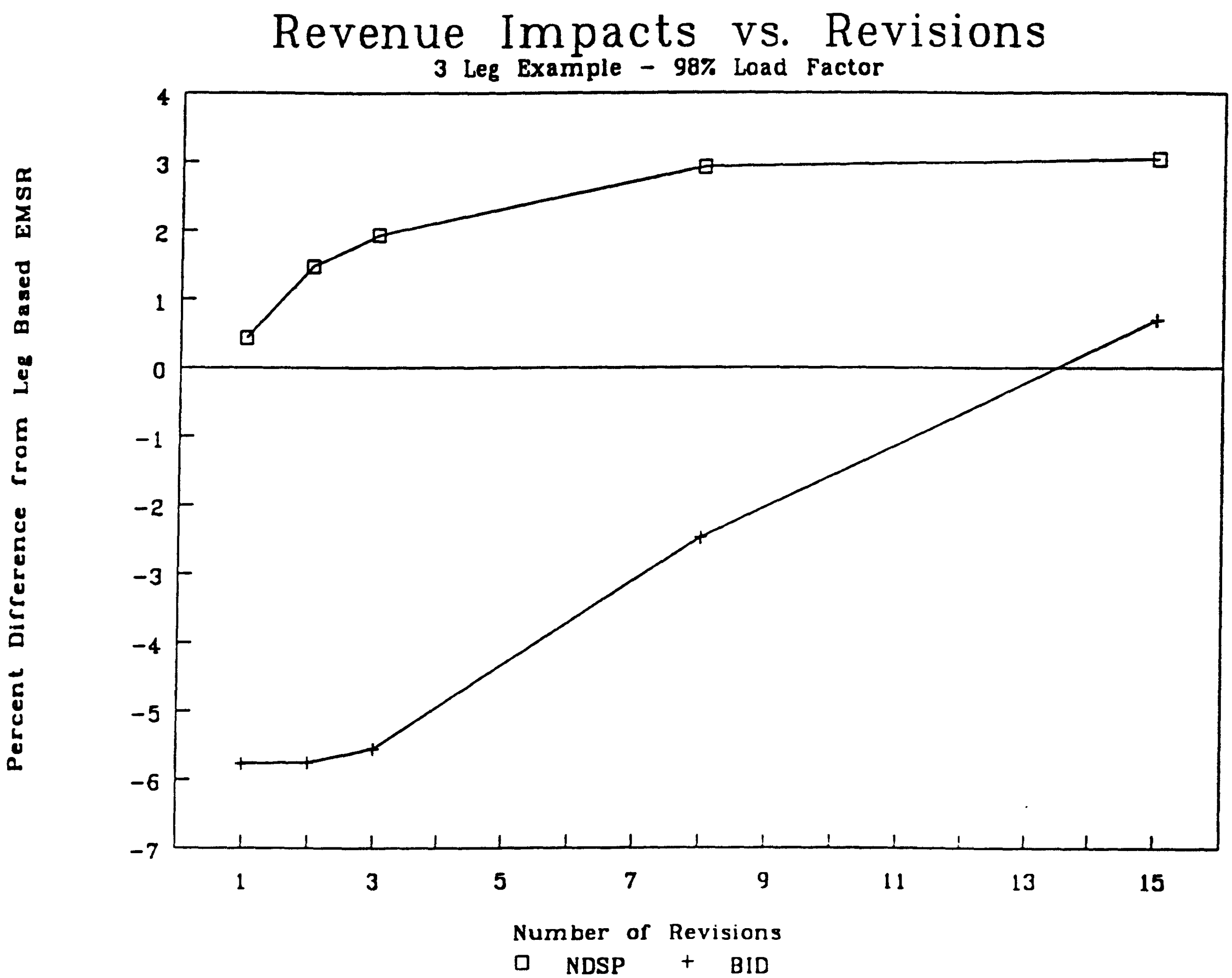
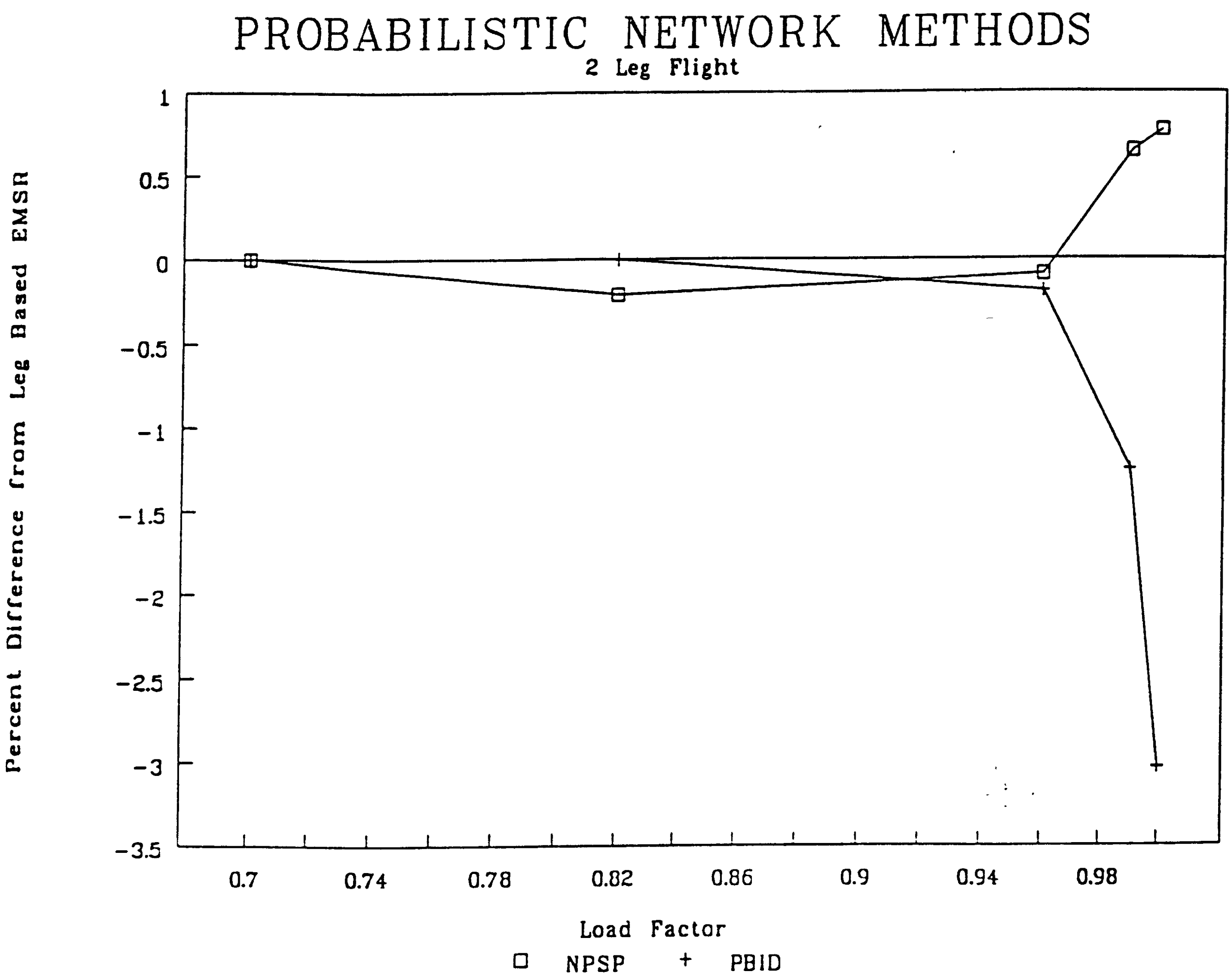
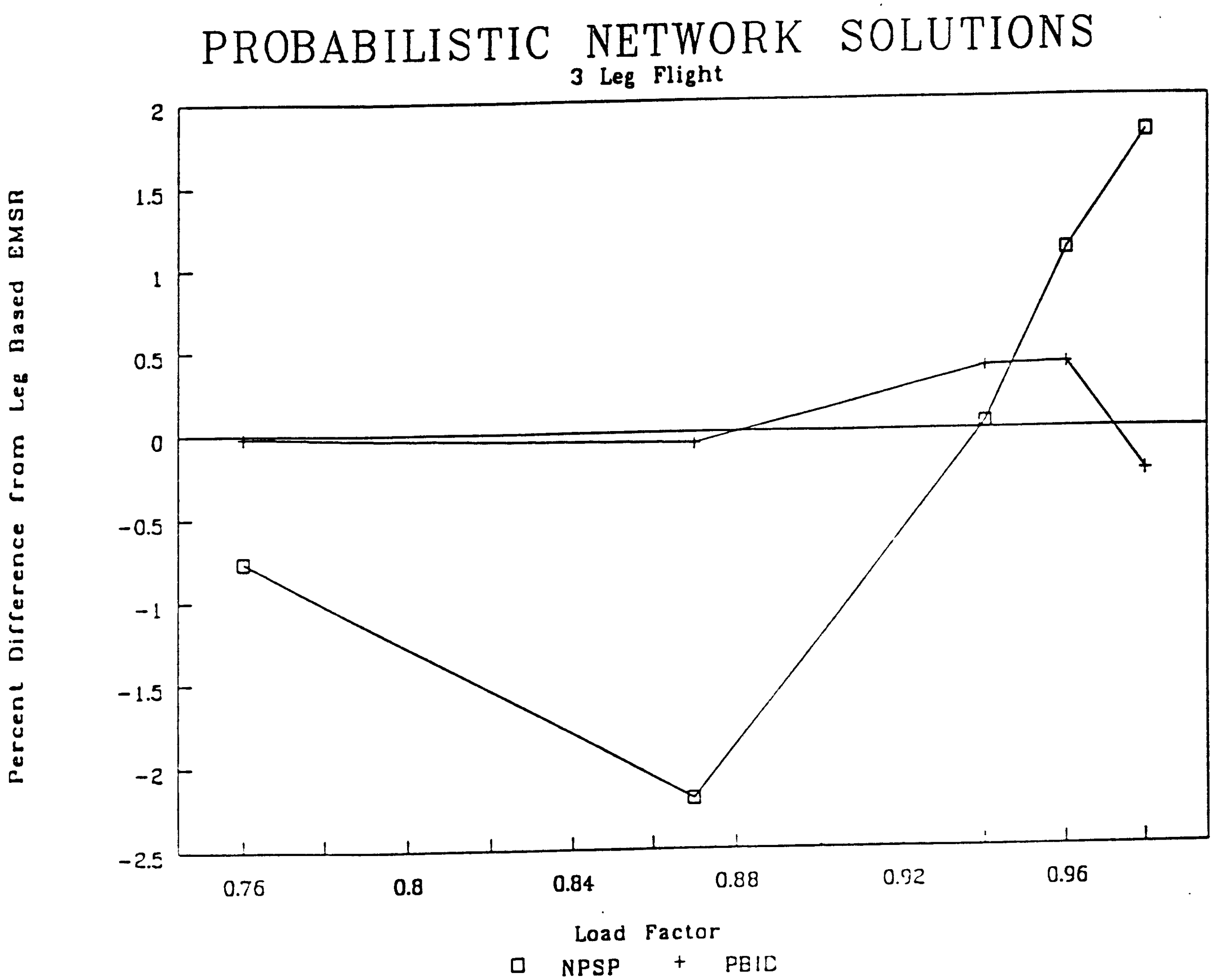
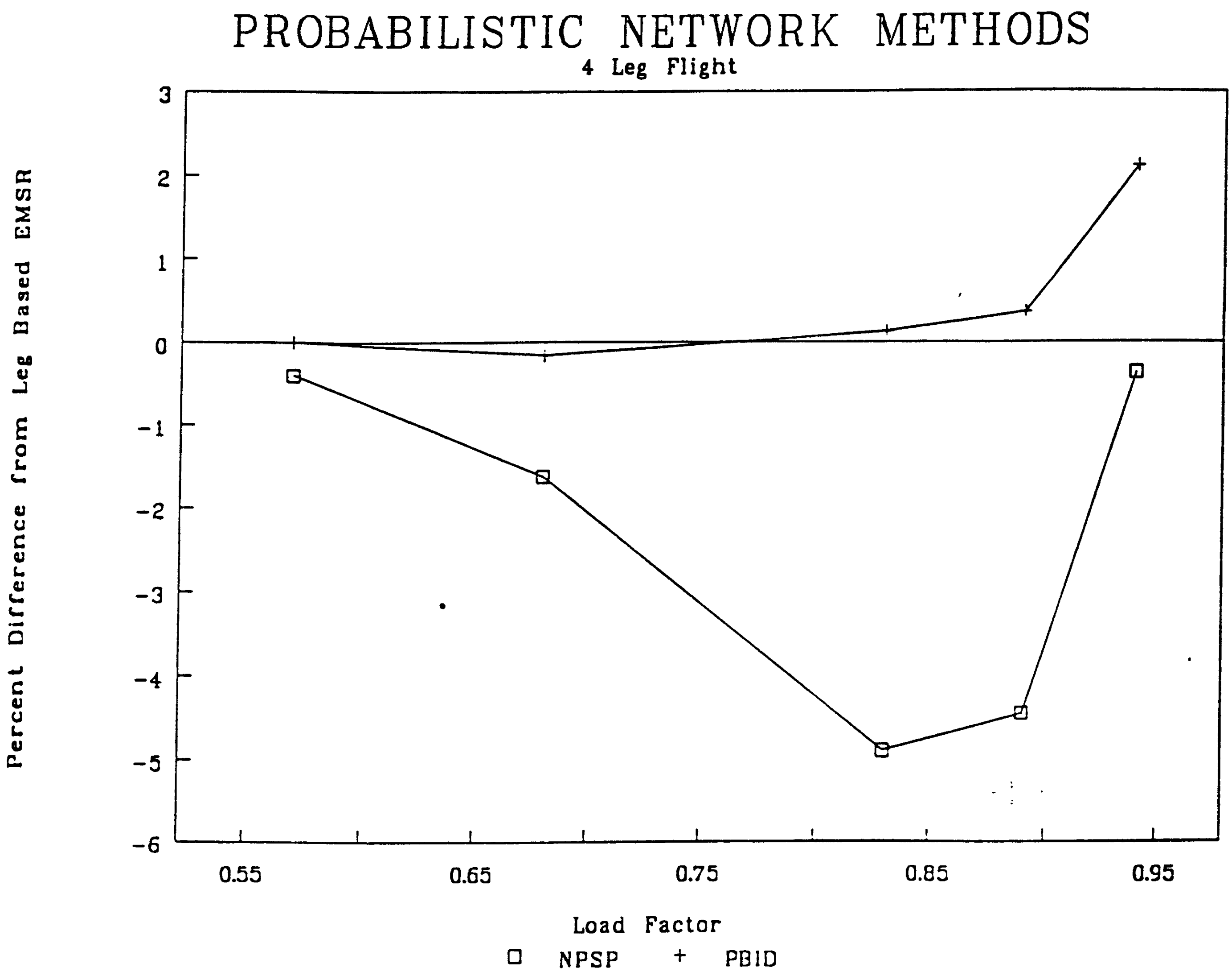
0.85
0.95
Load Factor
NDSP
BID


Revenue Impacts vs. Revisions
3 Leg Example - 98% Load Factor
Percent Difference from Leg Based EMSR
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
1
3
5
7
9
11
13
15
Number of Revisions
NDSP
BID


PROBABILISTIC NETWORK METHODS
2 Leg Flight
Percent Difference from Leg Based EMSR
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
0.7
0.74
0.78
0.82
0.86
0.9
0.94
0.98
Load Factor
NPSP
PBID


PROBABILISTIC NETWORK SOLUTIONS
3 Leg Flight
Percent Difference from Leg Based EMSR
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
0.76
0.8
0.84
0.88
0.92
0.96
Load Factor
NPSP
PBIC

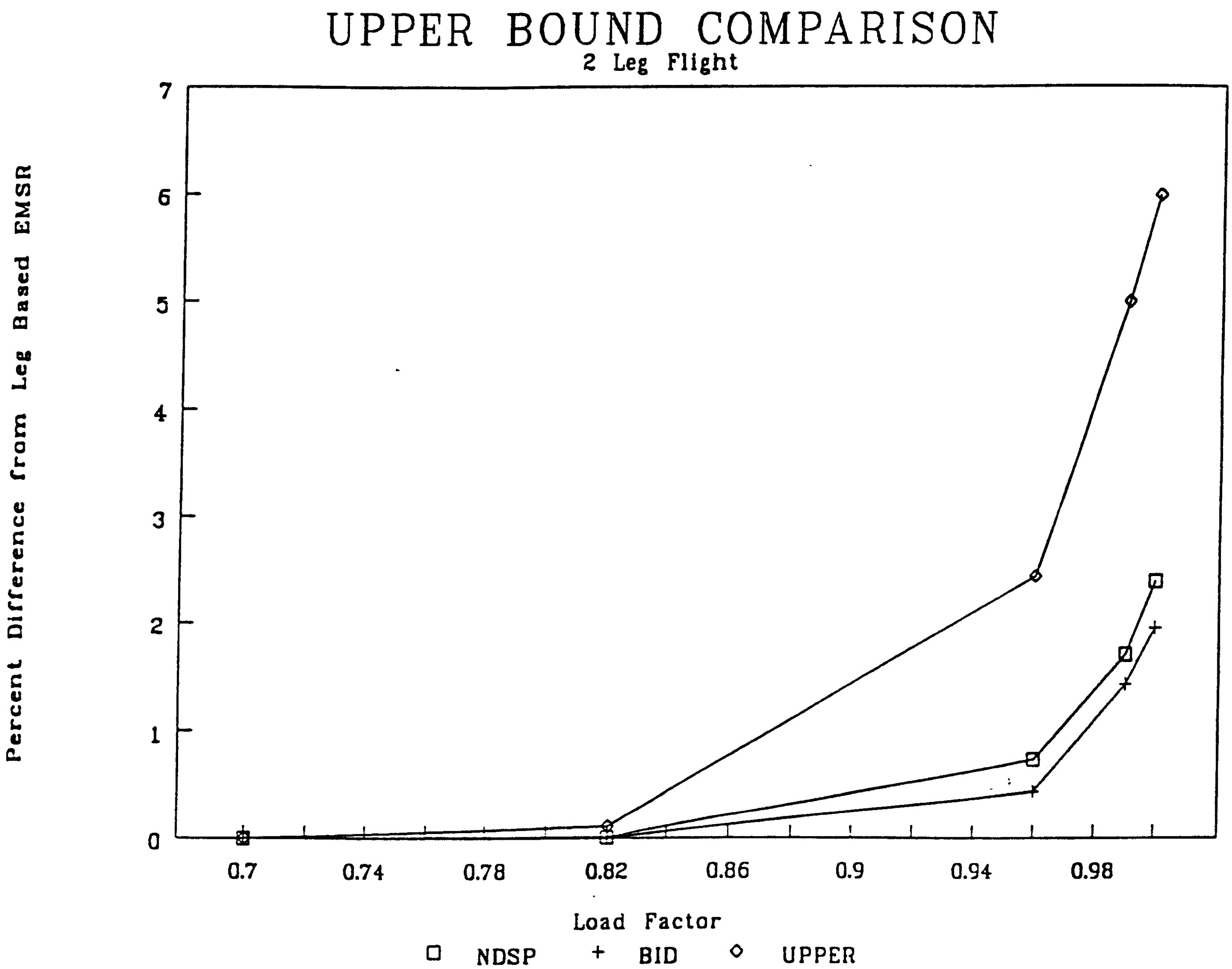

PROBABILISTIC NETWORK METHODS
4 Leg Flight
Percent Difference from Leg Based EMSR
3
2
1
0
-1
-2
-3
-4
-5
-6
0.55
0.65
0.75
0.85
0.95
Load Factor
NPSP
PBID

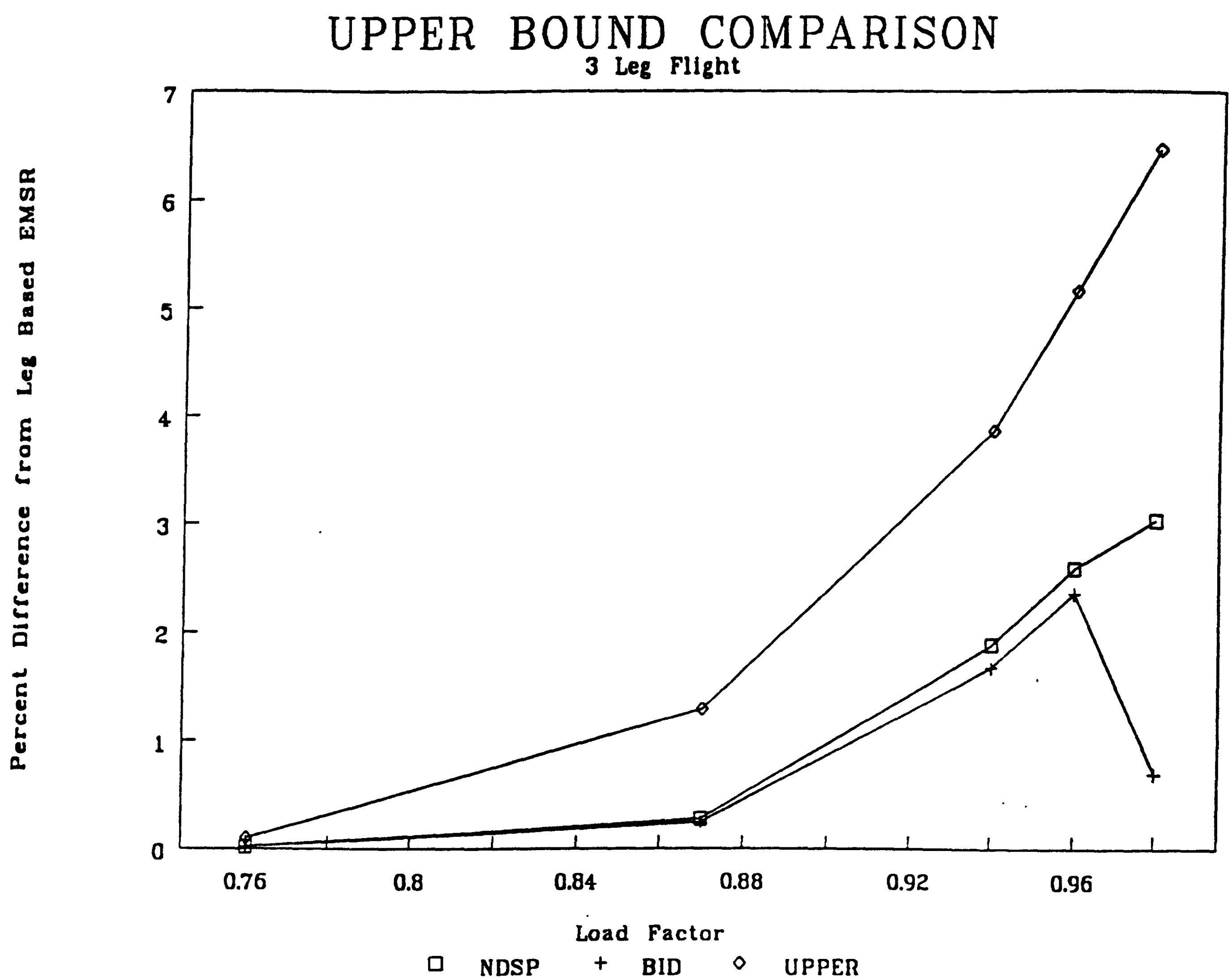
UPPER BOUND

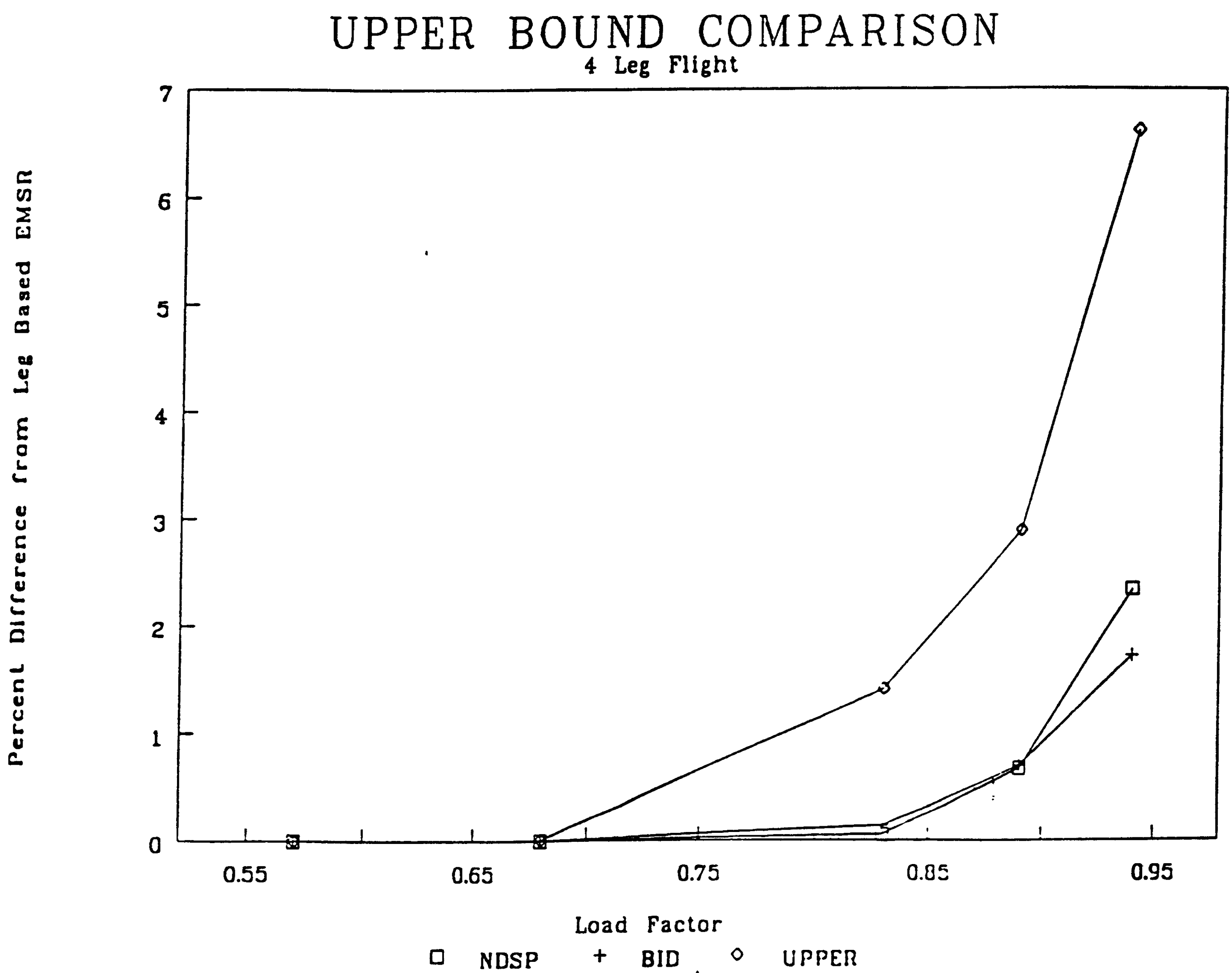
	MEAN	STD DEVI
ABY	36.12	14.91
ABB	9.94	13.92
ABM	18.61	16.01
ABQ	34.06	25.96

ACTUAL DEMAND

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

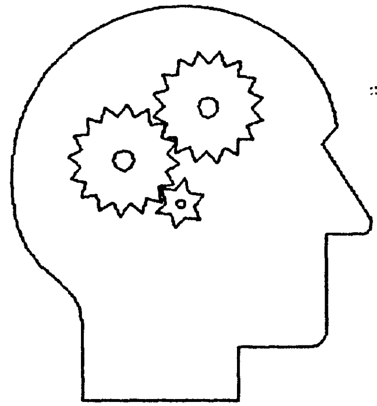

UPPER BOUND COMPARISON
2 Leg Flight
Percent Difference from Leg Based EMSR
0
1
2
3
4
5
6
7
0.7
0.74
0.78
0.82
0.86
0.9
0.94
0.98
Load Factor
NDSP
BID
UPPER


UPPER BOUND COMPARISON
3 Leg Flight
Percent Difference from Leg Based EMSR
0
1
2
3
4
5
6
7
0.76
0.8
0.84
0.88
0.92
0.96
Load Factor
NDSP
BID
UPPER


UPPER BOUND COMPARISON
4 Leg Flight
Percent Difference from Leg Based EMSR
0
1
2
3
4
5
6
7
0.55
0.65
0.75
0.85
0.95
Load Factor
NDSP
BID
UPPER

Summary

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



Planning and Scheduling of Tasks in a Dynamic Environment

Lyman R. Hazelton

23 May 1991

LRH-91-001

The Strategic Control of systems requiring *planning* and *scheduling* of activities is called

Operations Management

- Reasoning about the future in a dynamic environment.
- Determination of the time that a state or process should be maintained.
- Situation dependent objectives.
- No final system state.
- Often involve non-quantifiable parameters.

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

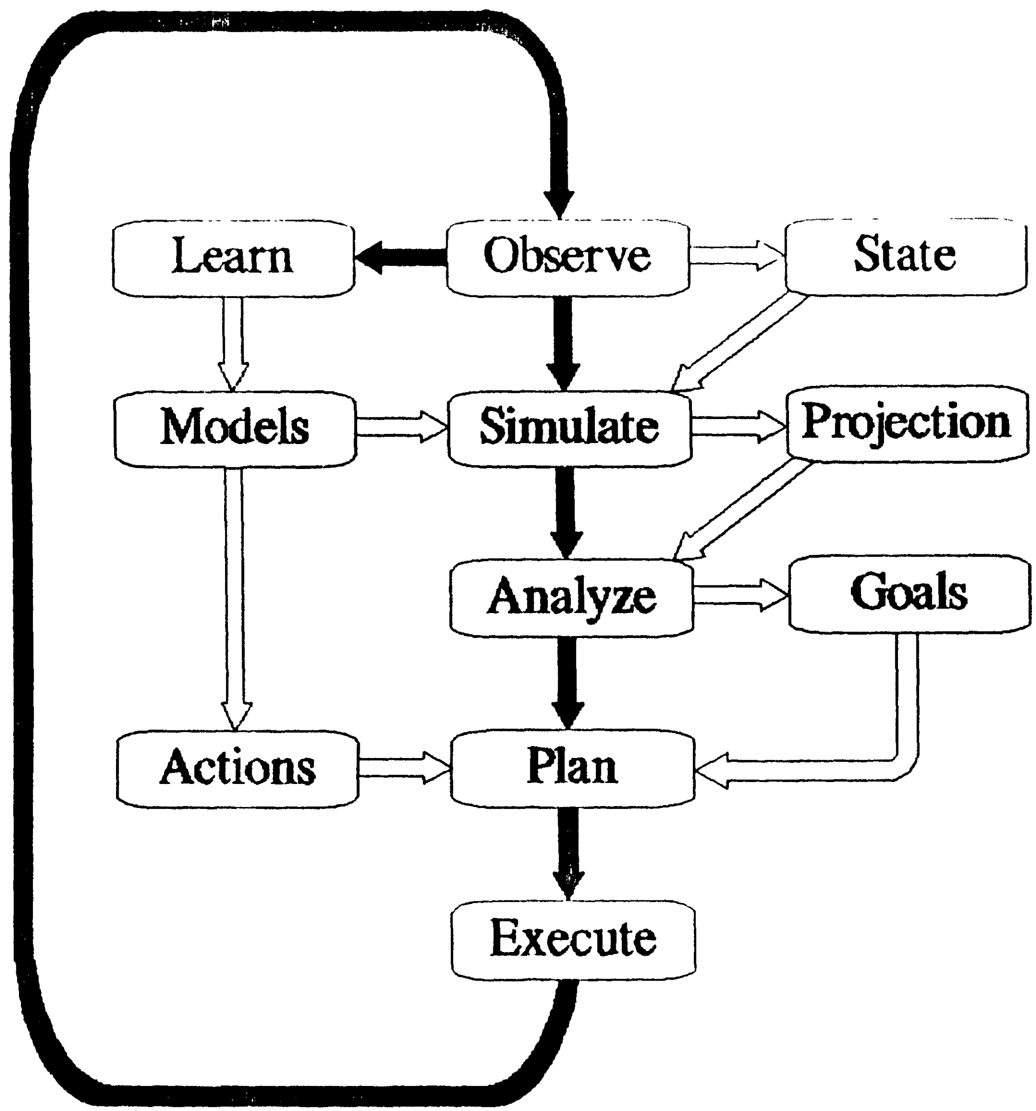
- Were based on a back-chained, goal seeking technology.
- Have been shown to be NP-hard or even Non-terminating for conjunctive goals.
- Assumed a single actor, non-stochastic universe.
- Had no logic or even representation for time dependent activities.

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

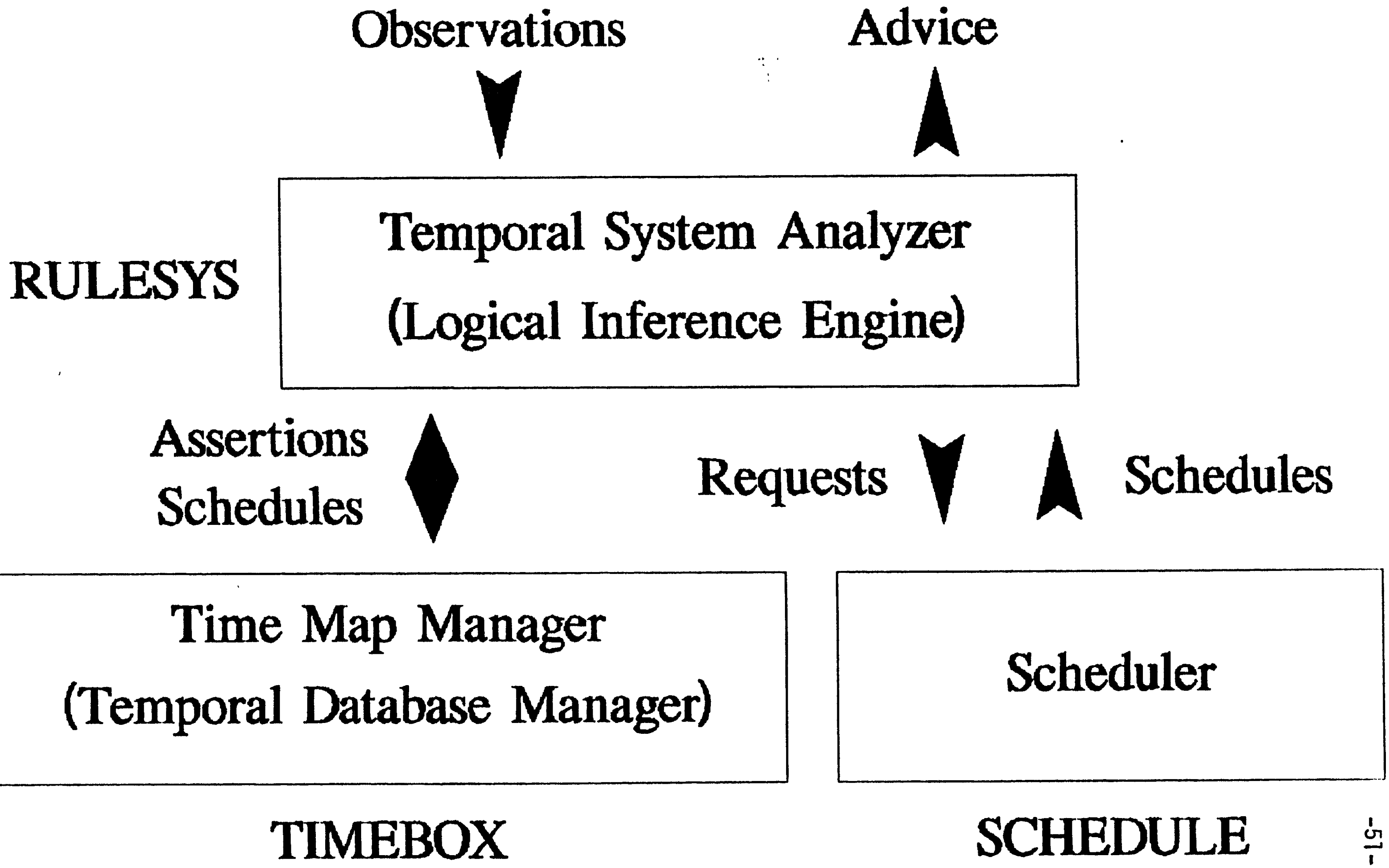
At the time the research was initiated:

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

Operations Management Model



LRH-90-01


Observations
Advice
RULESYS
Temporal System Analyzer
(Logical Inference Engine)
Assertions
Schedules
Requests
Schedules
Time Map Manager
(Temporal Database Manager)
Scheduler
TIMEBOX
SCHEDULE

- Rule
  - Antecedent
    - Search Section
      - Pattern-1
      - Pattern-2
      - Pattern-3
    - Test Section
      - Test-1
      - Test-2
  - Consequent
    - Assertion-1
    - Assertion-2

Goal:
PAINTED CEILING
and
PAINTED LADDER

Plan: PAINT LADDER

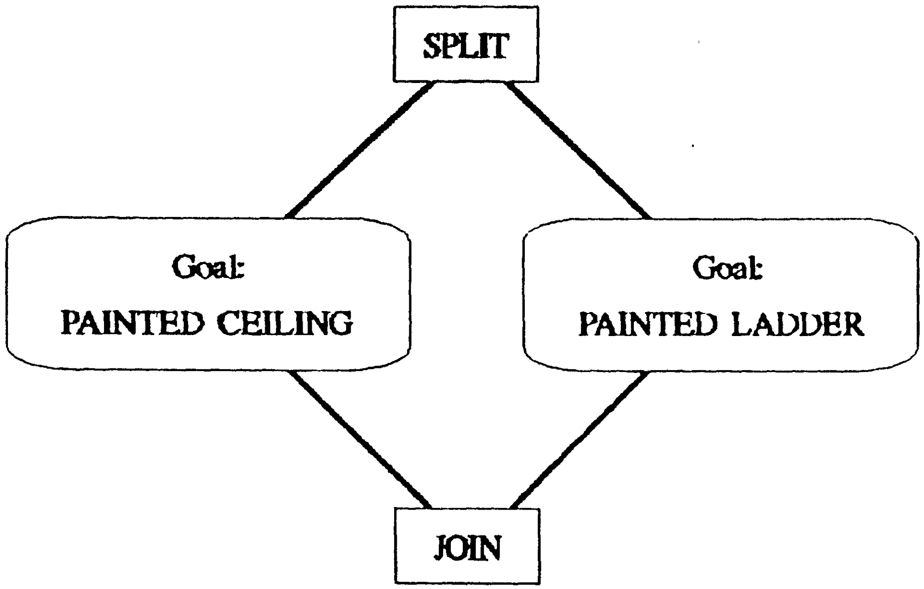
Procedure:
- GET PAINT
- GET LADDER
- APPLY-PAINT LADDER

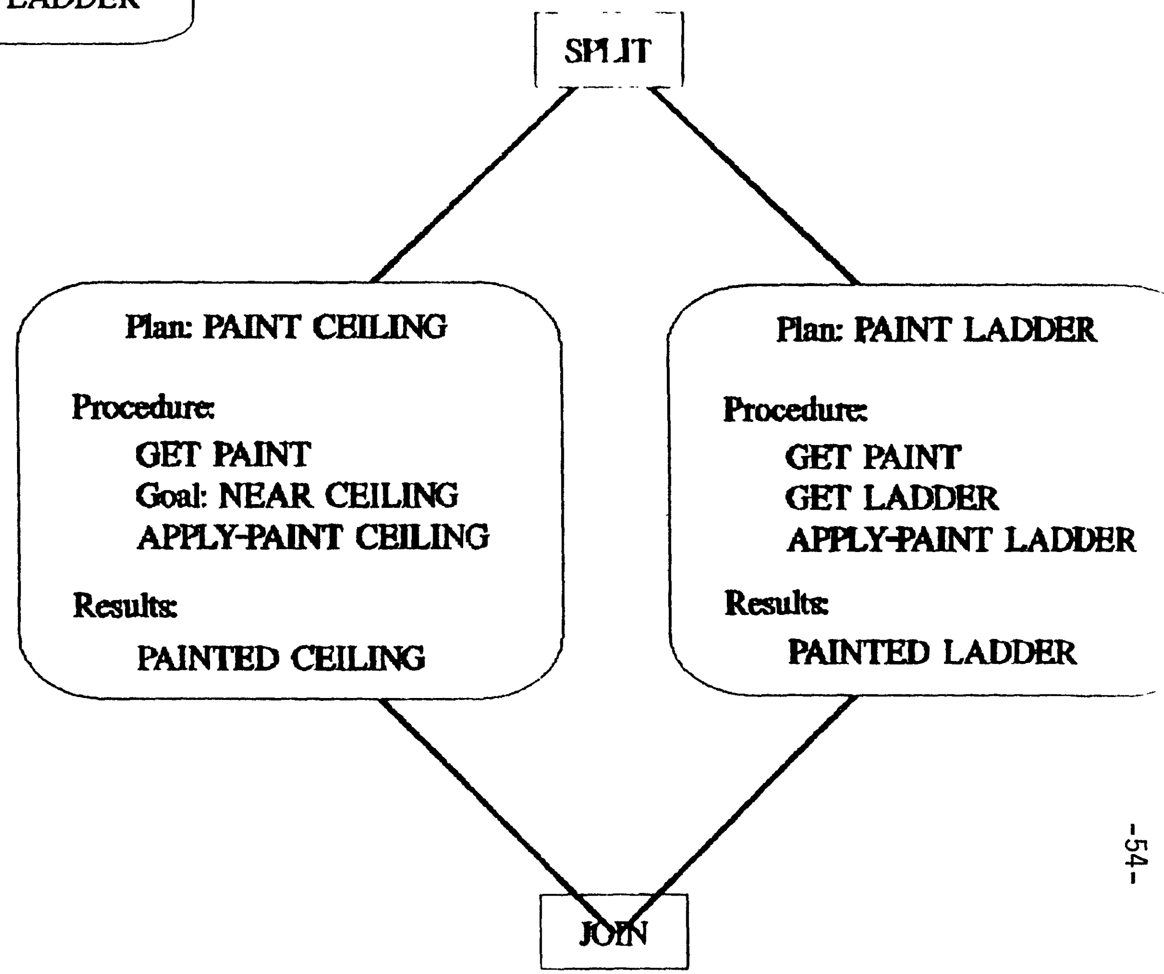
Results:
- PAINTED LADDER

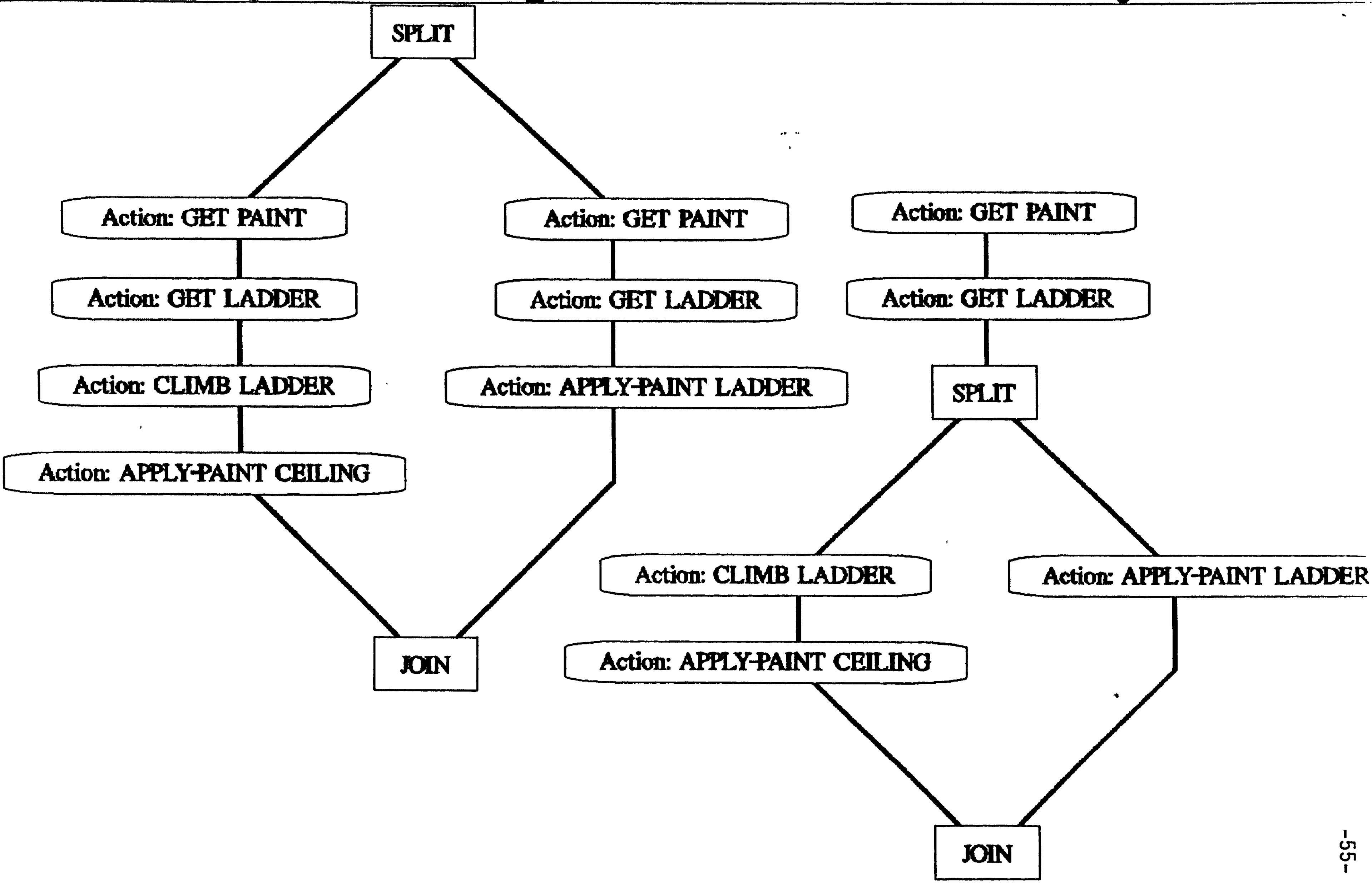
Plan: PAINT CEILING

Procedure:
- GET PAINT
- Goal: NEAR CEILING
- APPLY-PAINT CEILING

Results:
- PAINTED CEILING


SPLIT
Goal:
PAINTED CEILING
Goal:
PAINTED LADDER
JOIN


SPLIT
Plan: PAINT CEILING
Procedure:
GET PAINT
Goal: NEAR CEILING
APPLY-PAINT CEILING
Results:
PAINTED CEILING
Plan: PAINT LADDER
Procedure:
GET PAINT
GET LADDER
APPLY-PAINT LADDER
Results:
PAINTED LADDER
JOIN

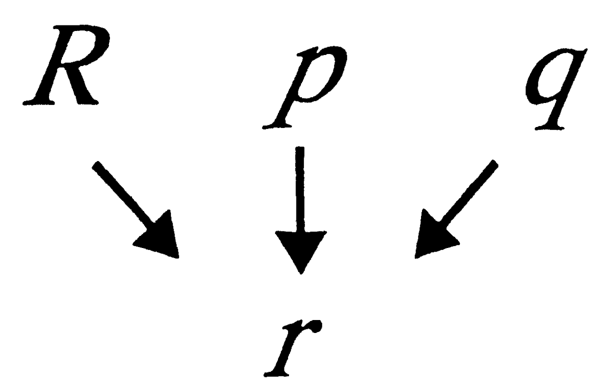

SPLIT
Action: GET PAINT
Action: GET LADDER
Action: CLIMB LADDER
Action: APPLY-PAINT CEILING
Action: GET PAINT
Action: GET LADDER
Action: APPLY-PAINT LADDER
JOIN
Action: GET PAINT
Action: GET LADDER
SPLIT
Action: CLIMB LADDER
Action: APPLY-PAINT CEILING
Action: APPLY-PAINT LADDER
JOIN

- # Truth Maintenance

  A first attempt to extend logic into a dynamic environment.

$$R\!: \; p \cdot q \rightarrow r \cdot \{R \; p \; q\} \top r$$

$$\sim p \mid \sim q \;\; \overline{>} \;\; r$$

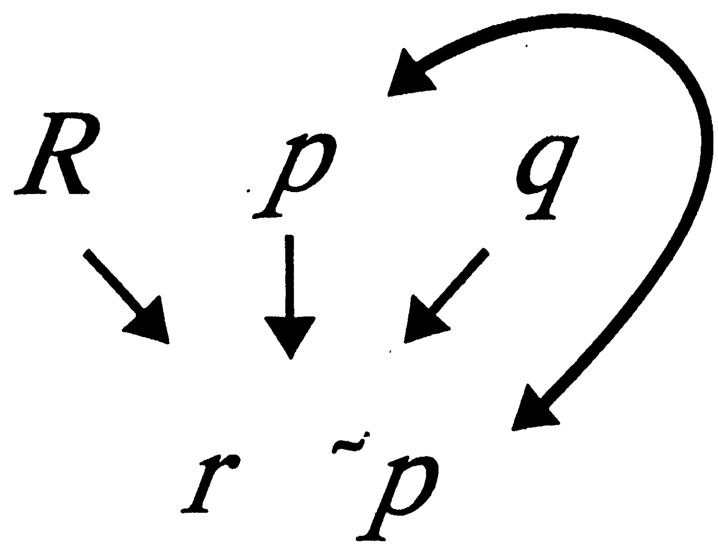


- Inferred evolution

$$R\colon\ p \cdot q \rightarrow r \cdot {\sim}p \cdot$$

$$\{R\ p\ q\} \top r$$

$${\sim}p \mid {\sim}q \quad \bar{>} \quad r \qquad \text{(TM)}$$



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

$$p(\tau)$$

where τ is a time interval having a starting time and an ending time.

- **Persistence:**

$$R:\; p \rightarrow q$$

$$\sim p \;\tilde{>}\; q \qquad \text{(NO TM)}$$

If it is raining (p), the roads will be wet (q).
But if it stops raining ($\sim p$), the roads do not instantly become dry. Wet roads persist.

- Temporal Logic (continued)
  - Rules of Inference

    Modus Ponens:

    $p \rightarrow q$

    $p(\tau)$

    $\therefore\ q(\tau)$ Non-persistent

    $\therefore\ q(\text{start}(\tau), \infty)$ Persistent

- # Inferred evolution revisited

$$R\colon p(\tau_1) \cdot q(\tau_2) \rightarrow r(\tau_1 \cap \tau_2) \cdot {}^{\sim}p(\tau_1 \cap \tau_2)$$

$$\{R\ p(\tau_1)\ q(\tau_2)\} \top r(\tau_1 \cap \tau_2)$$

$$\{R\ p(\tau_1)\ q(\tau_2)\} \top {}^{\sim}p(\tau_1 \cap \tau_2)$$

$$^{\sim}p(\tau) \mid {}^{\sim}q(\tau) \supset r(\tau)$$

$$R \quad p(\tau_1) \quad q(\tau_2)$$

$$\searrow \quad \downarrow \quad \swarrow$$

$$r(\tau_1 \cap \tau_2) \cdot {}^{\sim}p(\tau_1 \cap \tau_2)$$

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

There are TWO time intervals involved in temporal reasoning.

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

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

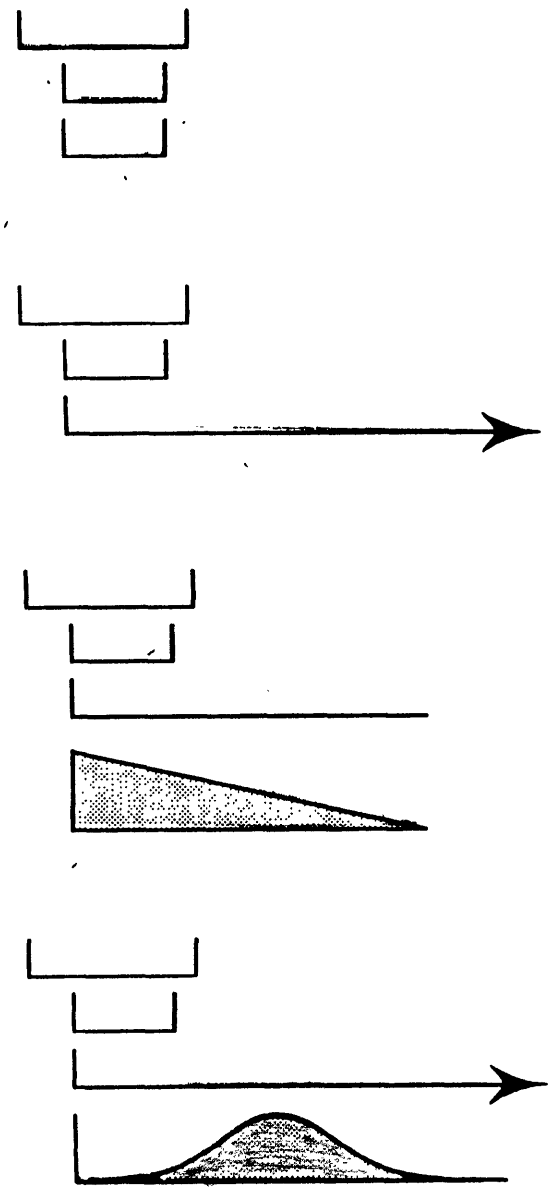
Types of consequents

Bounded

Persistent

Decayed

Probabilistic



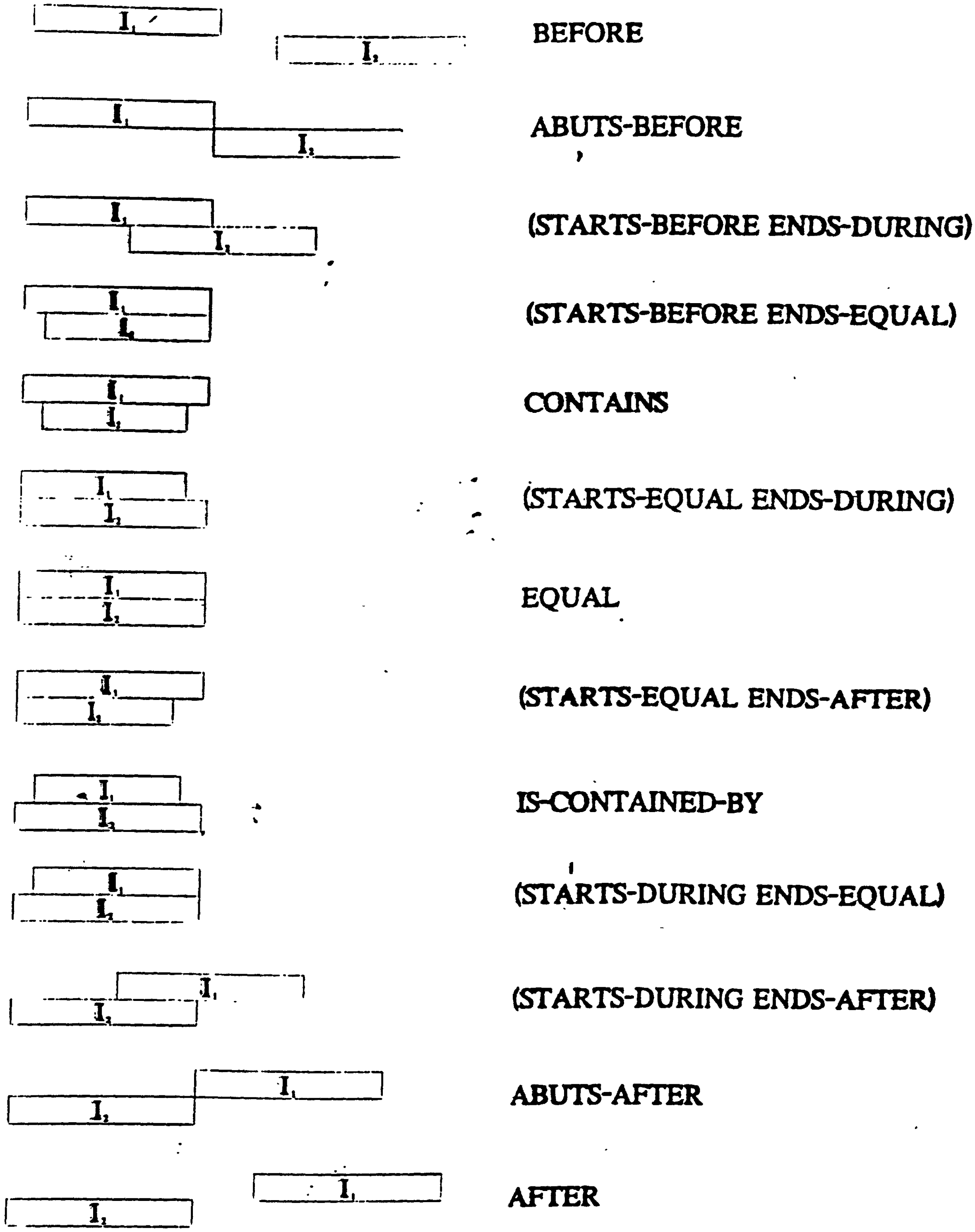
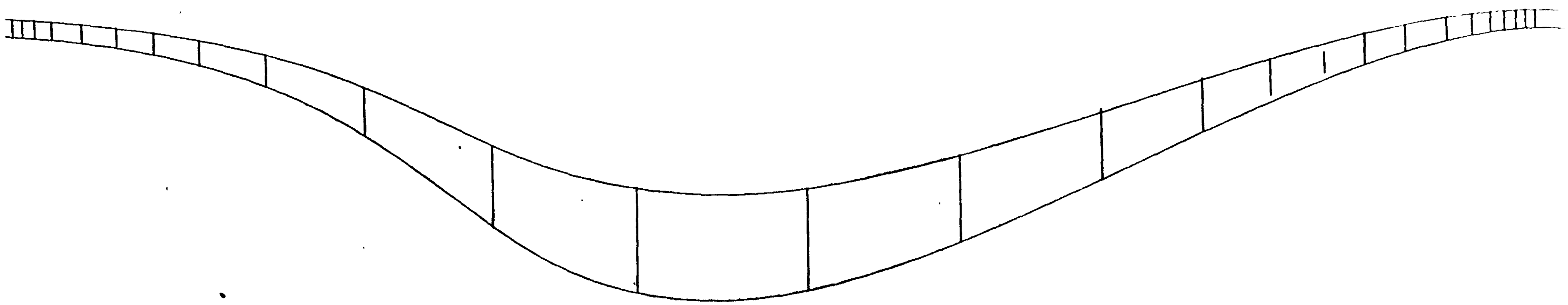


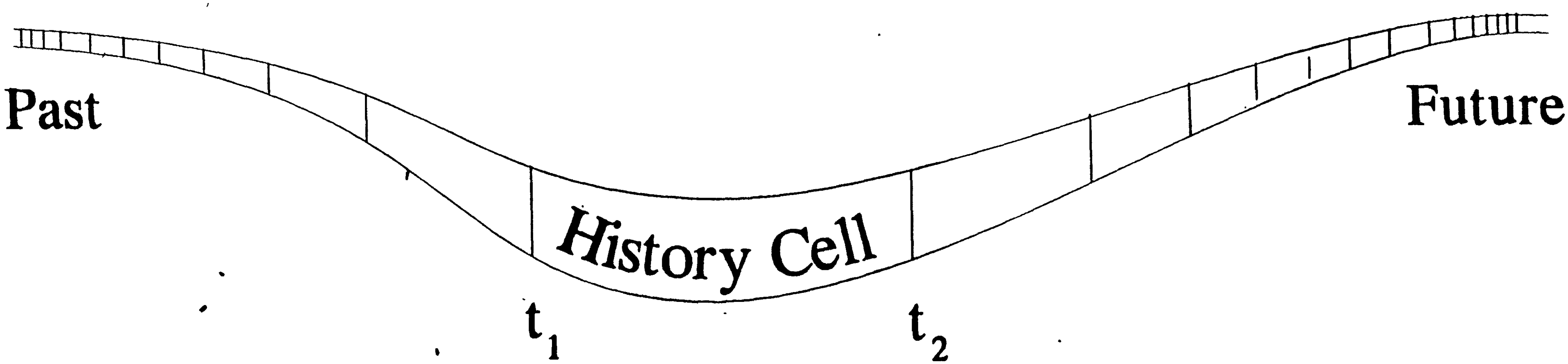
Figure 3.2: Temporal Relations

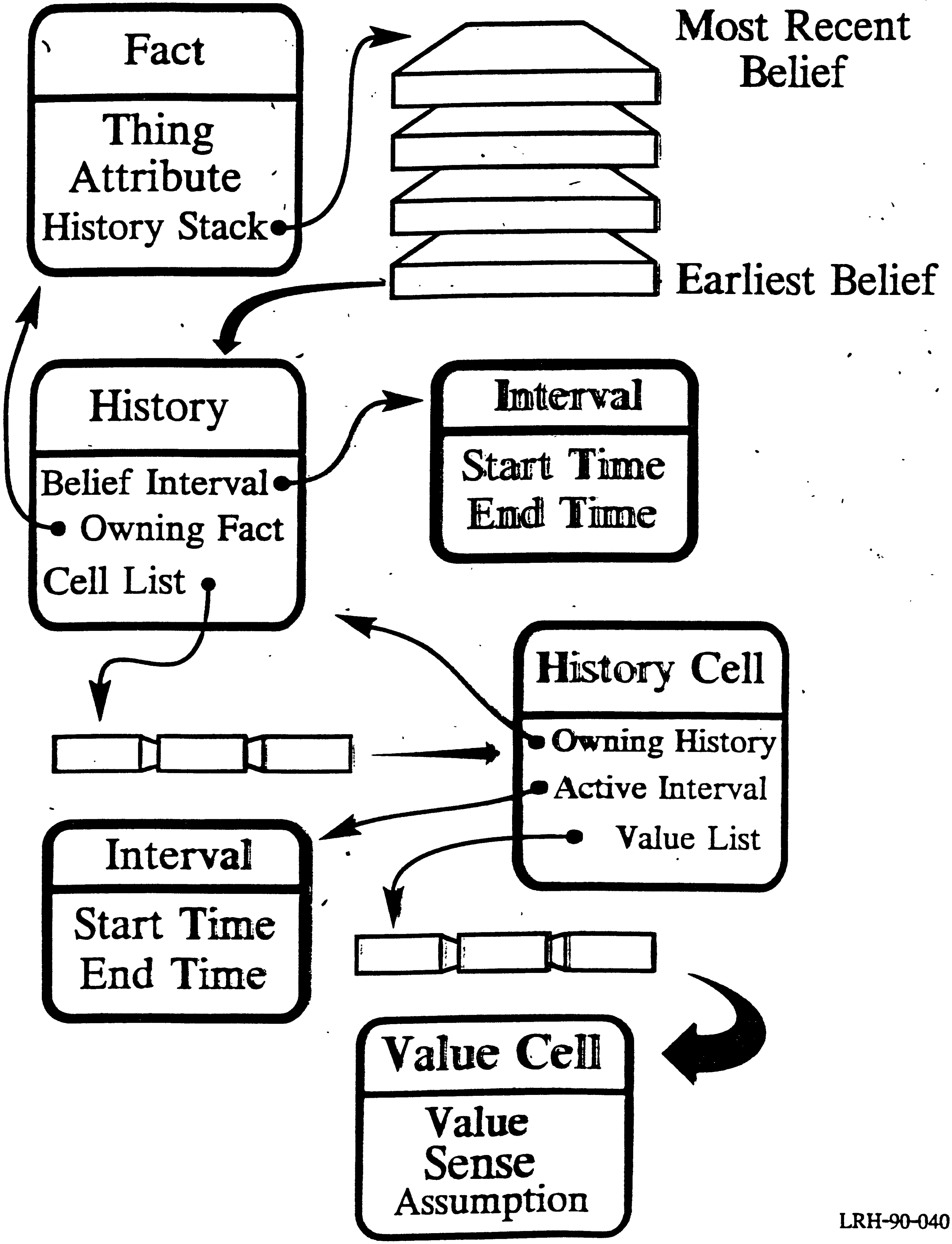


FACT:

thing

attribute




Fact
Thing
Attribute
History Stack
Most Recent
Belief
Earliest Belief
History
Belief Interval
Owning Fact
Cell List
Interval
Start Time
End Time
History Cell
Owning History
Active Interval
Value List
Interval
Start Time
End Time
Value Cell
Value
Sense
Assumption

LRH-90-040

CONTRIBUTIONS

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

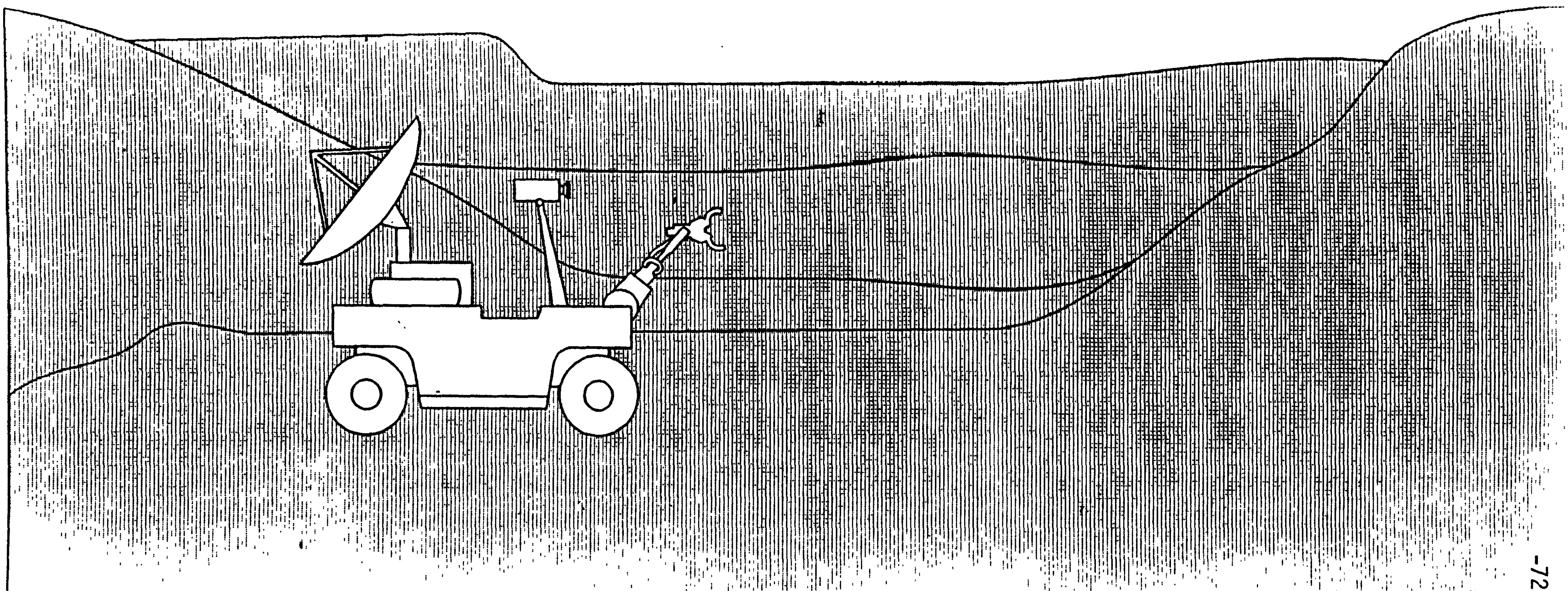
CONTRIBUTIONS
(continued)

- Implemented a Temporal System Analyzer employing Extended Temporal Logic and Persistence

- Created a Scheduler Program, thereby extending Domain Independent Planning to include Parallel, Time Bounded, Non-Instantaneous Actions

Novel ideas and methods developed for this system include

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



LRH-90-068

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

Jan Van Acker

Flight Transportation Laboratory
May 23, 1991

Agenda

I. Thesis Objective and Methodology

II. Analysis of Top 100 Markets

III. Analysis of Dominated City Markets

IV. Conclusions

I. Thesis Objective

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

Focus on Concentration in O-D City-Pairs

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

Measurement of Concentration

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

II. Changes in Concentration in Top 100 Markets

- Markets ranked 1-100 in terms of local passengers transported in 1989

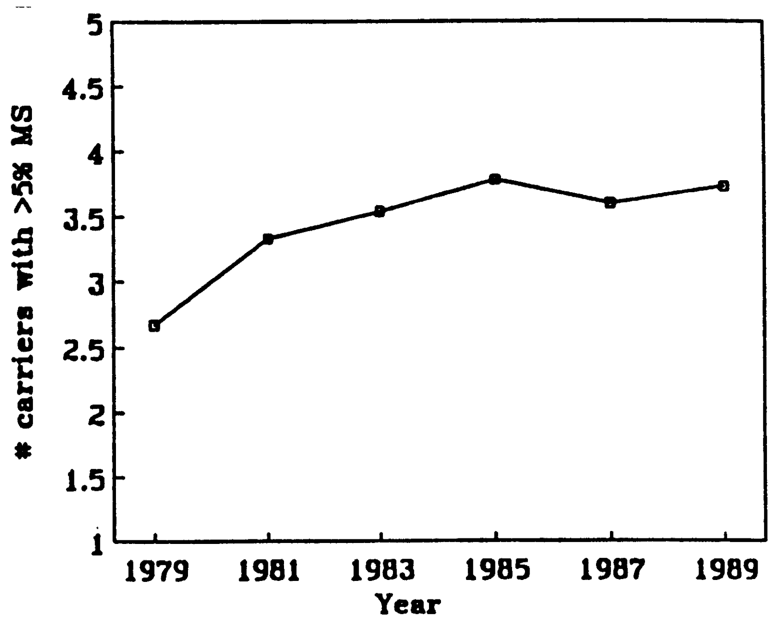
- Cumulative number of passengers was 31% of U.S. domestic total in 1989

- Years studied: 1979, 1981, 1983, 1985, 1987, 1989

- With focus on 1979, 1985, 1989

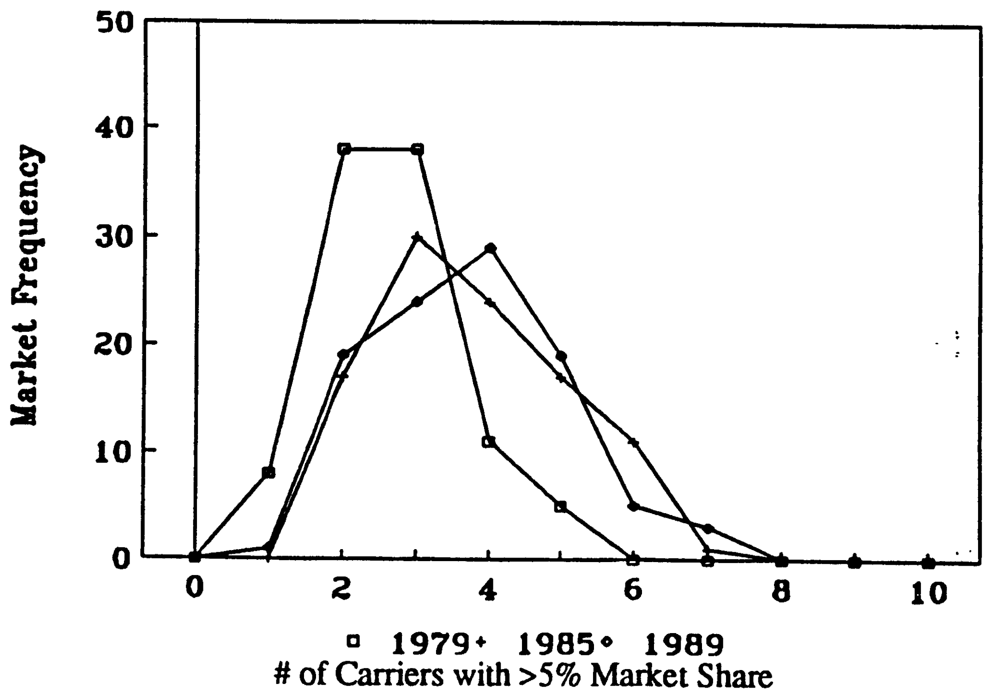
Average Number of Effective Competitors was One more in 1989 than in 1979

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



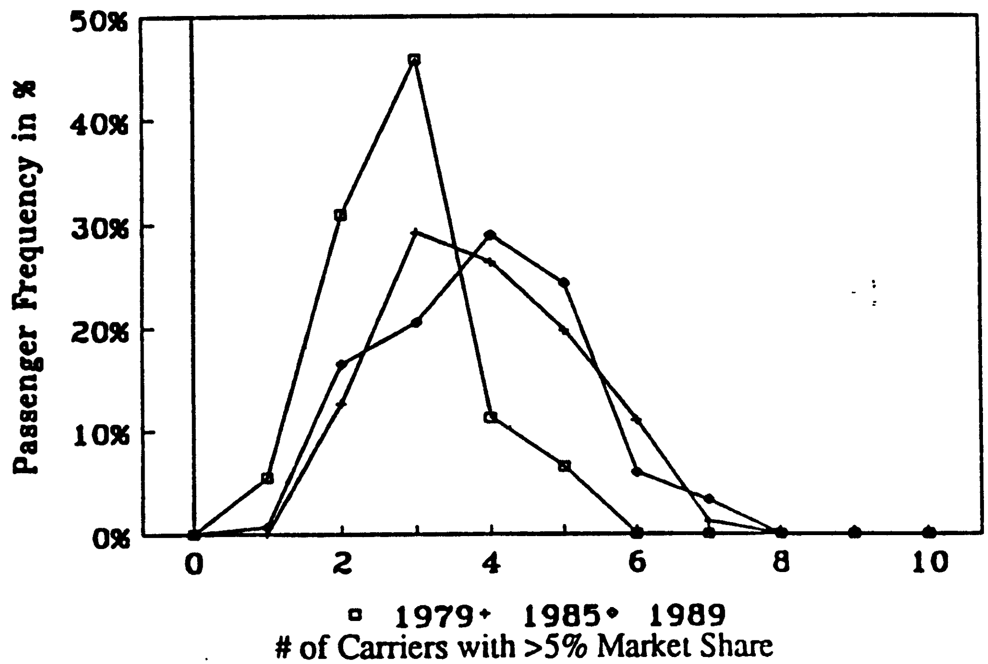
56 Markets Were Served by Four or More Effective Competitors in '89, as Compared to only 16 in '79

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



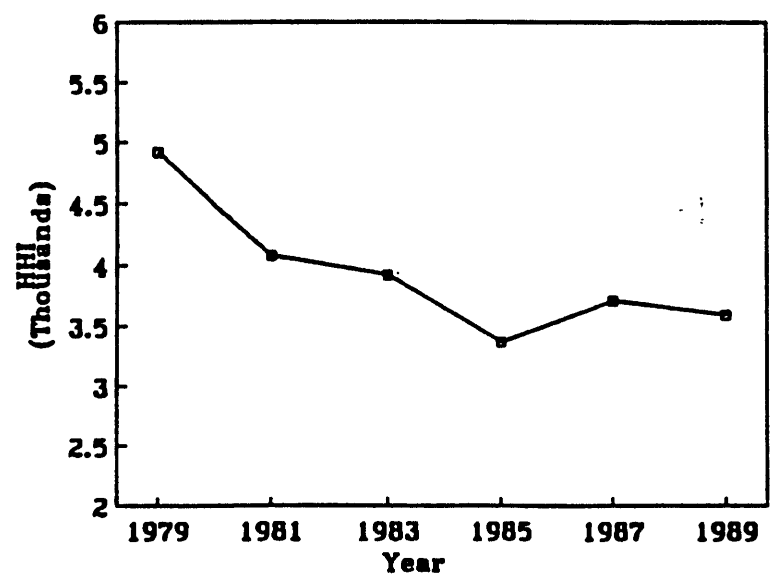
62% of the Passengers Flew in Markets Served by 4 or More Effective Competitors in '89 - - only 18% in '79

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



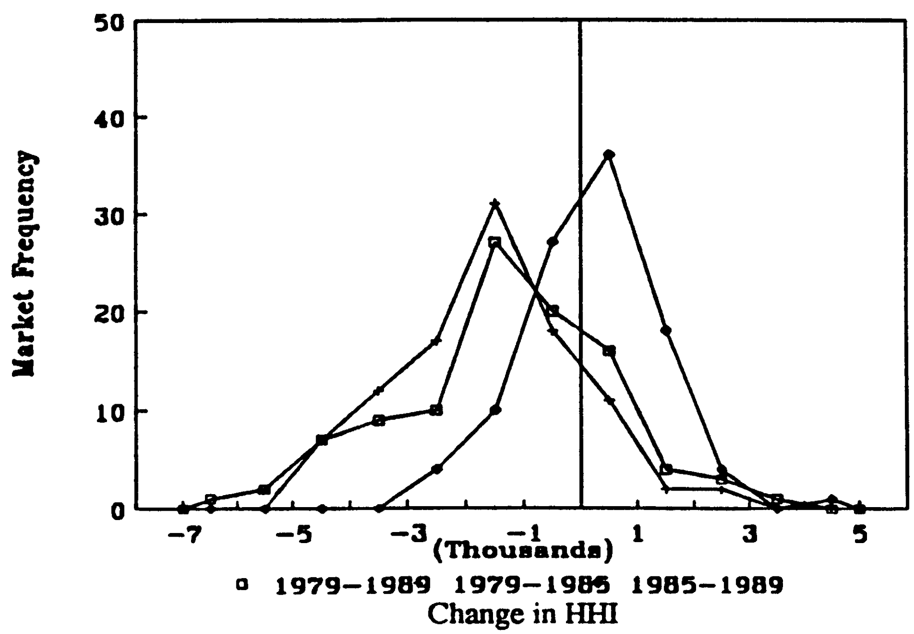
Average HHI Was Lower in 1989 than in 1979

Year	Average HHI
1979	4917
1981	4077
1983	3913
1985	3361
1987	3705
1989	3586



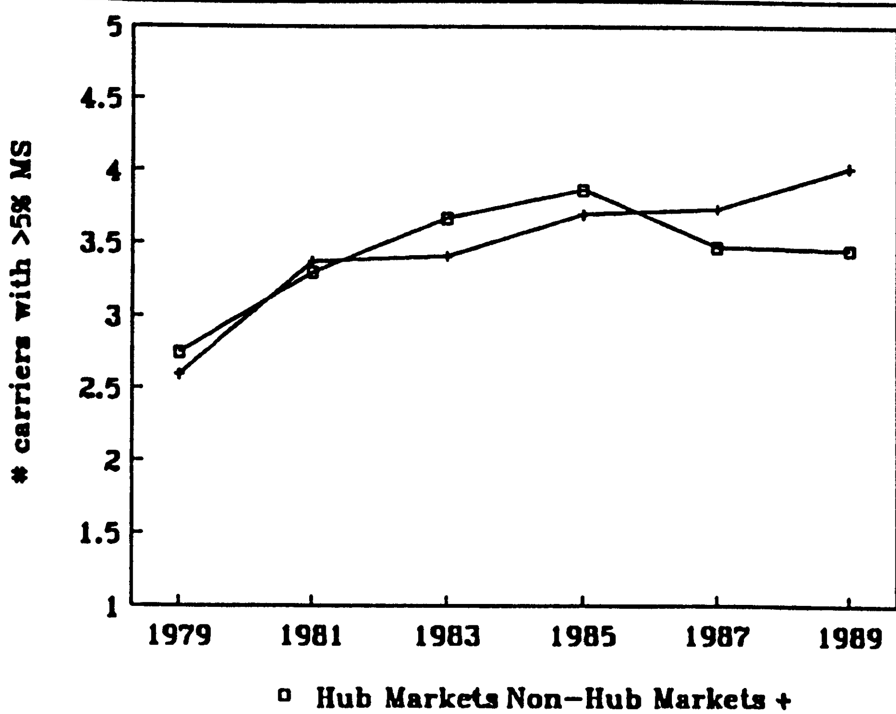
The Majority of the Markets Experienced a Decrease in HHI from 1979 to 1989

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



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

Year	Hub Markets	Non-Hub Markets
1979	2.7	2.6
1981	3.3	3.4
1983	3.7	3.4
1985	3.9	3.7
1987	3.5	3.7
1989	3.5	4.0



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

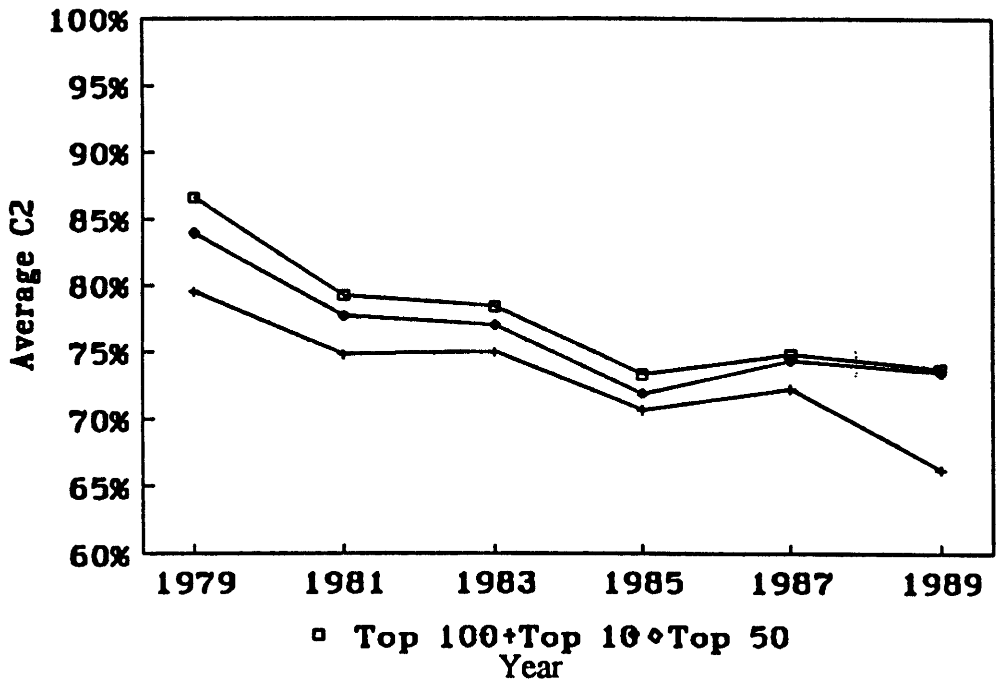
Change in # Carriers With >5% MS	'79-'89	'79-'85	'85-'89
-4 to -3	0	0	0
-2 to -1	1	5	11
0	8	11	19
1 to 2	33	24	17
3 to 4	7	9	2
5 to 6	0	0	0
Total Decreased	1	5	11
Total Increased	40	33	19
Average Change	1.10	0.33	1.43

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

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

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

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



Conclusions of Top 100 Markets Analysis

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

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

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

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

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

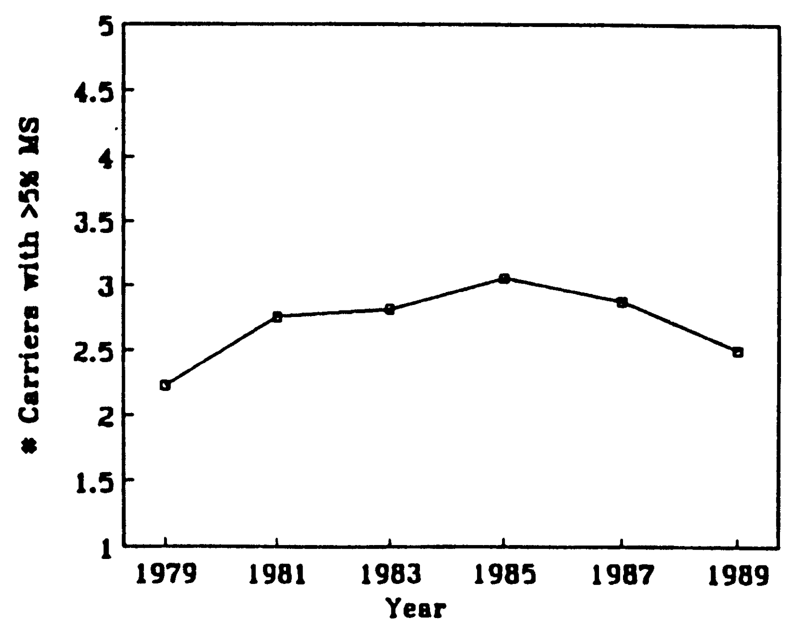
Changes in Concentration in Top Ten Markets out of Dominated Cities

- Years studied: 1979, 1981, 1983, 1985, 1987, 1989

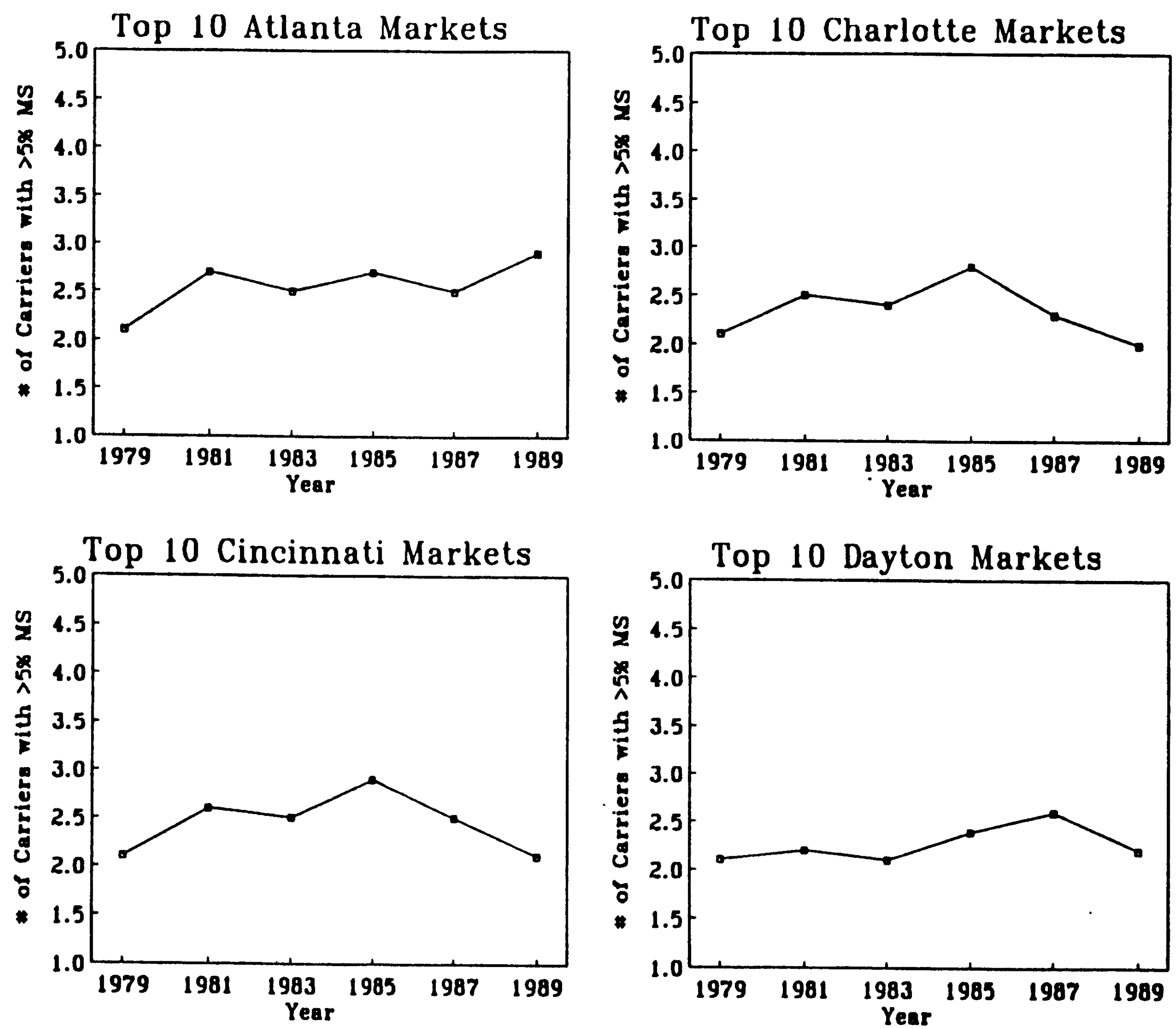
- With focus on 1979, 1985, 1989

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

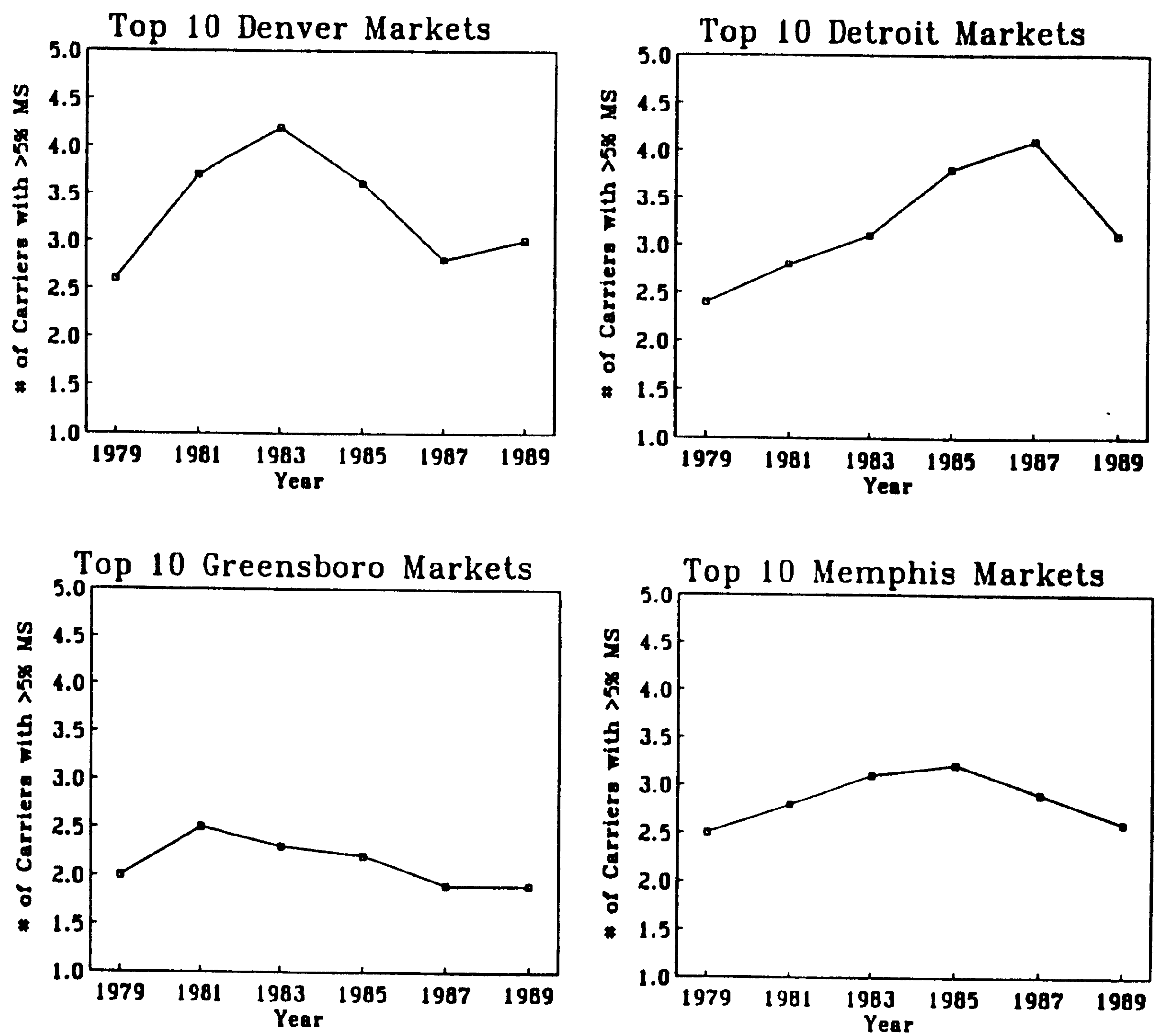
Year	Dominated Airport Markets
1979	2.2
1981	2.8
1983	2.8
1985	3.1
1987	2.9
1989	2.5



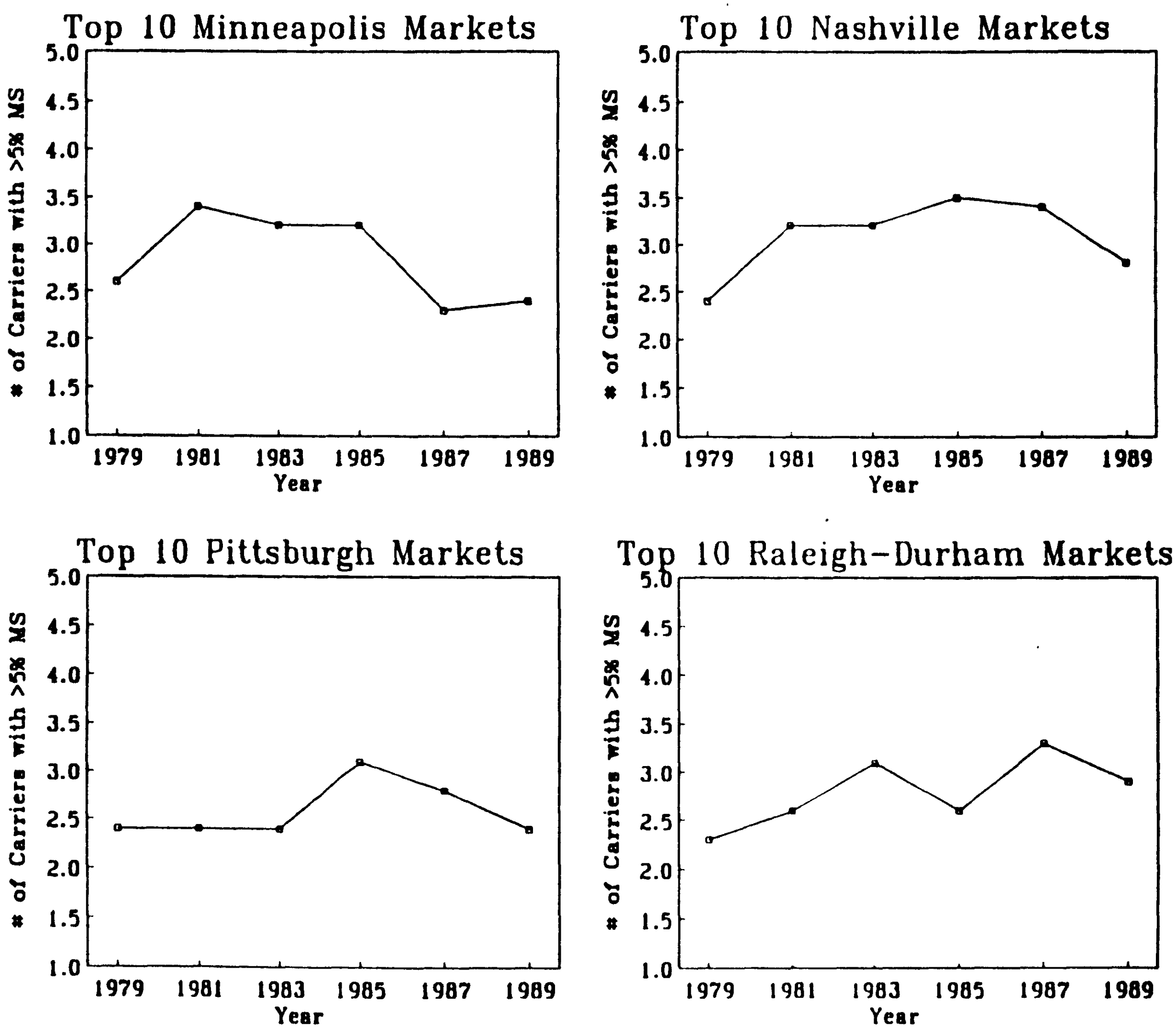
Average Number of Effective Competitors for each of the Dominated Cities



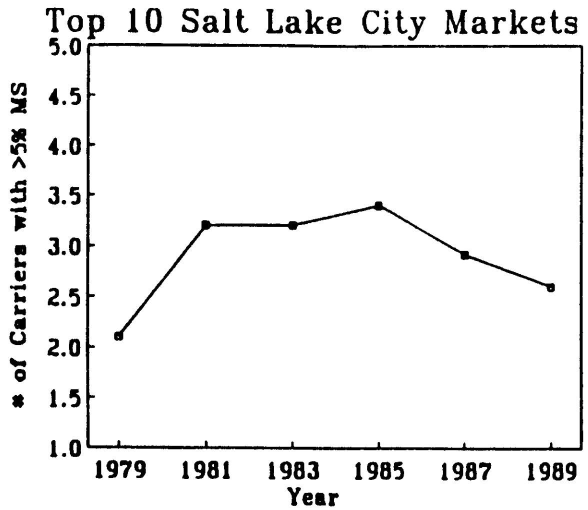
Average Number of Effective Competitors for each of the Dominated Cities

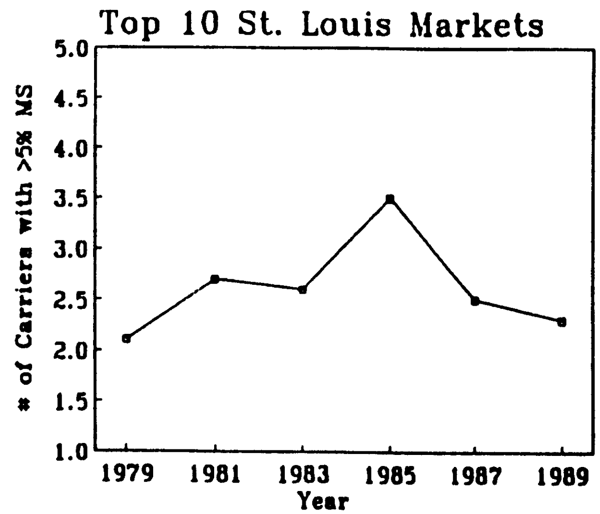


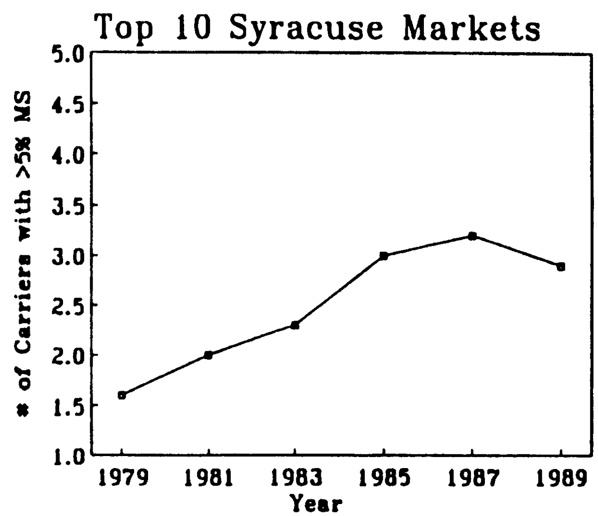
Average Number of Effective Competitors for each of the Dominated Cities



Average Number of Effective Competitors for each of the Dominated Cities







Changes in Concentration in the Top Ten Atlanta Markets

O-D City-Pair Markets		HHI	Change in HHI		
		1989	'79-'89	'79-'85	'85-'89
Atlanta	Boston	5446	455	-547	1002
Atlanta	Chicago	2949	-2538	-2031	-508
Atlanta	Dallas/Fort Worth	5932	-350	-1968	1618
Atlanta	Los Angeles	5089	-219	-656	437
Atlanta	Miami	3737	-1004	-885	-119
Atlanta	New York	3913	-935	-1294	359
Atlanta	Orlando	5608	482	-880	1362
Atlanta	Philadelphia	4097	-995	-410	-585
Atlanta	Tampa	6002	955	-637	1593
Atlanta	Washington	4701	-193	-721	528
Total Decreased			7	10	3
Total Increased			3	0	7
Average		4747	-434	-1003	569

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

O-D City-Pair Markets		HHI	Change in HHI		
		1989	'79-'89	'79-'85	'85-'89
Syracuse	Atlanta	4418	-5552	-4065	-1487
Syracuse	Boston	9045	175	-4091	4266
Syracuse	Chicago	4119	-5473	-5889	417
Syracuse	Detroit	8942	3967	-740	4707
Syracuse	Los Angeles	1585	-5234	-4924	-310
Syracuse	New York	5820	653	-1756	2409
Syracuse	Orlando	3047	-6014	-5507	-507
Syracuse	Philadelphia	9741	790	493	296
Syracuse	Tampa	2695	-5875	-5178	-697
Syracuse	Washington	8289	-1406	-4879	3473
Total Decreased			6	9	4
Total Increased			4	1	6
Average		5770	-2397	-3653	1257

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

O-D City-Pair Markets		HHI	Change in HHI		
		1989	'79-'89	'79-'85	'85-'89
St. Louis	Chicago	3347	-2161	-3019	858
St. Louis	Dallas/Fort Worth	4528	-506	-2037	1530
St. Louis	Denver	4671	-238	-2333	2095
St. Louis	Detroit	3306	-2180	-2200	20
St. Louis	Houston	3561	-916	-1626	710
St. Louis	Los Angeles	5486	-48	-654	606
St. Louis	New York	8860	2650	-1356	4006
St. Louis	Phoenix	4780	-320	-1360	1040
St. Louis	San Francisco	6567	155	-547	701
St. Louis	Washington	8252	302	-3798	4100
Total Decreased			7	10	0
Total Increased			3		10
Average		5336	-326	-1893	1567

Conclusions of Dominated City Markets Analysis

- Single trend of hub development led to decreased concentration through '85 at most of the cities, but to increases from '85 on

- Two-hub markets were less concentrated than one-hub markets in 1989

- Average concentration across the 150 markets was slightly lower in '89 than in '79

IV. Conclusions

- Concentration was lower in top 100 markets, both on average and in most of the markets

- Concentration in non-hub markets decreased throughout period '79-'89 because of development of hub-and-spoke networks

- These networks led to increases in concentration in most hub markets after 1985

Conclusions

- Single trend of hub development led to decreases in concentration through '85 at most of the dominated cities, but to increases from '85 on

- Concentration was on average slightly lower in the 150 markets out of dominated cities in 1979 than in 1989, and was lower in half of the markets

Pricing in the Airline Industry Current Practice and Future Research

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

Presentation Outline

Overview

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

Case Study Analysis

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

Nature of Airline Competition

- Hub and spoke route structures prevail in the industry allowing almost every major carrier to serve any O/D market

- Most competition on non-price level

- Dollar value of nonstop service is unclear

- Must consider strength of competitive position in each O/D market separately

- Characterize competition in all markets:
  - major players
  - level of service offered
  - number of flights per day offered
  - nonstop vs. nonstop competition

- Anticipate response to price changes:
  - who are the competitors?
  - do the competitors offer comparable service in the market?
  - how have competitors reacted to fare changes in the past?
  - what response will be given to hostile reactions by competitors?

Fare Product Differentiation

- Airlines seek to segment demand by offering differentiated fare products in different fare classes

- Delta offers tickets in 10 fare classes:
  1) F - full fare first class
  2) Y - full fare coach class
  3) B - reserved for military/ convention/negotiated fares
  4) M - highest discount coach fare
  5) H - discount coach class fare
  6) Q - discount coach class fare
  7) K - reserved for competitive filings
  8) L - reserved for competitive filings
  9) A - first class free tickets
  10) W - coach class free tickets

- Differentiation occurs within fare classes
  - peak vs. off-peak fares
  - weekday vs. weekend fares

Fare Product Differentiation (con't)

- Fare restrictions or "fences" used to control which type of consumer is able to purchase which type of ticket

- Common fare restrictions include:
  - advanced purchase requirements
  - Saturday night stayover
  - blackout periods
  - flight validity restrictions (good for travel between...)
  - ticket purchase restrictions (purchase tickets by...)
  - availability limits for discount fares
  - military discount fares
  - senior citizen discount fares

Seat Inventory Management (IM)

- Pricing sets O/D prices and restrictions

- IM decisions made with fixed prices and restrictions

- IM seeks to maximize revenue given fixed prices and restrictions

- IM controls price/seat quantity decisions
    - protect full fare seats
    - limit discount fares
    - strictly limit deep discount fare seat availability

- Matching stances require booking limits
    - strictly limited availability on competitive fare filings

Pricing Strategies and Their Effects

- Matching a fare
  - retain market share
  - possible drop in yield
  - remain listed on Page 1 of CRS
  - often done to remain competitive
  - viewed as price taker in the market

- Not matching a fare
  - possible loss of market share
  - maintain yield
  - may lose competitiveness
  - loss of goodwill

- Partially matching a fare
  - attempt to retain market share
  - reduce non-matching yield loss
  - market factors influence strategy
  - will be non-competitive at peak
  - accept that competitor offers low fare on <u>all</u> flights

Role of the Pricing Analyst

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

Ultimate Pricing Model

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

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

Theoretical Issues for Investigation

- Joint seat/price optimization problem
- Optimal differential pricing strategies
- Model development for pricing strategies
  - matching
  - not matching
  - other pricing strategies
- Impacts of price changes
- Measurements of price elasticity
- Explore impacts of pricing strategies on:
  - profitability
  - load factor
  - yield
  - customer satisfaction

Case Study Overview

- Close look at 10 O/D markets

- Representative cross section of markets flown by Delta Airlines

- Quarterly analysis

- Examine quarterly data 1986:1 - 1990:2

- Give consideration to:
  - published fares
  - competitive responses
  - major price level changes

- Use information from several data bases:
  - PIPPS (Historical ATP data)
  - DOT O/D traffic stats (10% sample)
  - Official Airline Guide

- Preliminary analysis on two markets:
  - ATL - BOS
  - ATL - STL

Case Study Objectives

- Initial look at revenue management from pricing perspective

- Develop market by market case studies
    - Present a market overview
    - Characterize pricing practices
    - Analyze competitive environment
    - Uncover competitive characteristics
    - Highlight major market events

- Analyze the quality and level of detail of the available data sources

- Relate market strength to fare level
    - between carriers
    - over time

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

- Determine selling fares during the period

- Use available data to determine the effects of pricing decisions

- Discuss future directions for research

O/D Market Choice

<u>Length of Haul</u>

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

<u>Nature of Competition</u>

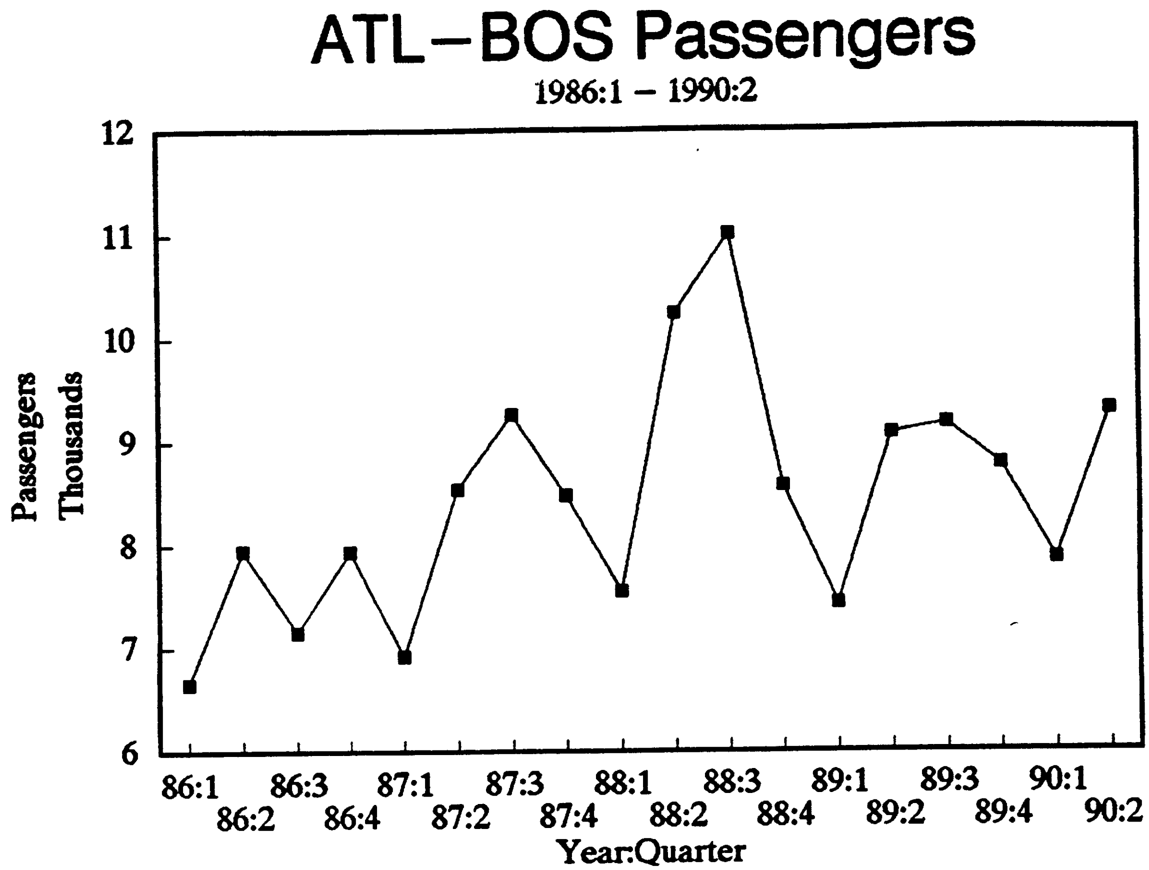
- Delta offers non-stop service
- Only competitors offer non-stop service
- No one offers non-stop service

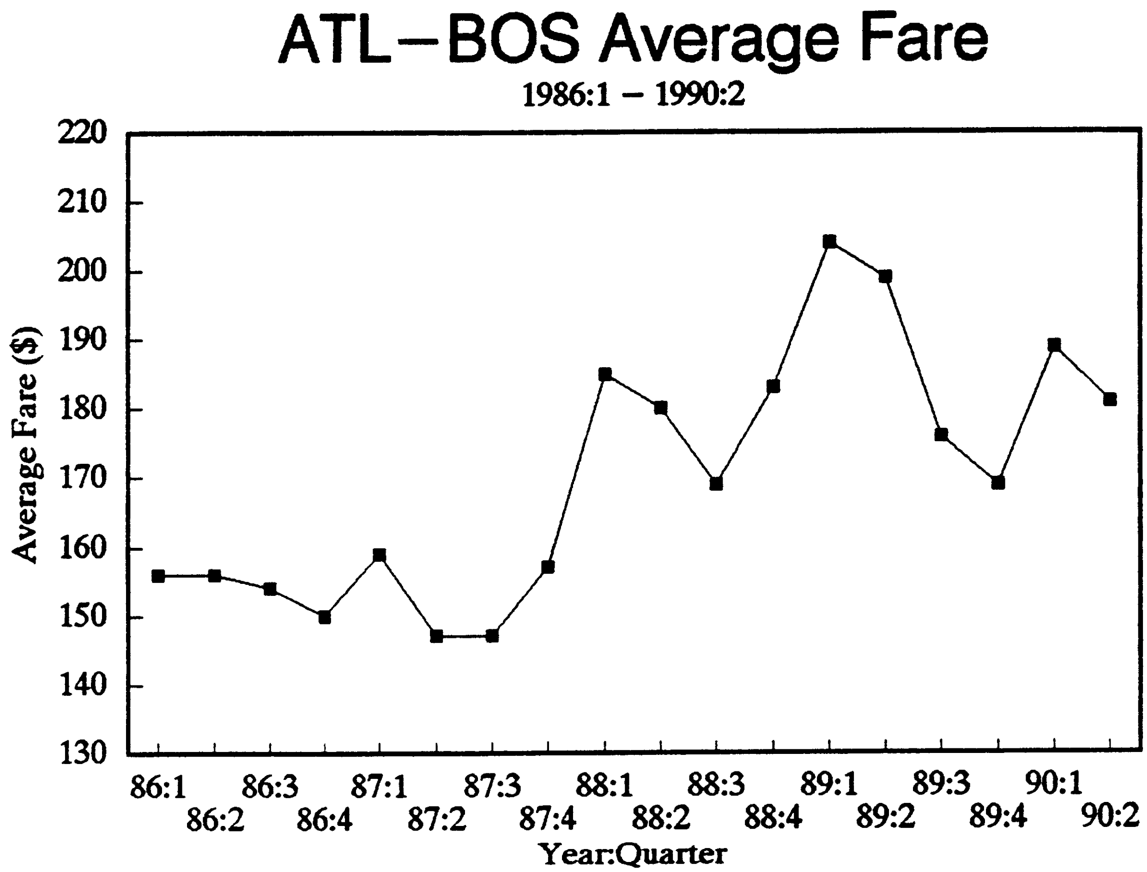
<u>Markets Chosen</u>

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

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

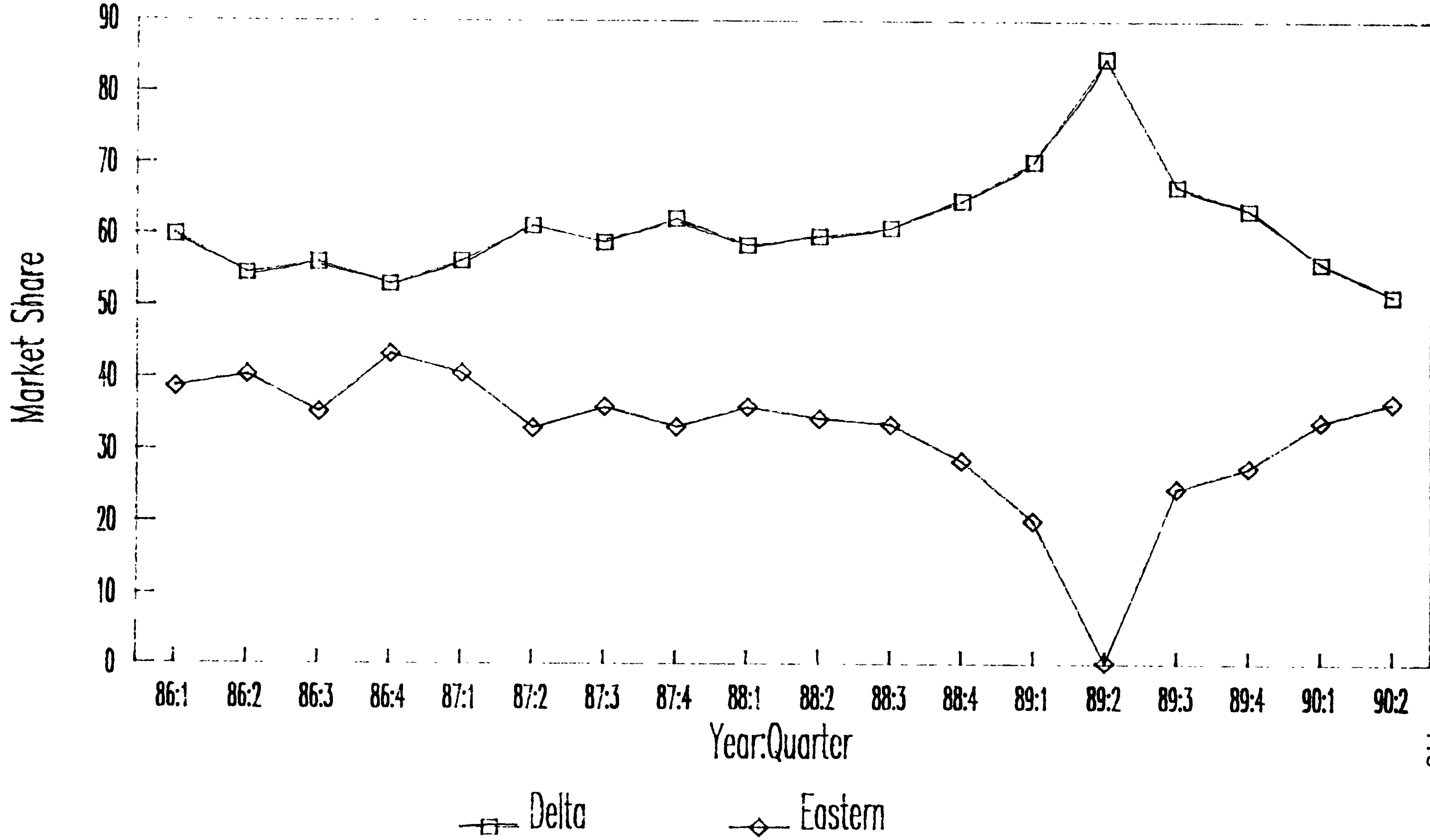
- Two non-stop carriers during the period
  - Delta
  - Eastern
- Non-stop carriers flew 93% of all pax
- Frequency of approximately 12 daily non-stops each way
- Total traffic level of 925 passengers per day in both directions
- Carriers with ATL hub
  - Delta
  - Eastern
- Eastern Airlines strike in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


ATL-BOS Passengers
1986:1 – 1990:2
Passengers
Thousands
12
11
10
9
8
7
6
86:1
86:2
86:3
86:4
87:1
87:2
87:3
87:4
88:1
88:2
88:3
88:4
89:1
89:2
89:3
89:4
90:1
90:2
Year:Quarter

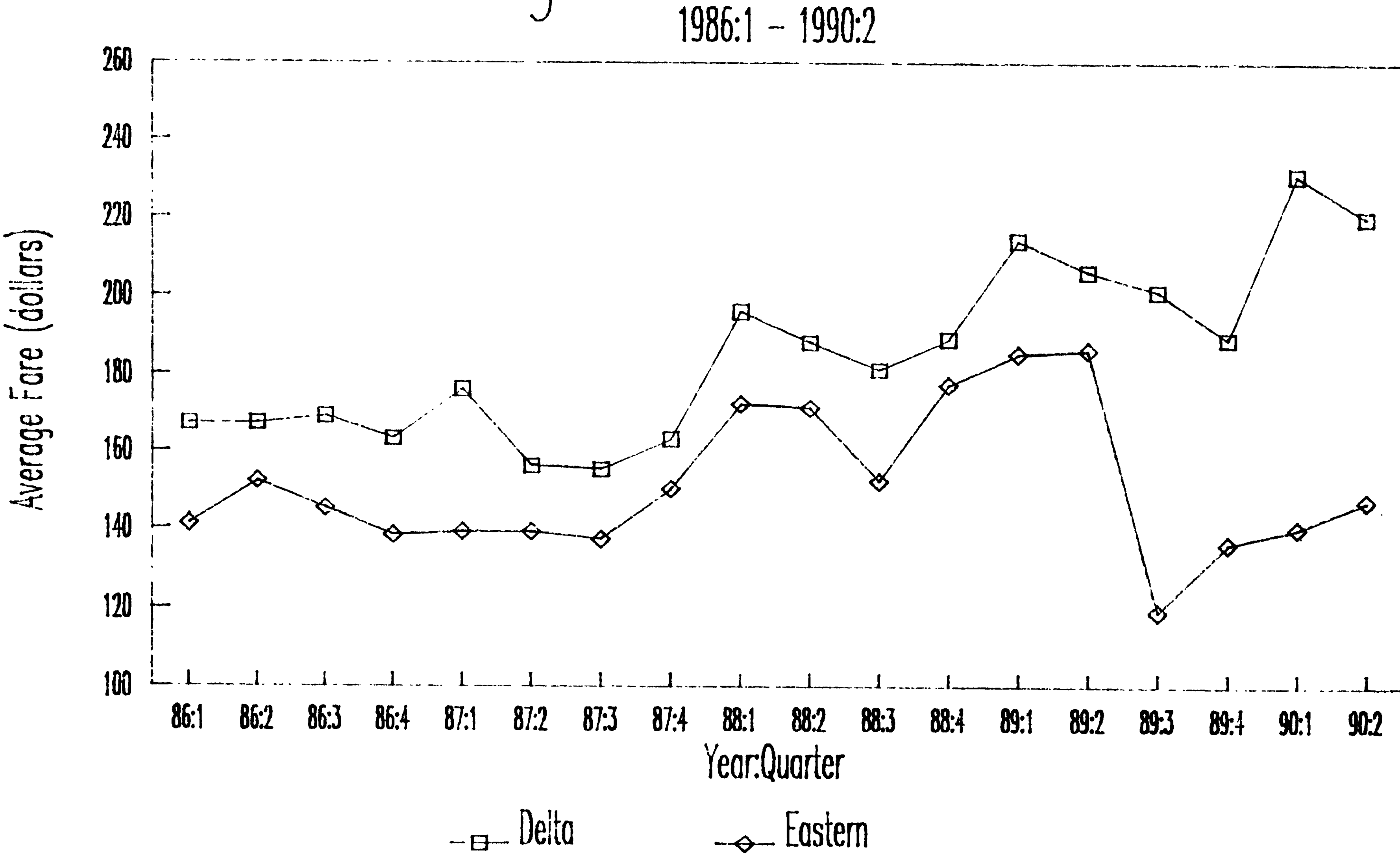

ATL-BOS Average Fare
1986:1 – 1990:2
Average Fare ($)
220
210
200
190
180
170
160
150
140
130
86:1
86:2
86:3
86:4
87:1
87:2
87:3
87:4
88:1
88:2
88:3
88:4
89:1
89:2
89:3
89:4
90:1
90:2
Year:Quarter

ATL-BOS Market Share

1986:1 - 1990:2



ATL--BOS Average Fare



ATL - BOS
Summary Table

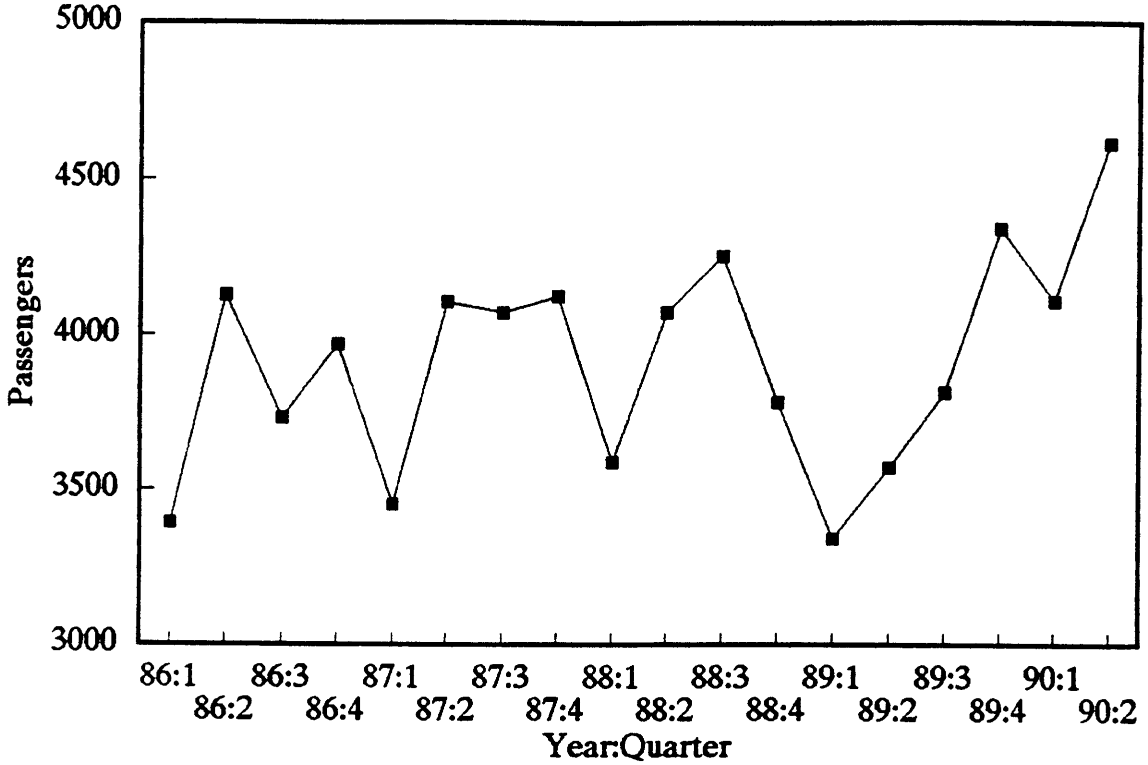
	Passengers	Revenues	Average Fare	Coupon Mileage	Passengers Per Day	Market Share	Revenue Share	Yield Per CPM
Delta 88:2	6118	1152456	188	5872057	67.2	59.74	62.63	19.63
Delta 89:2	7676	1584791	206	7372559	84.4	74.95	88.01	21.50
% Change	25.47	37.51	9.60	25.55	25.47	25.47	40.51	9.53
Eastern 88:2	3508	599469	171	3348572	38.5	34.25	32.58	17.90
Eastern 89:2	9	1674	186	8514	0.1	0.09	0.09	19.66
% Change	-99.74	-99.72	8.84	-99.75	-99.74	-99.74	-99.71	9.83
OA 88:2	615	88075	143	653125	6.8	6.01	4.79	13.49
OA 89:2	1387	214329	155	1429440	15.2	13.54	11.90	14.99
% Change	125.53	143.35	7.90	118.86	125.53	125.53	148.65	11.19
Market 88:2	10241	1840000	180	9873754	112.5	100.00	100.00	18.64
Market 89:2	9072	1800794	199	8810513	99.7	100.00	100.00	20.44
% Change	-11.41	-2.13	10.48	-10.77	-11.41	0.00	0.00	9.68

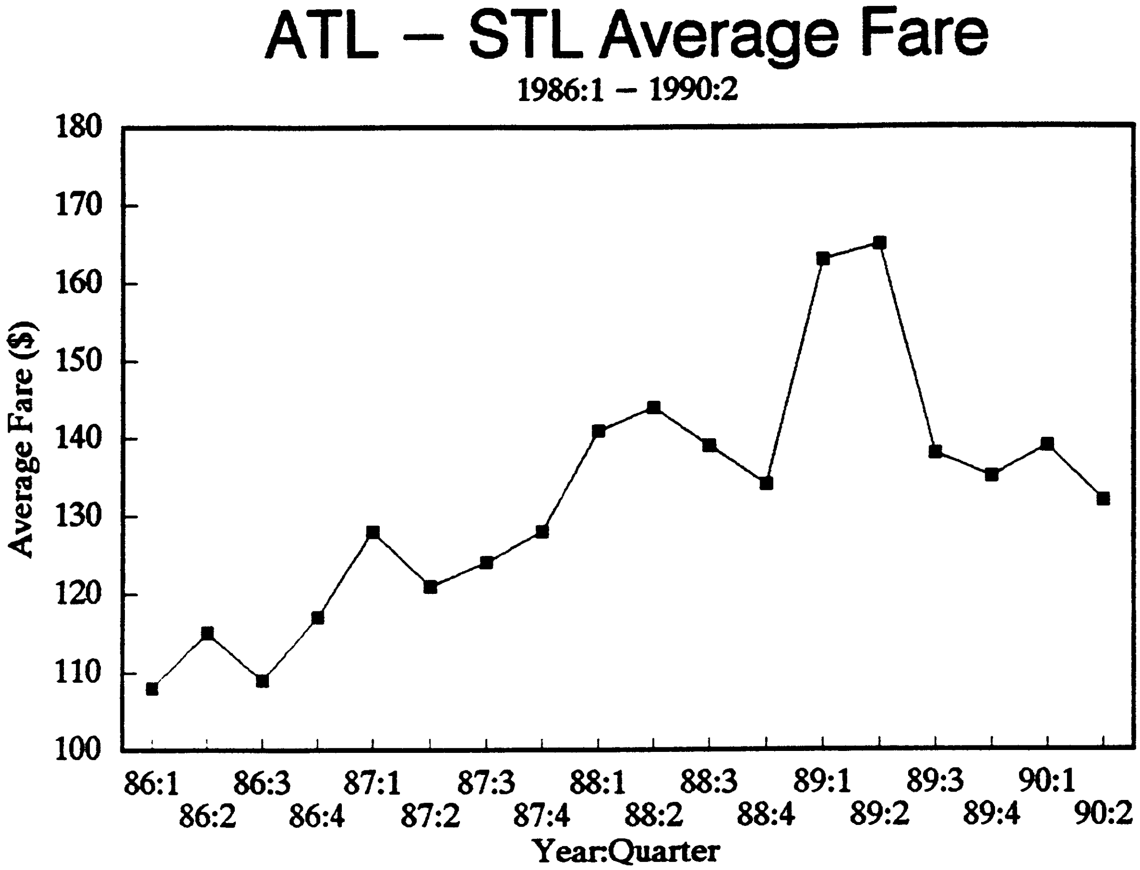
ATL - STL Market Characteristics 1986:1 - 1990:2

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

ATL – STL Passengers

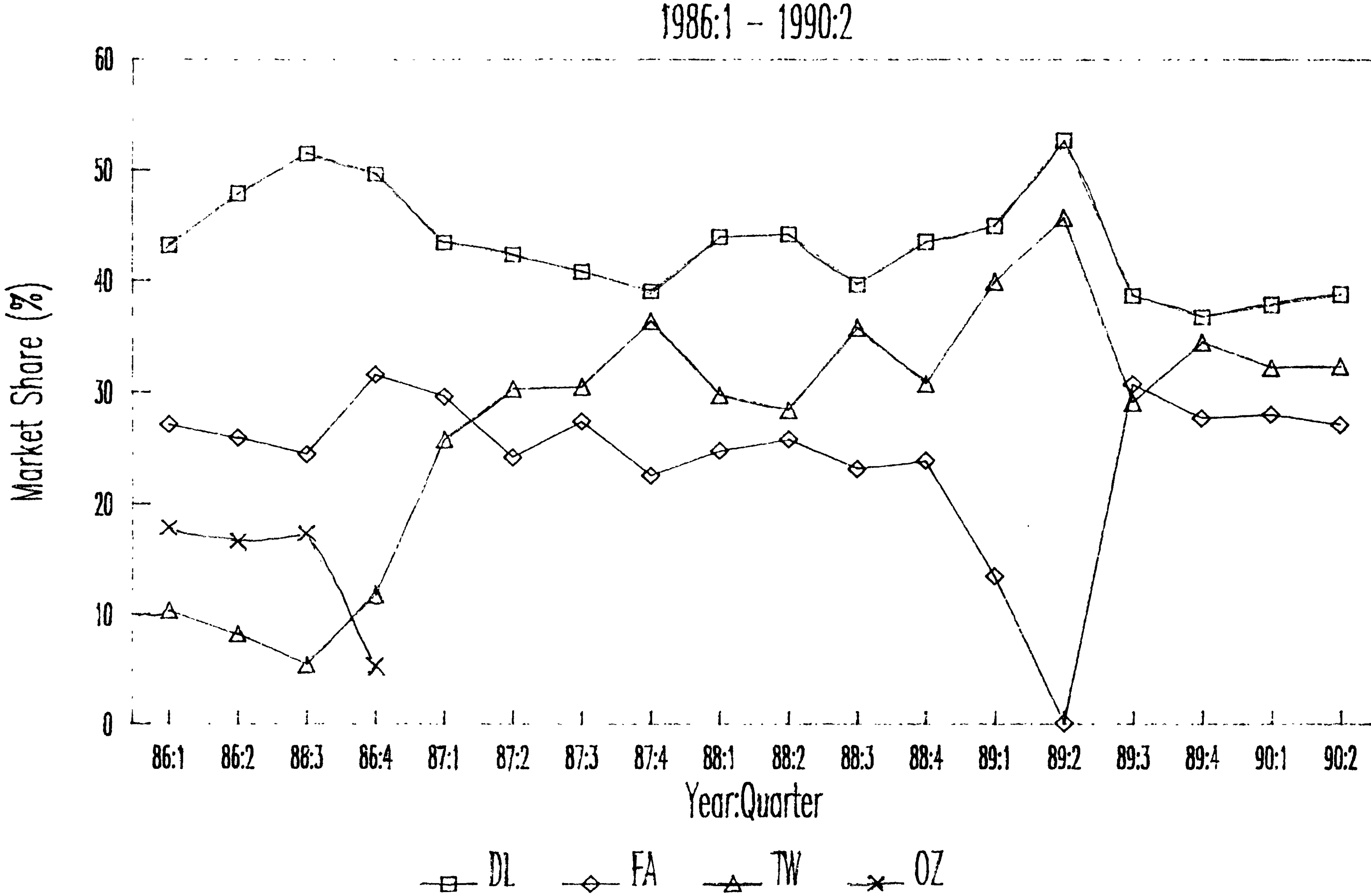
1986:1 – 1990:2



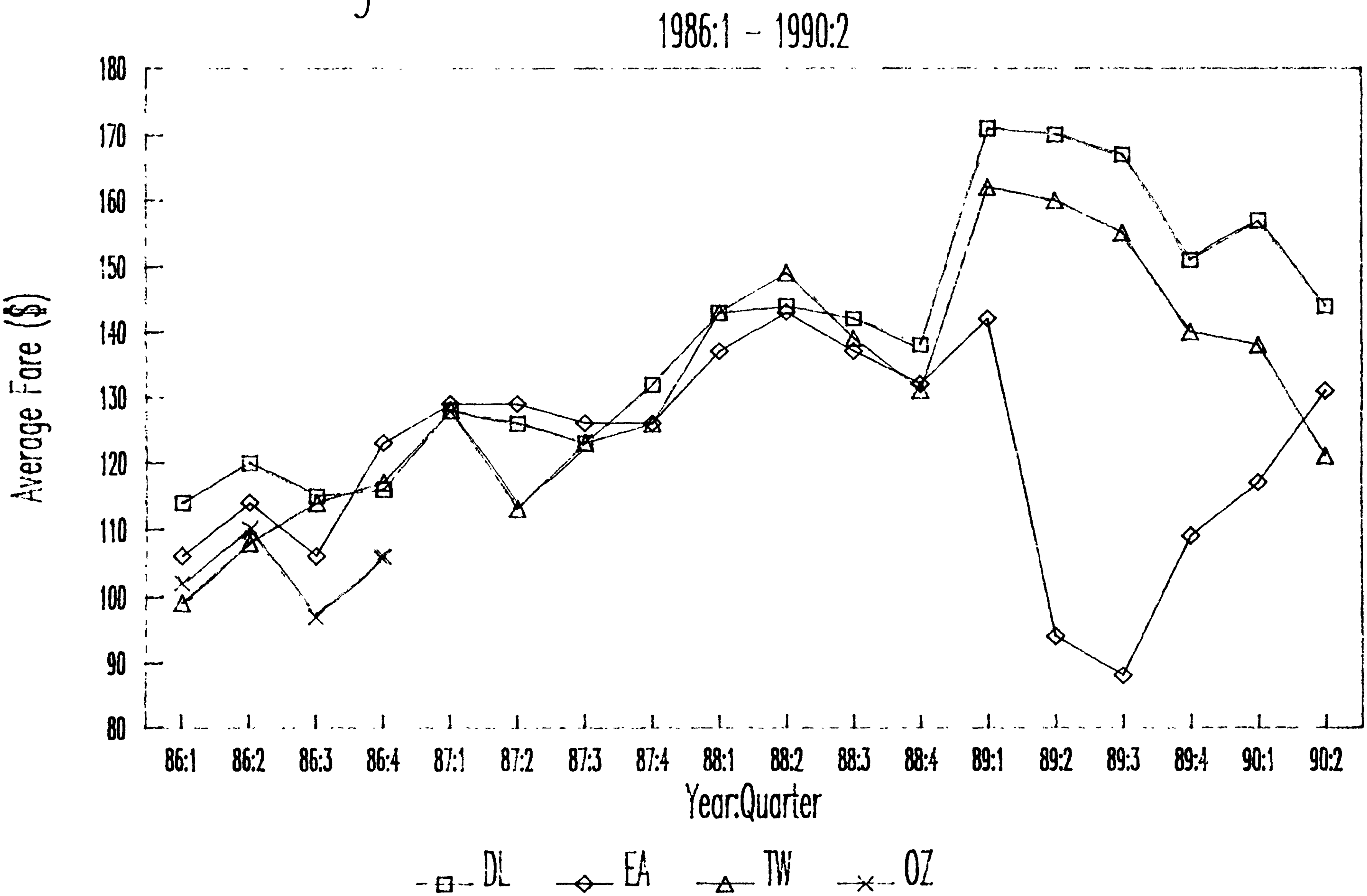


ATL – STL Average Fare
1986:1 – 1990:2
Average Fare ($)
180
170
160
150
140
130
120
110
100
86:1
86:2
86:3
86:4
87:1
87:2
87:3
87:4
88:1
88:2
88:3
88:4
89:1
89:2
89:3
89:4
90:1
90:2
Year:Quarter

ATL - STL Market Share



ATL – STL Average Fare



ATL - STL
Summary Table

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

Conclusions

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

Future Directions

- Quantify consumer price sensitivity and market share changes

- Determine relationships between market strength and fare levels

- Develop a model to characterize competitive structure of markets

CHANGES IN O-D PASSENGER TRAFFIC FLOWS

NEWARK AIRPORT

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

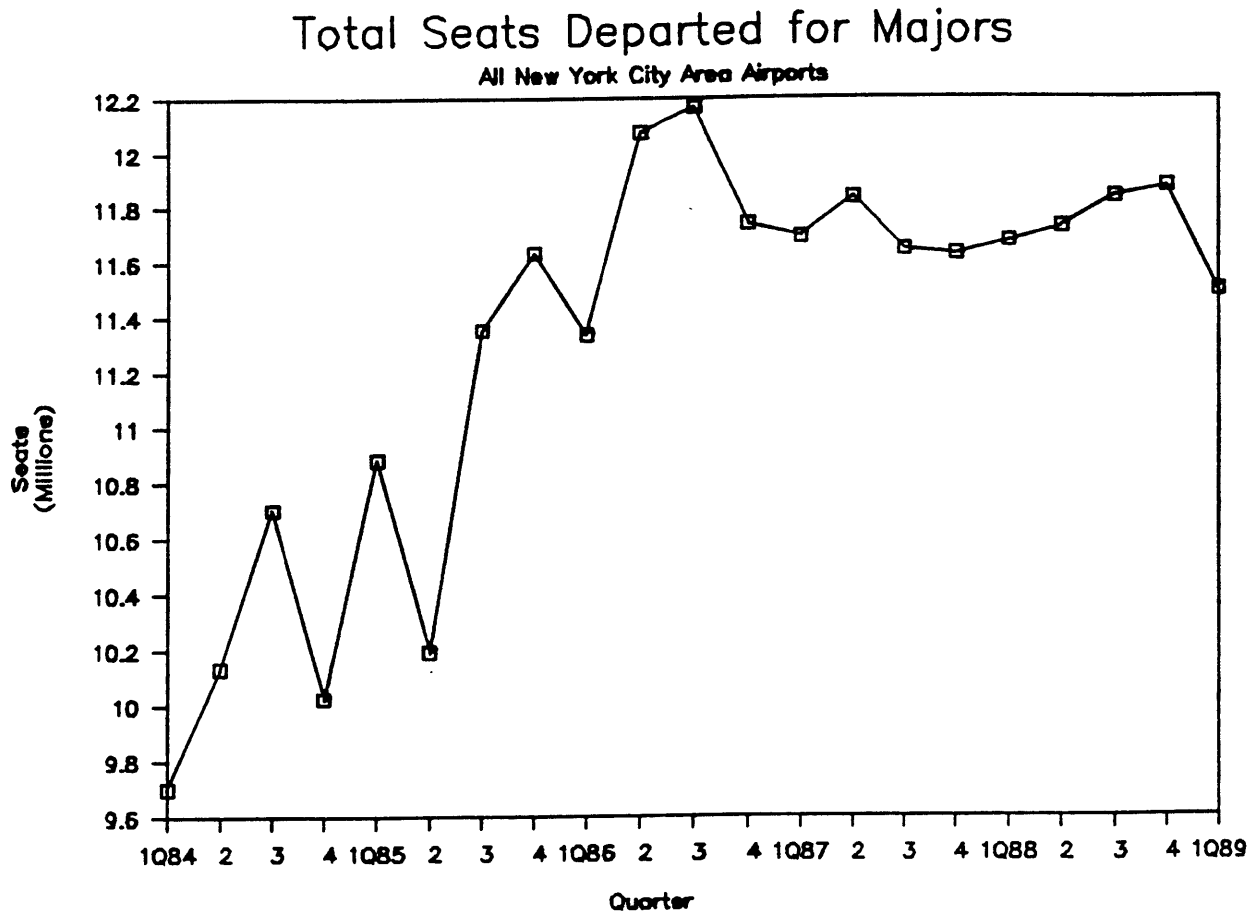
MIT / Industry Cooperative Research Program
Annual Meeting
May 24, 1991

BACKGROUND : PREVIOUS ANALYSIS

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

Newark Airport (EWR)

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



Total Seats Departed for Majors
All New York City Area Airports
Seats
(Millions)
12.2
12
11.8
11.6
11.4
11.2
11
10.8
10.6
10.4
10.2
10
9.8
9.6
1Q84 2 3 4 1Q85 2 3 4 1Q86 2 3 4 1Q87 2 3 4 1Q88 2 3 4 1Q89
Quarter

Figure 1.2

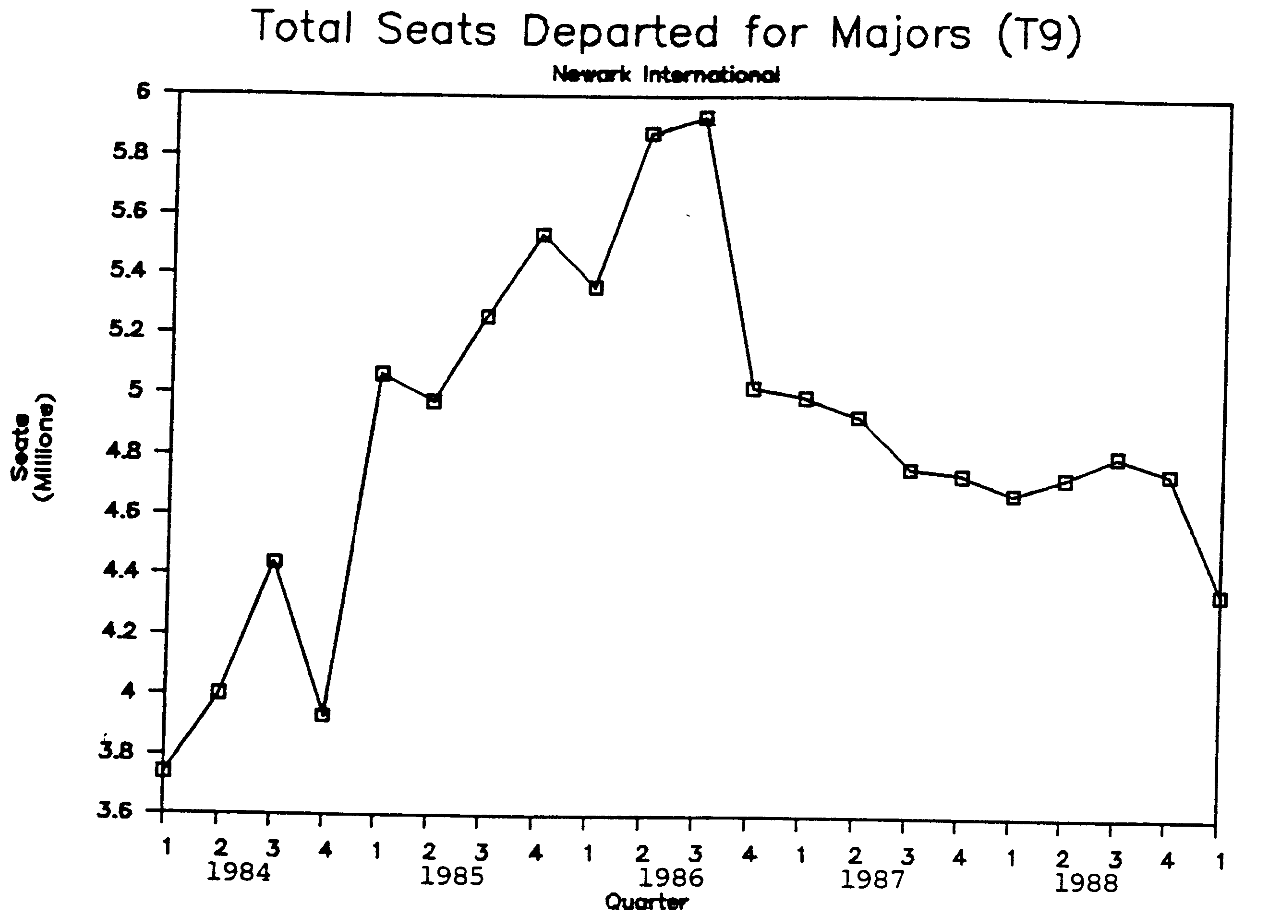

Total Seats Departed for Majors (T9)
Newark International
Seats
(Millions)
6
5.8
5.6
5.4
5.2
5
4.8
4.6
4.4
4.2
4
3.8
3.6
1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4 1
1984
1985
1986
1987
1988
Quarter

Figure 1.8

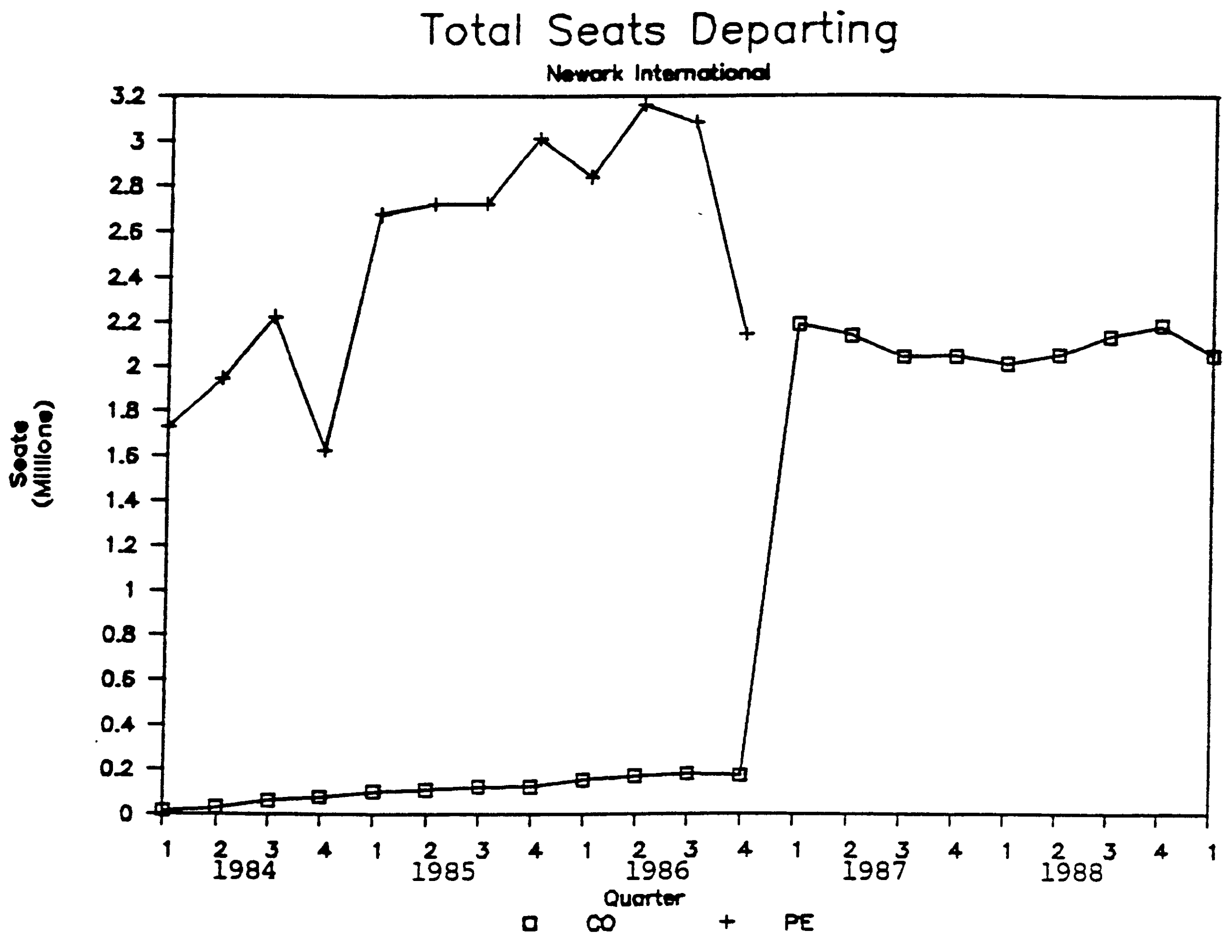

Total Seats Departing
Newark International
Seats (Millions)
3.2
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4 1
1984
1985
1986
1987
1988
Quarter
CO
PE

Figure 1.9

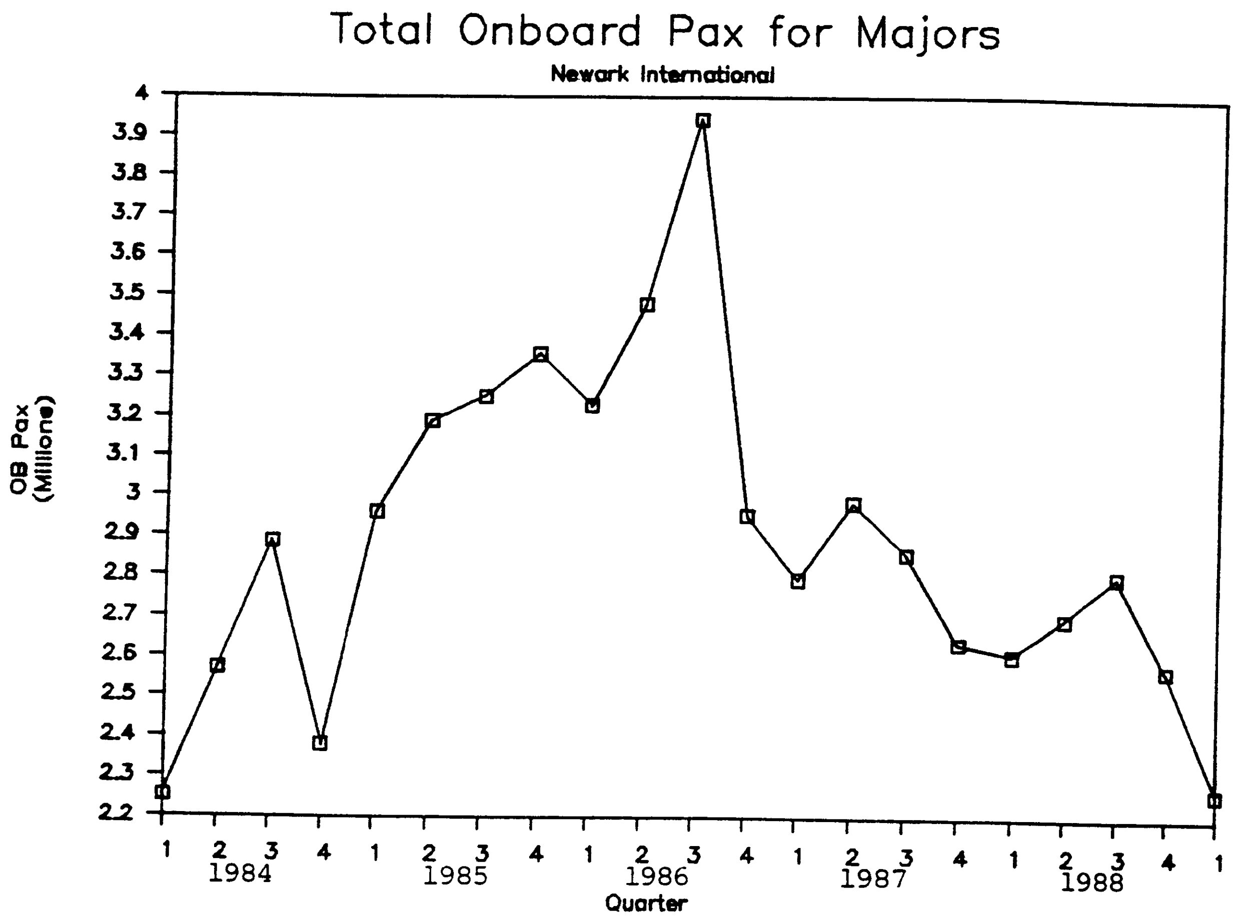
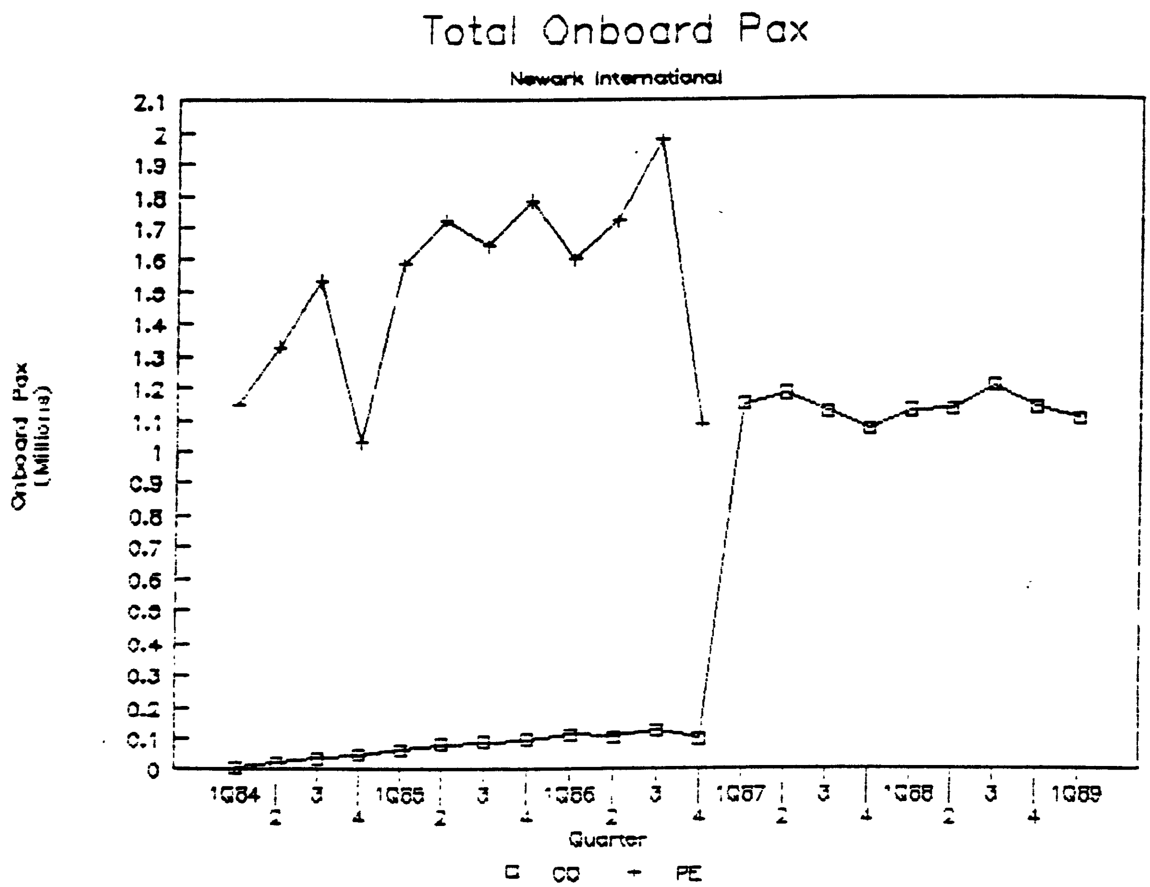

Total Onboard Pax for Majors
Newark International
OB Pax (Millions)
4
3.9
3.8
3.7
3.6
3.5
3.4
3.3
3.2
3.1
3
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4 1
1984
1985
1986
1987
1988
Quarter

Figure 2.3



Total Onboard Pax
Newark International
Onboard Pax (Millions)
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1Q84
2
3
4
1Q85
2
3
4
1Q86
2
3
4
1Q87
2
3
4
1Q88
2
3
4
1Q89
Quarter
CO
PE

Figure 2.6

Total Connecting Pax (EWR)

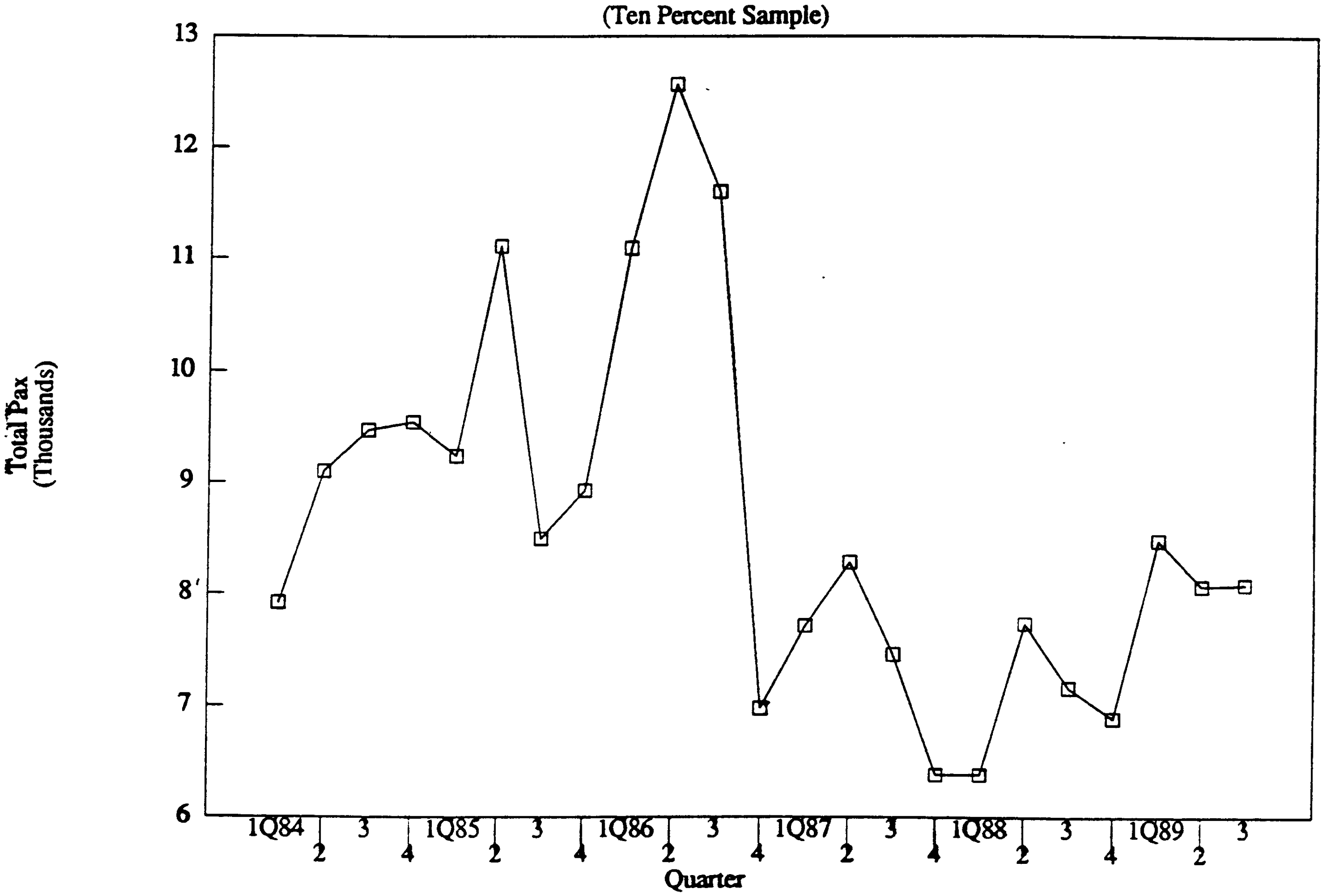


Figure 3.5

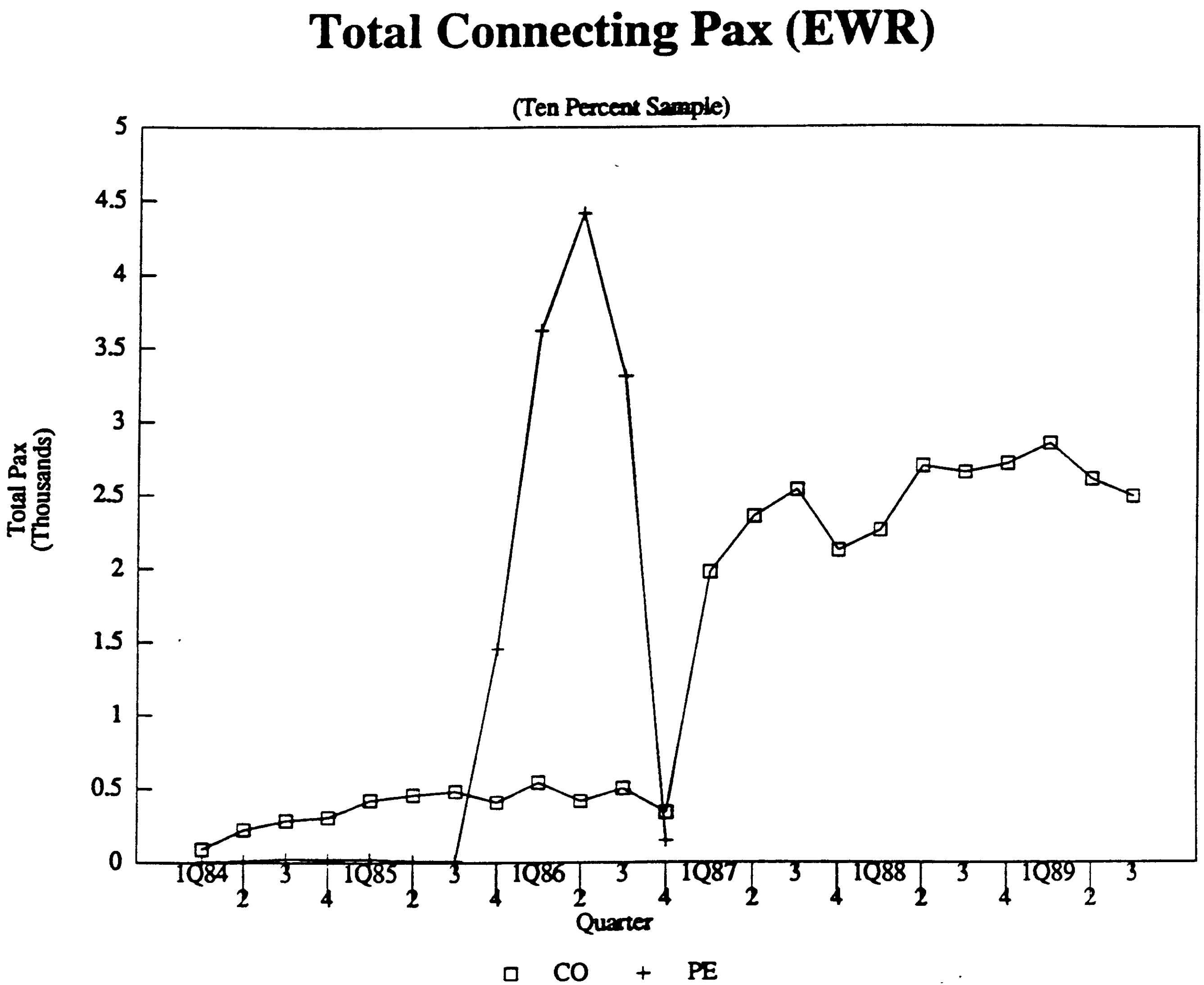

Total Connecting Pax (EWR)
(Ten Percent Sample)
Total Pax
(Thousands)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1Q84
2
3
4
1Q85
2
3
4
1Q86
2
3
4
1Q87
2
3
4
1Q88
2
3
4
1Q89
2
3
Quarter
CO
PE

Figure 3.8

NEWARK AIRPORT
TRAFFIC FLOW ANALYSIS (Phase 2)

OBJECTIVE

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

HISTORICAL DATA

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

PASSENGER TRAFFIC FLOW ANALYSIS

DEMAND AND SUPPLY MEASURES

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

AIR CARRIERS

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

ANALYSIS METHODOLOGY

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

20 SELECTED O-D MARKETS

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

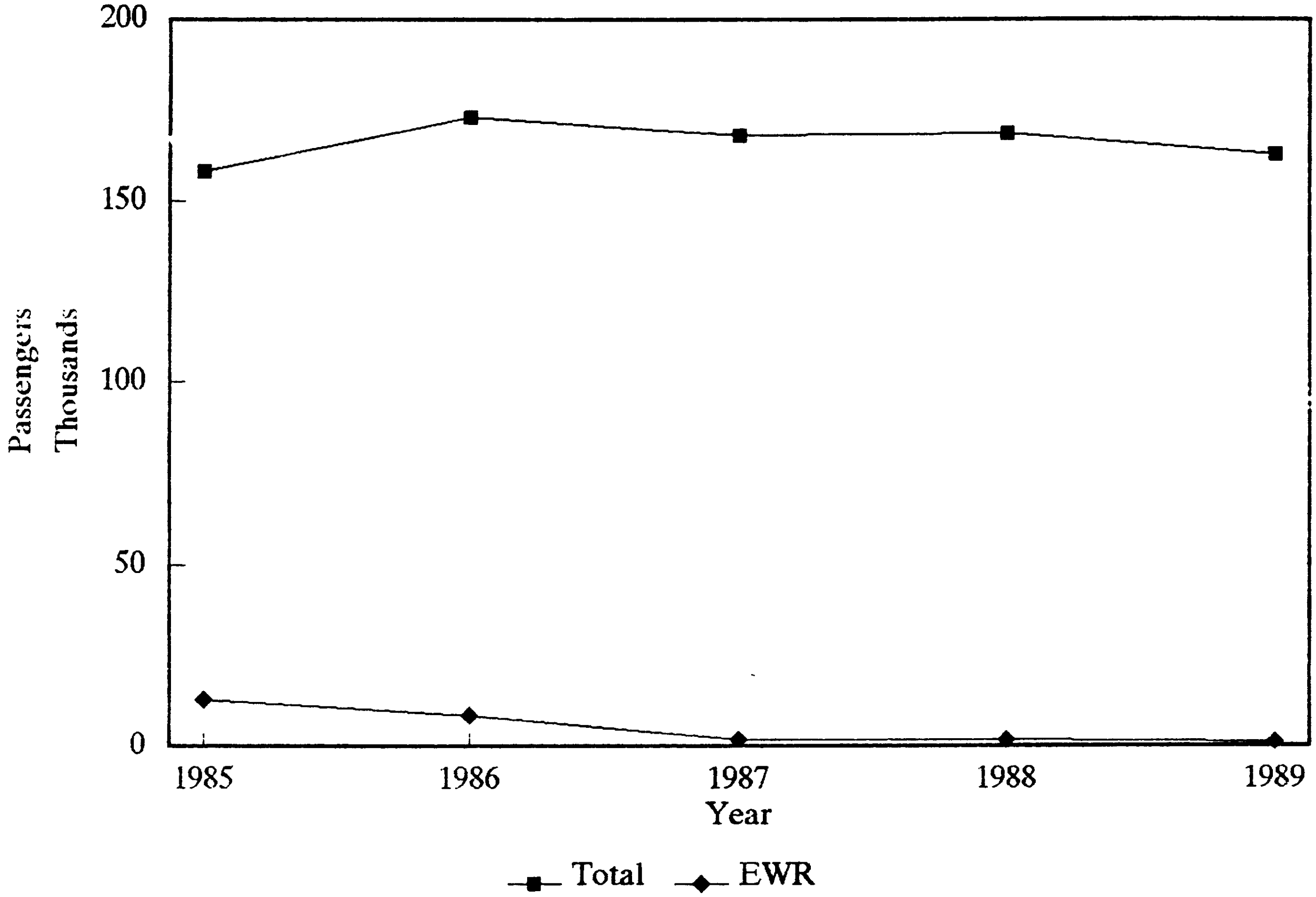
FINDINGS

Aggregate : 20 O-D Markets

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

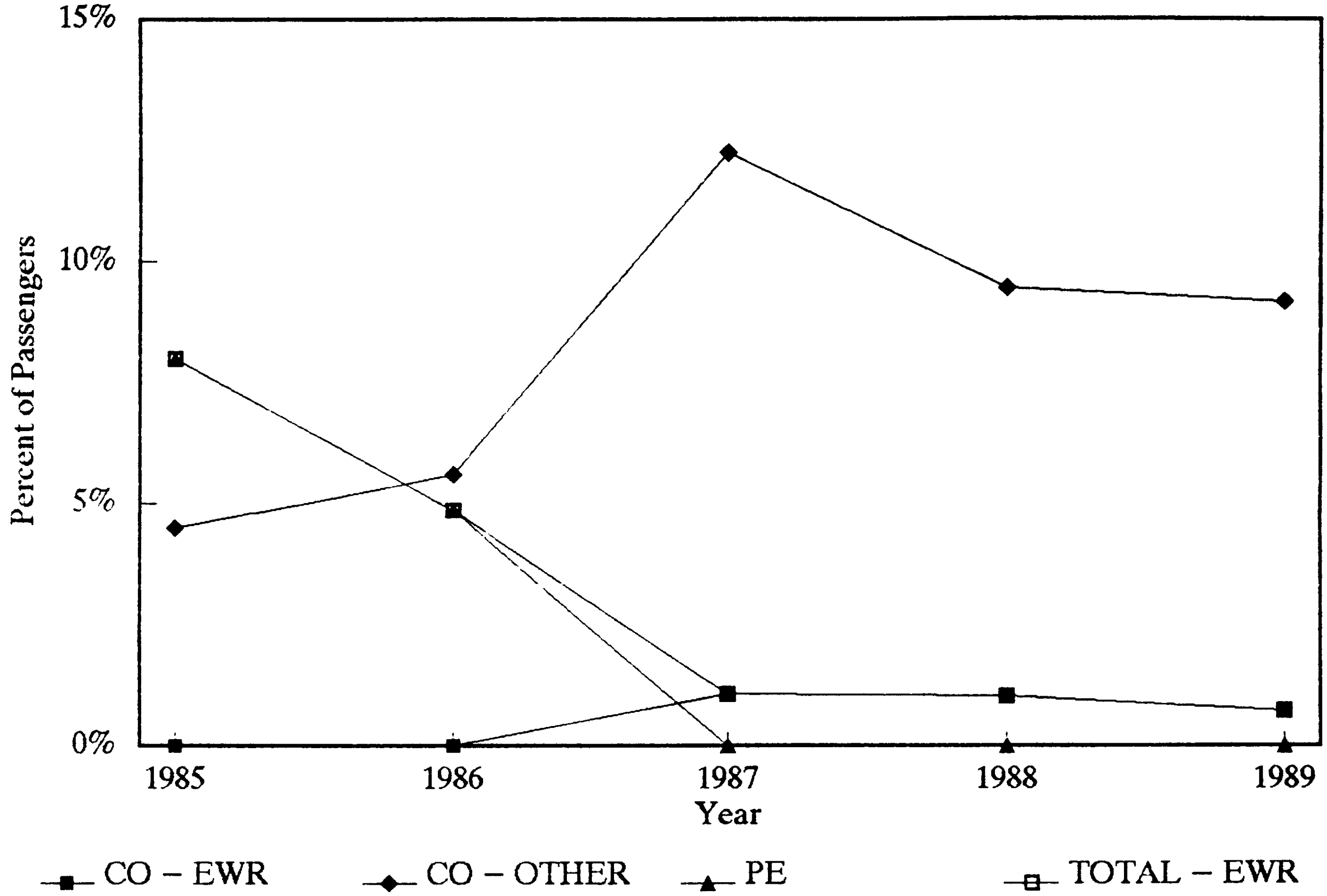
Total Passengers for 20 Selected Market

10% Sample



Total Market Share

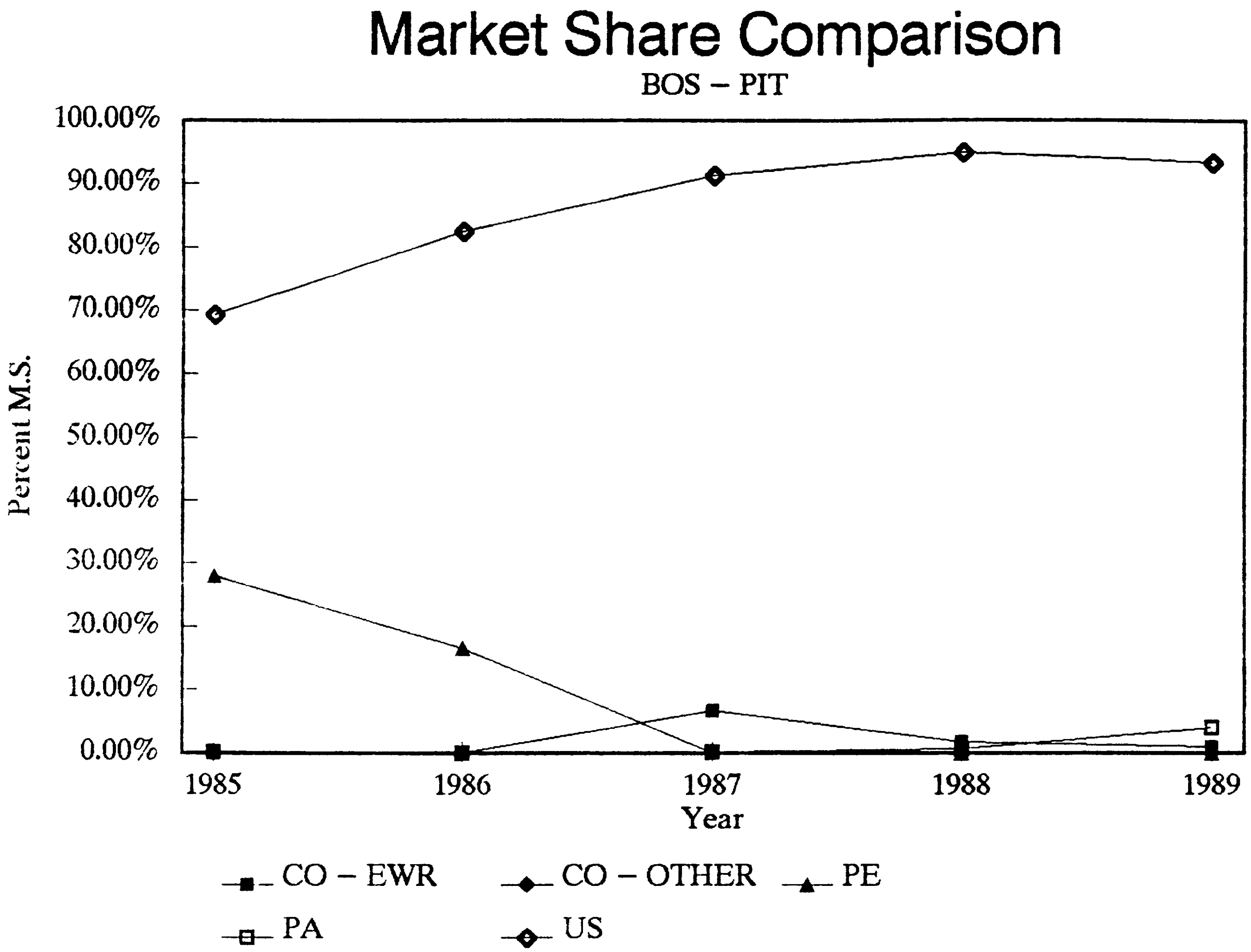
20 Selected Markets



Disaggregate Market Analysis

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

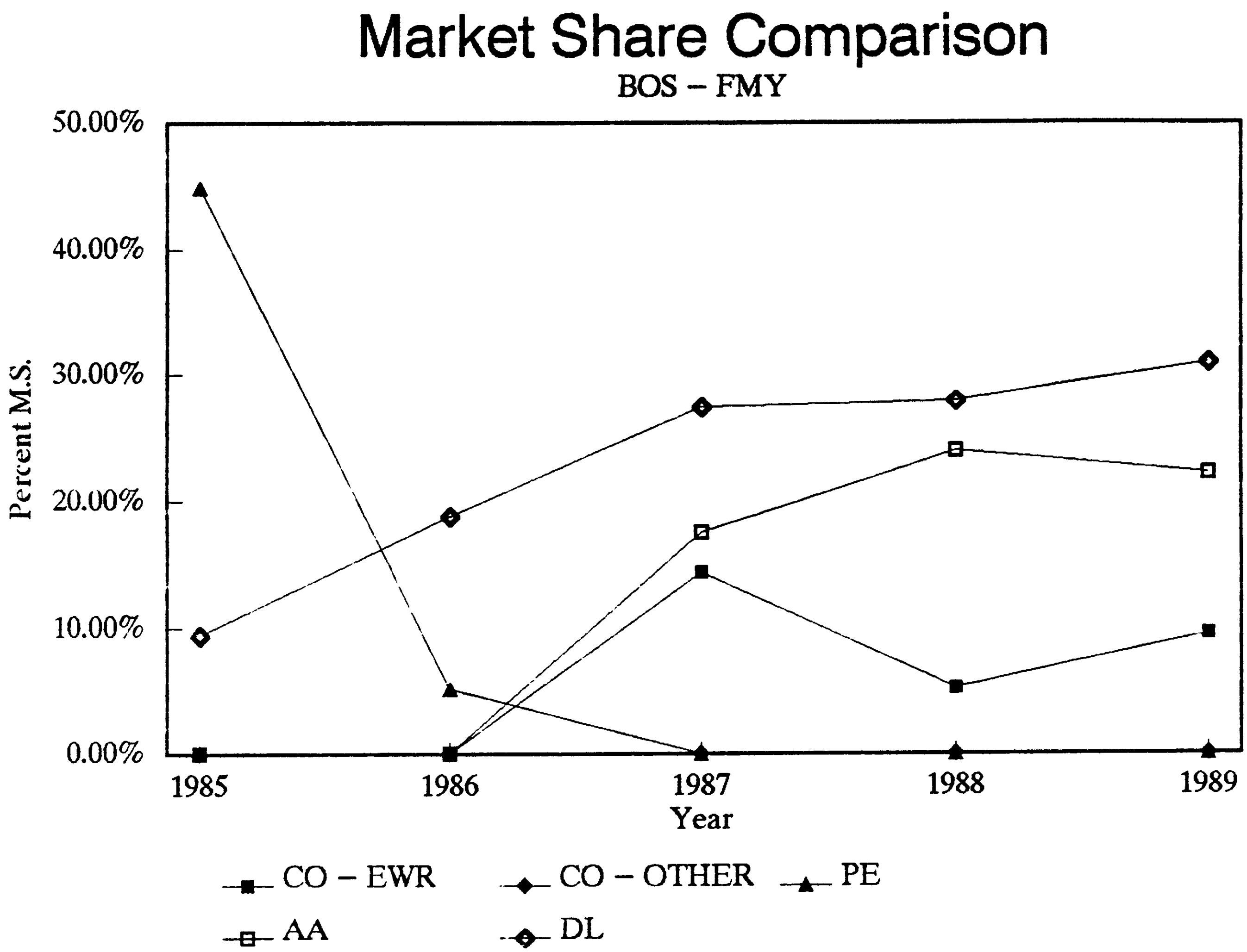
- "CO - Other" refers to Continental traffic routed primarily through other CO hubs.



<u>BOS-PIT :</u>

- PE had 28% market share in 1985, virtually all of which was taken over by USAir (non-stop service).

- CO never recaptured significant market share.

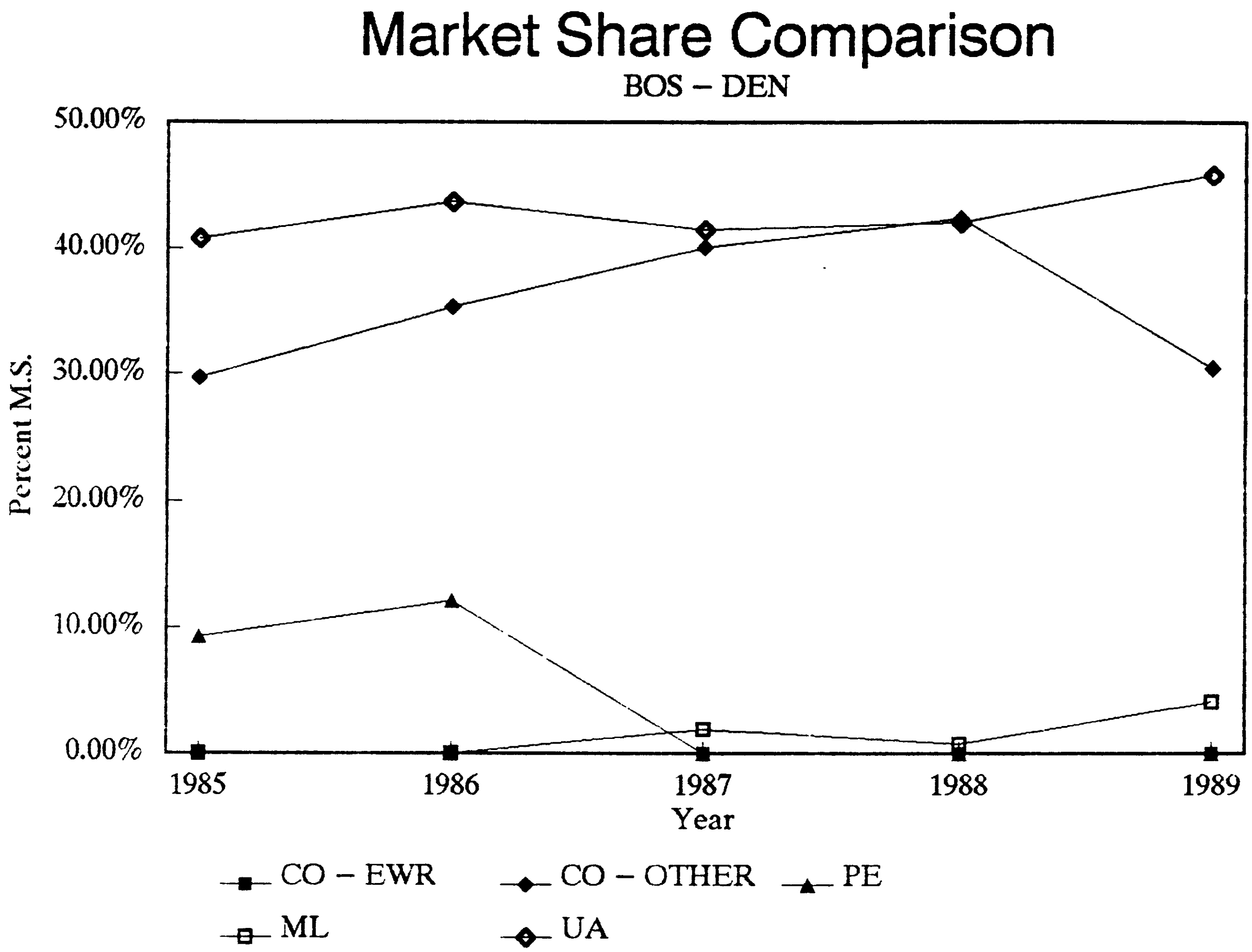


<u>**BOS-FMY :**</u>

- PE had peak market share of 45% in 1985, of which CO now carries only 9% via EWR.

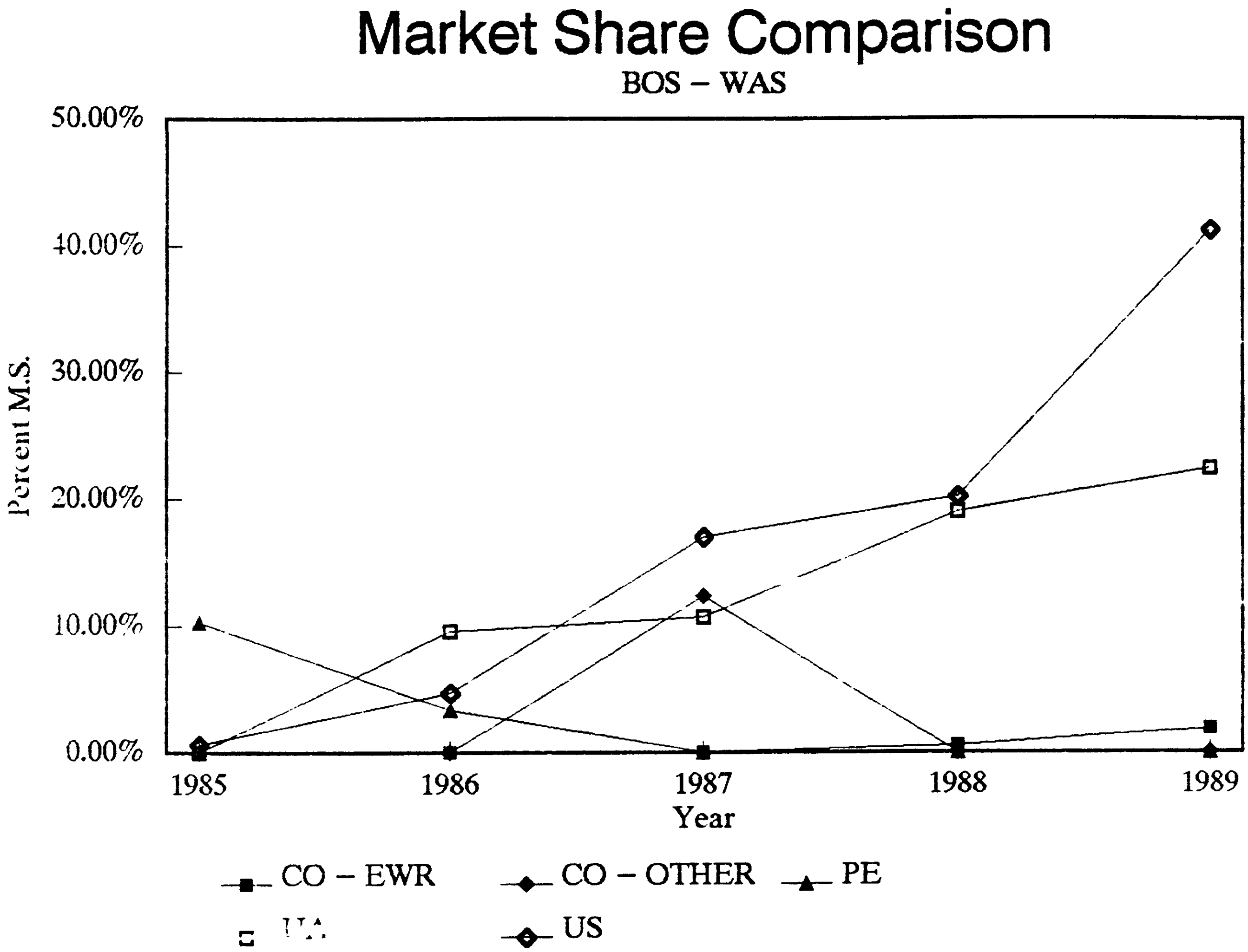
- AA market share grew from 0 to 24% (CNX via RDU).

- DL also took over market share (via ATL and CVG).



<u>BOS-DEN :</u>

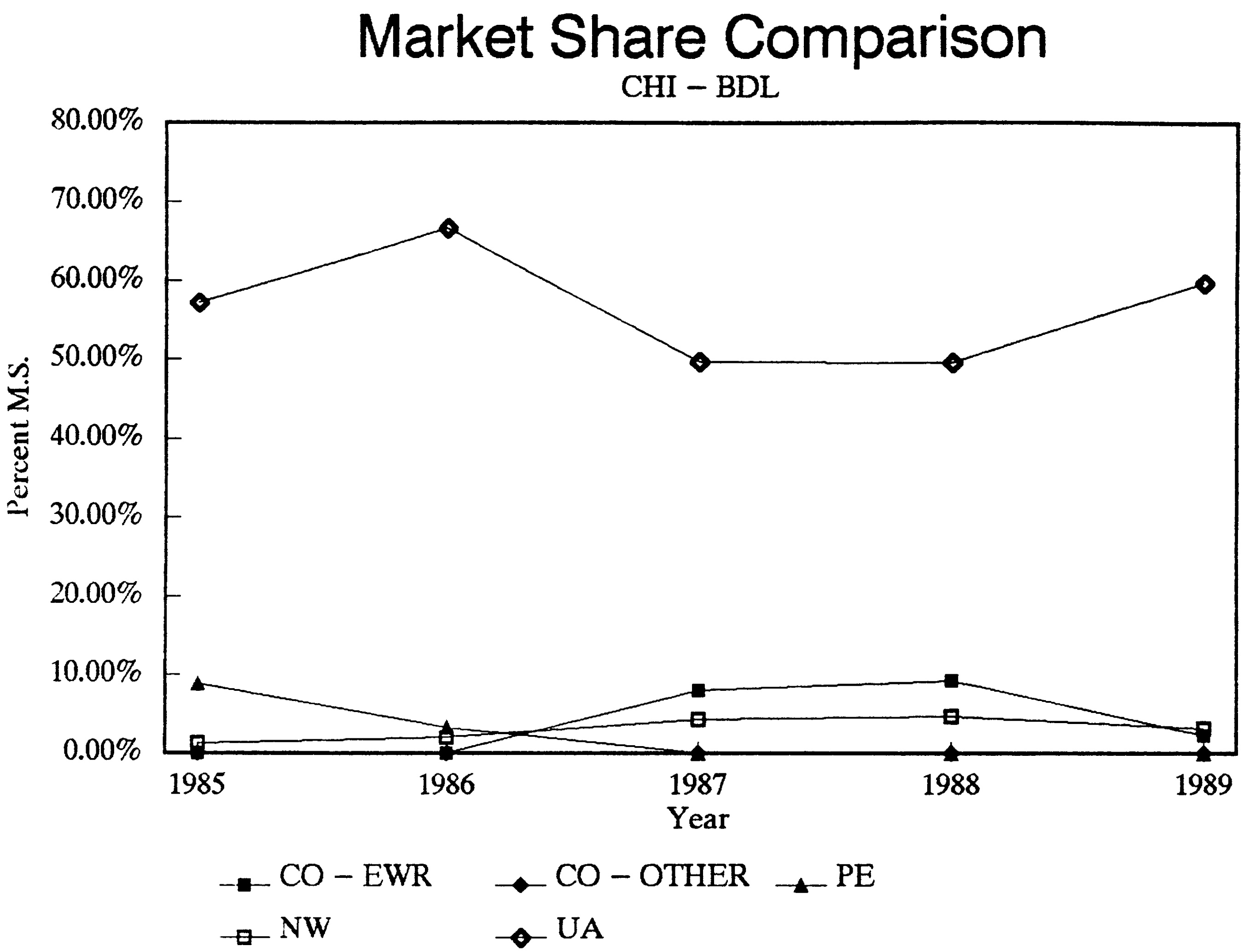
- **CO has captured most of PE's 12% market share, but on non-stop service. UA also shows market share growth (non-stop service).**



<u>BOS-WAS :</u>

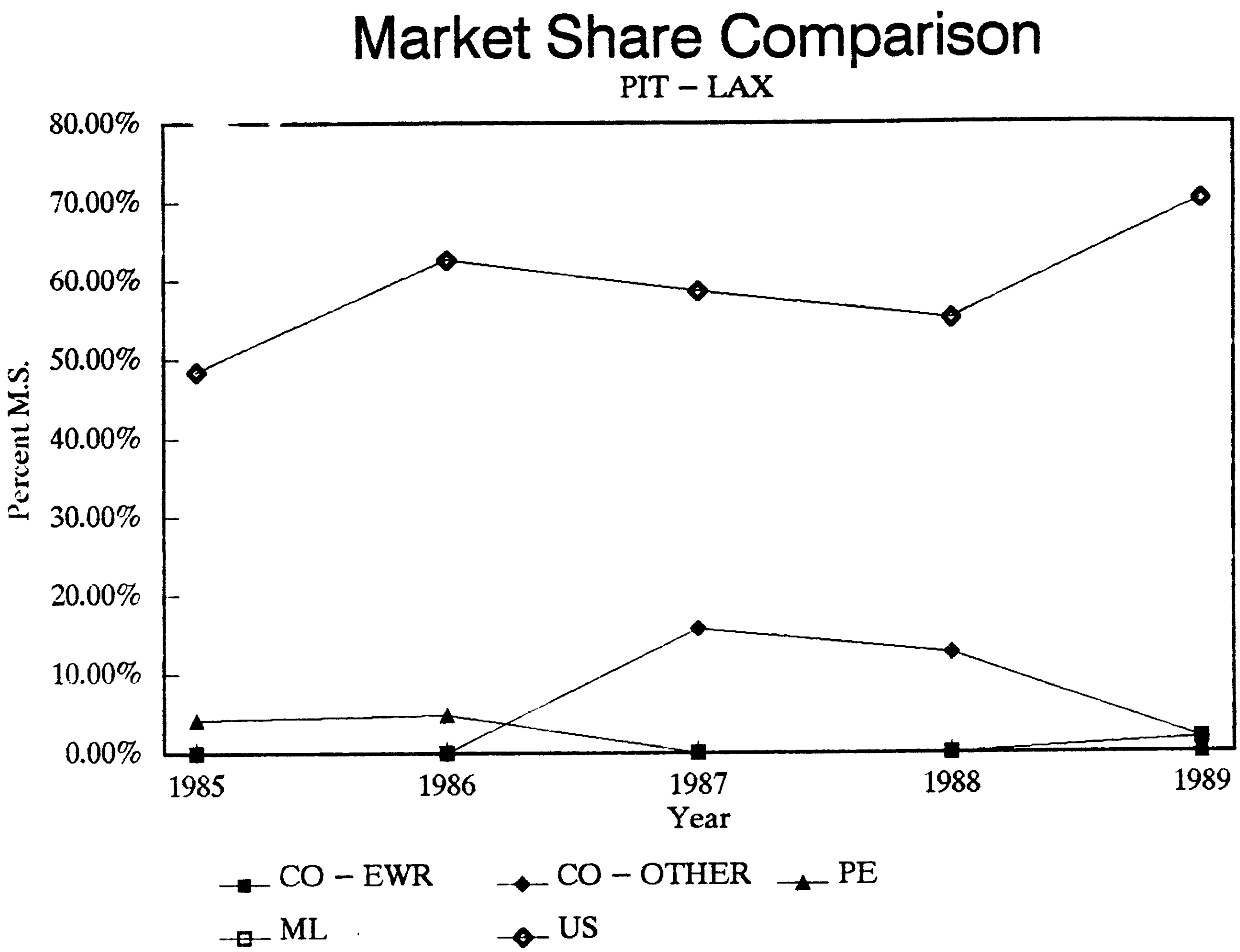
- PE had 10% market share in 1985. CO did not capture any of this traffic (via EWR), except in 1987 when CO offered non-stop service to IAD.

- Greatest MS growth by US and UA (both non-stop services).



CHI-BDL :

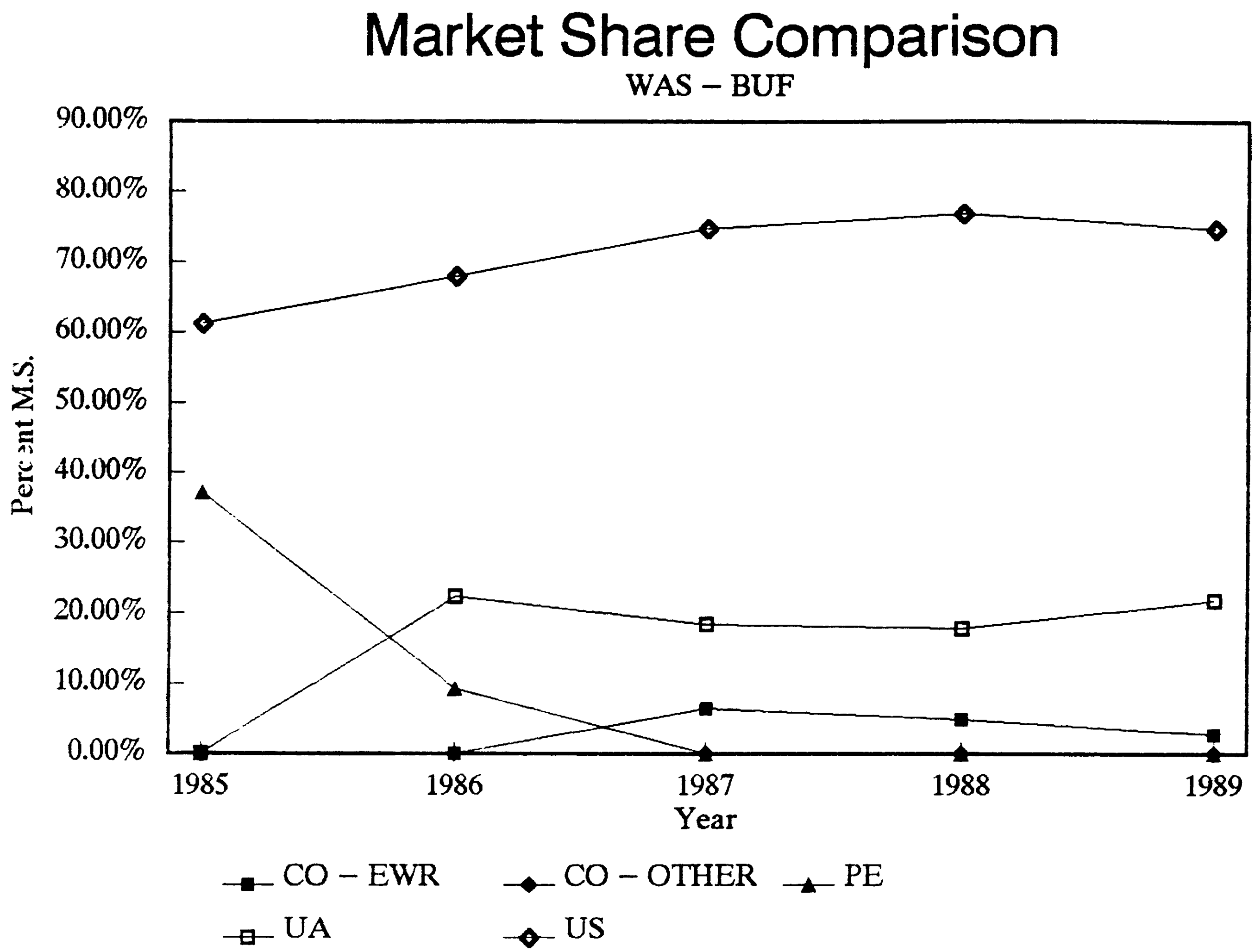
- PE's 9% market share in 1985 was captured by CO via EWR until 1988, when UA increased non-stop service.



PIT-LAX:

- PE carried up to 5% of market share in 1986 via EWR.

- CO increased its MS from 0 to 16% in 1987, but not via EWR (i.e. via IAH, DEN, CLE).



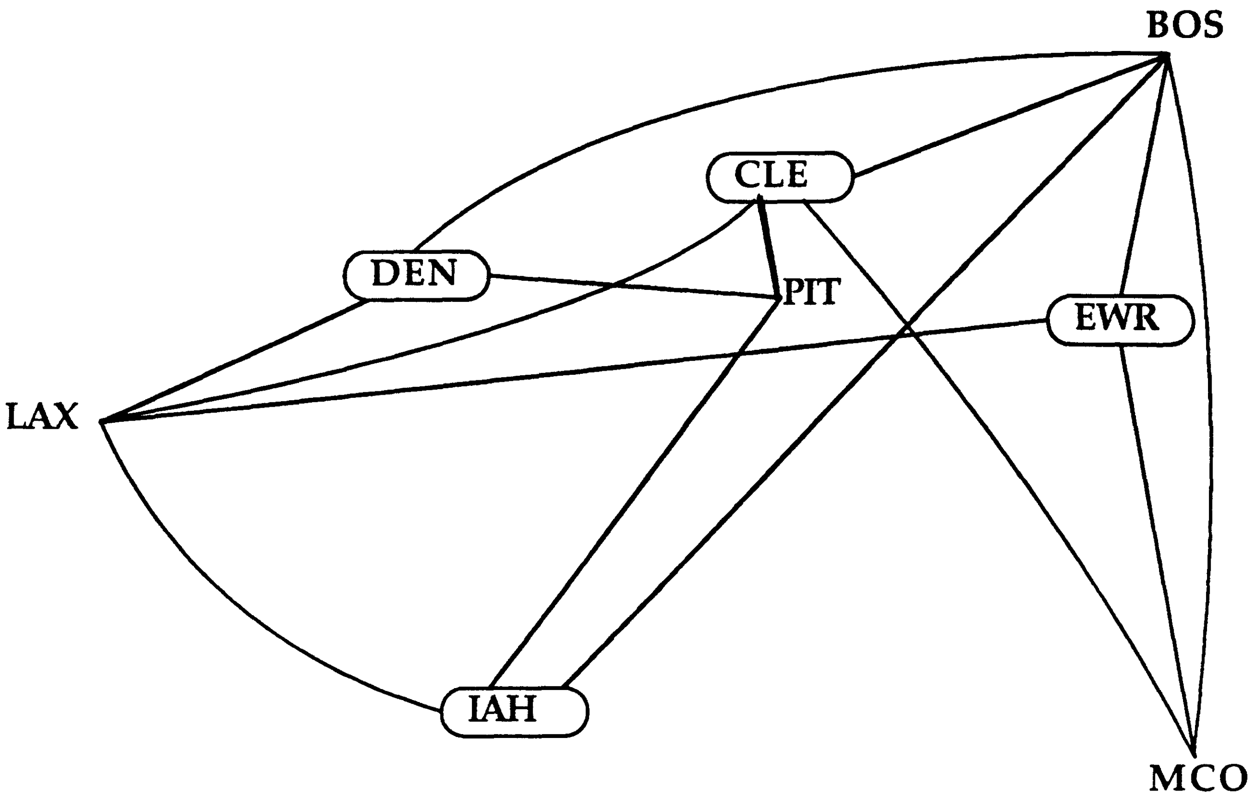
<u>**WAS-BUF:**</u>

- **PE carried 37% of market share in 1985, only 7% of which was captured by CO via EWR in 1987.**

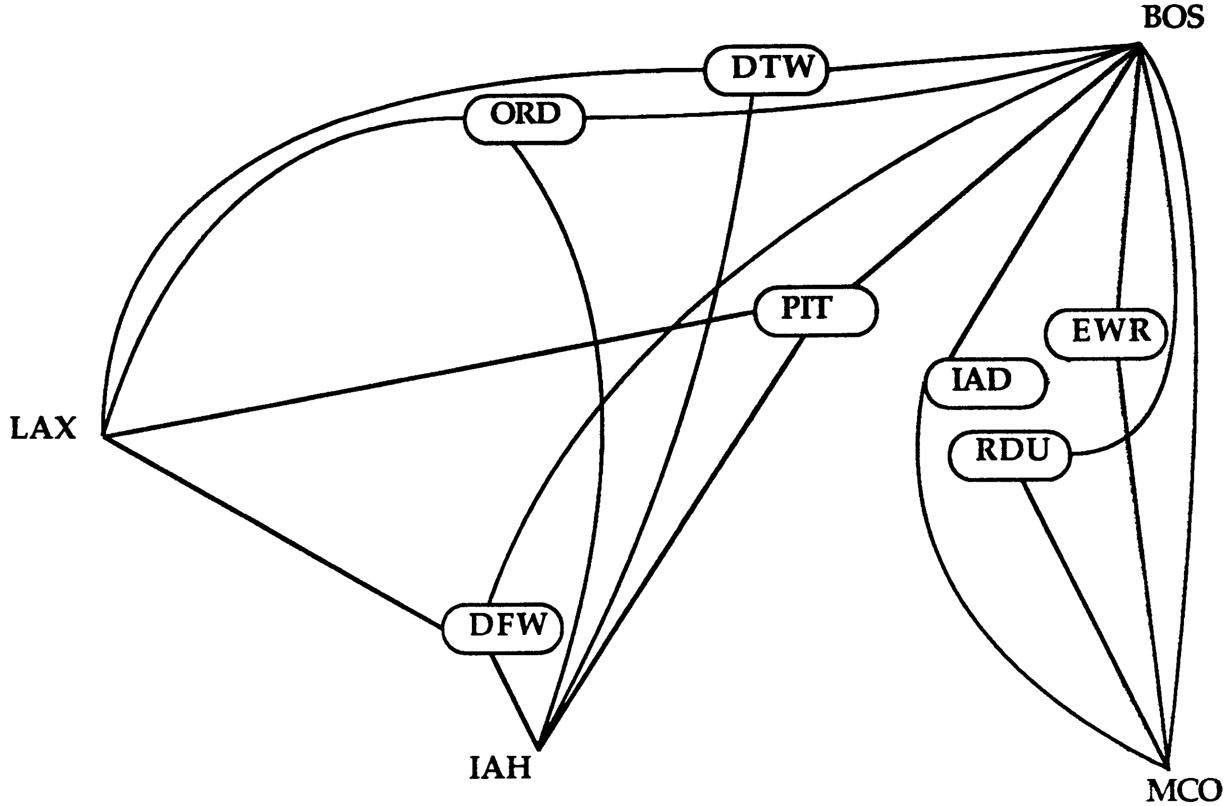
- **Biggest market share gains went to UA (non-stop to IAD) and US (non-stop to BWI/DCA).**

SUMMARY OF FINDINGS

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



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



O-D Routings
After PeoplExpress 1989
(Other Carriers)

CONCLUSIONS

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

Airline Seat Inventory Control

For Group Passenger Demand

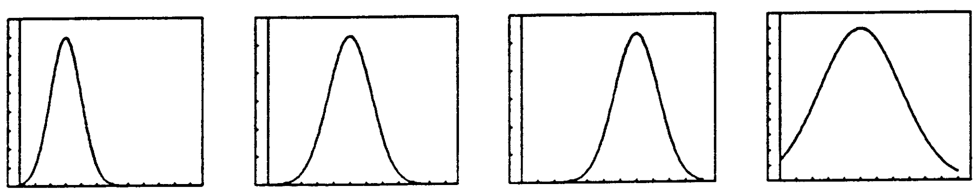
Presented by

Peter Belobaba
Tom Svrcek

May 1991

Individual Passenger Seat Inventory Control

Assumes Demand For Each Individual Fare Class Is Independent And Normally Distributed.



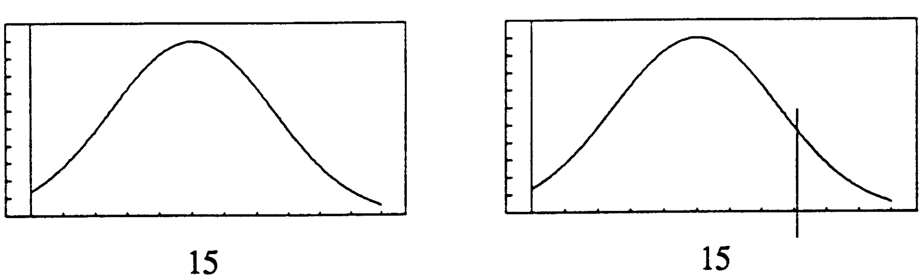
Y Class B Class M Class Q Class

Definition

Expected Marginal Revenue (EMR) Of An Additional Seat

Allocated To A Particular Fare Class Is

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



P(X > 0) = .999	P(X > 25) = .05
EMR(1) = $500	EMR(26) = $25

Individual Passenger Seat Inventory Control

Example : Setup

Total Fare Classes :	4
Aircraft Capacity :	100

Fare Class	Demand Mean	Demand Stdev	Average Revenue
Y	14	5	380
B	12	6	320
M	35	10	270
Q	42	12	220

Individual Passenger Seat Inventory Control

Results

Seat No.	Y	B	M	Q	Highest EMR
1	378.94	312.78	269.90	219.92	378.94
2	378.16	309.39	269.87	219.90	378.16
3	376.86	304.77	269.82	219.87	376.86
4	374.74	298.65	269.76	219.83	374.74
5	371.43	290.79	269.68	219.78	371.43
6	366.43	280.99	269.57	219.73	366.43
7	359.24	269.16	269.43	219.65	359.24
8	349.31	255.22	269.25	219.56	349.31
9	336.20	239.24	269.00	219.44	336.20
10	319.63	221.34	268.69	219.30	319.63
11	299.47	201.81	268.29	219.19	312.78
12	275.85	181.12	267.77	218.89	309.39
13	249.13	160.00	267.10	218.61	304.77
14	220.07	138.88	266.26	218.26	299.47
15	190.00	118.19	265.21	217.83	298.65
16	159.93	98.66	263.91	217.32	290.79
	...	...	...	...	
					.
					.
					.
					158.48
					156.37
					152.17

Fare Class Allocations	
Y	16
B	13
M	34
Q	37

Group Passenger Demand

Why Is Group Demand Different From Individual Passenger Demand ?

- Group Demand Is Realized Many Months In Advance
  Examples : Rose Bowl, Mardi Gras ...

- Groups Negotiate For A Lower Fare
  (Bulk Pricing)

- Unused Bookings Are Absent From Seat Inventory For Months, Potentially Displacing Individual Passengers

- Cancellation Penalties Often Difficult To Enforce
  Due To Competitive Environment

Problem Statement

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

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

"Answer:"

$$\text{Min. Group Fare} = \frac{\text{Total Expected Revenue Of Displaced Individual Pax}}{\text{Size Of Group Request}}$$

$$\text{Example: } \frac{\$\,2{,}200}{20} = \$\,110 \quad \text{Per Group Pax}$$

Group Passenger Seat Inventory Control

Two Solution Methodologies

Case 1:

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

Case 2:

Relax Indivisibility Constraint. Find Optimal Split Over N Possible Alternatives For Each Group Request.

Group Passenger Seat Inventory Control

Large Hub and Spoke Networks Operated by Today's Major Carriers Allow for Several Different Routings (with Similar Departure and Arrival Times) For Many Origin – Destination Pairs.

For Example, Delta Air Lines Service Between:

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

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

Group Passenger Seat Inventory Control

Numerical Example : Setup

Dept Date : 12 JUL 91
Group Size : 15

Possible Outbound Itineraries

1)

DL	583	EWR	950A	CVG	1142A	72S
DL	623		108P	SEA	245P	72S

2)

DL	99	EWR	340P	ATL	640P	757
DL	197		652P	SEA	910P	757

3)

DL	887	EWR	1155A	DFW	226P	72S
DL	833		312P	SEA	510P	72S

4)

DL	281	EWR	820A	DFW	1055A	72S
DL	233		1152A	SEA	145P	72S

Published Fares for EWR/SEA on 12 JUL 91		
Y	$642.00	O/W
B	$425.00	O/W
M	$325.50	O/W
Q	$277.00	O/W

Group Passenger Seat Inventory Control

Numerical Example: Results

Itinerary #1

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

Min. Group Fare Calculation => 1426.75 / 15 = $95.12

Group Passenger Seat Inventory Control

Group Booking Model Output

Rank	Itin Out	Displacement Cost Estimate Per Passenger Outbound Leg 1	Leg 2	Total	Min. Group Fare Request for 15 Pax
1	4)	0.00	87.80	87.80	$87.80
2	1)	16.48	78.64	95.12	$95.12
3	3)	0.00	137.93	137.93	$137.93
4	2)	79.38	157.13	236.51	$236.51

Lowest Published Fare for EWR/SEA on 12JUL91 :	$277.00
Minimum Group Fare :	$87.80

Negotiation Does The Rest !

Group Passenger Seat Inventory Control

What Is The Optimal Reduced Fare ?

For The Carrier:

$277.00

For The Group:

$87.80

Competitive Advantage

Carrier Implementing Displacement Cost Strategy Has

$277.00 – $87.80 = $189.20

Of "Competitive Leverage".

Group Passenger Seat Inventory Control

Case 2: Relaxation Of Indivisible Group Constraint

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

Model Output

Optimal Split Over All Itineraries

Itinerary 1	5 Pax
Itinerary 4	10 Pax

Minimum Group Fare (Divided) $81.79

Minimum Group Fare (Undivided) $87.80

Group Passenger Seat Inventory Control

Question:

Why Are Groups Different From Traditional Bulk Pricing ?

Answer:

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

Example:

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

But:

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

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

The Larger The Group, The Higher The Average Fare

Group Passenger Seat Inventory Control

User Optimal Strategy

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

Carrier Optimal Strategy

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

Conclusions

- Minimum Group Fare Based On Displacement Of Individual Passengers

- No Distribution Assumptions Necessary For Group Passenger Demand

- Given N Outbound Itineraries And R Return Itineraries, We Can Find The Best Of N * R Possible Combinations

- Optimal Mix Of Divisible Group is No More "Difficult". All Necessary Information Exists !

- Better Utilization Of Excess Capacity Means Greater Revenue Potential For Airlines

Airline Crew Scheduling Re-visited

Presentation at the
MIT/FTL -Industry Cooperative Research Program Review
May 23 /24, 1991

Professor Robert W. Simpson

Problem Statement

GIVEN:

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

   - a flight is one or more flight legs
   - arrival / departure times are fixed
   - schedule is cyclic over a day or week, C
   - schedule remains in effect over planning horizon,H

2. A set of crew bases B where a number of crews N_B are domiciled to fly this type of aircraft

FIND:

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

- a crew trip t consists of a series of flights to be flown starting from base and returning within one or more days

- a work schedule b is a set of trips away from base on various days of the planning horizon, H

Typical Crew Work Rules - 1

1. Regulatory Rules

(imposed by civil aviation authorities for safety)

- Maximum Daily Flight Hours
- Maximum Weekly (or 7 day period) Flight Hours
- Maximum Monthly Flight Hours
- Maximum Duty Hours (duty time is time without rest)
- Minimum Off-Duty Interval

Note- Crew trips and bidlines which conform to these rules will be called legal or feasible.

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

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

Basis for Crew Costs

There are two kinds of crews: cockpit and cabin.

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

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

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

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

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

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

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

Typical Crew Work Rules - 2

2. Airline/Union Trip Agreements

- Daily Flight Guarantee (eg. min. hours if called to duty)
- Flight/Duty Ratio Guarantee (eg. flight/duty time > 0.5)
- Flight/ Trip Ratio Guarantee (eg. flight/trip time > 0.25)
- Maximum No. of Daily Landings
- Deadhead Time is Flight Time

Note- These rules may cause a "penalty" to the airline in the form of extra pay and hourly credit to be assigned to a particular crew trip if it violates them. The total flight hours paid in a crew schedule may exceed the number of hours flown in the aircraft schedule.

Deadheading is flying the crew as passengers to/from base to other stations where their flying begins or ends.

Typical Crew Work Rules - 3

3. Airline/Union Bidline Agreements

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

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

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

The Current Airline Crew Scheduling Process

Stage 1. - Generation of Feasible Crew Trips from Bases

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

Stage 3. - Construction of Crew Bidlines for Bases

Stage 4. - Construction of Reserve Crew Bidlines for Bases

Stage 5. - Execution of Crew Bidding Process

Note: 1. It is a sequential, heuristic Process and is not optimal, even if some of the stages are done optimally.

2. There should be some feedback of crew scheduling problems into the aircraft scheduling and airline market service planning. At present, this feedback does not exist since crew scheduling is done by airline flight operations personnel late in the airline schedule planning process. There is a need for some early assessment of crew scheduling problems in airline schedule development.

3. The availability and continual use of reserve crews affects the desirability of detailled optimal planning of fixed monthly bidlines.

4. A related process is crew re-scheduling by flight operations personnel when deviations from schedule plan are occuring. There is a need for good methods of solving real time, operational crew scheduling problems to minimize additional costs from disruptions.

Stage 1 - Generate Feasible Crew Trips

STEP 1 - Establish "Flights", F

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

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

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

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

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

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

1. All flights in the aircraft schedule must be covered by the selected set of crew trips.

2. Since each trip starts at a given crew base, the flying assigned to that crew base by selecting a set of trips must be proportional to the number of crews domiciled at that base.

3. The Selection Problem takes two mathematical forms:

   a) The Set Covering Version;

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

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

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

   b) The Set Partitioning Version;

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

Example of Trip Selection

		c_1	c_2	c_3	c_4	c_5	c_6	c_7	c_8	c_9			
Trips, t_j		0	1	1	0	1	1	0	0	0		....	= Cost = $c_2 + c_3 + c_5 + c_6$
Flights, f_i	f_1	0	0	0	0	0	1	0	1	0		....	= 1
	f_2	0	1									....	= 1
	f_3	1	0	1				1				....	= 1
	f_4	0	0	0	1	0	1	0	1	0		....	= 1
	f_5	0	0	0	1	0	1	0	0	0		....	= 1
	f_6	1	0			1						....	= 1
	f_7	0	1	0	1					1		....	= 1
	f_8	0	1	0				1	0			....	= 1
Bases, B	a		5		8		6		7	8		....	> 10
	b			7		4					6	....	< 15
	c	6						6				....	< 5

Cheapest solution to this Set Partitioning Problem is the set of trips (2,3,5,6)

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

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

The Crew Tree - A New Method for Constructing Crew Trips

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

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

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

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

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

Handling Overnight Trips

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

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

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

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

Stage 2 - Constructing the Bidlines

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

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

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

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

Conclusions

1. There are some new approaches to creating interactive methods to support the crew scheduler in finding good low cost schedules for the crews.

2. There is a need to create methods for re-scheduling crews when deviations occur in executing the schedule. This should affect the current use of reserve crews

3. There seems to be a need to create similar methods for the cabin crews which are responsive to their differences in scheduling rules.

4. There is a need to provide some "early warning" methods for market and aircraft schedulers to cause a feedback of expensive crew scheduling problems before the aircraft schedule is finalized.

SCHEDULING SYSTEMS:

COMPUTER AIDS FOR EXECUTION RESCHEDULING

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

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I. EXECUTION RESCHEDULING

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

INPUTS:
- Operational schedule
- Operational deviations
    - Weather, breakdowns
    - Late arrivals
- Expected traffic loads and revenues
- Short term operating costs

OUTPUTS:
- Modified execution schedule
- Cancellations
- Delays

II.The Influence of Rapid Advances in Computer Technology

Old Approach

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

New Approach

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

III. THE AIRLINE SCHEDULING WORKSTATION (ASW)

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

1. Table top Engineering Workstations with a speed of 1-4 mips and disk storage of 100 -1000 MB working together on a local area network, interfaced with existing airline mainframe systems.

2. Large (19 inch), high-quality color displays with interactive,instantaneous, manipulation of schedule graphics information using a "mouse".

3. Object-oriented programming to provide modular code, easily extendable to handle time-varying scheduling constraints, policies, etc., and to reduce programming support.

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

IV. DEVELOPMENT APPROACH FOR AN ASW

GENERAL DEVELOPMENT STRATEGIES

- Involve schedulers at all development stages-- (there will be cultural and organizational shock)

- provide familiar systems and reports first to ensure that the new system will not preclude doing certain schedule 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. (e.g., 3 workstations at $15,000 each). (Establish a "Schedule Generation" workroom).

- Develop modern, transportable, modular, object-oriented software, for automation of sub-processes in scheduling
    - easily extendable
    - easily supported
    - C, PASCAL, LISP language
    - good data structures

- A Two-Stage development process
    - STAGE 1: introduction of manual, interactive graphics scheduling system
    - STAGE 2: introduction of automated decision support

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

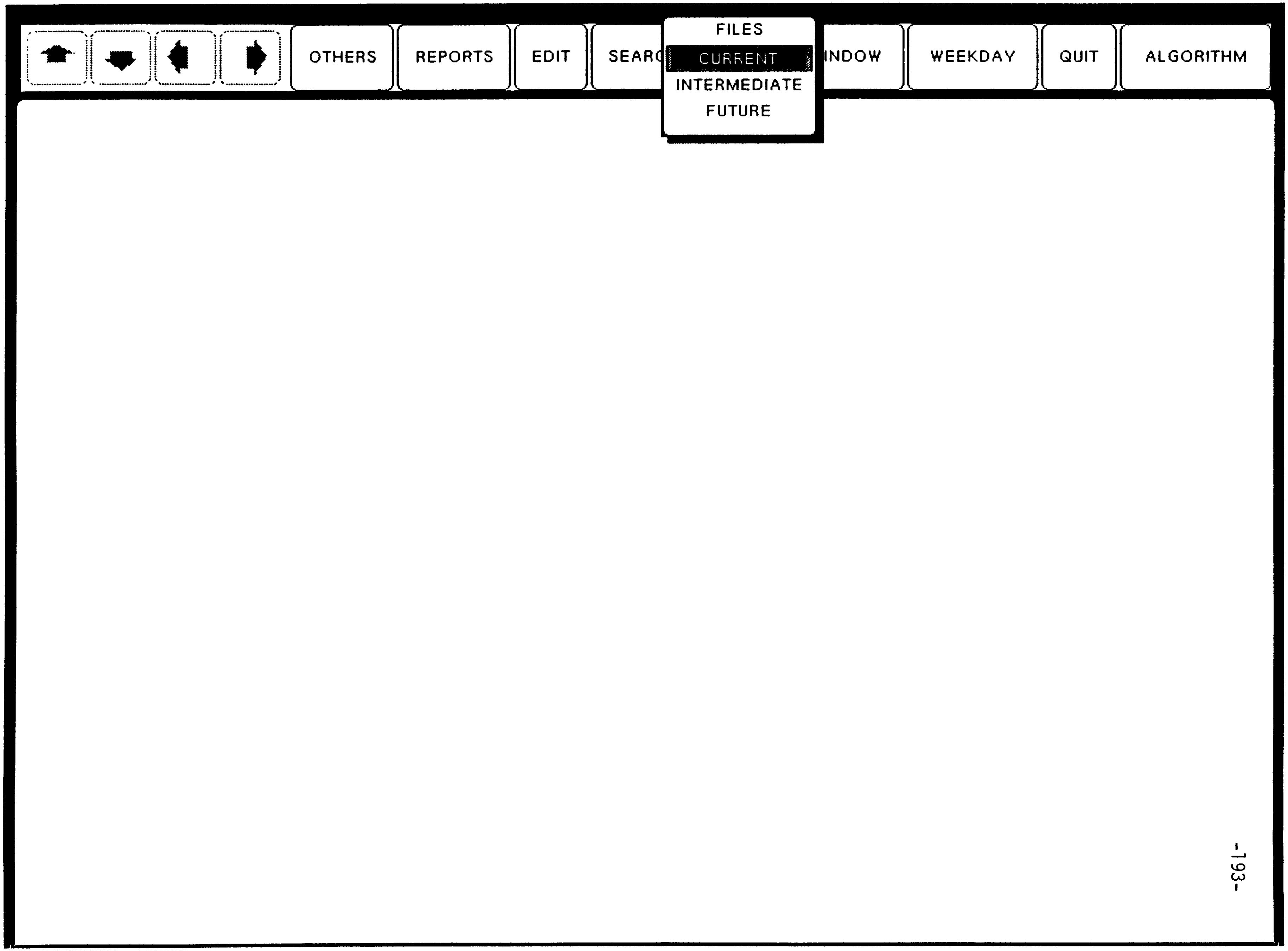
A) Provide computer graphic displays of schedule information
- instantaneously modifiable by mouse
- global data base modification
- selectable screen data -- by fleet, station
- save alternate solutions
- audit trail
- memo pad for scheduler
- keyed to input data, and assumptions used
- automated search routines, etc. to minimize keyboard and mouse work

B) Provide instantaneous error flagging (even if error occurs off-screen)
- e.g., insufficient gates, flow imbalance, double crew layover, violation of turnaround or transit times, insufficient aircraft.

C) Integrate crew, gate, maintenance schedule with aircraft schedule

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

E) Provide interface to mainframe data system to maintain current scheduling processes.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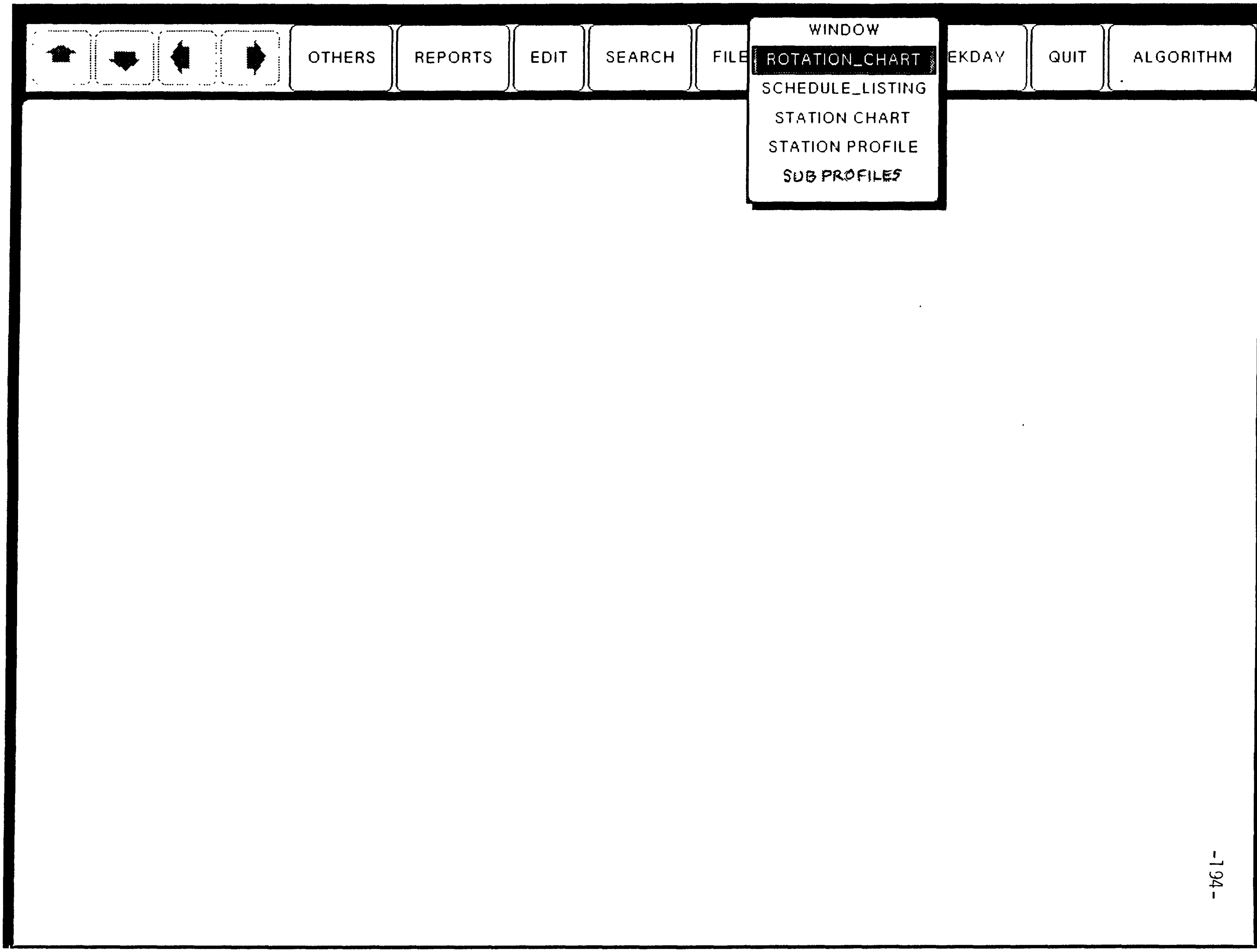
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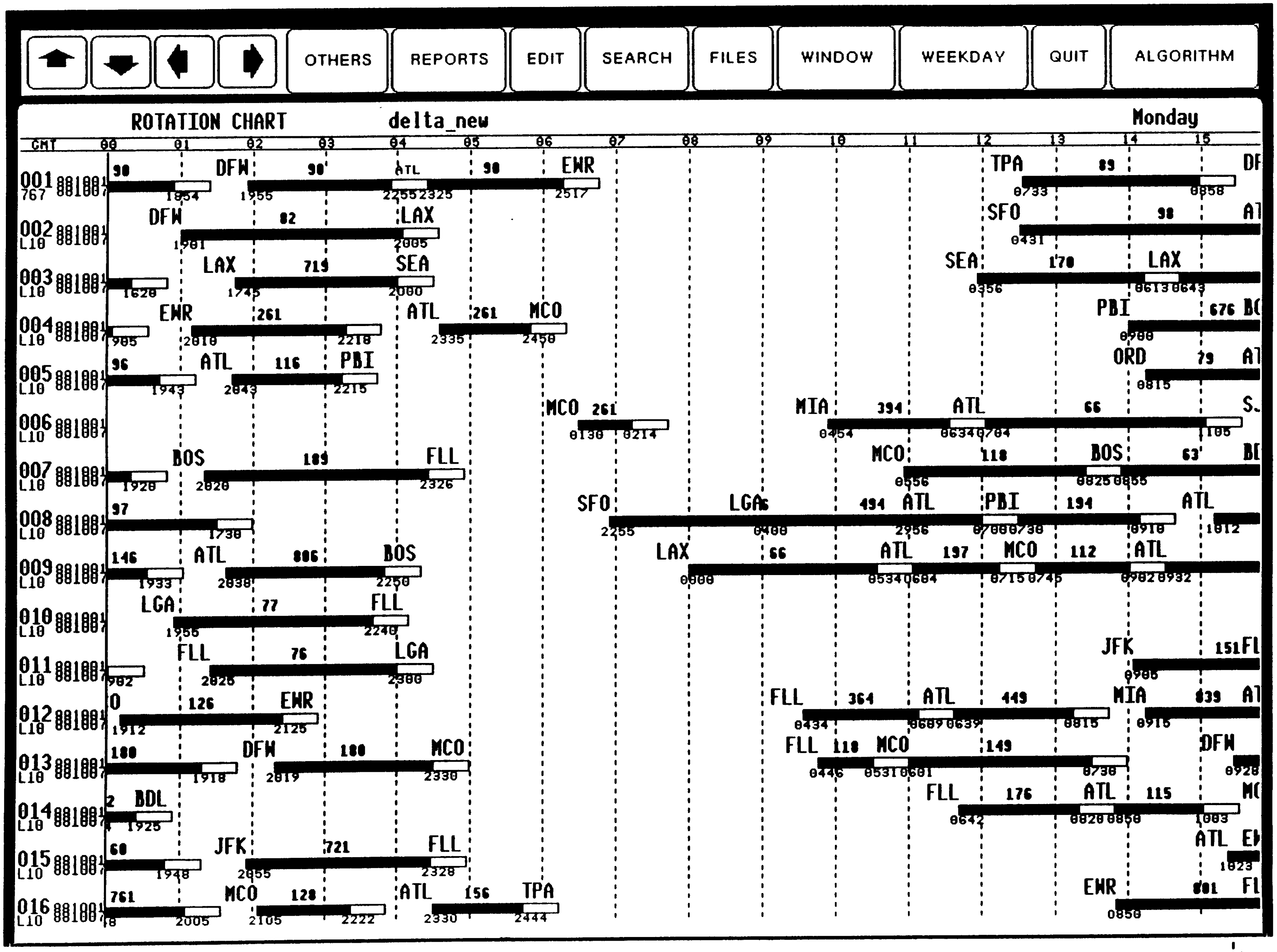

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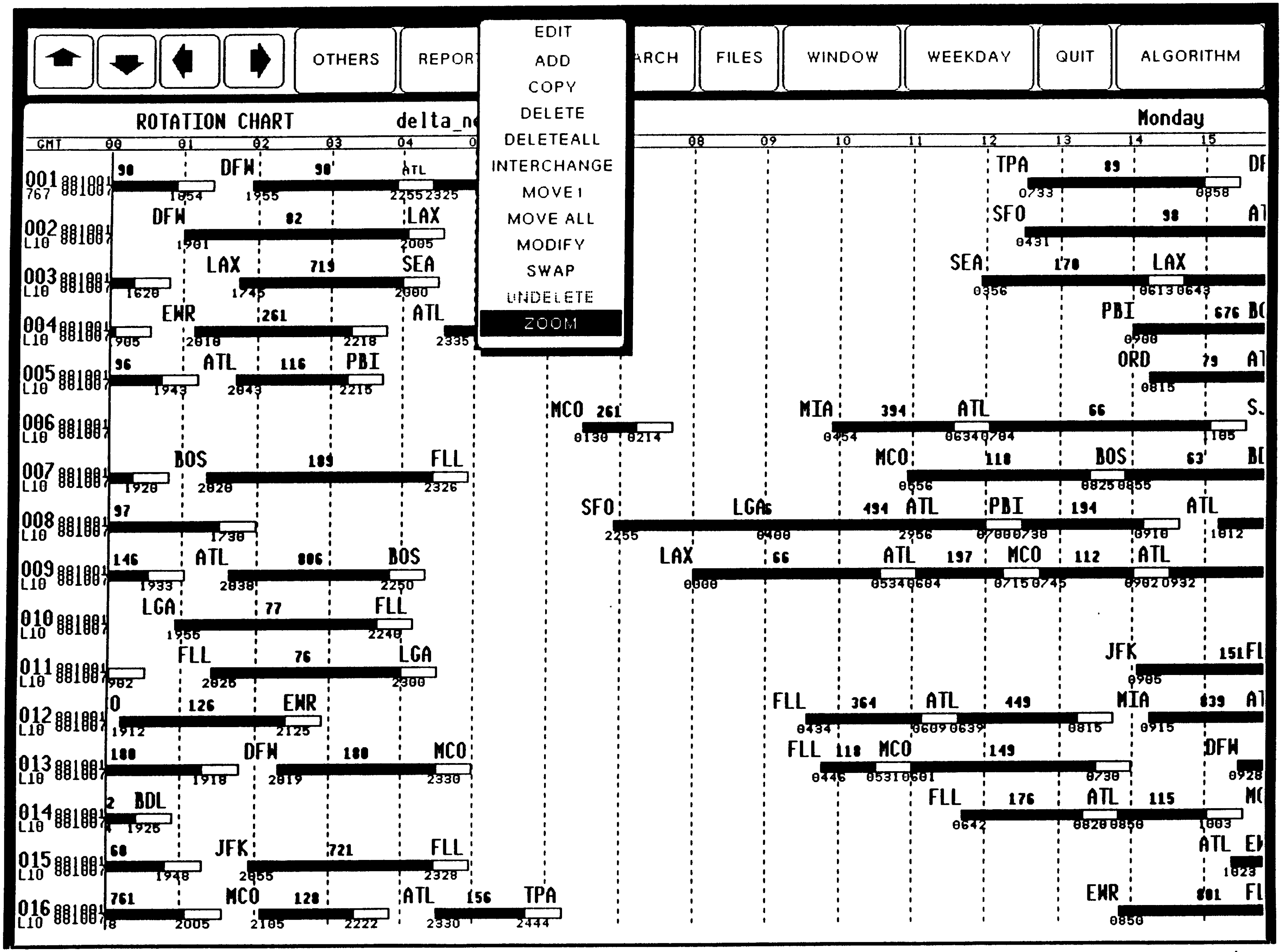
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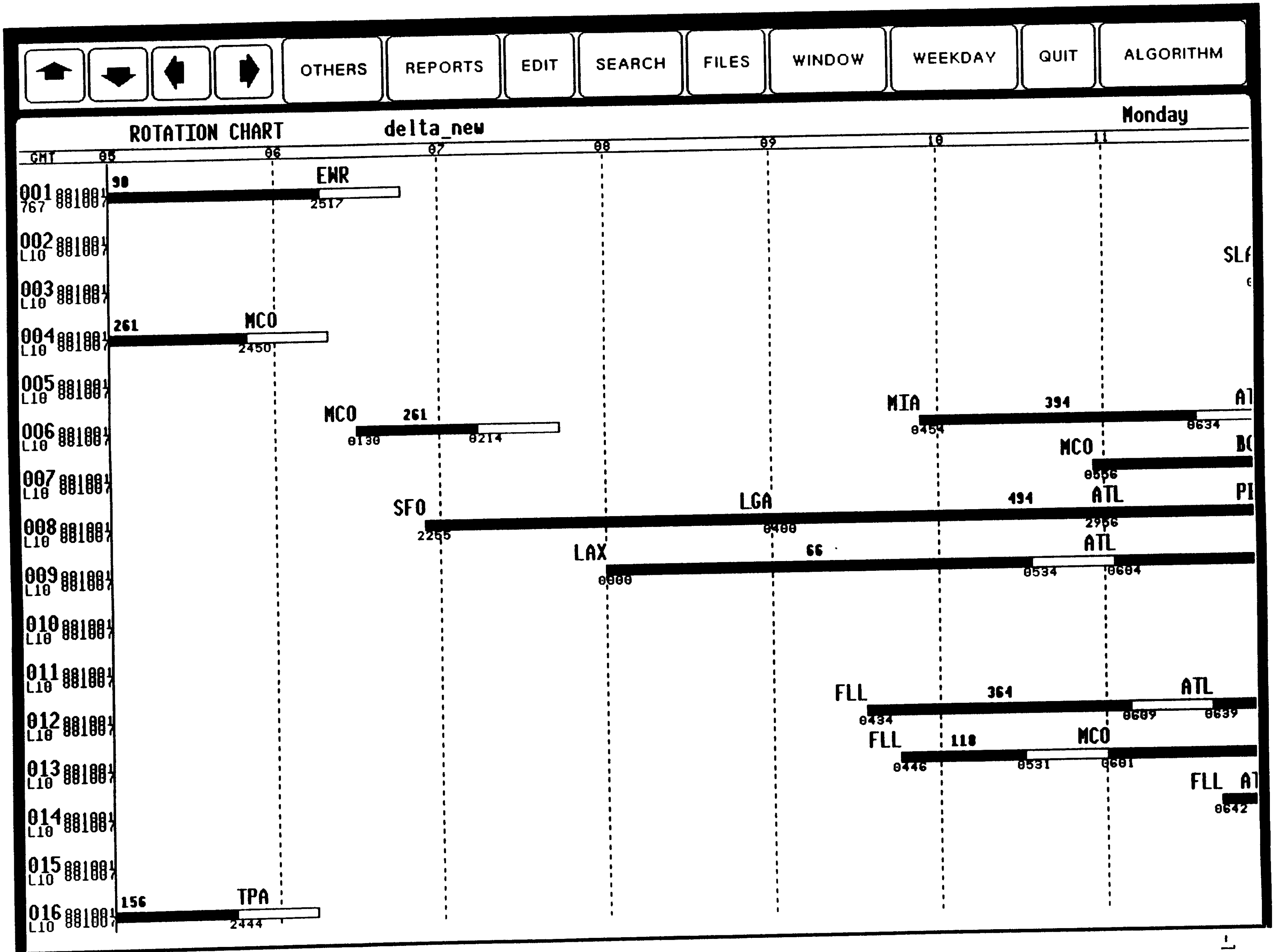
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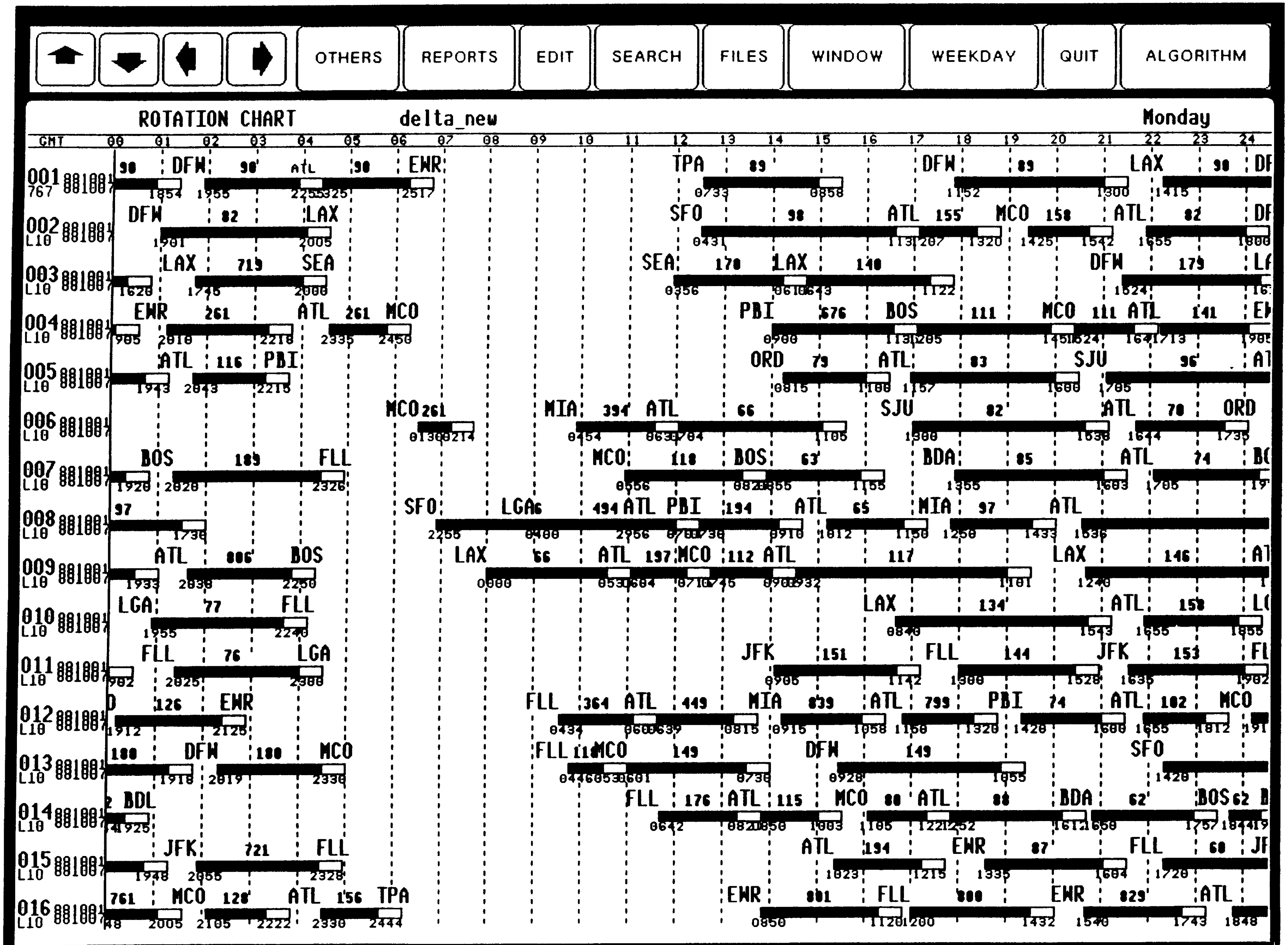
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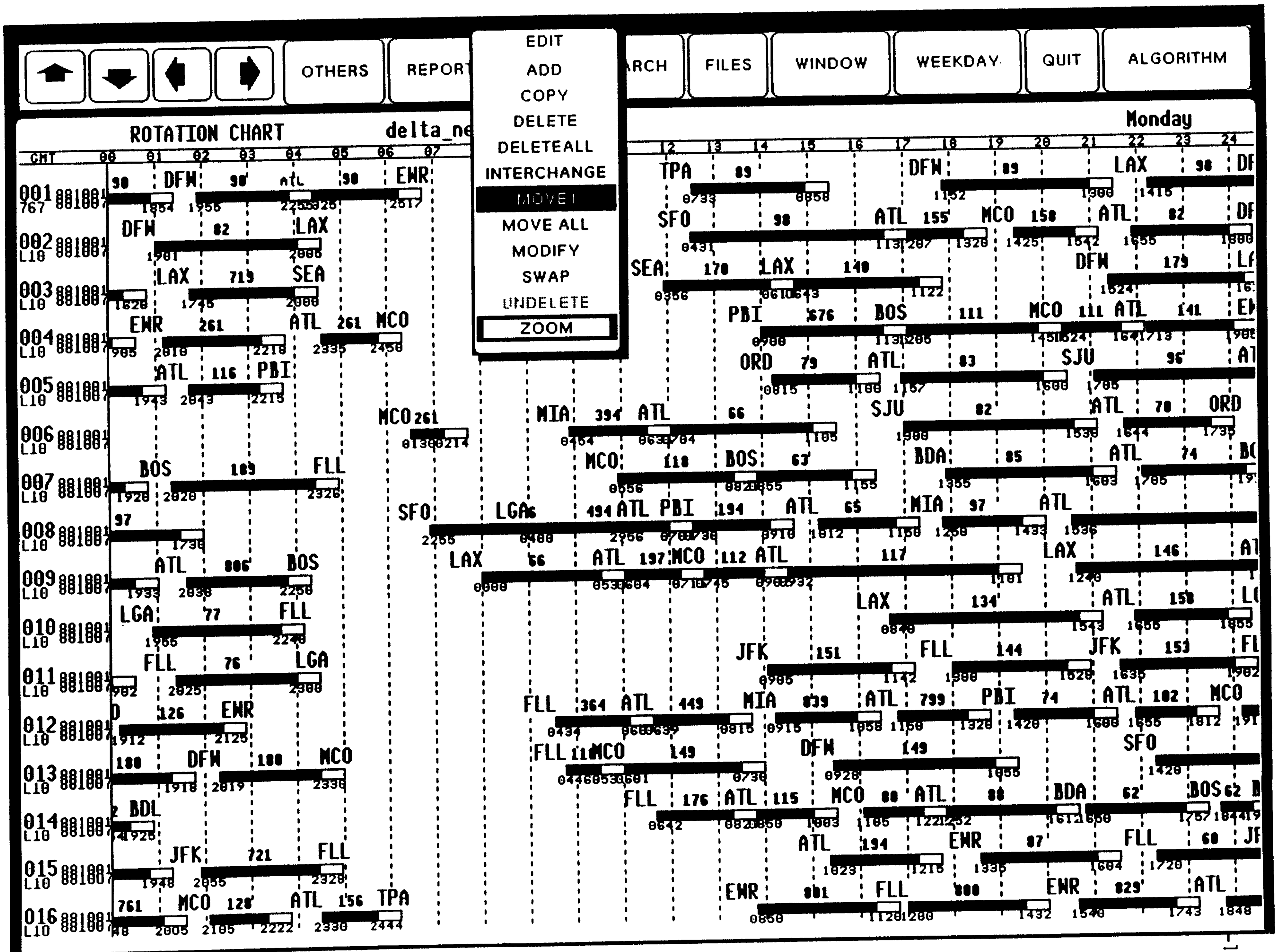
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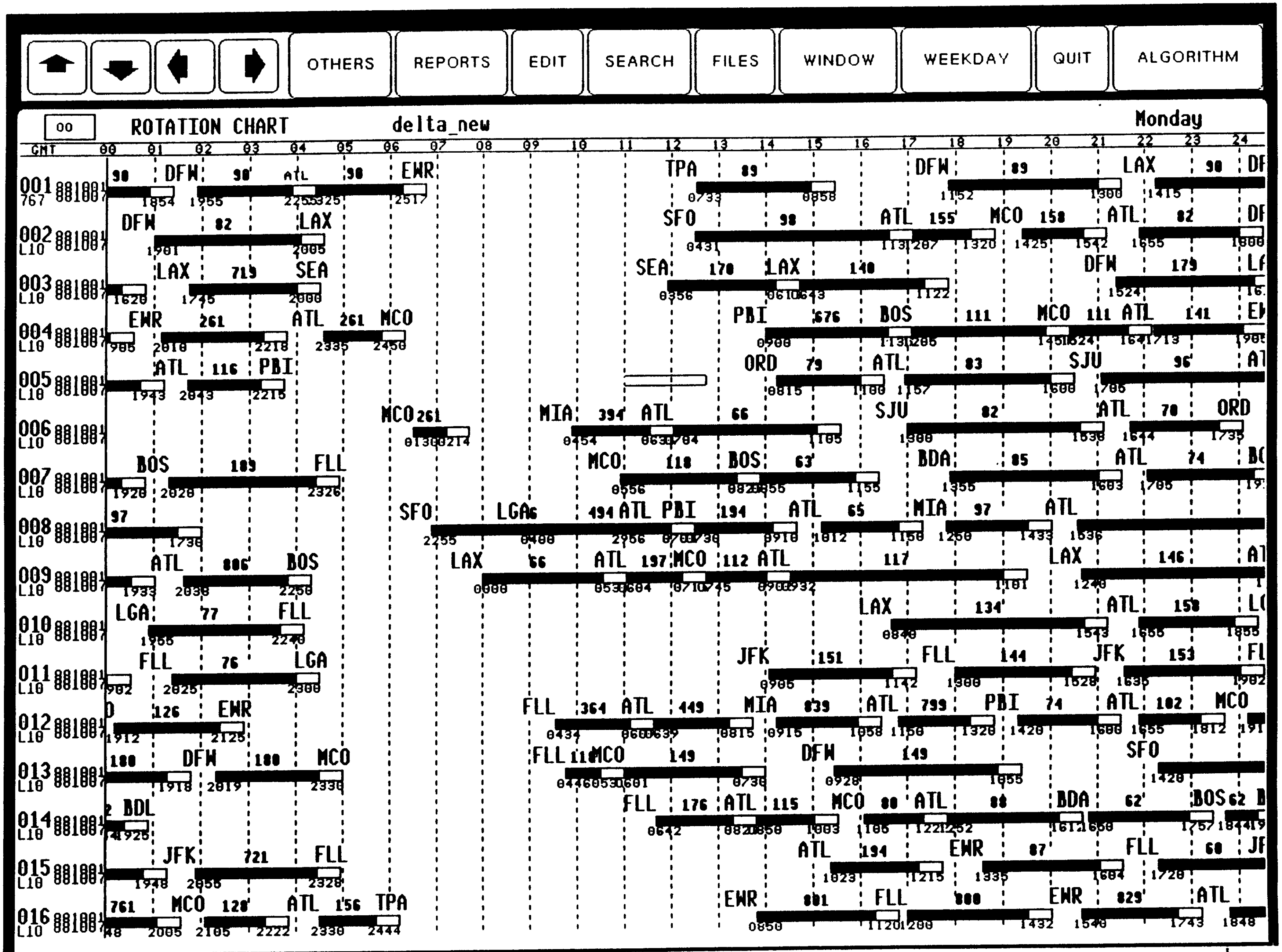
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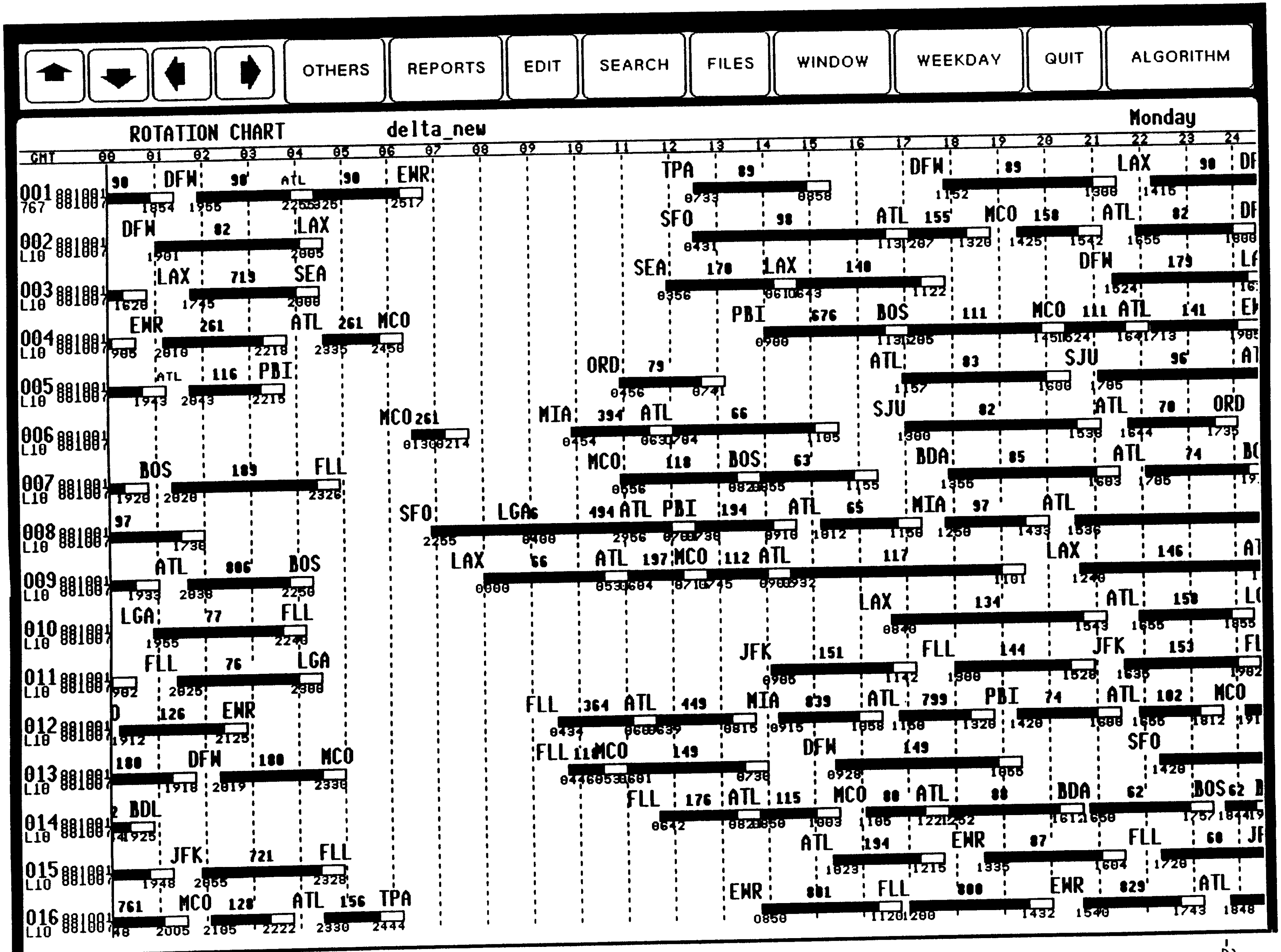
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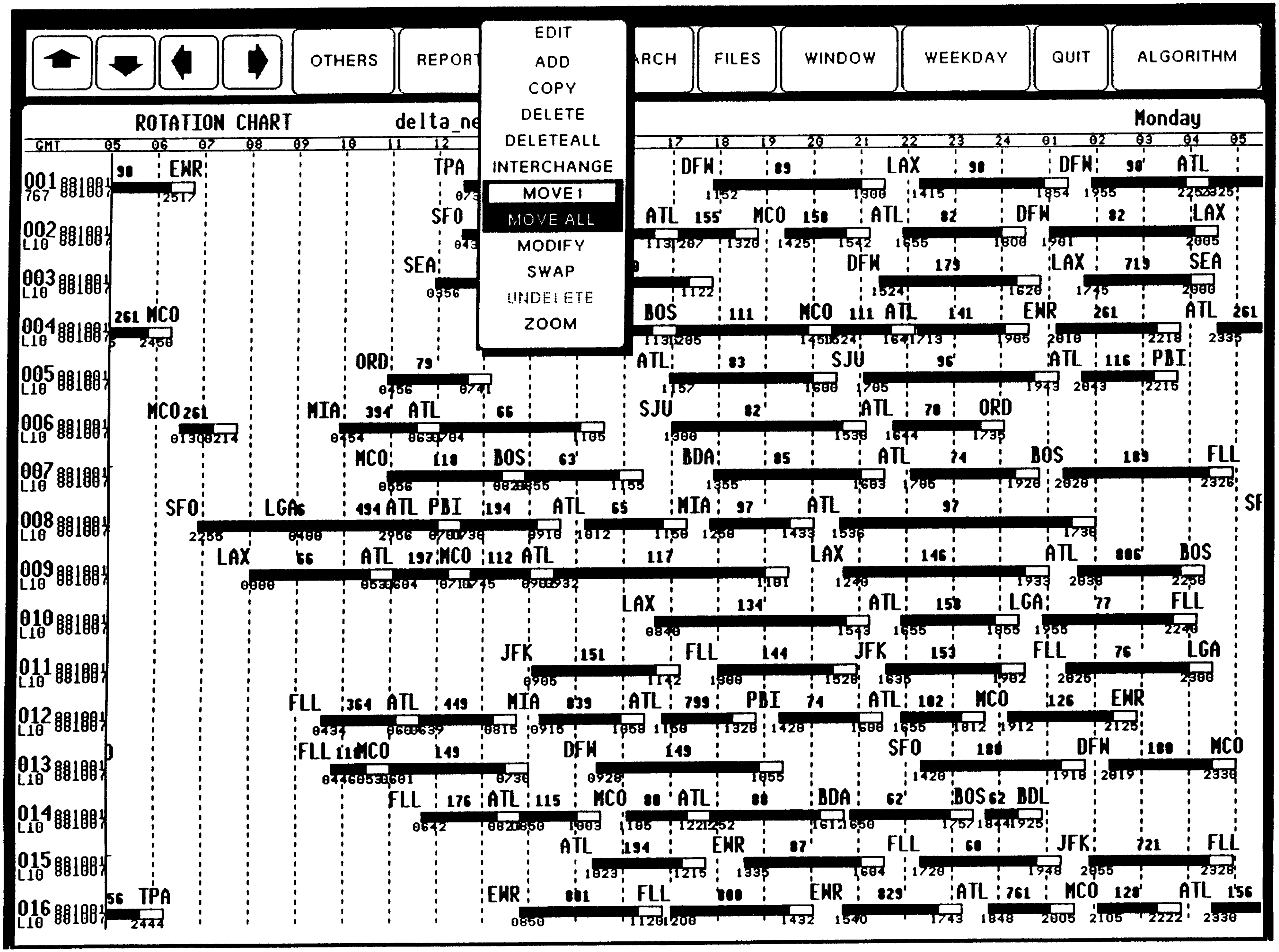
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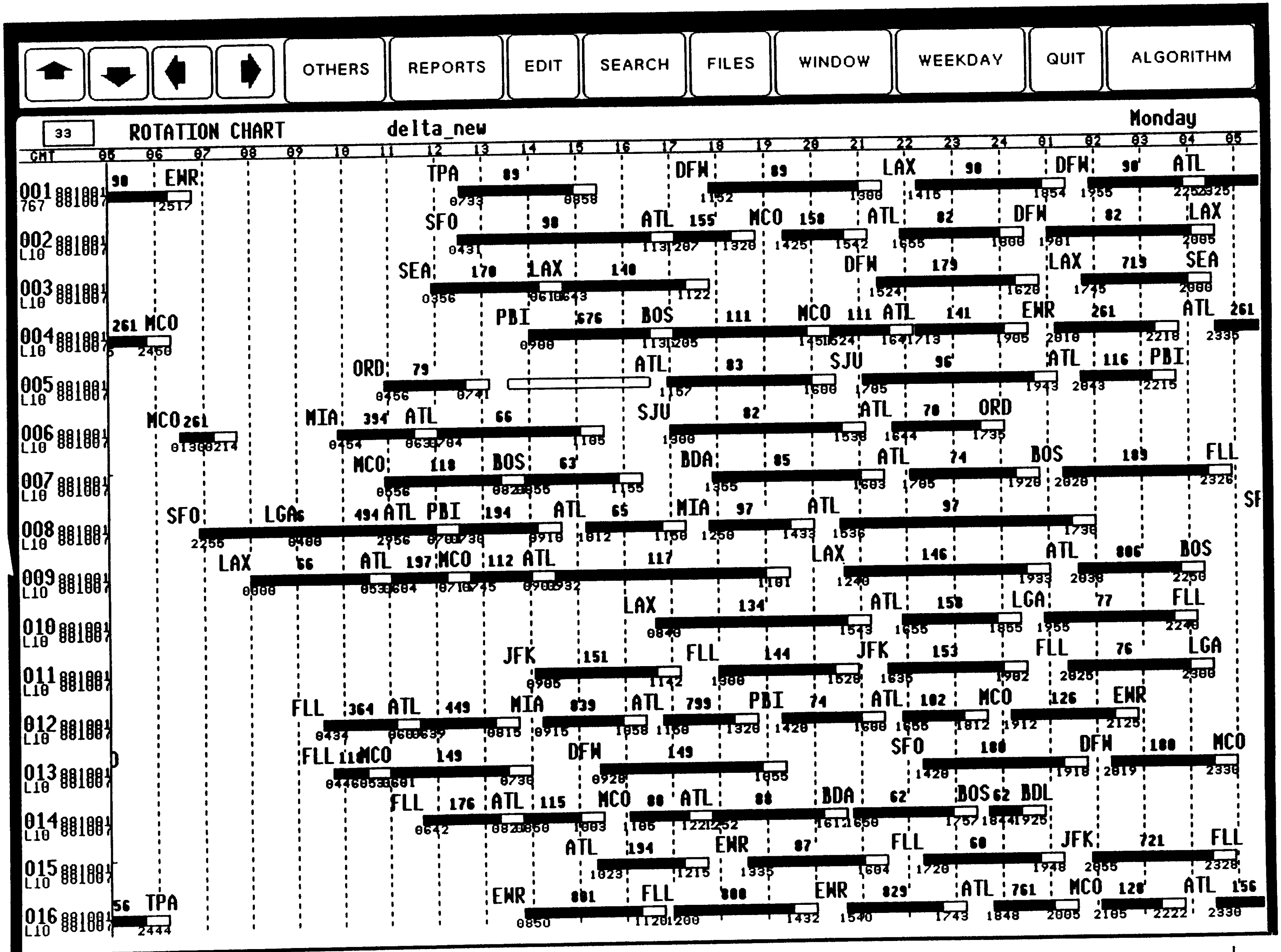
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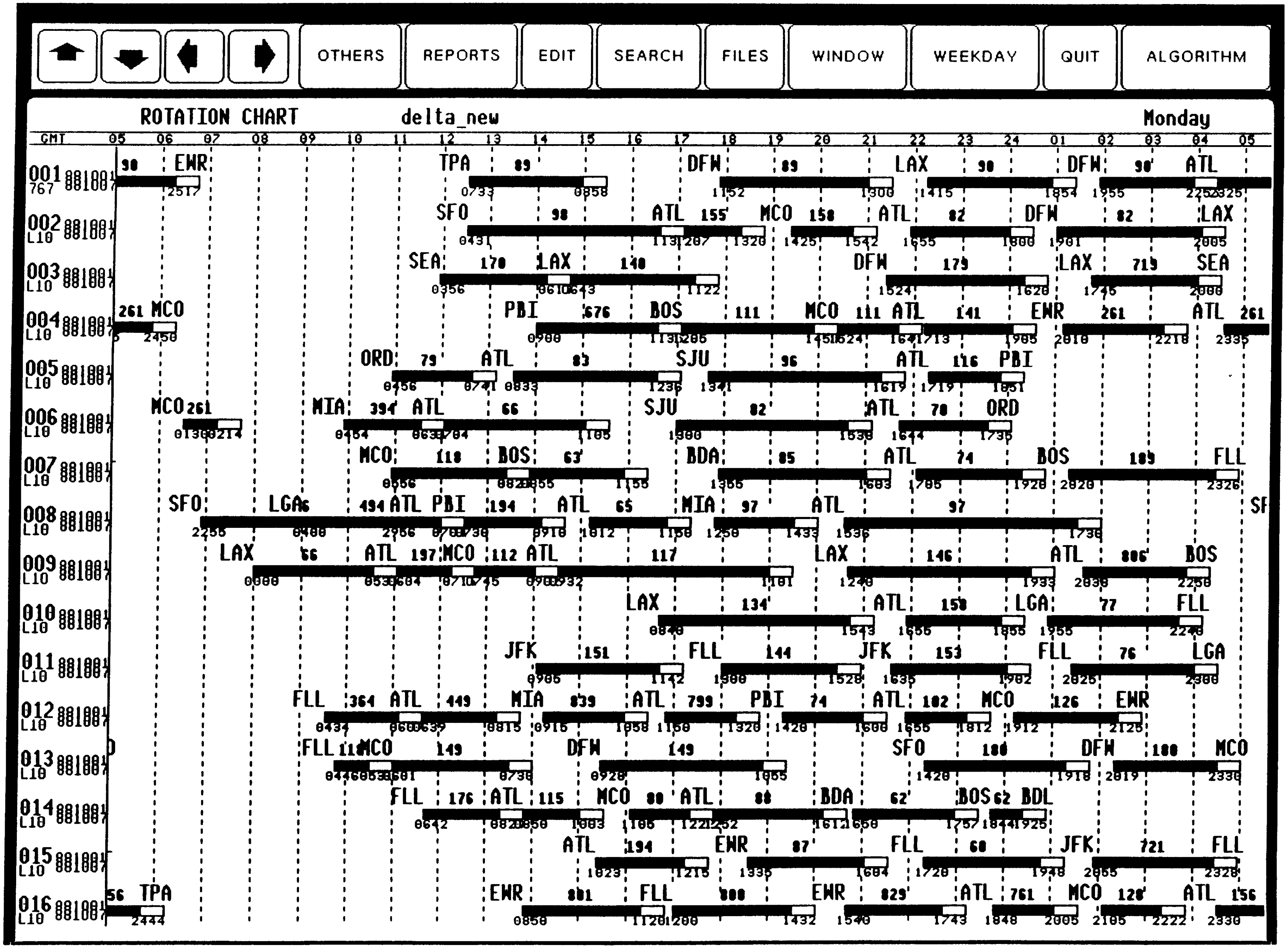

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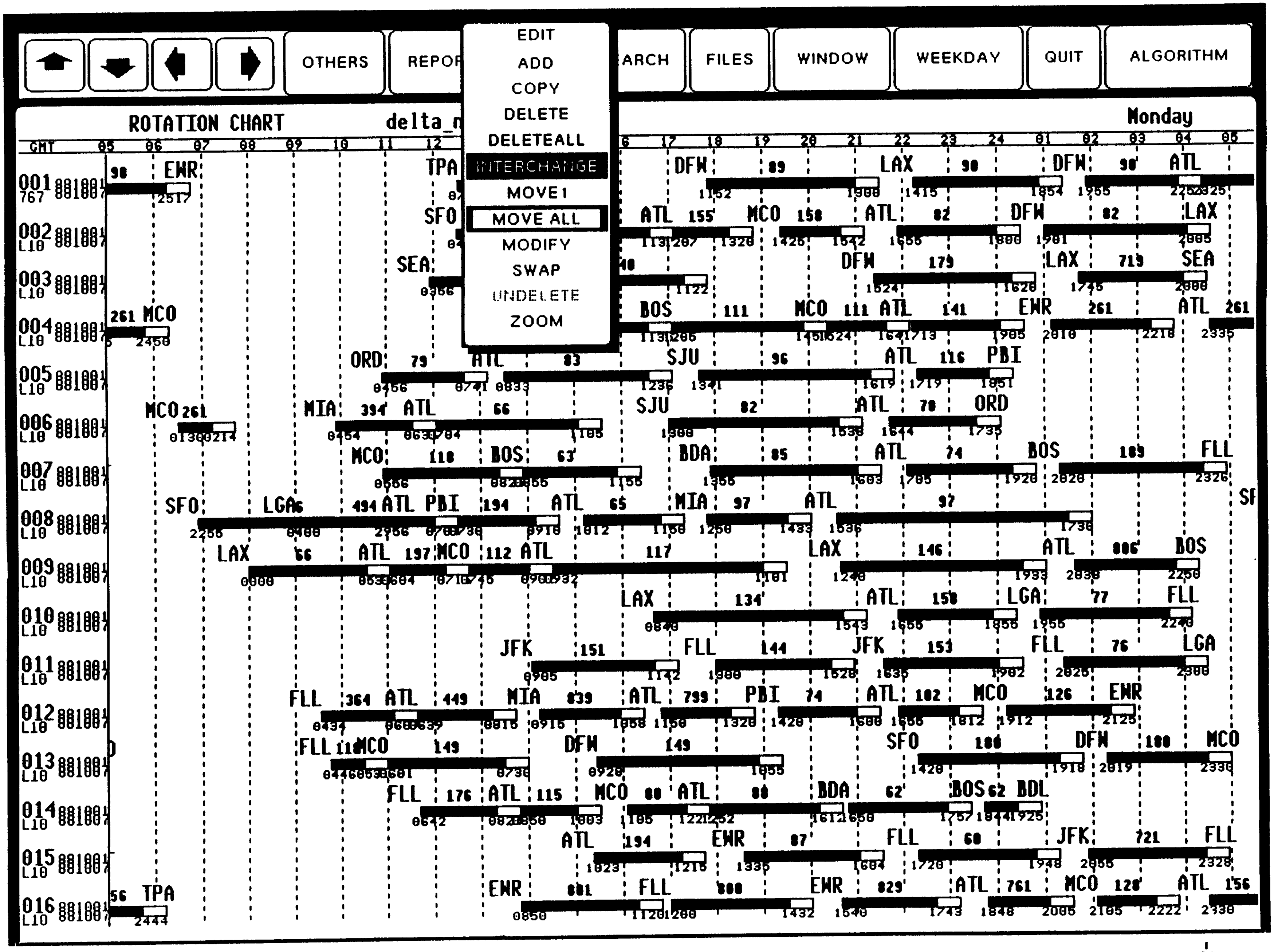
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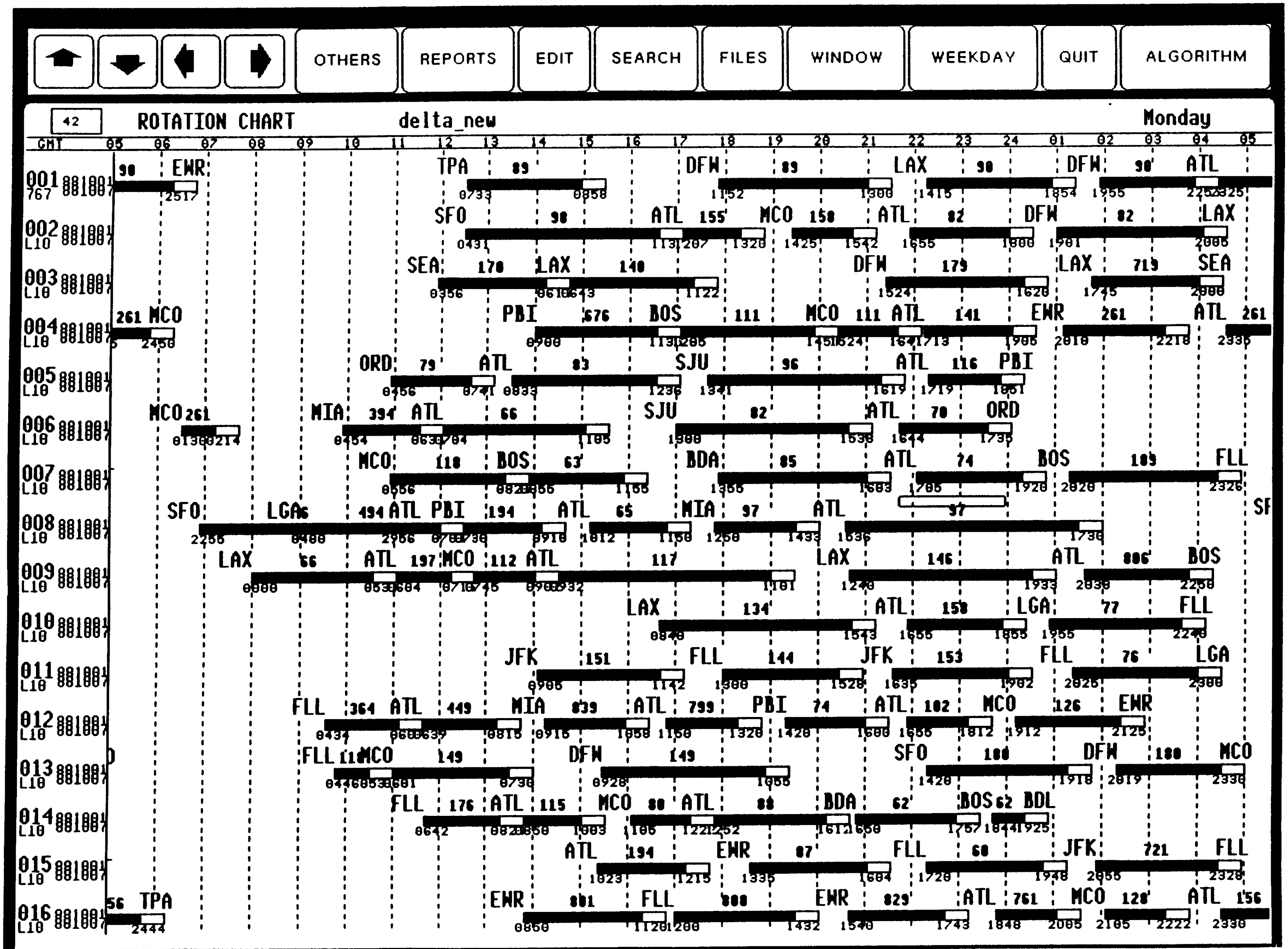
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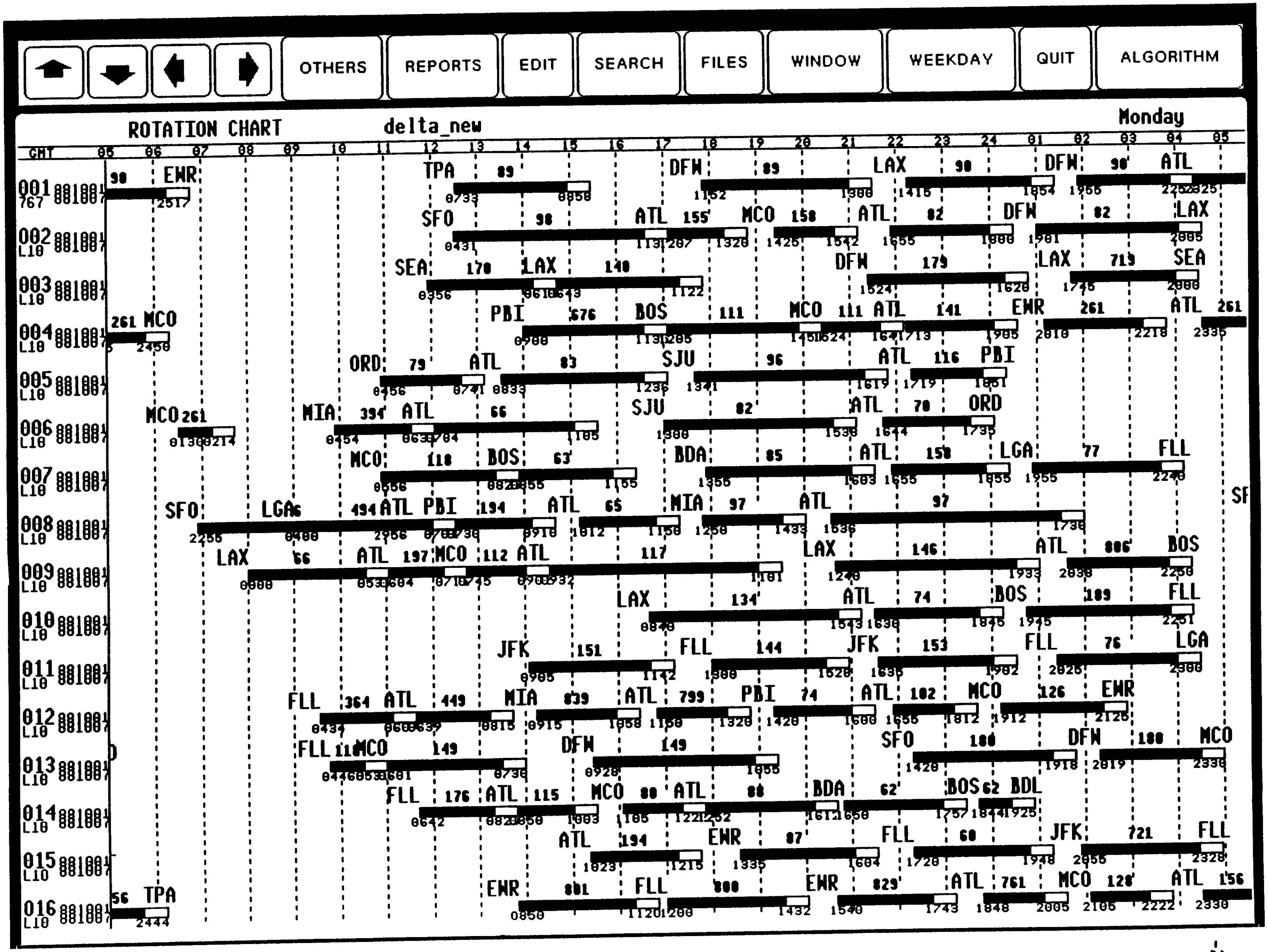
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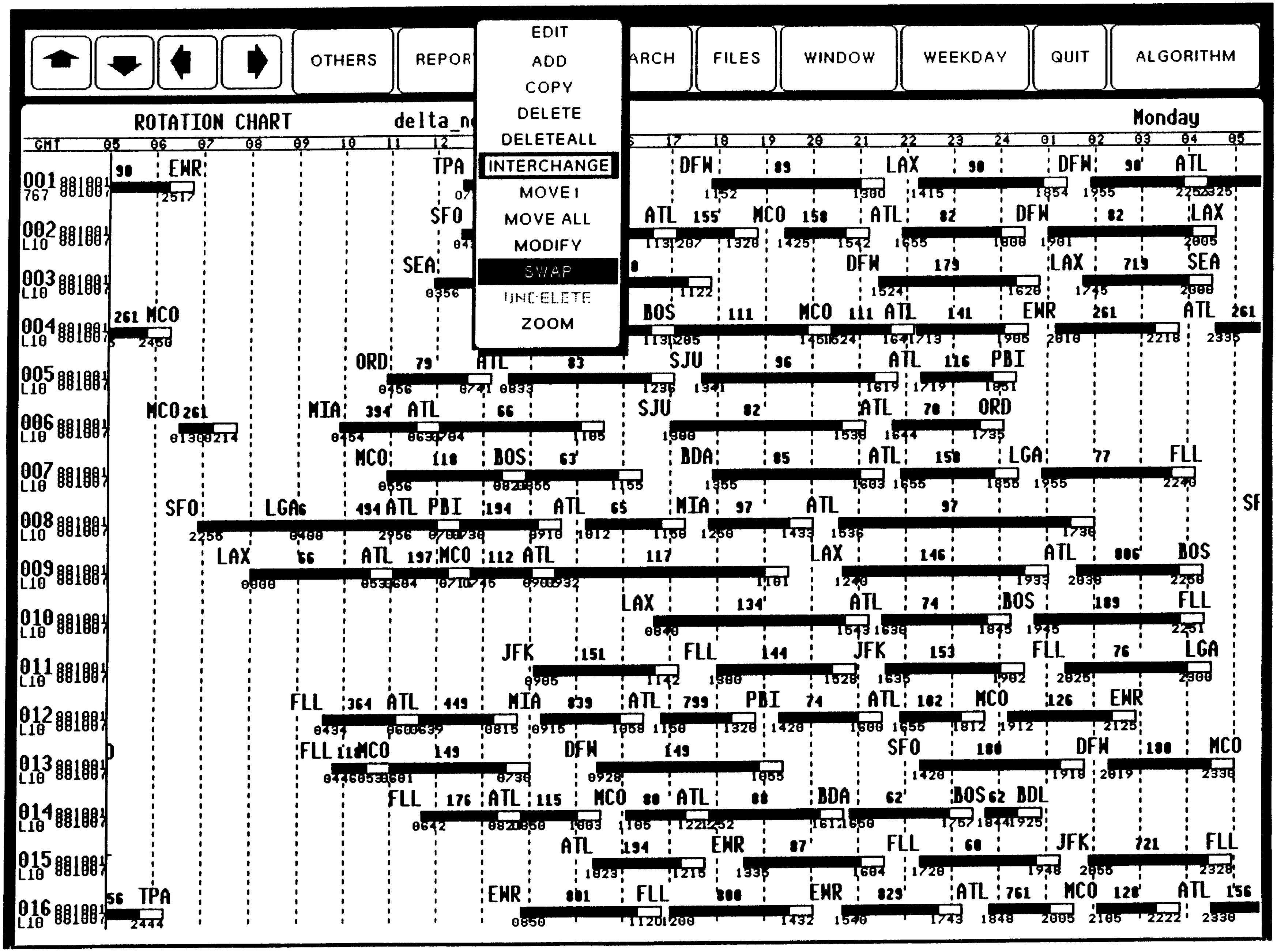
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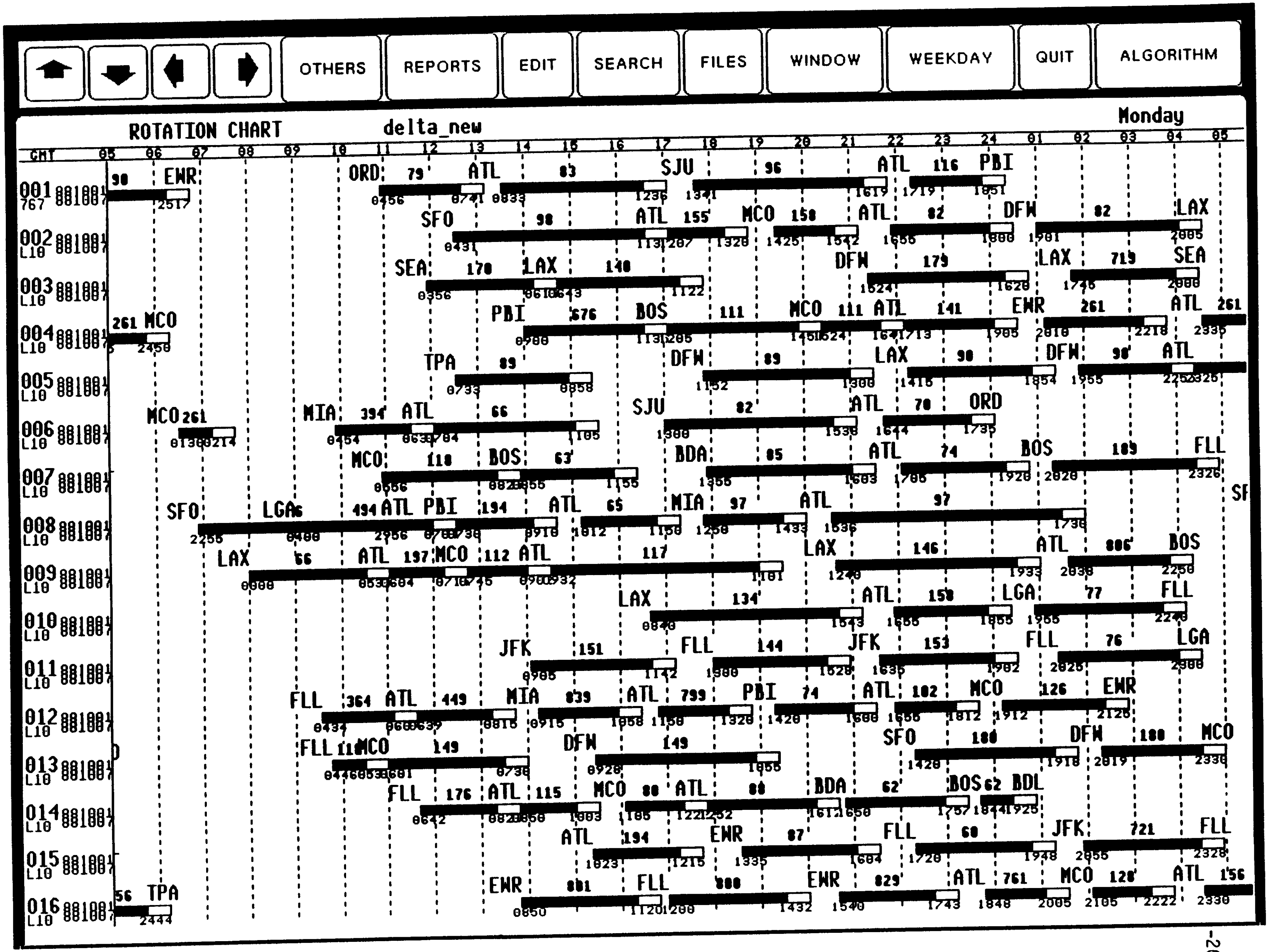
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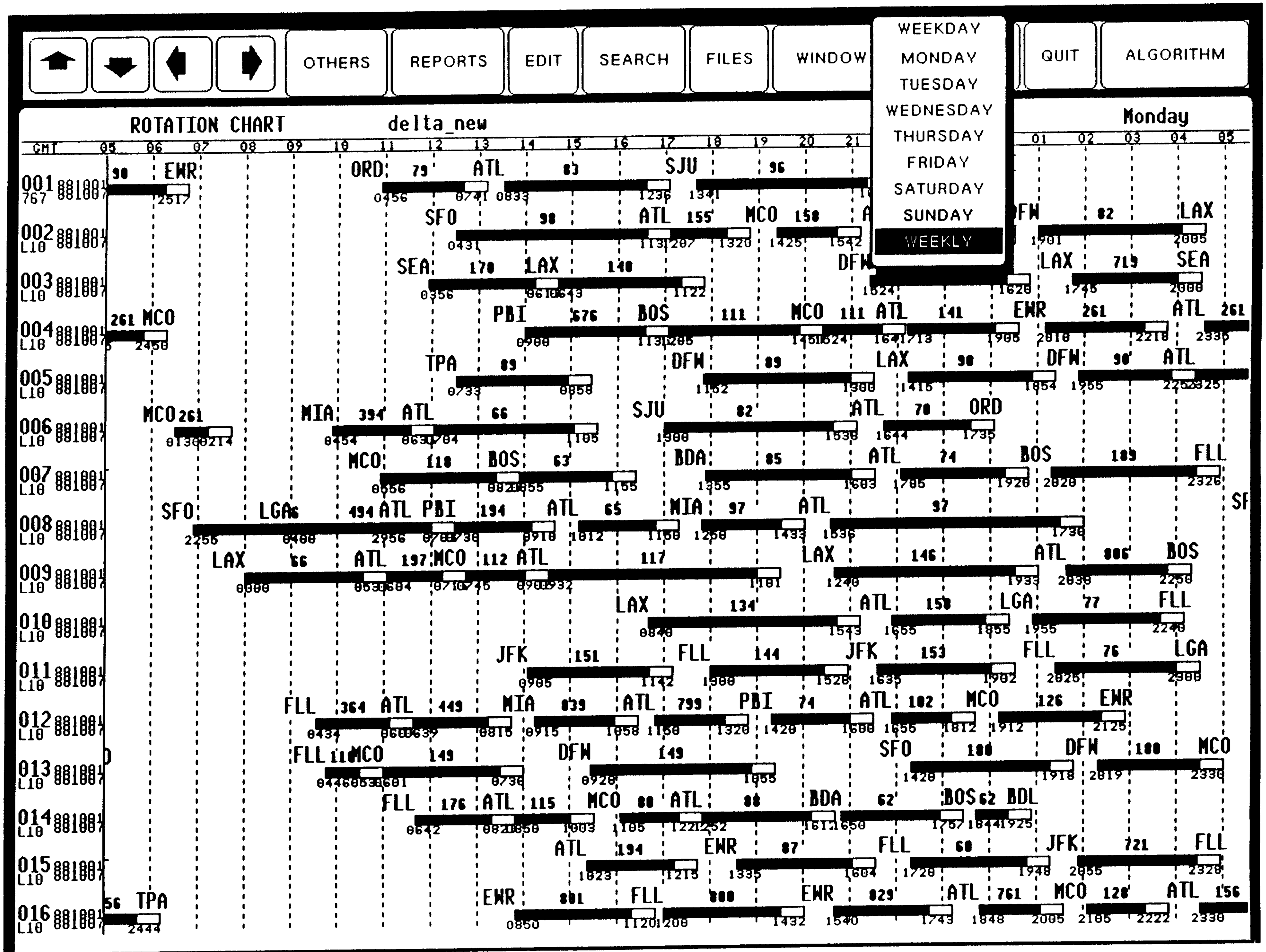
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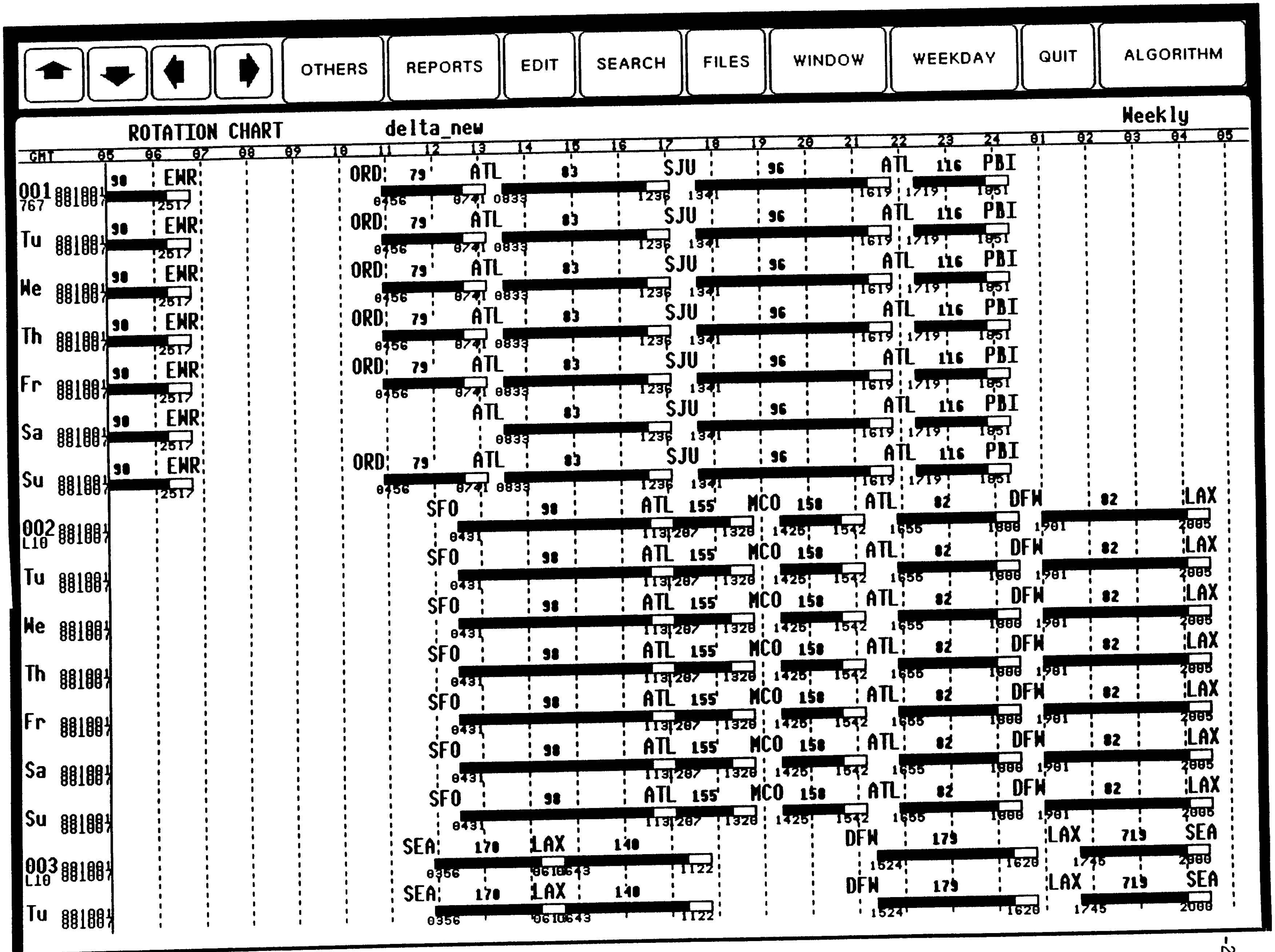
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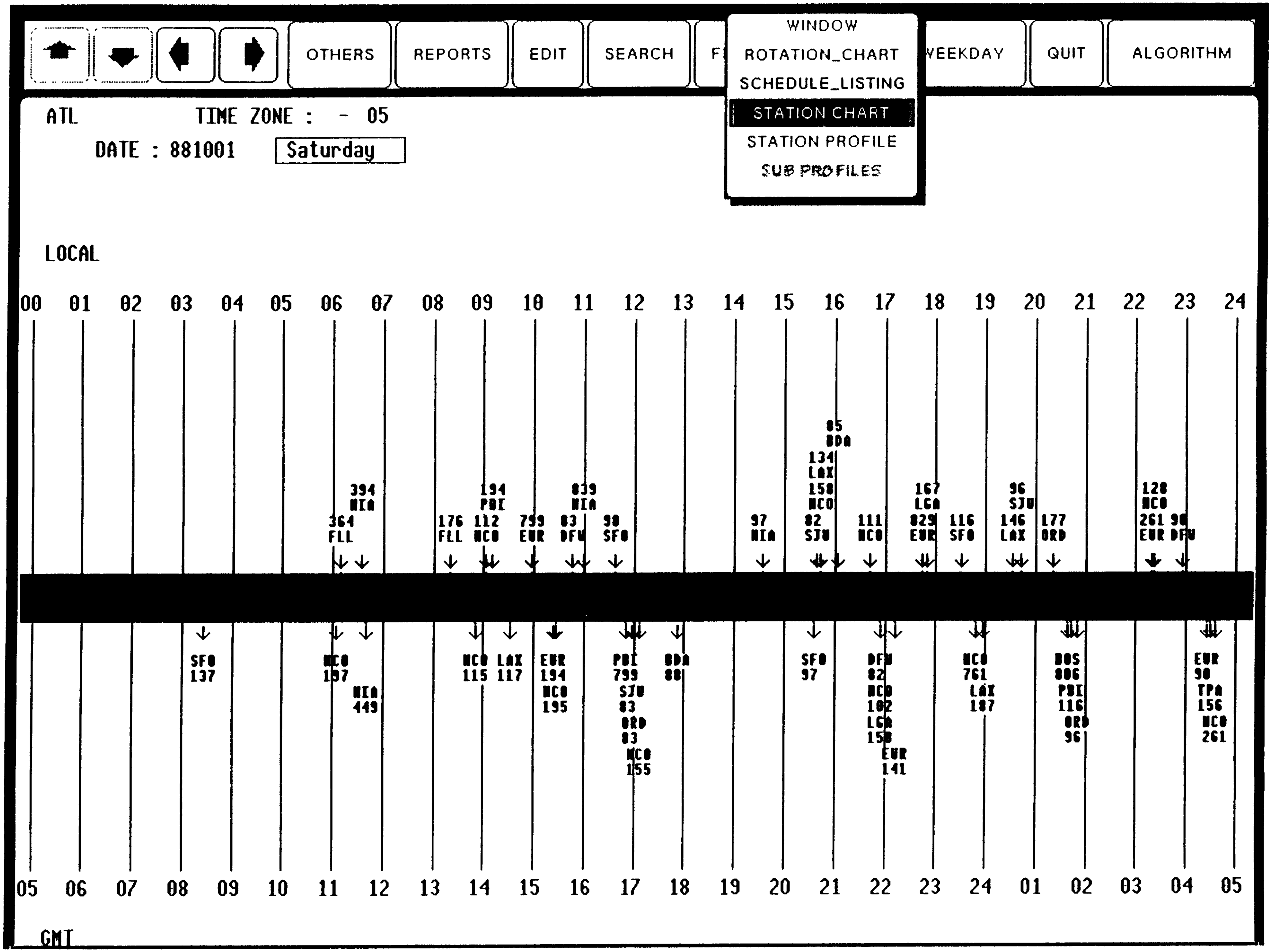
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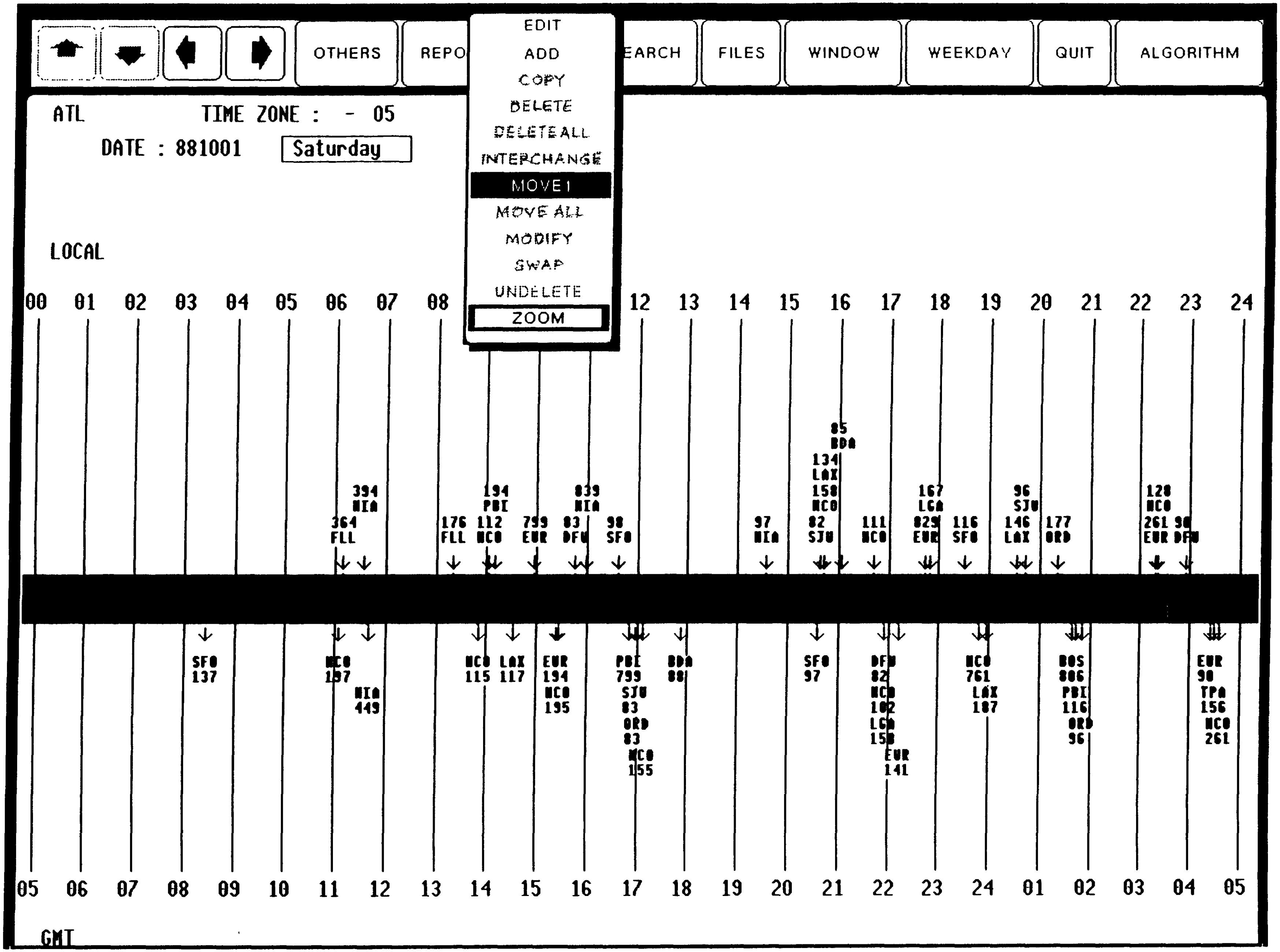
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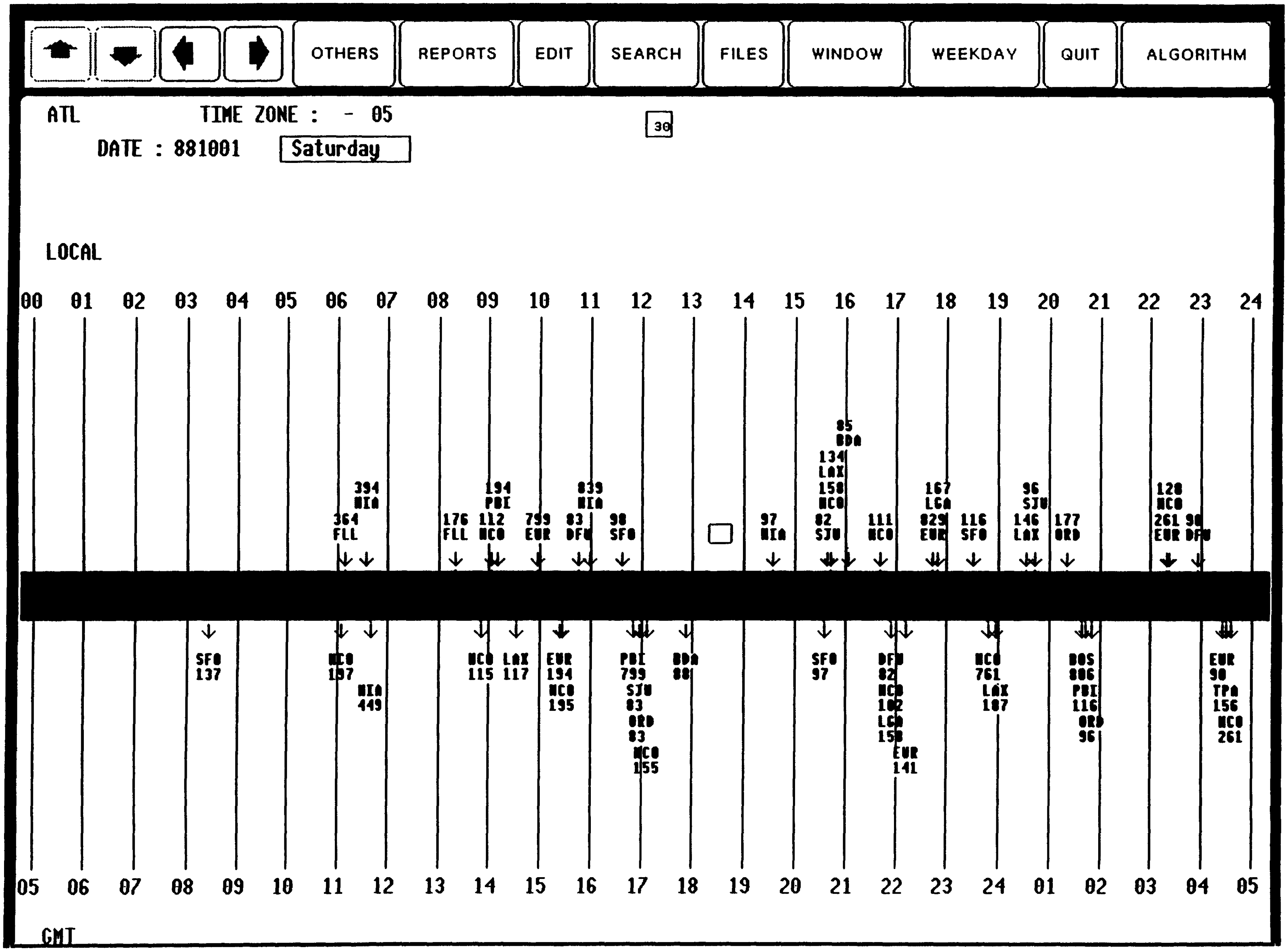
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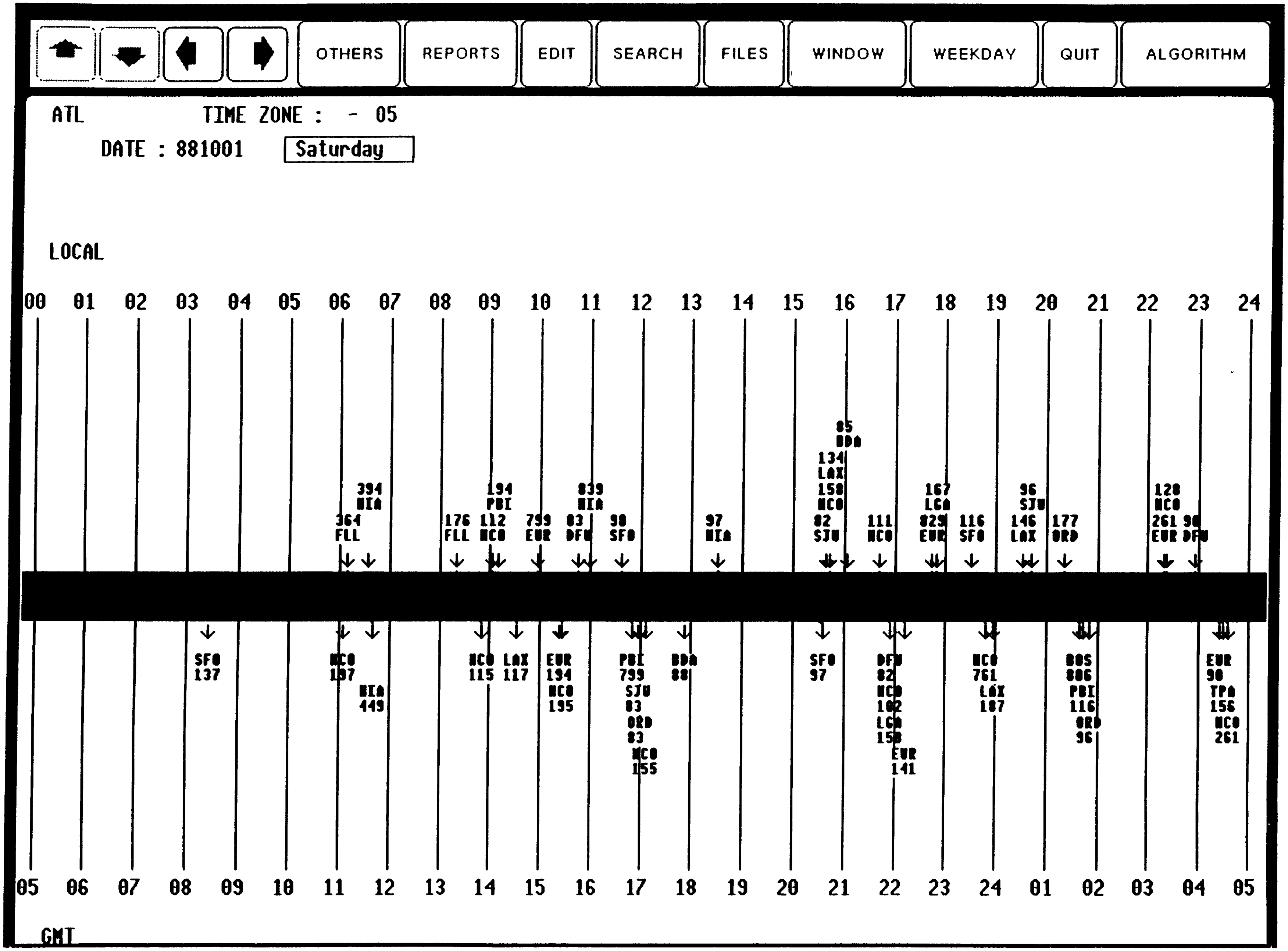
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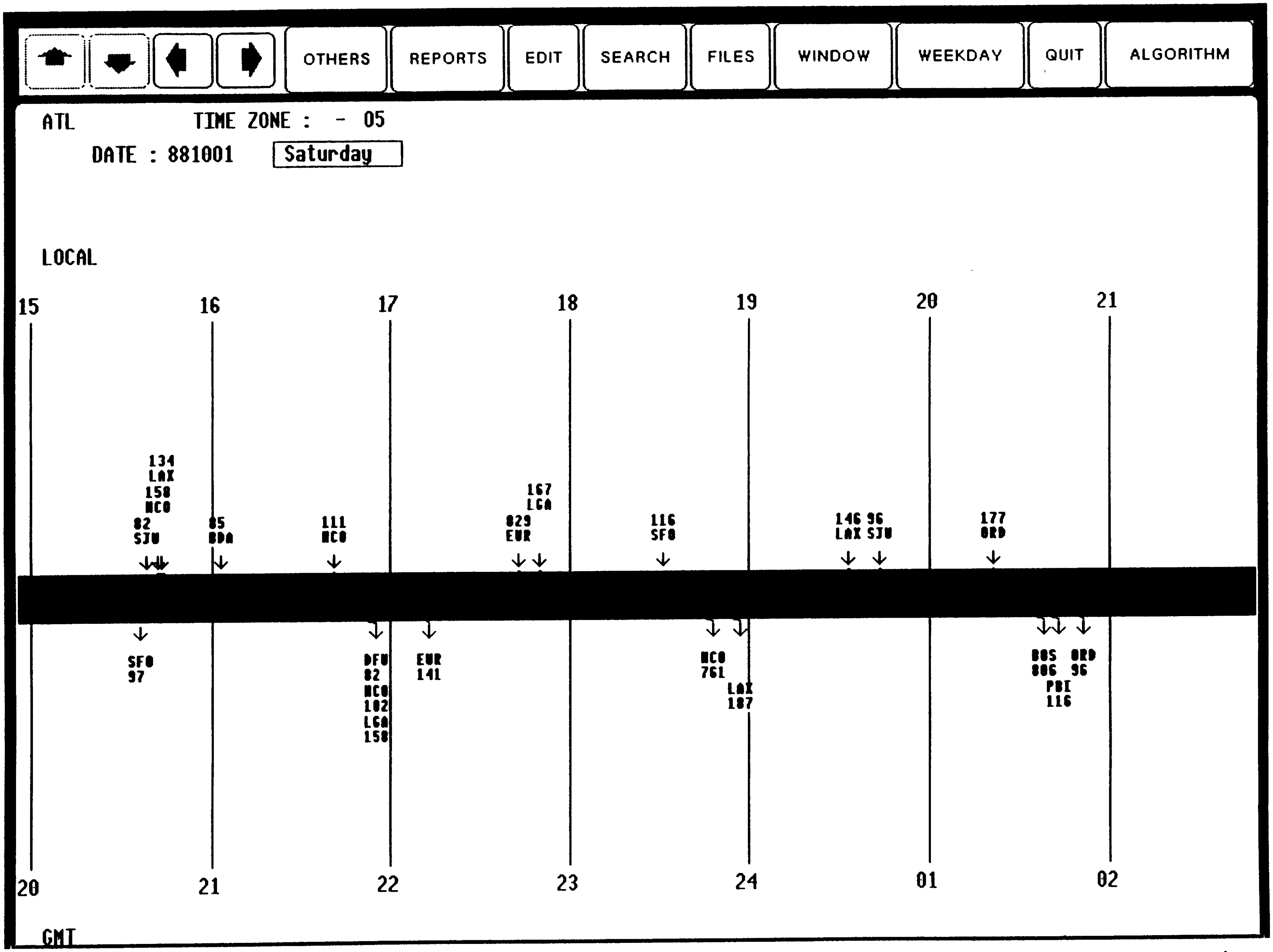
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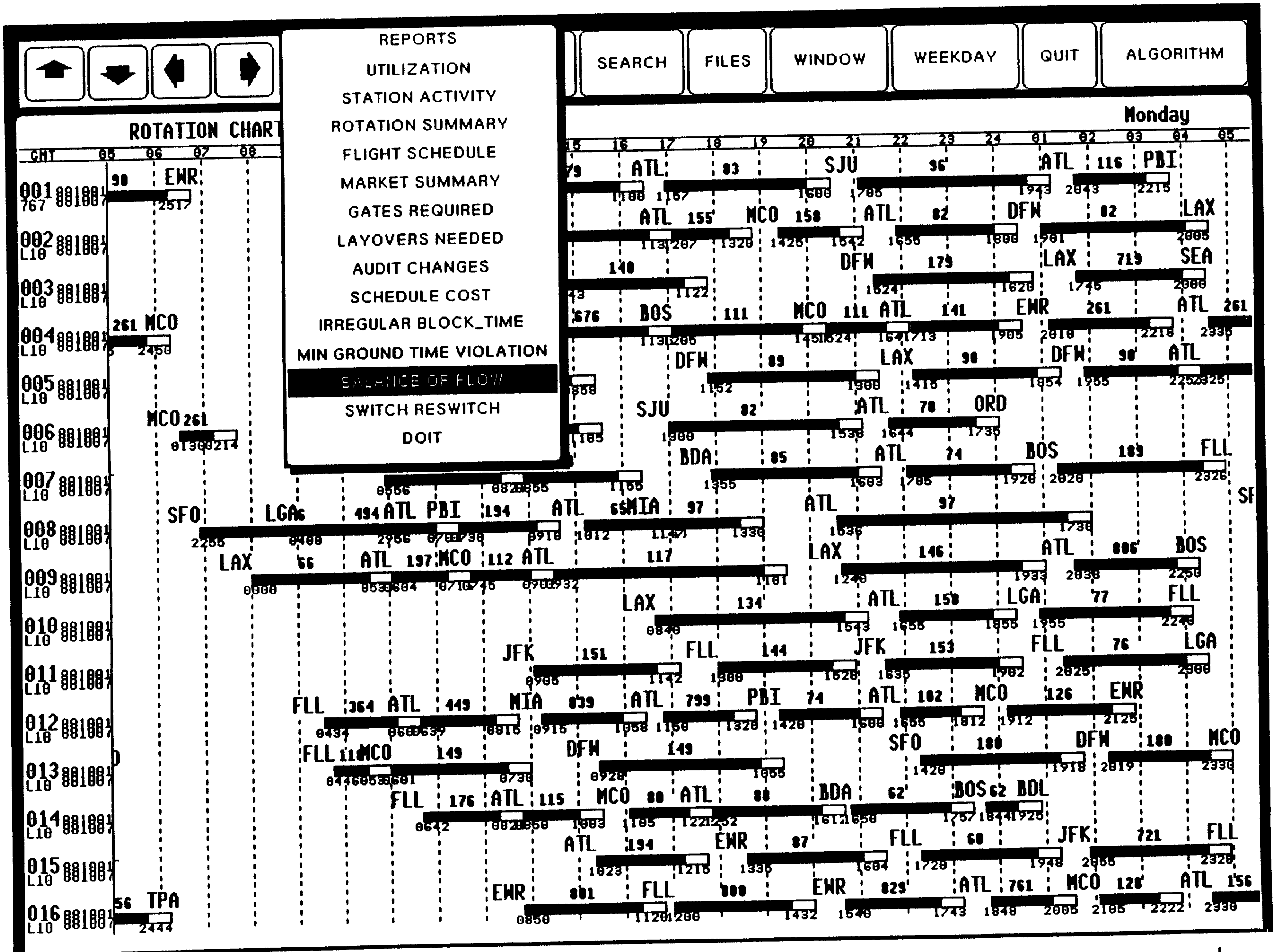
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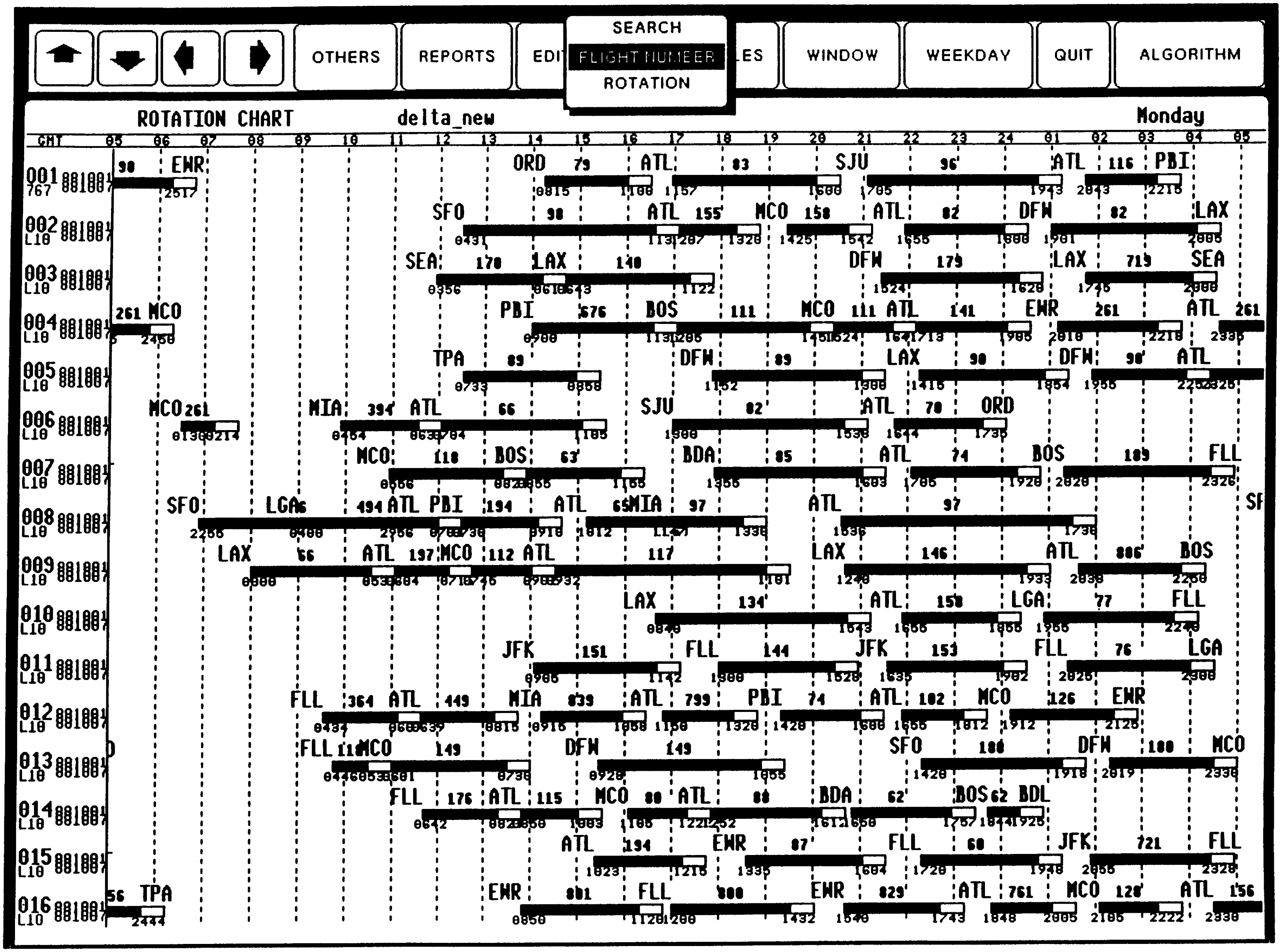

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VI. STAGE 2 - AUTOMATED DECISION SUPPORT

INTRODUCTION OF AUTOMATED ALGORITHMS, EXPERT SYSTEMS

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

EXAMPLES OF EXISTING AUTOMATED DECISION SUPPORT ALGORITHMS

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

VI. AUTOMATED DECISION SUPPORT

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

Fleet Routing Models

- use network flow algorithms

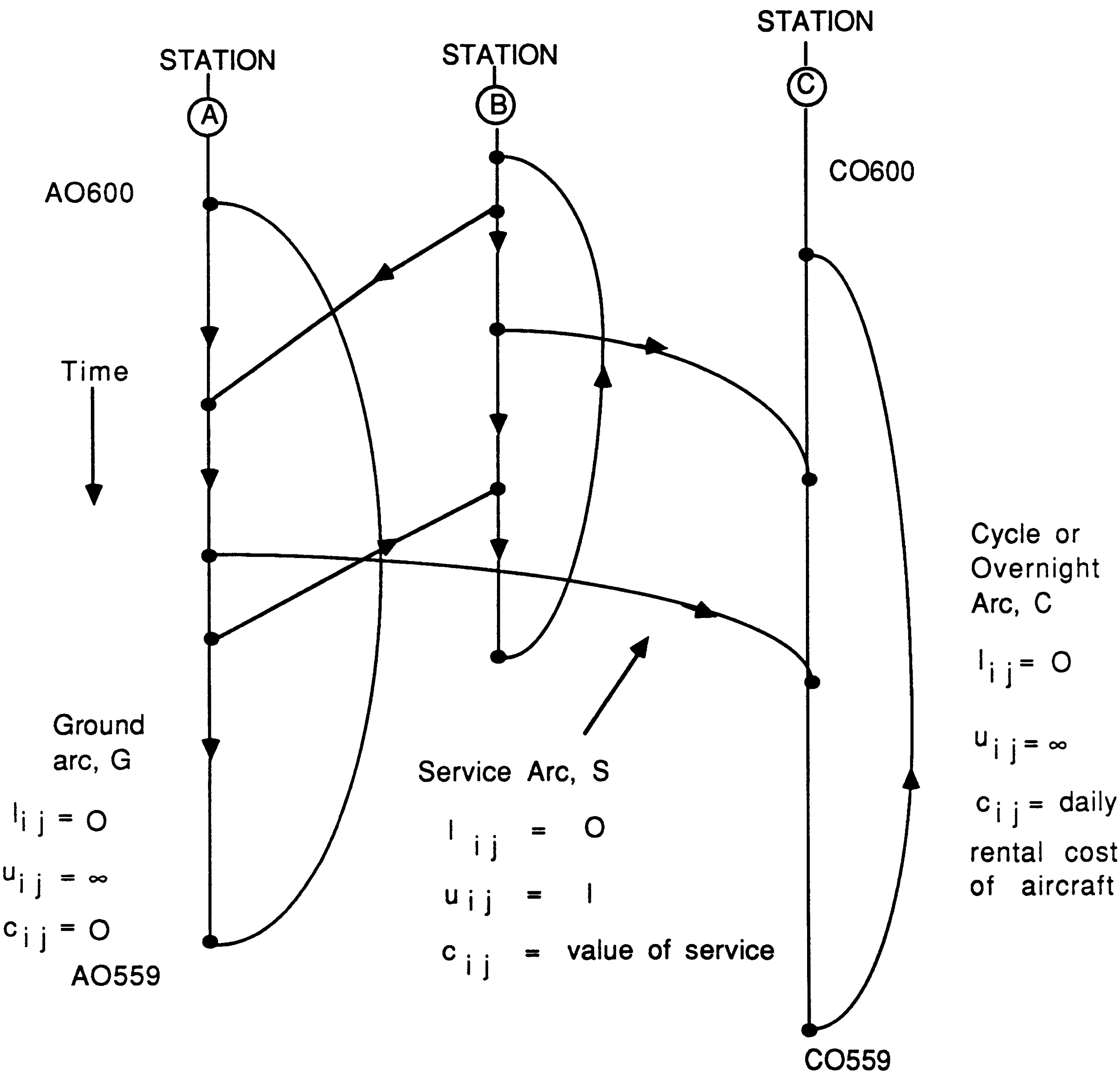
OBJECTIVE:
Maximize Operating Income

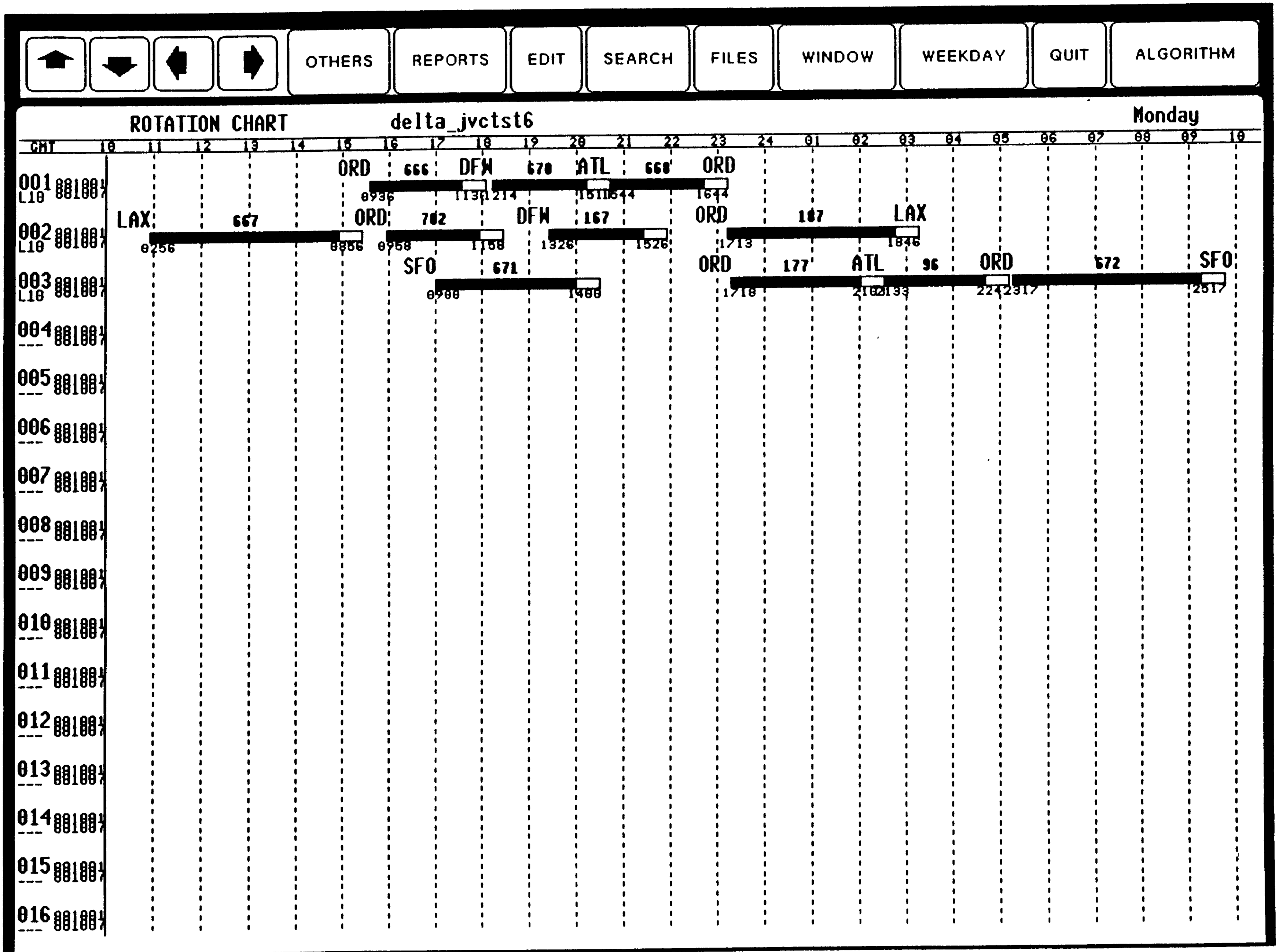
GIVEN:
- Set of potential services to be flown with fixed operating times and known net operating income
- Daily ownership costs of aircraft
- Desired overnights
- Fixed number of available aircraft

OUTPUT:
- "Best" services to be flown
- Marginal value for services not flown
- Marginal value of adding an aircraft to fleet

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

SCHEDULE MAP

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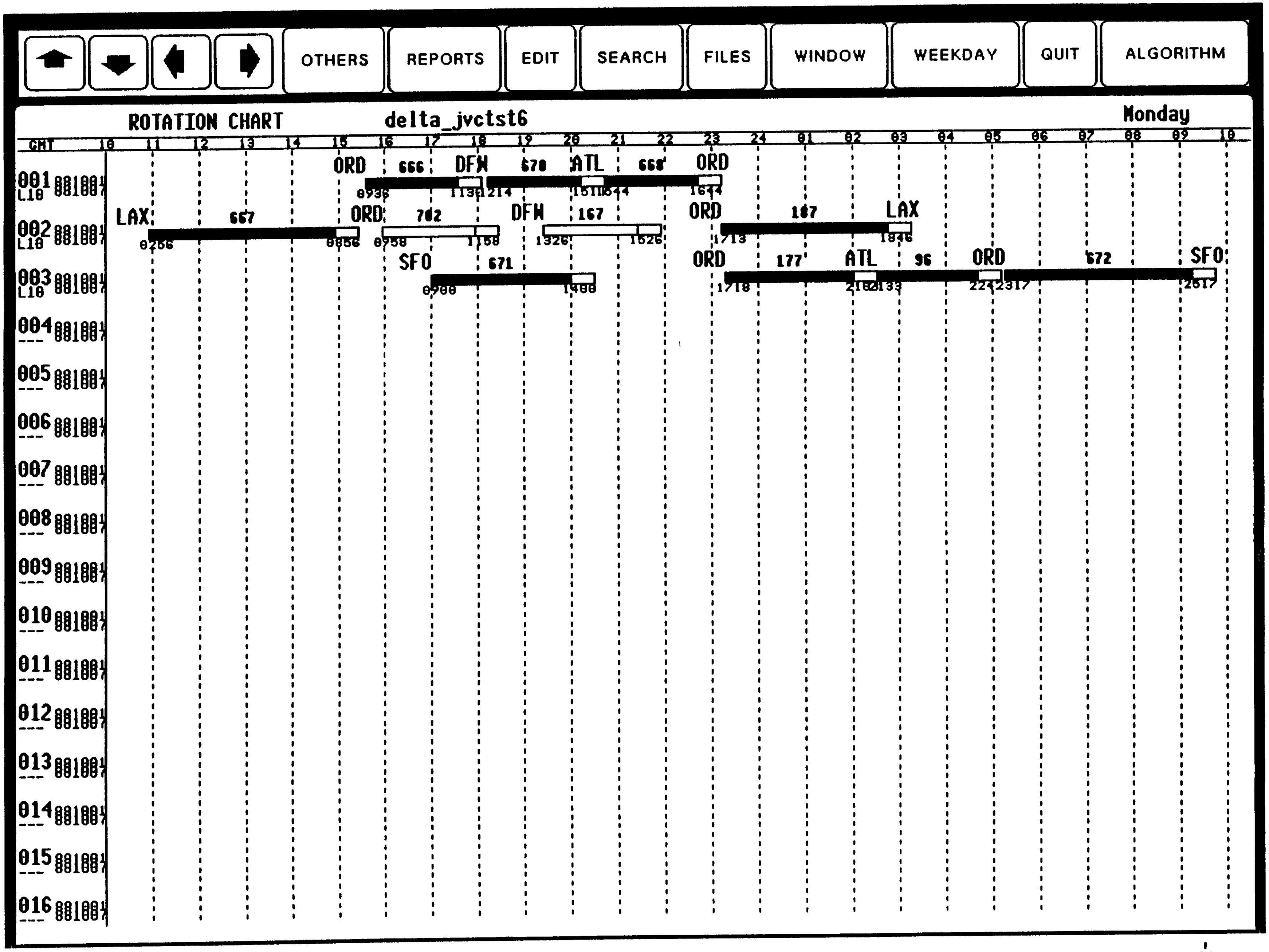
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VII. SUMMARY - STATE OF THE ART IN COMPUTERIZED SCHEDULING

Conclusions

1. We cannot create analytical models which are adequate to describe mathematically the complete airline scheduling problem.

2. For existing models which promise utility, we generally do not have the correct data inputs, and it is difficult to conceive of creating the necessary models for passenger behavior in today's competitive markets. The existence of large scale solution techniques is not sufficient to justify their use at present.

3. We can provide quick, accurate answers to many 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.

4. It is attractive to consider a single, integrated system to be used by various airline personnel as the scheduling process moves from initial planning to final execution.

5. People will remain an important part of the airline scheduling process. They are responsible for generating good schedules, and need "decision support" in their activities. There never will be a "push - button" scheduling system.

6. The desired approach is an incremental introduction of computerized assistance via graphic workstations. The strategy should be to create evolutionary stages:

   Stage 1 - Introduce the Scheduling Workstations
   Stage 2 - Introduce Automated Decision Support
   Stage 3 - Extend to real time Execution Rescheduling

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

7. The scheduling process is not permanent
   - as time goes by, the problems change (perhaps temporarily), and the markets evolve, and there will be emphasis on different aspects. It will not be possible to create a completely automated decision maker which keeps up with changes.

8. As these tools are developed, they have their impact on the Scheduling Process
   - it will change in its flow of information, the sequence of processing will change, and eventually the airline's organizational structures will change. The introduction of computer automation must be adaptive to allow these changes to occur.

9. 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.