European Network of Excellence in AI Planning

Managing Schedule Evolution
Through Minimal Schedule Perturbation
An Airlines Perspective

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parc technologies

Overview

- Background: Parc Technologies & IC-Parc
- Motivation
- Schedule Evolution in Airlines
- Parc Retimer
  - Model
  - Evolution Criterion
  - Algorithm
- Results

Background: PT & IC-Parc

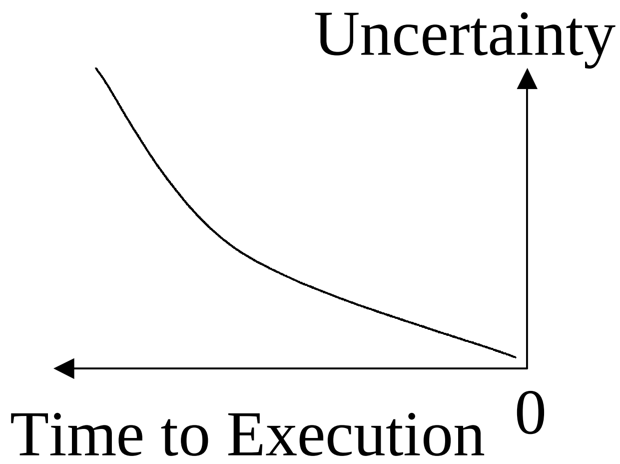
- Goal:

  To research, develop & deliver tools for strategic planning & resource control

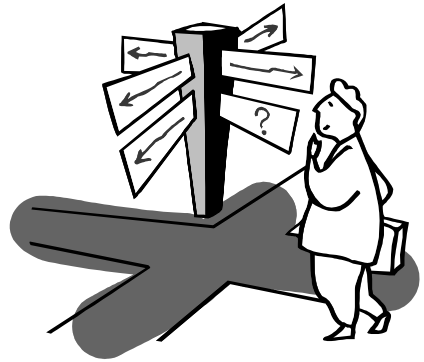
- Research Arm (Imperial College) : ic·parc
  - Problem Research
  - The ECLiPSe Platform
- Commercial Arm : parc technologies
  - Sectors
    - Logistics • Airlines • Networking
  - Ownership
    - Venture Capital : 3i & other
    - Imperial College
    - IC-Parc & Parc Technologies Staff

Motivation: (I) Problem Uncertainty

- Schedule Uncertainty
  - Uncertain Activities
    - Variable demand for activities
      - E.g. Passenger demand in transport
  - Uncertain Resources
    - Variable supply of resource
      - E.g. Breakdowns of machines
  - Uncertain Constraints
    - Changing time factors
      - Deadlines
      - Delays



Motivation: (II) Problem Refinement

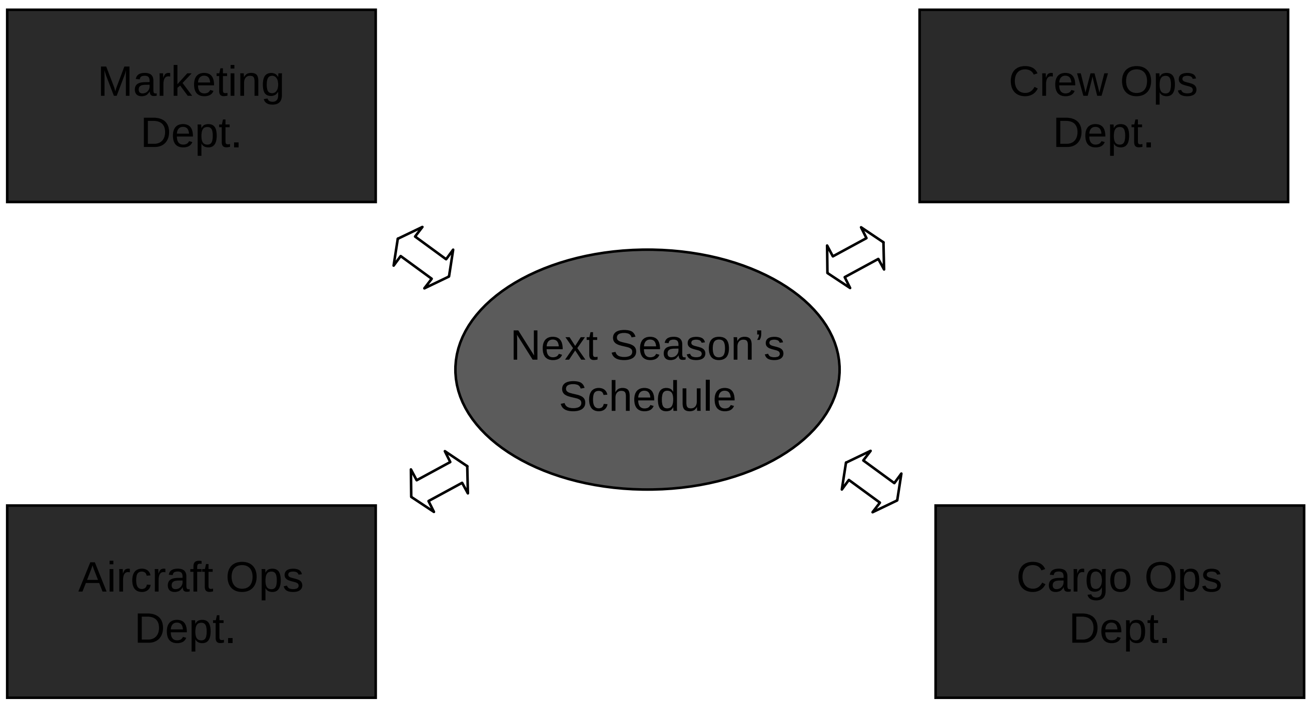


- Refining the Problem Definition
- WHAT-IF Analysis
  - IF we add/remove activities, WHAT is the impact on the schedule?
  - IF we add/remove resources, WHAT is the impact on the schedule?
  - IF we shorten/lengthen activities/setup-times/etc., WHAT is the impact on the schedule?
  - ….

Motivation - The Business Problem

- Problem Uncertainty + Problem Refinement = Changing Problem
- OBJECTIVE: Evolve Schedule To
  - SATISFY Changed Constraints
  - MINIMISE Perturbation
    - Avoid costs of plan changes
    - Avoid organizational confusion
  - OBSERVE Optimization Criteria
    - Maximise revenue
    - Minimise makespan
    - …

Schedule Evolution in Airlines



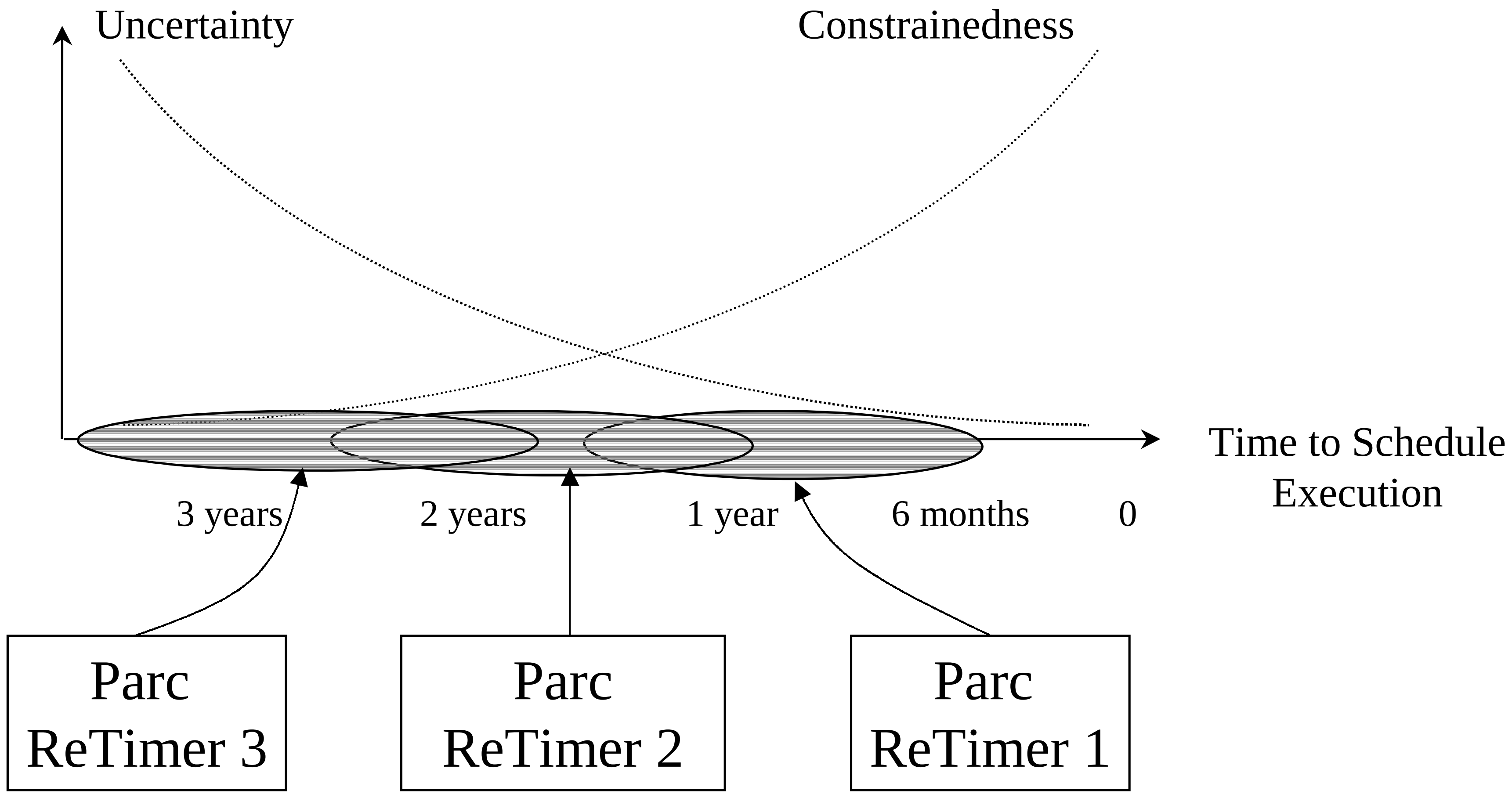
Parc ReTimer Suite

- IC-Parc
  - 3 Years Research into

    Dynamic Scheduling for AIRLINES
- Parc Technologies
  - Productization of the “Parc ReTimer” Suite:

    A Suite of Schedule Evolution Tools for AIRLINES

Parc ReTimer Suite



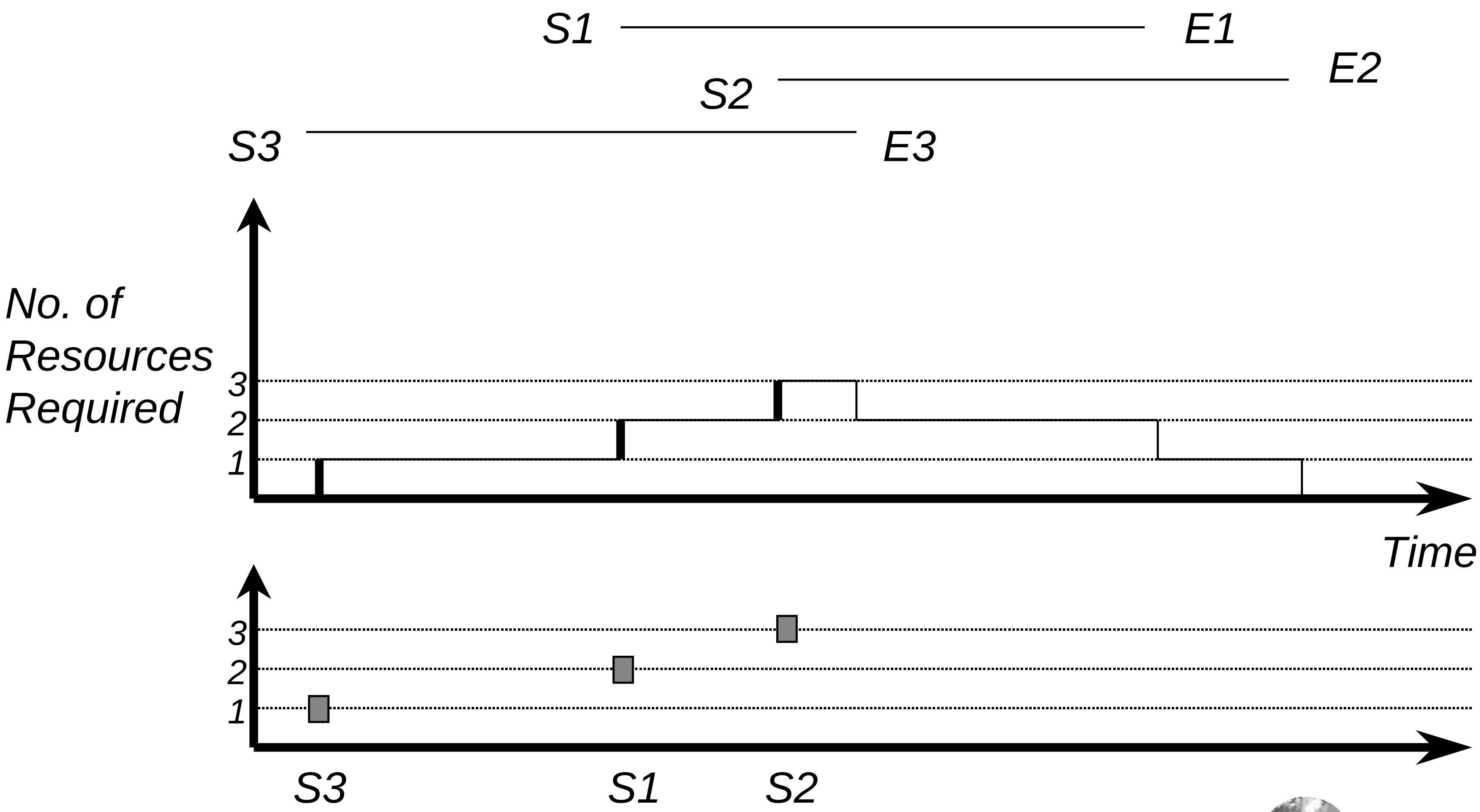
Parc ReTimer 1

- Objectives
  - Retime scheduled *flights*
  - Observing *constraints*
  - Minimising *changes* to existing schedule
- Business Applications
  1. Aircraft Utilisation – fewer aircraft
  2. Slots – fewer expensive “slots”
  3. Punctuality – greater “buffer times”
- Status
  - Delivered to first airline
  - Saved a 767 in first month

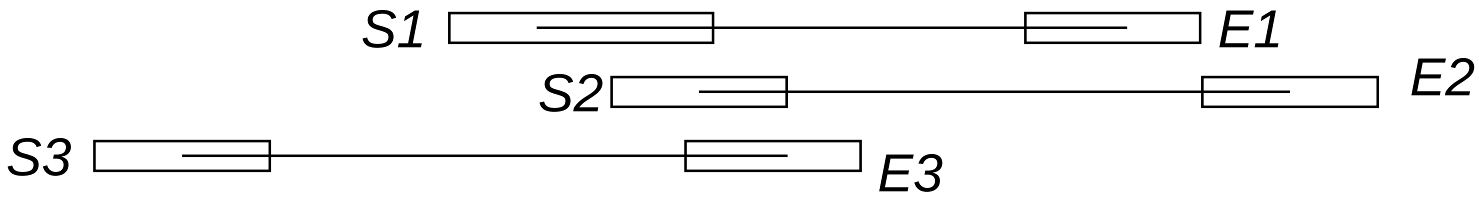
Parc ReTimer 1 for Aircraft Utilisation

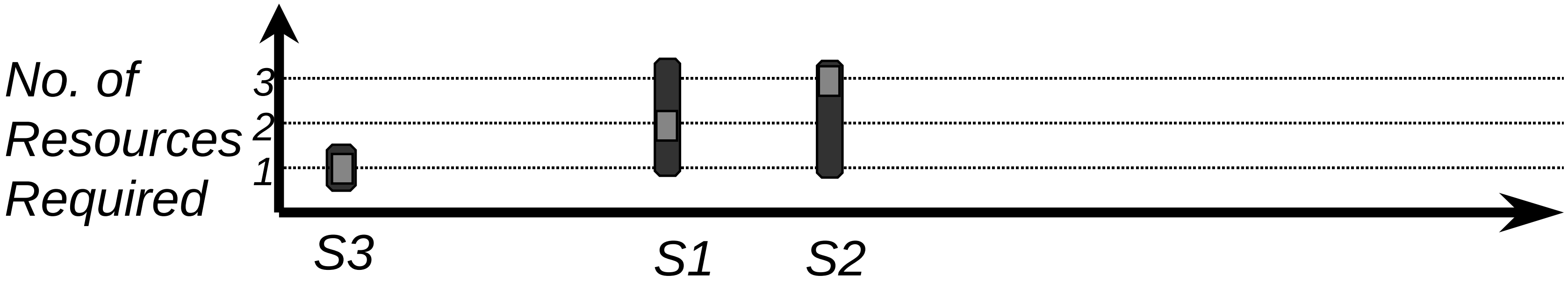
- Inputs
  - an <u>existing schedule</u>
  - description of <u>tolerable changes</u> to the schedule
  - <u>constraints</u>
    - runway <u>slots</u>
    - curfews
    - daily and shuttle flights (a fixed time apart)
    - ...
- Output
  - A <u>new schedule</u> that
    - needs fewer aircraft
    - minimizes changes
    - satisfies constraints

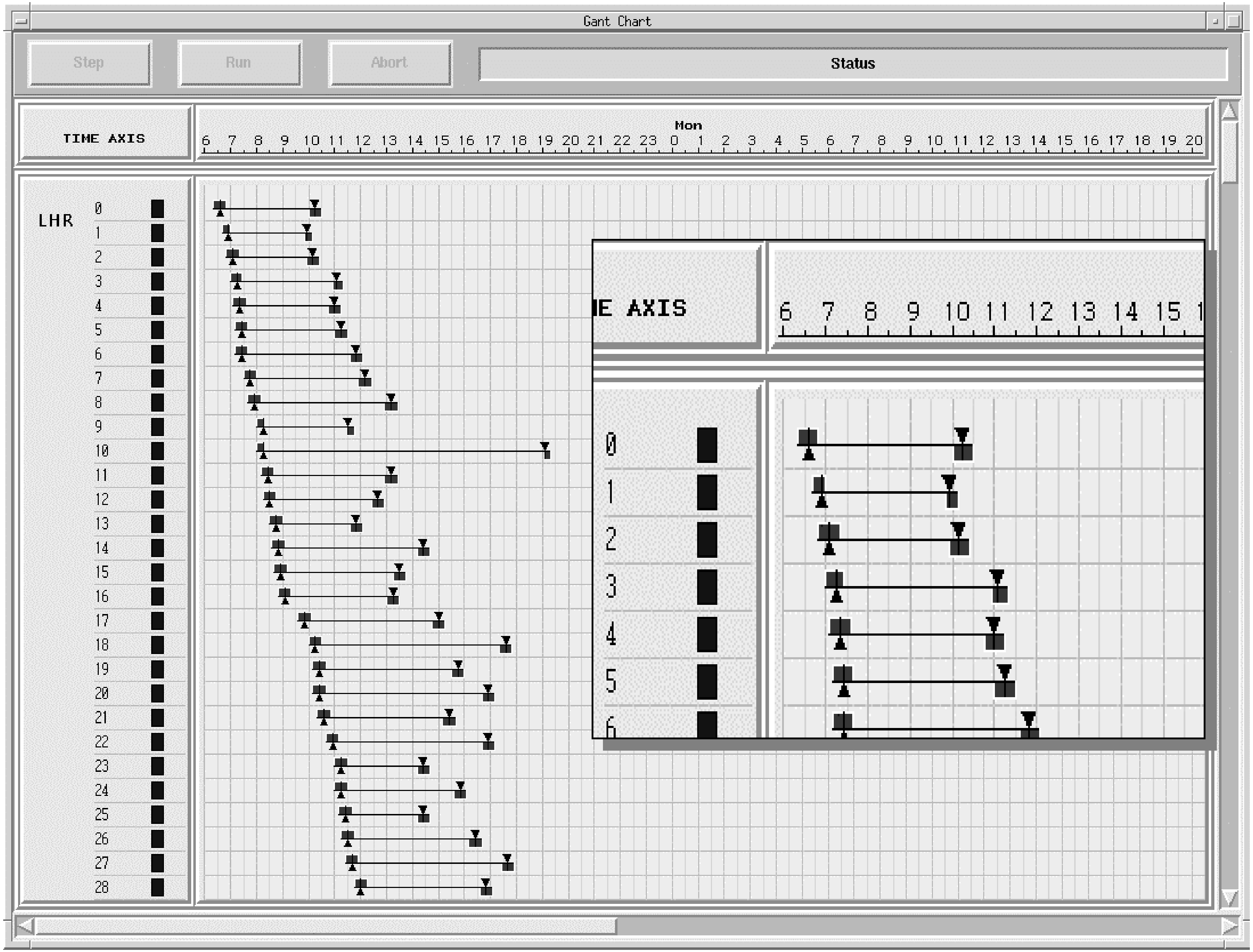
Aircraft Utilisation ~ Fixed Times



Aircraft Utilisation ~ Variable Times



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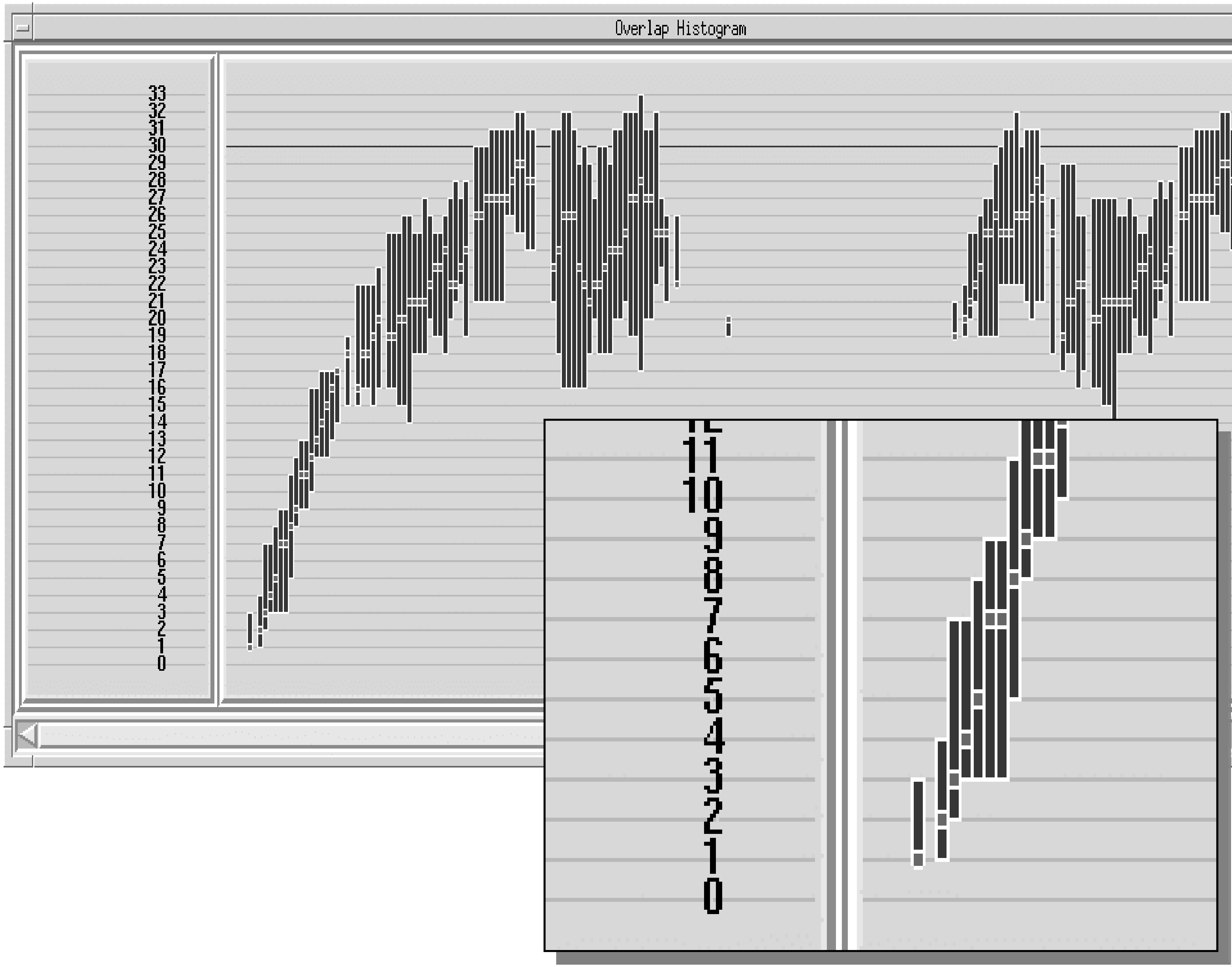
Overlap Histogram
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Slot View

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Monday	{0}0 {0}0	{0}0 {0}0	{0}0 {0}0	{0}0 {0}0	{0}0 {0}0	{0}0 {0}0	{0}0 {0}0	{0..6}4 {0}0	{0..8}2 {0}0	{0..6}6 {0}0	{0..6}1 {0..1}1	{0..3}1 {0..2}0	{0..3}1 {0..4}3	{0..6}4 {0..6}3	{0..7}2 {0..4}2	{0..5}4 {0..6}1	{0..3}1 {0..7}4	{0..4}3 {0..3}2	{0..7}1 {0..4}3	{0..5}4 {0..9}3	{0..2}2 {0..6}4	{0..1}0 {0..1}0	{0..1}1 {0..1}1	{0..1}0 {0}0
Tuesday	{0}0 {0}0	{0}0 {0}0	{0}0 {0}0	{0}0 {0}0	{0}0 {0}0	{0}0 {0}0	{0}0 {0..1}0	{0..6}4 {0..4}2	{0..8}2 {0..5}3	{0..6}6 {0..4}2	{0..6}1 {0..4}3	{0..3}1 {0..4}1	{0..3}1 {0..5}3	{0..6}4 {0..6}3	{0..7}2 {0..4}2	{0..5}4 {0..6}1	{0..3}1 {0..7}4	{0..4}3 {0..3}2	{0..7}1 {0..4}3	{0..5}4 {0..9}3	{0..2}2 {0..6}4	{0..1}0 {0..1}0	{0..1}1 {0..1}1	{0..1}0 {0}0
Wednesday	{0}0 {0}0	{0}0 {0}0	{0}0 {0}0	{0}0 {0}0	{0}0 {0}0	{0}0 {0}0	{0}0 {0..1}0	{0..5}3 {0..4}2	{0..7}2 {0..5}3	{0..6}6 {0..4}2	{0..6}1 {0..4}3	{0..3}1 {0..4}1	{0..3}1 {0..4}2	{0..5}4 {0..5}3	{0..6}1 {0..4}2	{0..5}4 {0..6}1	{0..3}1 {0..7}4	{0..4}3 {0..3}2	{0..7}1 {0..4}3	{0..5}4 {0..8}3	{0..2}2 {0..5}3	{0..1}0 {0..1}0	{0..1}1 {0..1}1	{0..1}0 {0}0
Thursday	{0}0 {0}0	{0}0 {0}0	{0}0 {0}0	{0}0 {0}0	{0}0 {0}0	{0}0 {0}0	{0}0 {0..1}0	{0..6}4 {0..4}2	{0..8}2 {0..5}3	{0..6}6 {0..4}2	{0..6}1 {0..4}3	{0..3}1 {0..4}1	{0..3}1 {0..5}3	{0..6}4 {0..6}3	{0..7}2 {0..4}2	{0..5}4 {0..6}1	{0..3}1 {0..7}4	{0..4}3 {0..3}2	{0..7}1 {0..4}3	{0..5}4 {0..9}3	{0..2}2 {0..6}4	{0..1}0 {0..1}0	{0..1}1 {0..1}1	{0..1}0 {0}0
Friday	{0}0 {0}0	{0}0 {0}0	{0}0 {0}0	{0}0 {0}0	{0}0 {0}0	{0}0 {0}0	{0}0 {0..1}0	{0..6}4 {0..4}2	{0..8}2 {0..5}3	{0..6}6 {0..4}2	{0..6}1 {0..4}3	{0..3}1 {0..4}1	{0..3}1 {0..5}3	{0..6}4 {0..6}3	{0..7}2 {0..4}2	{0..5}4 {0..6}1	{0..3}1 {0..7}4	{0..4}3 {0..3}2	{0..7}1 {0..4}3	{0..5}4 {0..9}3	{0..2}2 {0..6}4	{0..1}0 {0..1}0	{0..1}1 {0..1}1	{0..1}0 {0}0
Saturday	{0}0 {0}0	{0}0 {0}0	{0}0 {0}0	{0}0 {0}0	{0}0 {0}0	{0}0 {0}0	{0}0 {0..1}0	{0..5}4 {0..4}2	{0..7}1 {0..5}3	{0..6}6 {0..4}2	{0..6}1 {0..4}3	{0..3}1 {0..4}1	{0..3}1 {0..4}3	{0..5}3 {0..3}1	{0..5}2 {0..3}2	{0..3}2 {0..7}1	{0..2}1 {0..7}4	{0..4}3 {0..2}2	{0..5}2 {0..2}2	{0..2}1 {0..5}1	{0}0 {0..4}2	{0}0 {0..1}1	{0..1}1 {0}0	{0..1}0 {0}0
Sunday	{0}0 {0}0	{0}0 {0}0	{0}0 {0}0	{0}0 {0}0	{0}0 {0}0	{0}0 {0}0	{0}0 {0..1}0	{0..5}3 {0..2}2	{0..7}2 {0..4}1	{0..6}6 {0..5}3	{0..6}1 {0..3}2	{0..3}1 {0..3}1	{0..3}1 {0..4}3	{0..6}4 {0..4}2	{0..6}2 {0..4}2	{0..3}2 {0..7}1	{0..2}1 {0..7}4	{0..1}1 {0..2}2	{0}0 {0..3}2	{0}0 {0..8}3	{0}0 {0..6}3	{0}0 {0..2}1	{0}0 {0..1}1	{0}0 {0}0

The Research Problem

- A Minimal Perturbation Problem
  - A CSP — (V,D,C)
  - A solution to the CSP — α
  - Sets of constraint additions & deletions — C_{add} C_{del}
  - A perturbation function — $\delta(\alpha, \beta)$
- An optimal solution β is such that
  - the new CSP $(V, D, (C \setminus C_{del}) \cup C_{add})$ is satisfied by β
  - $\delta(\alpha, \beta)$ is minimal

Solution Strategy

- Solution Strategy
  - a <u>model</u> that can capture many scheduling problems
  - a suitable <u>evolution criterion</u>
  - a generic scheduling <u>algorithm</u> for optimising this criterion

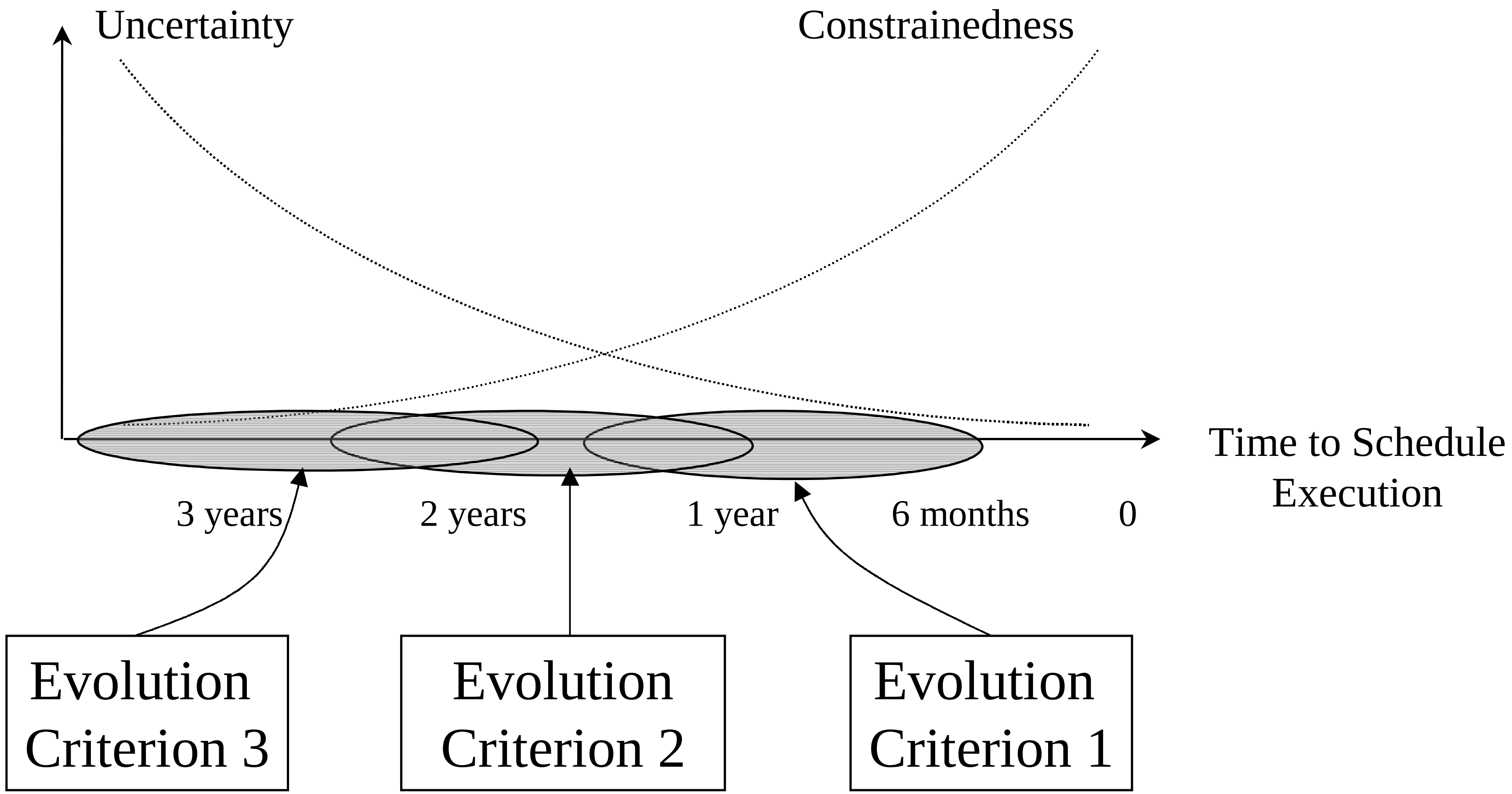
The Model

- Resource Feasibility Problem
  - [El-Kholy & Richards,ECAI96]
- Simple RFP
  - A set *A* of activities and a resource bound *B*
  - for each activity a_i, temporal start and end vars s_i,e_j
  - a set *L* of temporal linear equality and inequality constraints, e.g.:

$$e_1 \leq s_2 + 20$$

- A solution
  - satisfies the constraints in *L* and the resource bound *B*

Evolution Criteria for Parc ReTimers



Evolution Criterion for Parc ReTimer 1

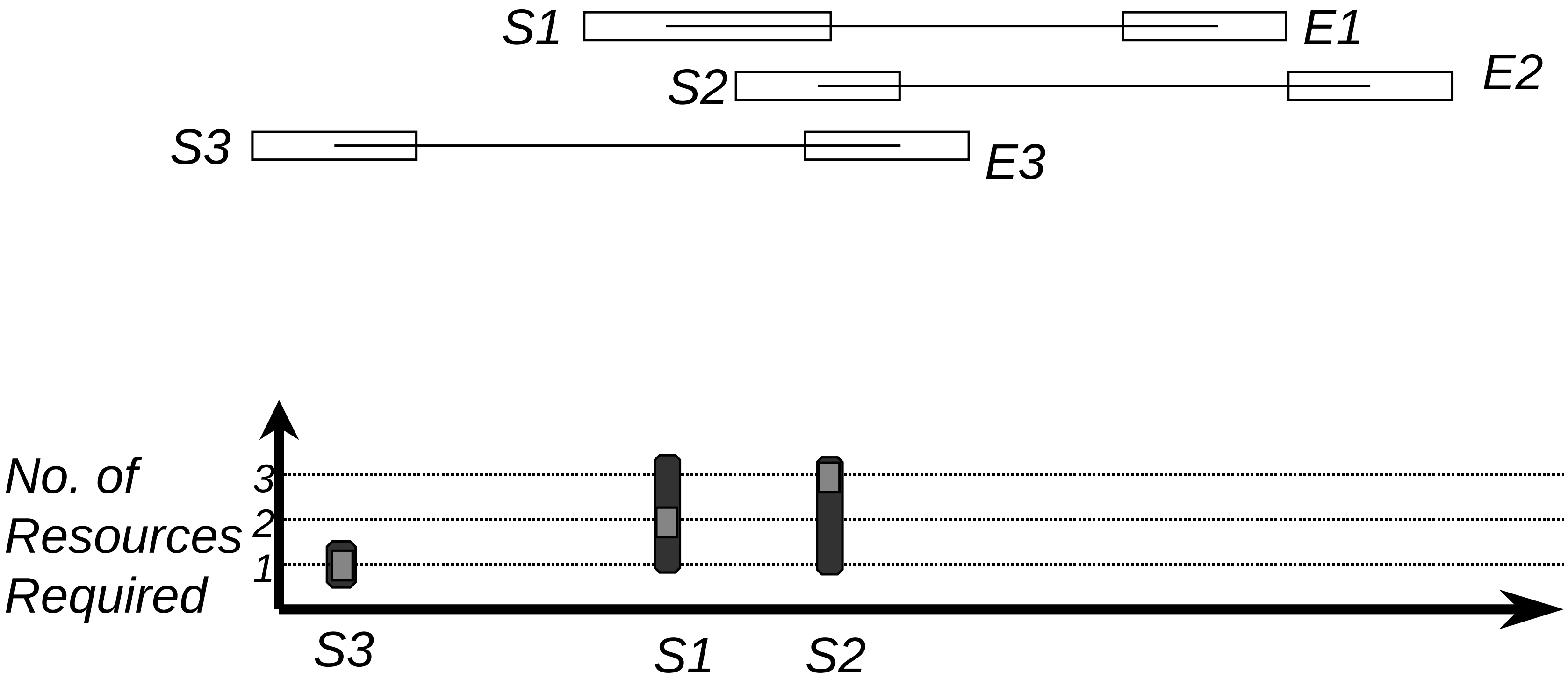
- Flights already positioned for good Revenue

$\Rightarrow$ Minimal Perturbation is only component of evolution criterion

$$\text{optimisation function}(\delta) = \sum |u - u_0|$$

$$\text{where } u, v \text{ are temporal variables}$$

Repeat: Variable Times



Algorithms for Flight Retiming

- Structure
  - Linear optimization function
  - Linear temporal constraints
  - Disjunctive scheduling constraints
- Possible solution methods
  - Traditional CSP
    - Strength disjunctive constraints
    - Weakness no global focus on optimization criteria
  - MIP
    - Strength focus on optimization function
    - Weakness not well suited to satisfaction of disjunctive
    - constraints

Applied Algorithm

- Unimodular Probing (the discrete LP case)
  - Discrete problems / disjunctive constraints / linear optimization fn.
  - inc. a broad range of dynamic scheduling problems
  - Most suited to minimal perturbation
- Probe Backtracking (the general case)
  - Decompose problem into tractable & intractable parts
  - Generate tractable sub-problem probes
    - good assignments with high level of consistency
    - and/or optimization quality
  - Use probe repair to dynamically focus search

Hybridization

CSP
hard set

$$\sum Bool_{ij} \leq B$$

$$Bool_{ij} \text{ iff } s_j \leq s_i \wedge s_i \leq e_j$$

$$u \leq v \pm \mathrm{c}$$

$$\text{optimisation function } (\delta) = \sum |u - u_0|$$

AC-B
lookahead resource bound checking
Heuristics
Repair
Decisions

chosen and inferred constraints

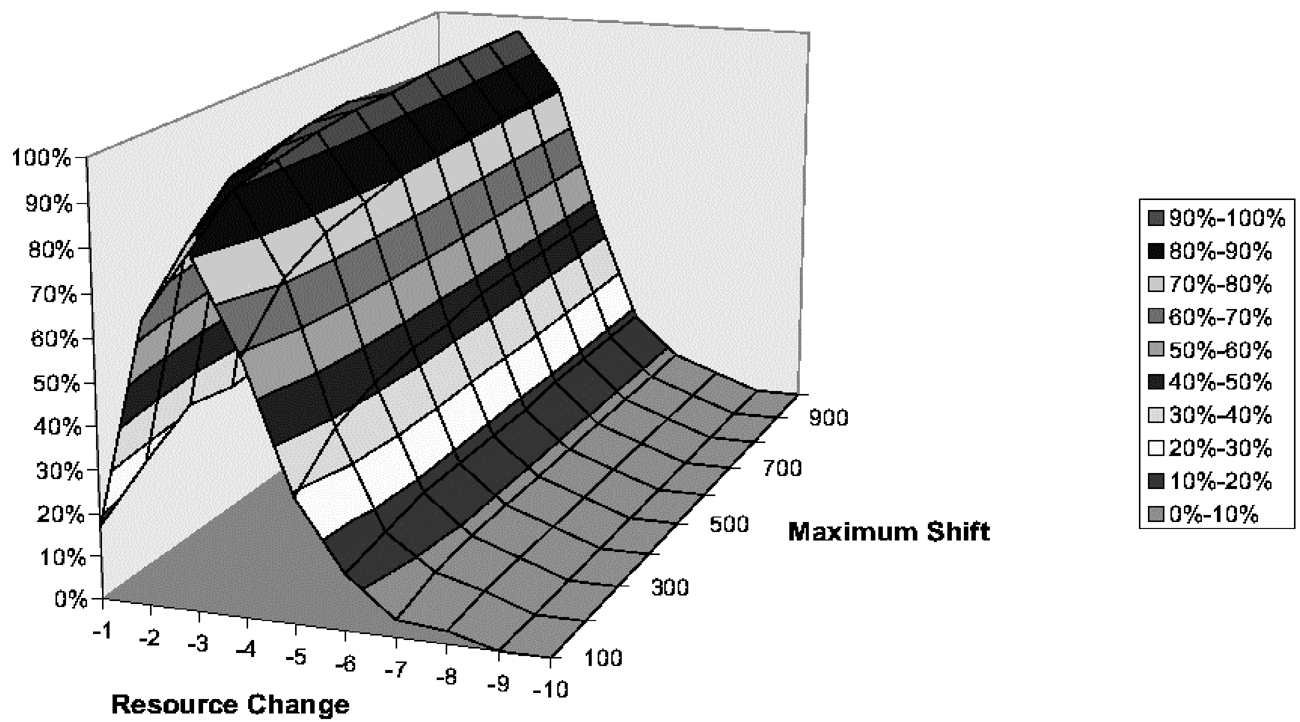
LP
easy set

$$u \leq v \pm \mathrm{c}$$

$$\text{optimisation function } (\delta) = \sum |u - u_0|$$

Global cost propagation
Optimal suggested values

Timeout % - MIP



100%
90%
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70%
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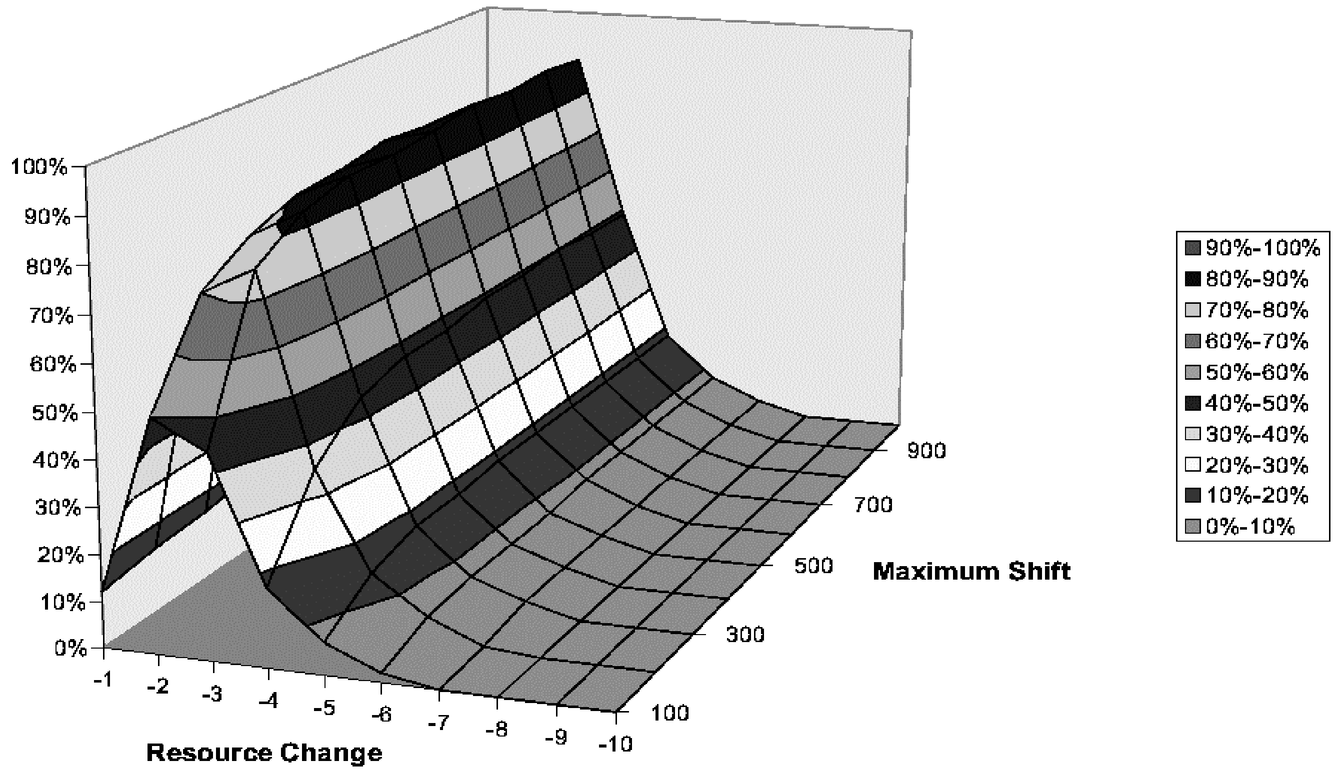
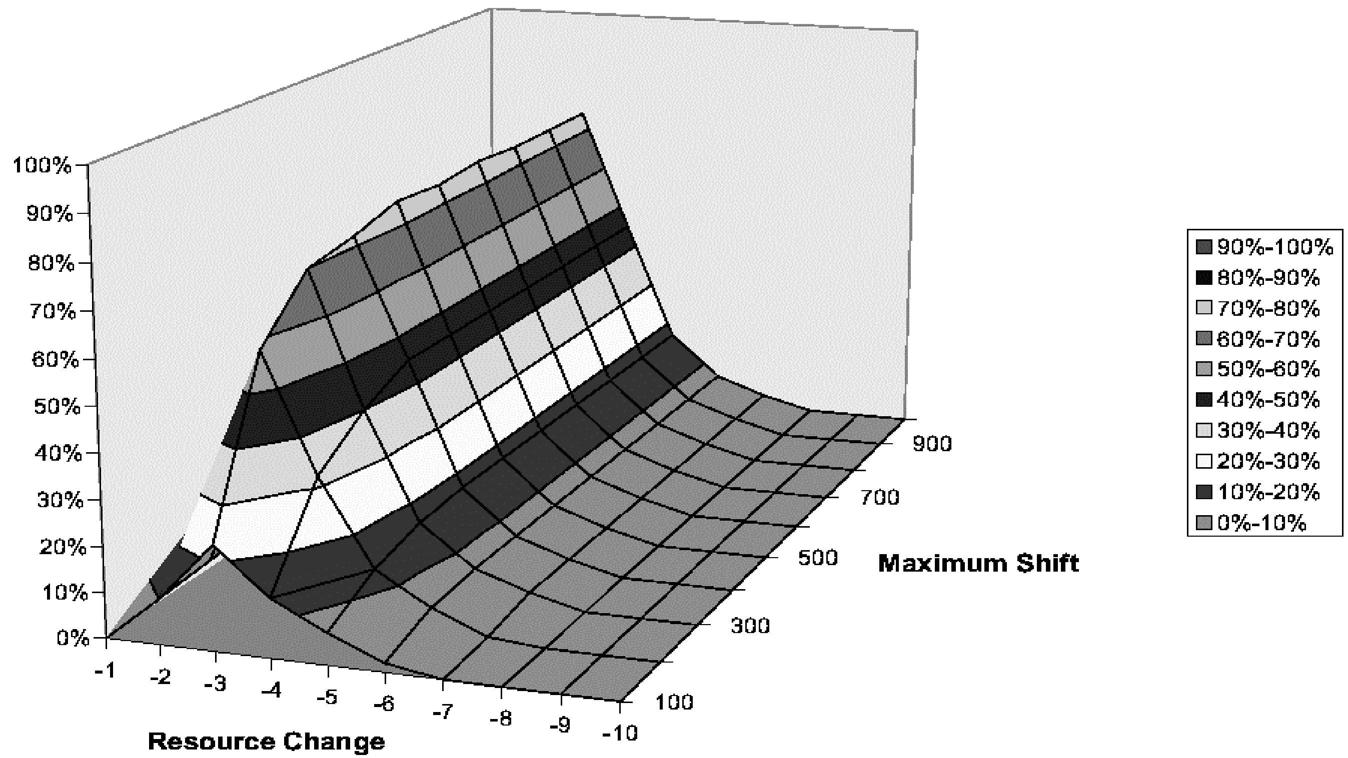
10%
0%
-1 -2 -3 -4 -5 -6 -7 -8 -9 -10
Resource Change
100
300
500
700
900
Maximum Shift
90%-100%
80%-90%
70%-80%
60%-70%
50%-60%
40%-50%
30%-40%
20%-30%
10%-20%
0%-10%

Timeout % - Ordinary CLP(FD)+LP



Timeout % - Unimodular Probing



Commercial Result

- Aircraft Savings
  - up to 1000 activities, total of over 70 resources, 6 types
  - Saved Boeing 767 prior to installation
- Performance systematically better than other methods
  - Structured BT search
  - Repair-based BT Search
  - Structured BT search + LP at final stage
  - Repair-based BT Search + LP at final stage
  - MIP Search

Conclusions

- Schedule Evolution
  - Minimal perturbation scheduling is extremely useful for Airlines at Parc Retimer 1 time frame
  - Other time frames, Parc Retimers 2 and 3
  - Other application domains
- Application-Driven vs. Technique-Driven Research
    - Unimodular Probing
    - Probe Backtracking
    - The ECLiPSe Repair library

References

- Publications
  - “Minimal perturbation in dynamic scheduling”, [ECAI-98]
    - Hani El Sakkout, Tom Richards, Mark Wallace
  - “Improving backtrack search: Three case studies of localized dynamic hybridization”, [PhD Thesis 99, Imperial College]
    - Hani El Sakkout
  - “Probe backtrack search for minimal perturbation in dynamic scheduling”, [Constraints Journal, to appear 00/01]
    - Hani El Sakkout, Mark Wallace
- Manuals
  - ECLiPSe User Manual
  - ECLiPSe Repair Library Manual