Managing Schedule Evolution
Through Minimal Schedule Perturbation
An Airlines Perspective

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Overview

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

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

- Research Arm (Imperial College)
  - Problem Research
  - The ECLiPSe Platform

- Commercial Arm
  - 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

Next Season’s Schedule

- Marketing Dept.
- Air Ops Dept.
- Cargo Ops Dept.
- Crew Ops Dept.
• 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
Time to Schedule

Uncertainty

Constrainedness

3 years
2 years
1 year
6 months
0

Parc ReTimer 3
Parc ReTimer 2
Parc ReTimer 1
Objectives

- Served a 767 in first month
- Delivered to first airline

Status

- greater "buffer times"
- fewer expensive "slots"

Business Applications

- Minimizing changes to existing schedule
- Observing constraints
- Retime scheduled fights
- Objective 1

- Aircraft Utilization
  1.
- Slots
  2.
- Punctuality
  3.
- Business Applications
  •
Parc ReTimer 1 for Aircraft Utilisation

• Inputs
  – an existing schedule
  – description of tolerable changes to the schedule
  – constraints
    • runway slots
    • curfews
    • daily and shuttle flights (a fixed time apart)
    • ...

• Output
  – A new schedule that
    • needs fewer aircraft
    • minimizes changes
    • satisfies constraints
Aircraft Utilisation ~ Fixed Times

No. of Resources Required

Time

S1 ——— E1
S2 ——— E2
S3 ——— E3

S3
S1
S2

3
2
1

3
2
1
Aircraft Utilisation ~ Variable Times

![Diagram showing aircraft utilisation with variable times]

- **No. of Resources Required**
  - S3: 1
  - S1: 2
  - S2: 3

**Time Intervals**
- S1
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- E1
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- E3
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The Research Problem

• A Minimal Perturbation Problem
  – A CSP $(V,D,C)$
  – A solution to the CSP $\alpha$
  – Sets of constraint additions & deletions $C_{\text{add}} \ C_{\text{del}}$
  – A perturbation function $\delta(\alpha, \beta)$

• An optimal solution $\beta$ is such that
  – the new CSP $(V, D, (C \setminus C_{\text{del}}) \cup C_{\text{add}})$ is satisfied by $\beta$
  – $\delta(\alpha, \beta)$ is minimal
Solution Strategy

- a model that can capture many scheduling problems
- a suitable evolution criterion
- a generic scheduling algorithm 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

Uncertainty

Constrainedness

3 years  2 years  1 year  6 months  0

Time to Schedule Execution

Evolution Criterion 3
Evolution Criterion 2
Evolution Criterion 1

Uncertainty

Constrainedness

3 years  2 years  1 year  6 months  0

Time to Schedule Execution

Evolution Criterion 3
Evolution Criterion 2
Evolution Criterion 1
Evolution Criterion for Parc ReTimer 1

• Flights already positioned for good Revenue

⇒ Minimal Perturbation is only component of evolution criterion

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

where \( u, v \) are temporal variables
Repeat: Variable Times

No. of Resources Required

S1 S2 S3
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
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

\[
\sum_{ij} \text{Bool}_{ij} \leq B
\]

\[
\text{Bool}_{ij} \text{ iff } s_j \leq s_i \land s_i \leq e_j
\]

\[
u \leq v \pm c
\]

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

CSP hard set

AC-B lookahead resource bound checking

Heuristics

Repair

Decisions

Global cost propagation

Optimal suggested values

\[
\sum_{ij} \text{Bool}_{ij} \leq B
\]

\[
\text{Bool}_{ij} \text{ iff } s_j \leq s_i \land s_i \leq e_j
\]

\[
u \leq v \pm c
\]

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

LP easy set

chosen and inferred constraints
Timeout % - Unimodular Probing
• 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
• 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