Freie Universität Berlin

DEPARTMENT OF INFORMATION SYSTEMS

SCHOOL OF BUSINESS & ECONOMICS

Robust Efficiency of Airline Resource Schedules

Lucian Ionescu

DoWoNO – Magdeburg 05/30/2013

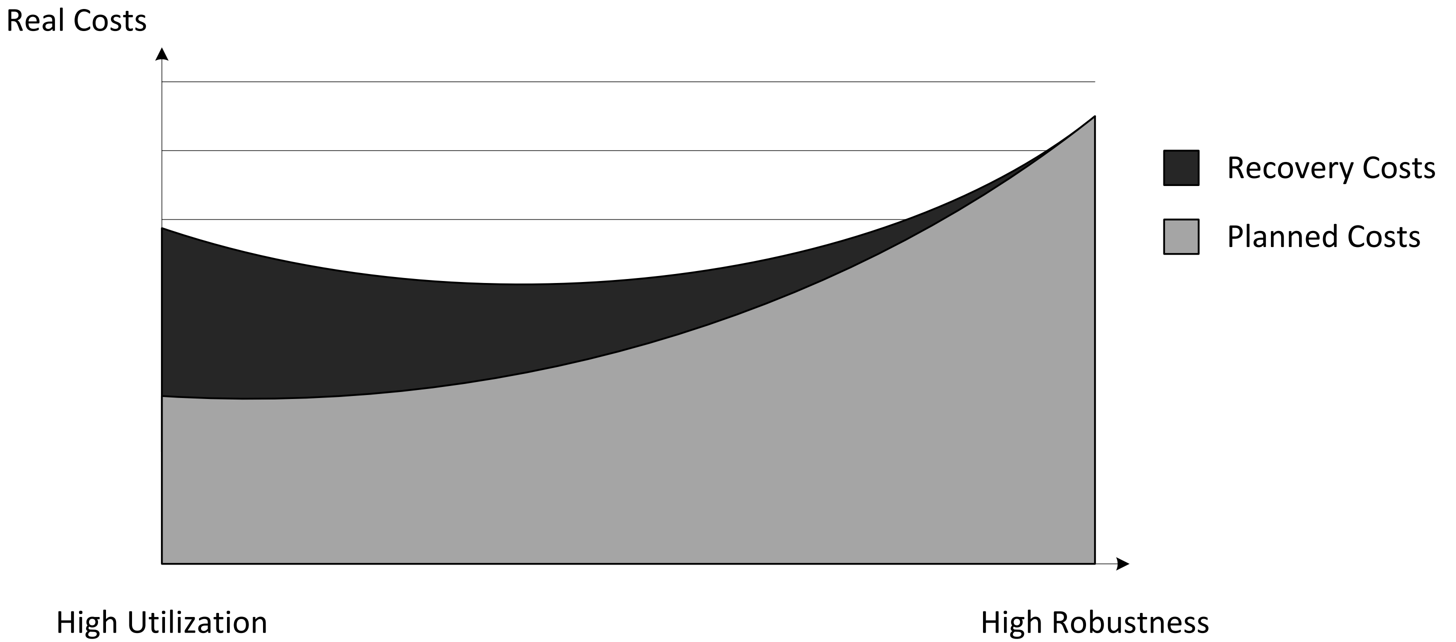
Delays are a considerable Problem for Airlines

1.25 billion Euros
overall costs due to
delays in Europe

81 Euro on average
per minute of delay
in Europe

Cook, D. A. (2011) European airline delay cost reference values. London: University of Westminster.
(Report worked out for the Performance Review Unit, EUROCONTROL, Brussels)

Minimizing the Real Costs of Airline Operations



Practical Goal Conflicts in Regular Daily Operations

Robust Efficiency

Construct schedules which …

Cost-Efficiency

… use resources at high utilization levels.

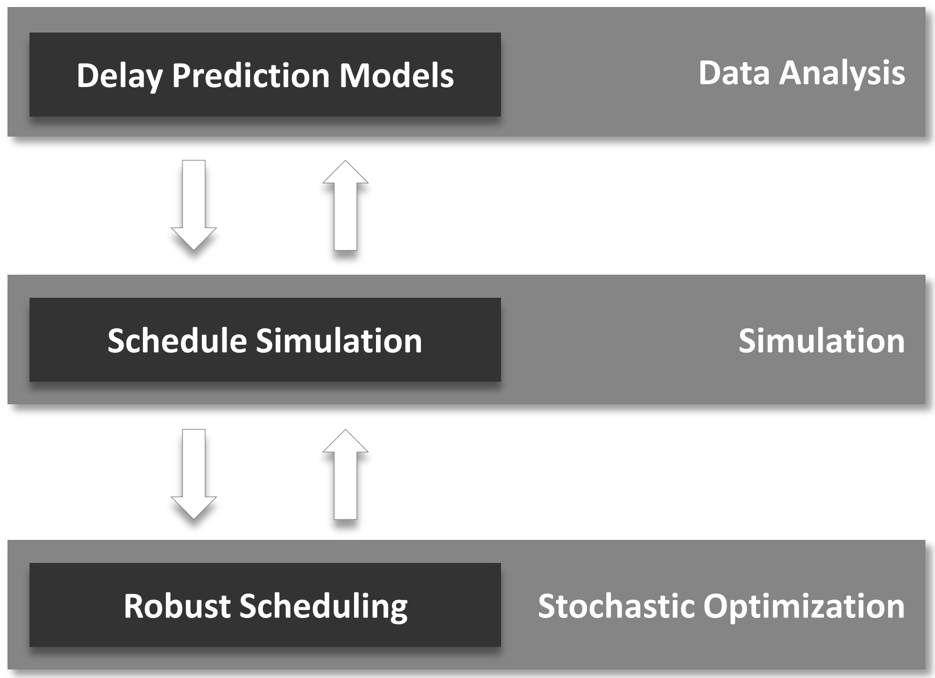
Stability

… absorb disruptions due to changes of environment.

Flexibility

…offer simple possibilities to react to disruptions.

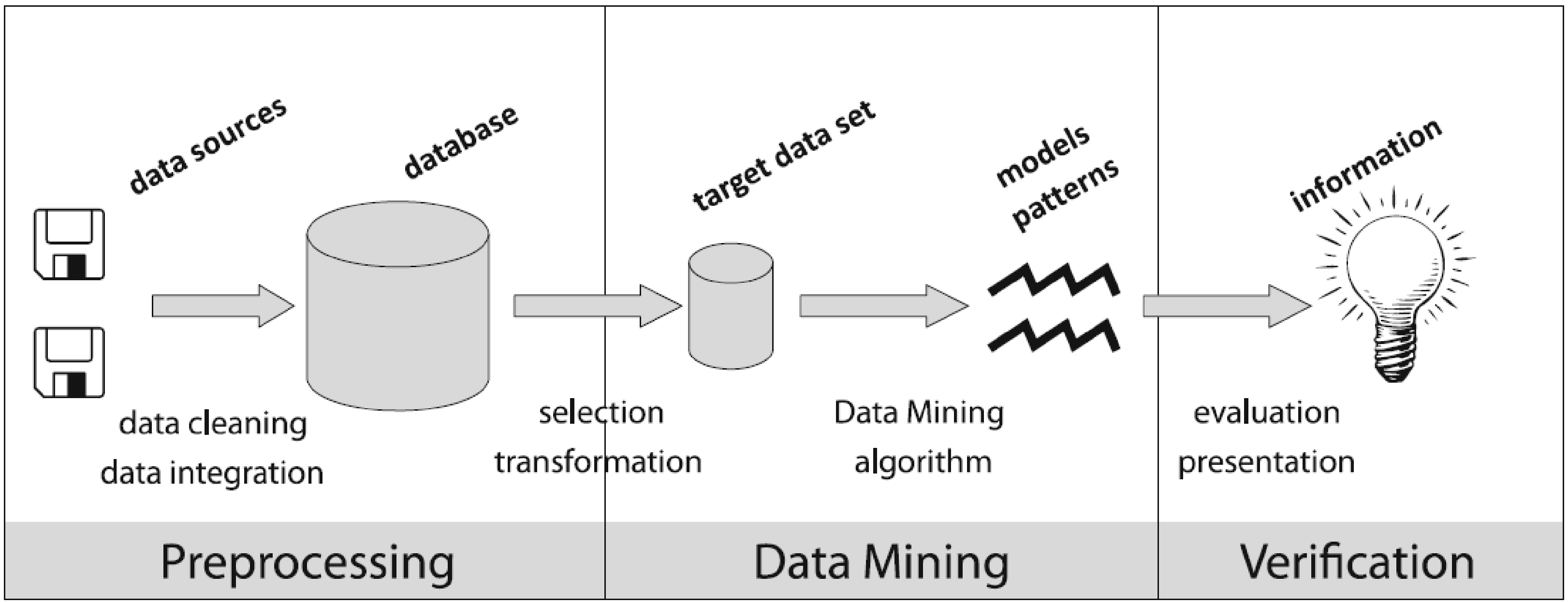
Scope of the Project



Data Analysis

How do we realistically model Delays?

Knowledge Discovery in Databases (KDD)



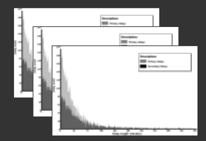
Ehmke, J. F. (2012) Integration of information and optimization models for routing in city logistics. Springer.

Target: A Prediction Model for Flight Departure Delays

Historical Data

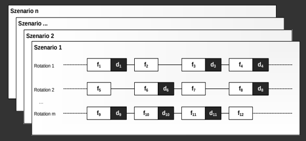
Data Analysis →

Delay Prediction Model



Disruption Generator →

Delay Scenarios

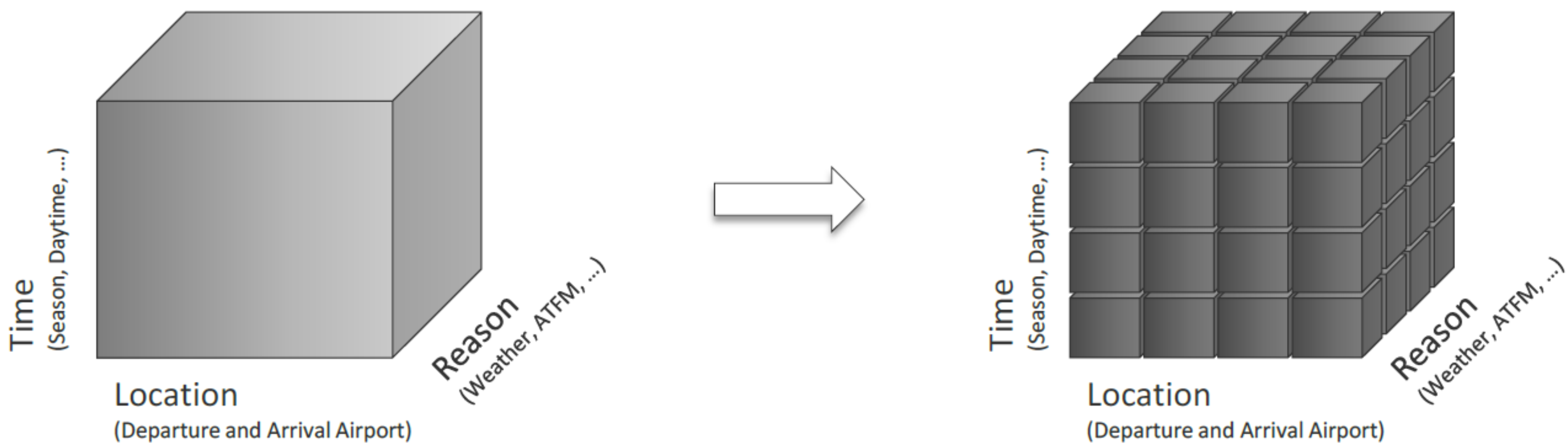


We do not need to know *why*

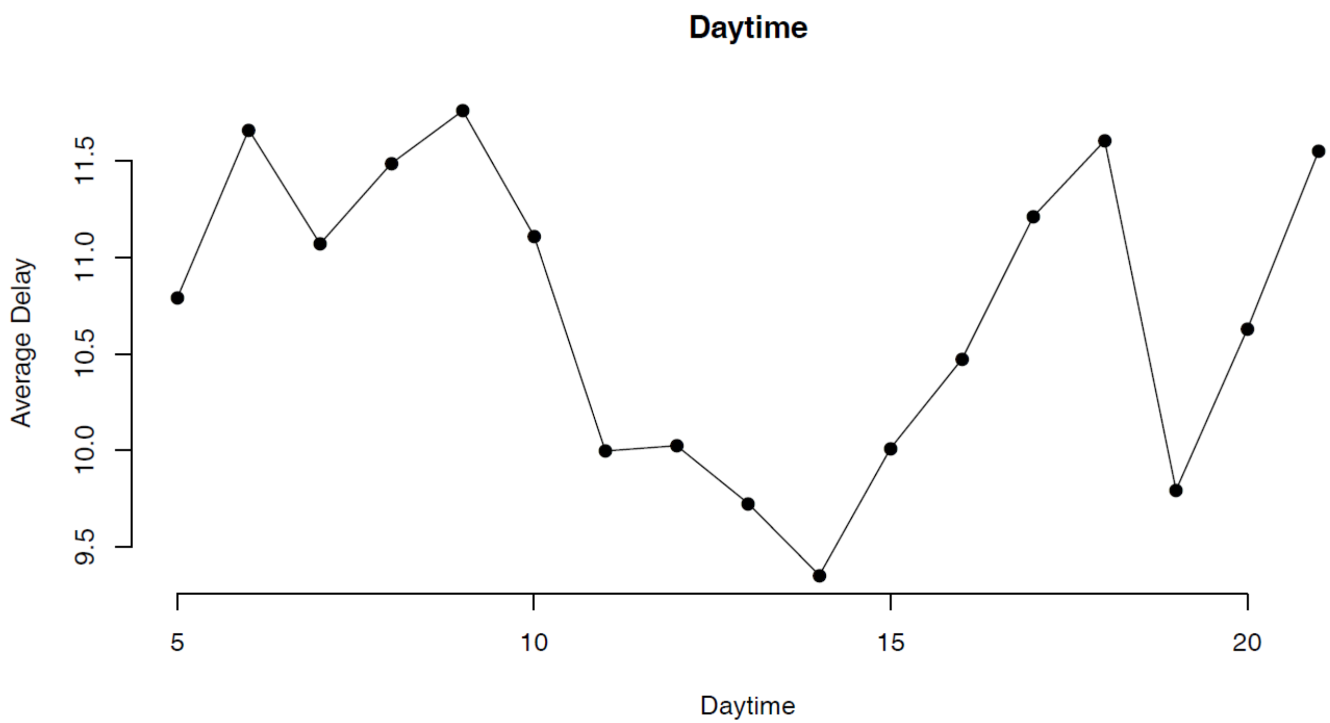
but *where* and *when* delays occur.

Available Data

- 2.2 million real-world flight delay records
- Selected time span is 2003-2007

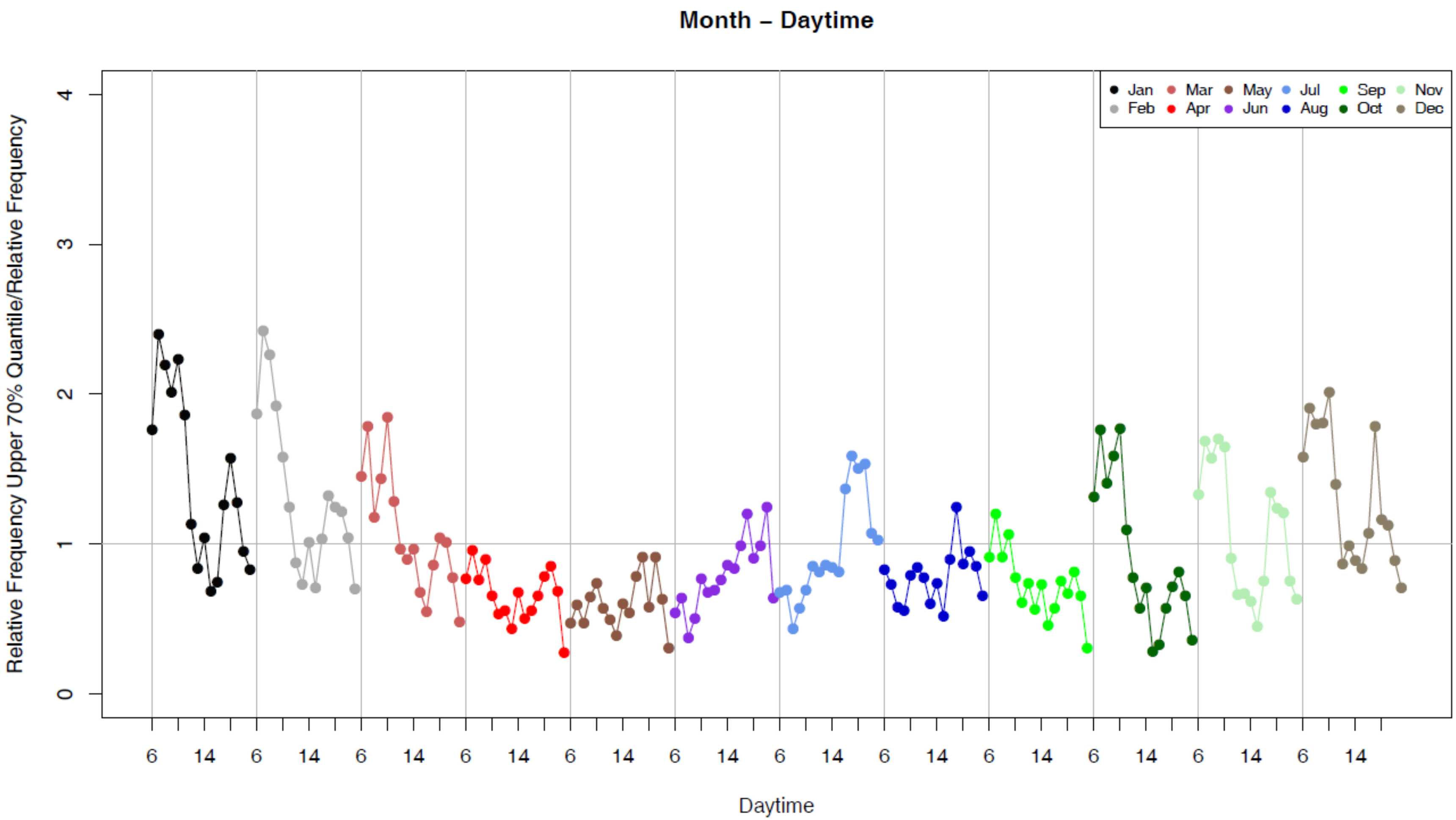


Slicing the Data using the Example of Daytime



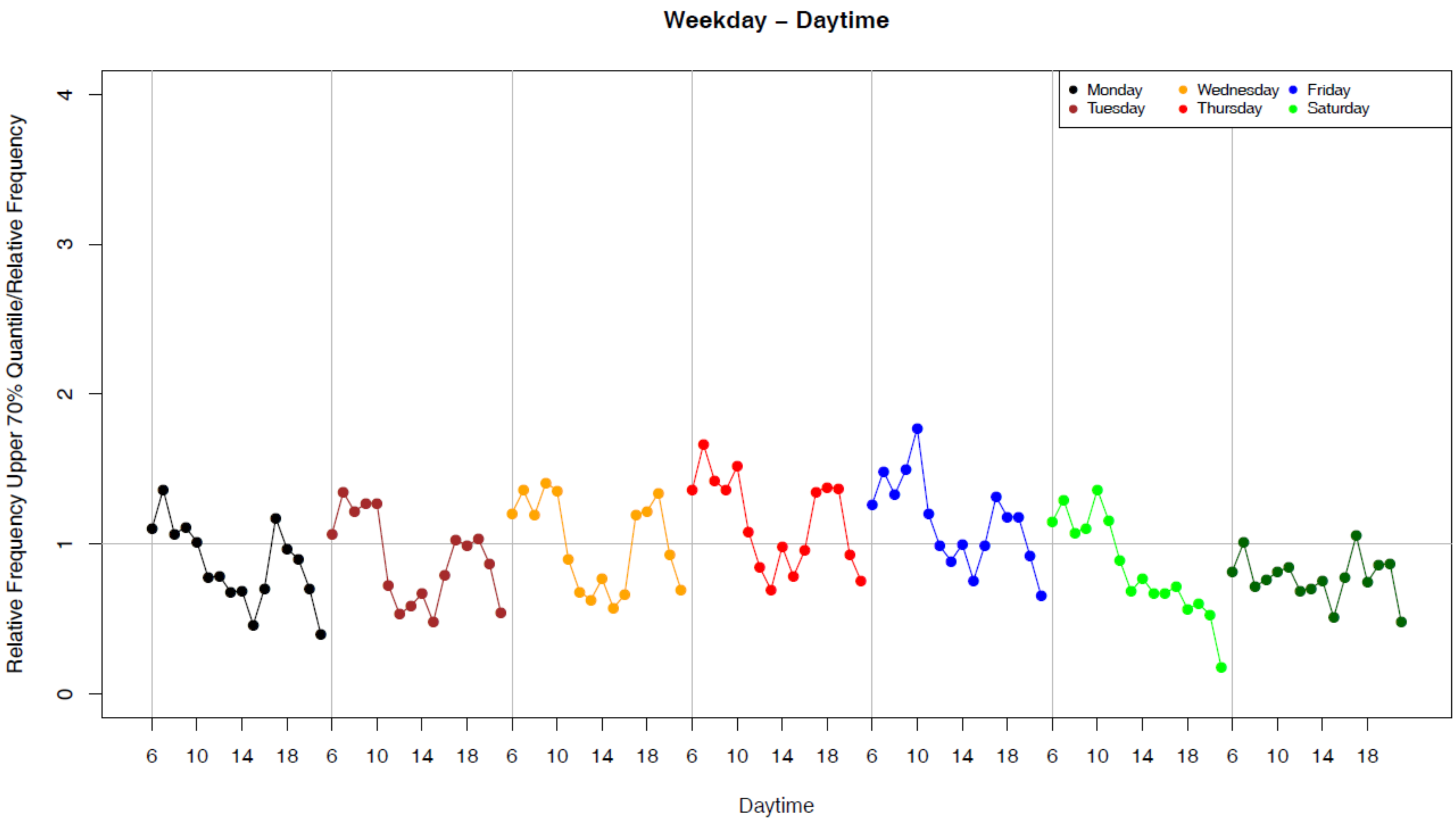
Are these results repeatable when combining the dimensions?

Combining the Dimensions



Average delay per daytime differs by month!

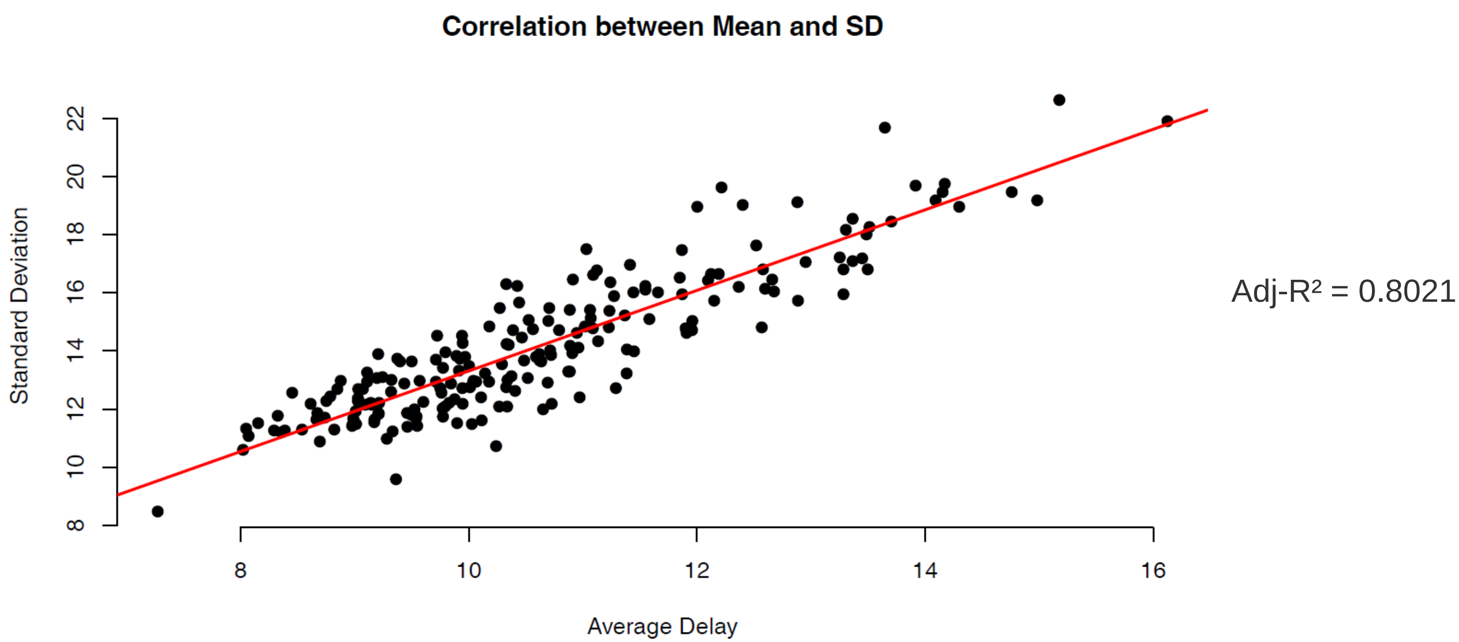
Combining the Dimensions (2)



Average delay per daytime does not differ by workday!

Considering the Moments of the Delay Distributions

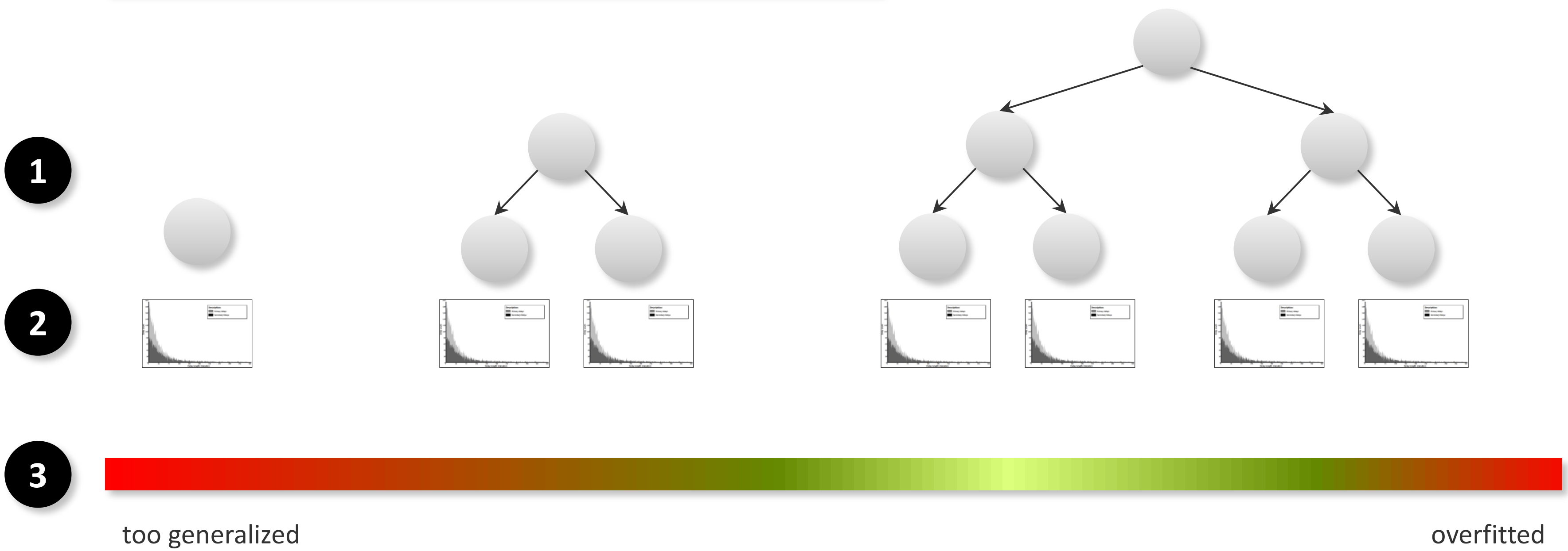
- We have a high correlation between the first three moments (Mean, Standard Deviation, Skewness)



Use the mean value as a location parameter for distributions?

Prediction Models for Delays

1. Build Decision Trees *(Training Set)*
2. Predict unknown Data *(Validation Set)*
3. Goodness-of-Fit can be tested by
   - Akaike Information Criterion (AIC)
   - Kullback-Leibler-Divergence (KLIC)



Simulation

How do we evaluate the Robustness of Schedules?

Evaluating Airline Resource Schedules by Simulation

- How will schedules perform in Operations?
- Regular Operations vs. Irregular Operations

- Simulated Recovery Actions
  - Delay Propagation / Delay Absorption
  - Swaps of Resources
  - Cancellations
  - Reserve Crews
  - Repositioning
  - Rescheduling
- Mutual impacts and interdependencies of Crew Pairings and Aircraft Rotations

Measuring the Delay Absorption Capacity of a Schedule

- How many delays can be absorbed by buffers during simulation?
- Model for propagation over several network layers, e.g. crew and aircraft

$$r_f = \max\{ s_f^A, d_f + t_f \}, \qquad \forall f \epsilon F$$

$$d_f = \max\left\{ s_f^D, \max\begin{Bmatrix} r_{a(f)} + g_{a(f),f}^a \\ r_{c(f)} + g_{c(f),f}^c \end{Bmatrix} \right\} + X_f, \qquad \forall f \epsilon F$$

$$D_f = r_f - s_f^A, \qquad \forall f \epsilon F$$

$$R_f = D_f - X_f, \qquad \forall f \epsilon F$$

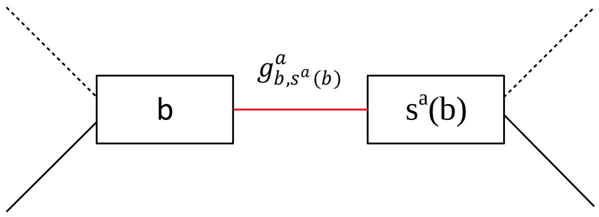
Propagate over aircraft rotations

Propagate over crew pairings

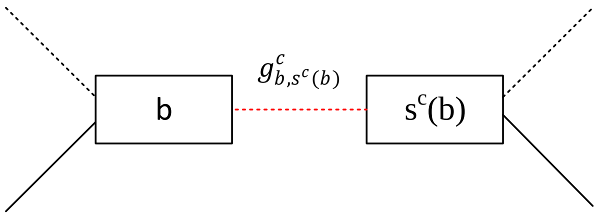
Dück V., Ionescu L., Kliewer N., Suhl L. (2012): Increasing stability of crew and aircraft schedules. Transportation Research C, Vol. 20(1), 47-61.

Simulating rule-based Recovery for Crew and Aircraft

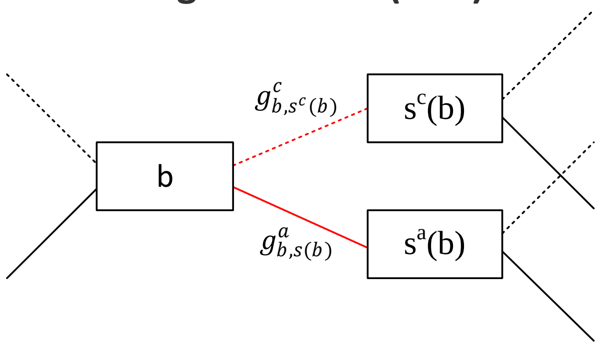
Aircraft Only (AC)



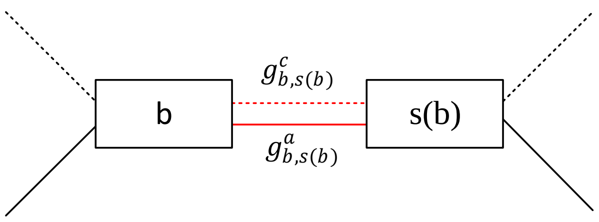
Crew Only (CR)



Crew Changes Aircraft (CCA)

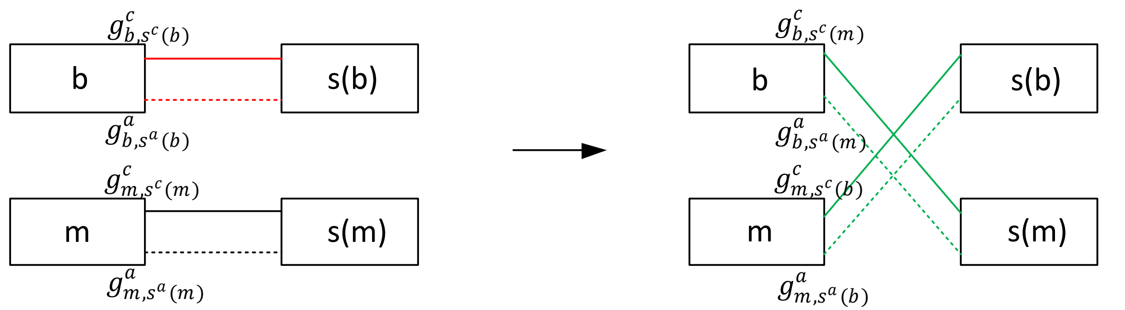


Crew Follows Aircraft (CFA)

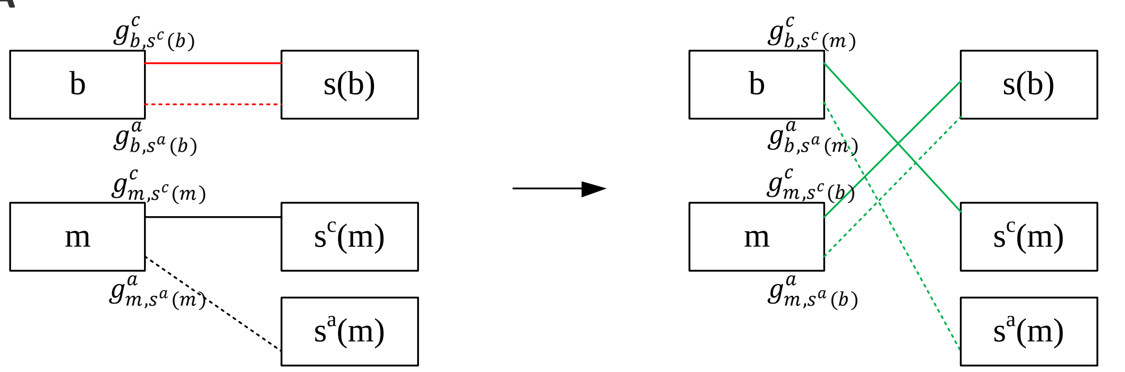


Simulating rule-based Recovery for Crew and Aircraft (2)

CFA-CFA



CFA-CCA



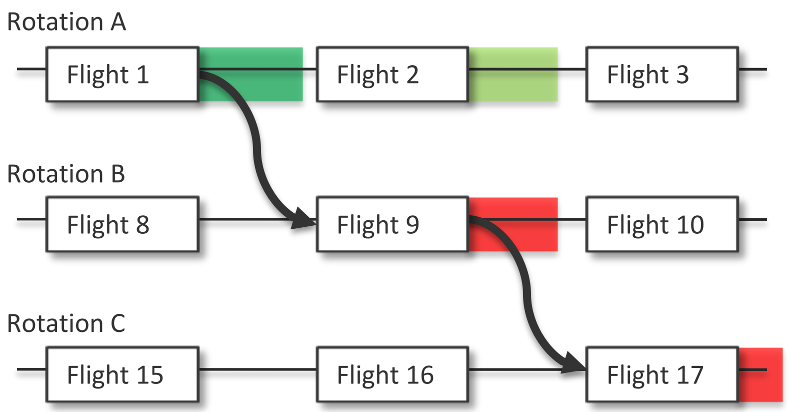
Robust Scheduling

How do we increase the Robustness of Schedules?

Delay Risk Evaluation of Flights

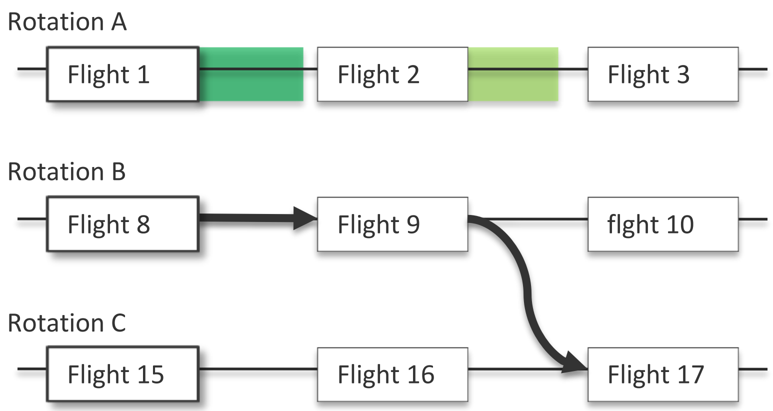
- Risky connections between flights
- Follow-ons of flights may have different contexts

Aircraft Change with History (Flight1, Flight9)



Sequence (1;9) (9;17) propagates a Delay

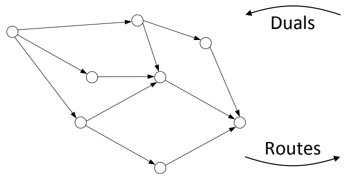
Aircraft-Change without History



Sequence (8;9) (9;17) propagates no Delay

Increasing Stability – Integrated Solution Approach

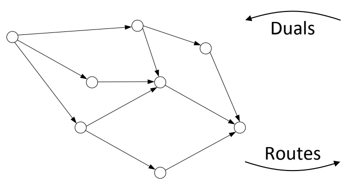
Crew Scheduling



	Route 1	Route 2	Route 3	Route 4	∑
Leg 123	1		1		= 1
Leg 435		1	1	1	= 1
Leg 52	1	1			= 1
Leg 344				1	= 1
...					

1. Check termination criteria
2. Increase Penalty Costs

Aircraft Routing



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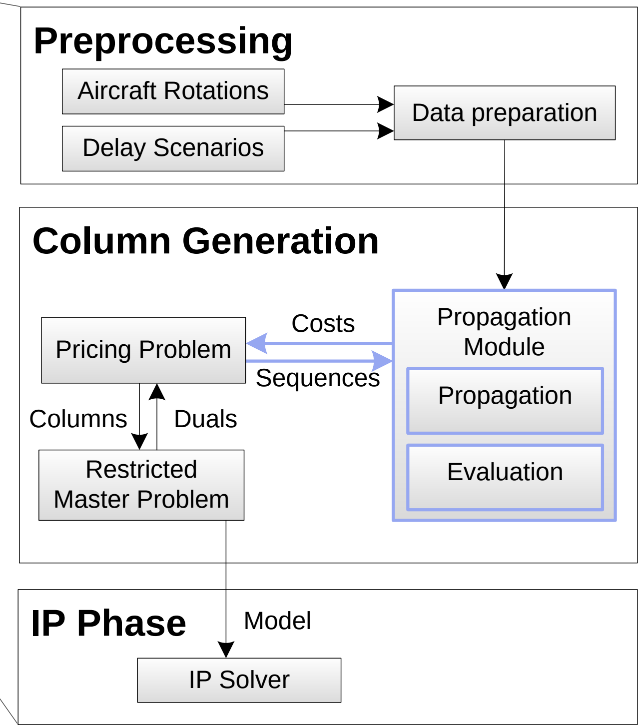
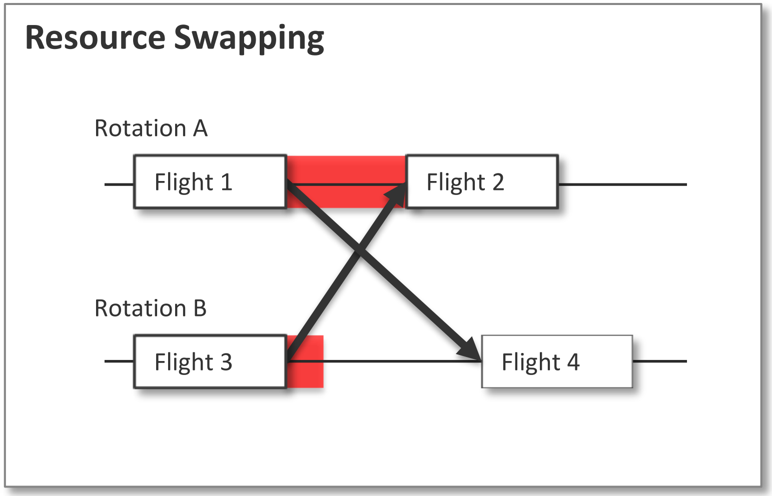


Further details and computational results in: Dück V., Ionescu L., Kliewer N., Suhl L. (2012): Increasing stability of crew and aircraft schedules. Transportation Research C, Vol. 20(1), 47-61.

Iterative Approach adapted from: [Weide et al. (2009)] Weide, O., D. Ryan, and M. Ehrgott. An iterative approach to robust and integrated aircraft routing and crew scheduling. Computers & Operations Research 37 (5):833-844, 2010.

Motivation for Flexibility by Swap Opportunities

- High marginal costs for stability
- Uncertainty of the real delays during scheduling
- Do swap opportunities provide a reasonable enhancement to stable scheduling?



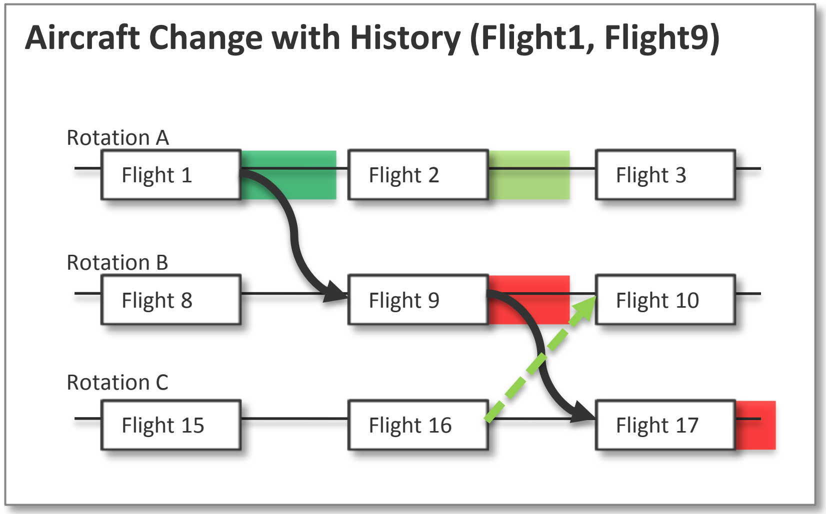
Increasing Flexibility by Swap Opportunities

- If a follow-on $[f, s(f)]$ is likely to be disrupted in a specific context h
  - Insert penalty variable $z \in \{0,1\}$:

$$\frac{|\omega \epsilon \Omega: \delta^{\omega}_{[f\ s(f)]_h} > t_\delta|}{|\Omega|} \cdot c \cdot z$$

  - Insert constraints for *all* pairings containing this follow-on:

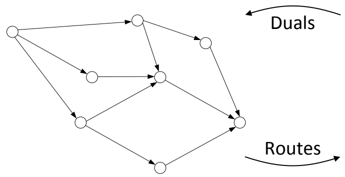
$$x - \sum_i y_i - z \leq 0, \qquad \forall\, x \in P, [f, s(f)]_h \in p$$



Symbols
x: pairing containing a risky follow–on
y: pairings that offer a swap opportunity for x
$\omega \epsilon \Omega$: delay scenarios
t_δ: delay tolerance
c: cost multiplicator

Increasing Flexibility – Integrated Solution Approach

Crew Scheduling



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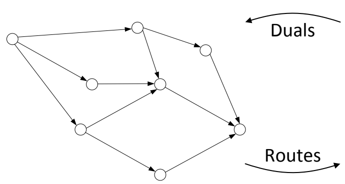
Aircraft Routing



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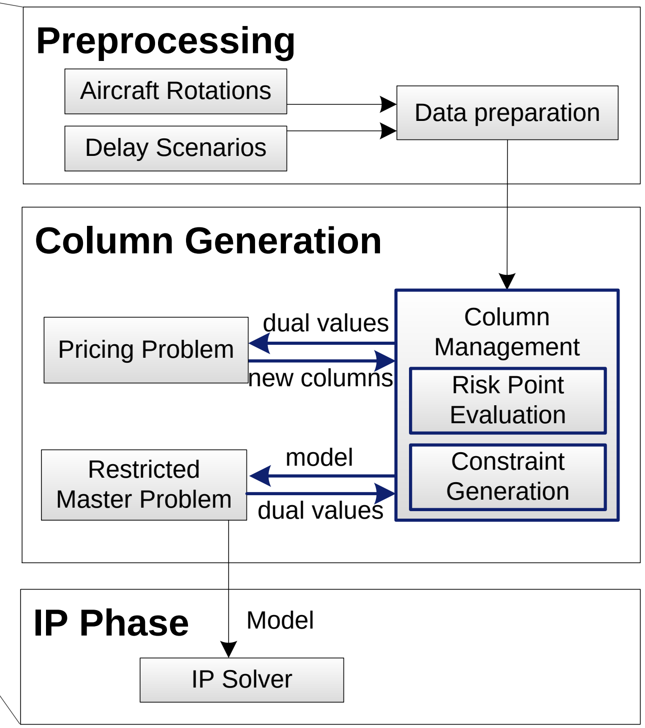

Summary & Outlook

- Explorative Data Analysis ✓
- Decision Tree Modeling ×

Delay Prediction Models — Data Analysis

- Propagation Model ✓
- Rule-based Recovery ✓

Schedule Simulation — Simulation

- Stochastic Modeling ✓
- Column Generation ✓

Robust Scheduling — Stochastic Optimization

Put it all together and start final tests…?

Thank you for your attention!

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Lucian Ionescu
Dipl. Wirt.-Inf.

Information Systems Department
School of Business Administration
Freie Universität Berlin

mail: lucian.ionescu@fu-berlin.de
phone: +49 (30) 838 54057