Robust and Recoverable Maintenance Routing Schedules

N. Eggenberg, M. Salani, M. Bierlaire

Transport and Mobility Laboratory, EPFL, Switzerland

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Introduction

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Some numbers

- Huge economical impact[1]
  - $1.7 billion loss of revenue for first week
  - $400 million a day for the first 4 days
  - 1.2 million affected passengers / day

- Spill out due to disrupted / blocked passengers

[1] *www.iata.org/pressroom*, Press release No 15, 21 April 2010

Why robustness appeals for airline scheduling

- Airlines have low profitability
  - < 2% profit margin (US, 2007)

- High delays and implied delay costs[2]
  - 4.3 Billion hours delay (US, 2008)
  - $41 Billion delay costs (US, 2008)

[2] *Your flight has been delayed again* (2008), Joint Economic Committee www.jec.senate.gov

Worse is still to come

- Growth:
  - 2.5% more flights annually
  - Every 1% additional flights incur an additional 5% delays (Schaefer et al., 2005)
  - => Yearly increase of delays of 12.5%

- Europe: 50% of flights in 2030 depart or land at congested airports

- Airlines must react – we try to help
  - Improve operations in a congested network

Questions

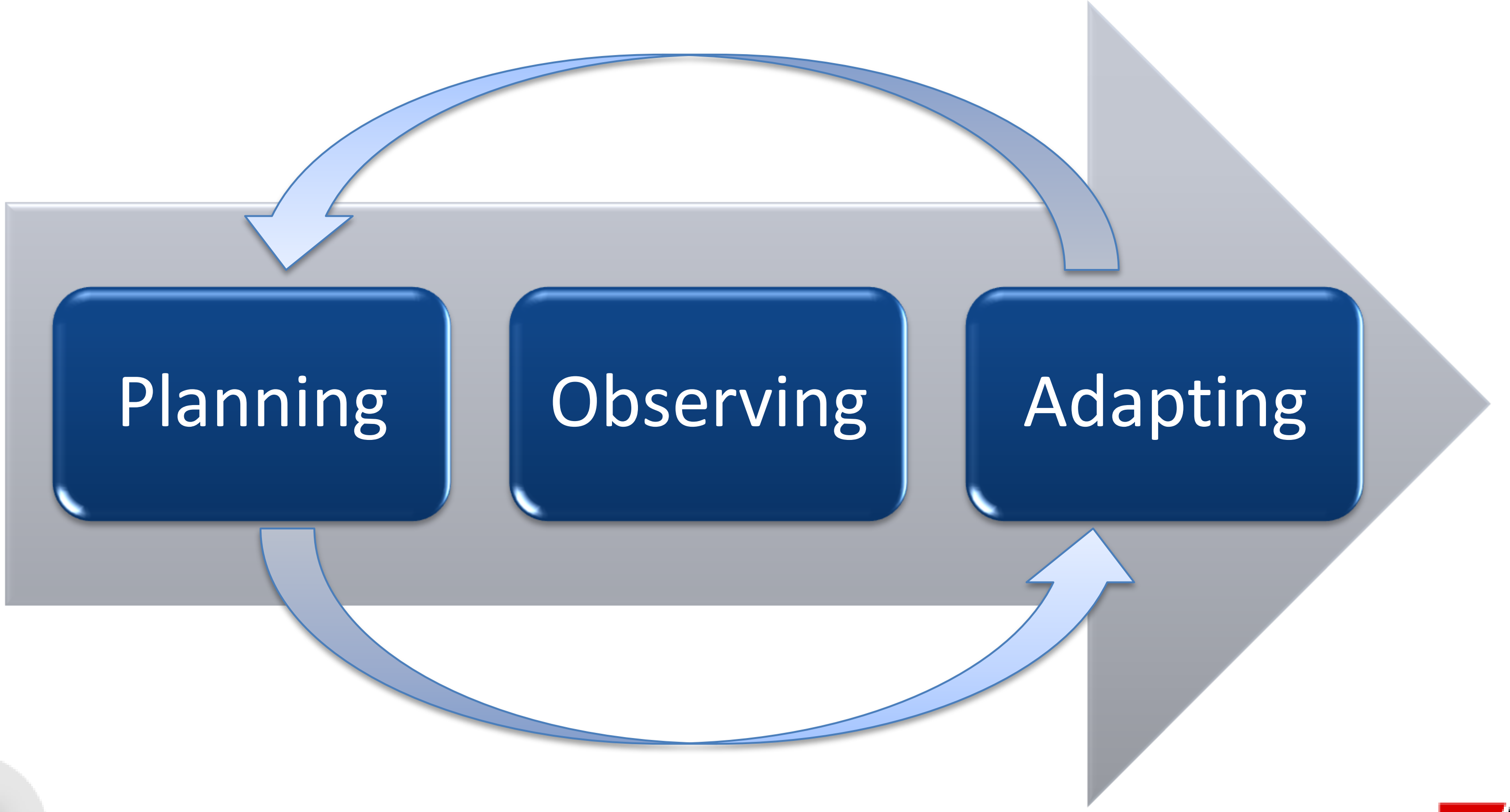
- Are these (potential) costs considered at the planning phase?

- What would change?

Outline

- Optimization under uncertainty
  - In general
  - In airline scheduling
- Robust Maintenance Routing Problem
  - Definitions
  - “Robust” and “Recoverable” models
- Simulation – preliminary results
  - Methodology to evaluate and compare robust solutions
  - Preliminary a priori and a posteriori results

General Optimization Problems



Other meanings of robustness

- Robustness is also used as a
  - "***stability***" measure
    - Absorbs disruptions
    - Does not require recovery
  - "***flexibility***" measure
    - Facilitates recovery
    - Reduces recovery costs
- We differentiate
  - **ROBUSTNESS** vs **RECOVERABILITY**

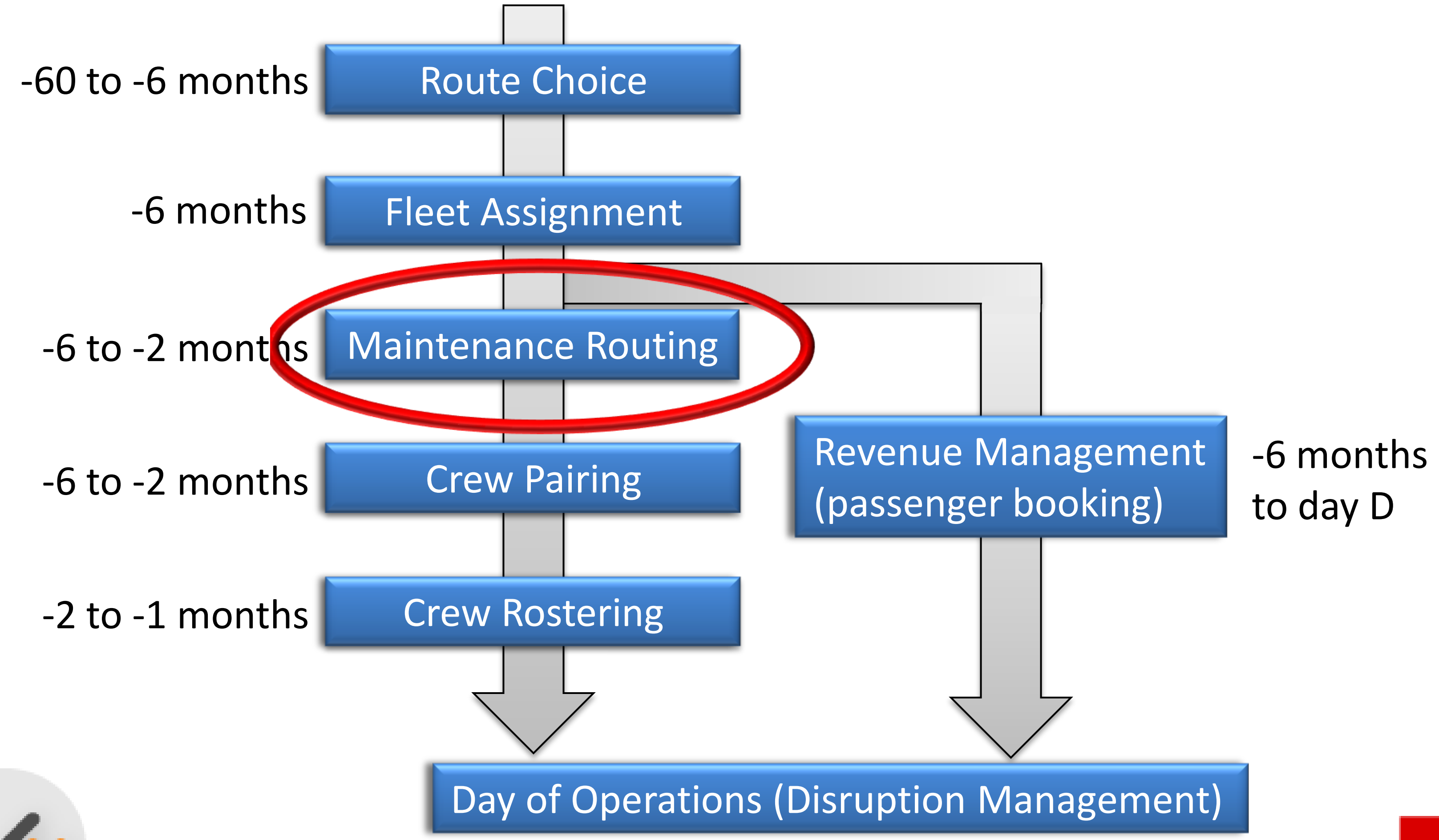
Our objectives

- Examine how robustness proxies and performance metrics are correlated

- Robustness proxies are structural a priori properties of the schedule
  - Expected propagated delay
  - Total slack in aircraft routes
  - Total passenger connection time
  - …

- Performance metrics are a posteriori metric
  - Observed propagated delay
  - Total passenger delay
  - Recovery costs
  - …

Airline Scheduling: An iterative Process



Robust Maintenance Routing Problem (MRP)

- Deterministically known
  - Original schedule (1 maintenance route/aircraft)
- To determine
  - New routes for each aircraft
  - And/or new departure times for each flight
- Constraints
  - Maintenance routes are feasible for each aircraft
  - All flights are covered exactly once
  - Each flight is retimed by at most ±15
  - Total retiming of all flights of at most *C* minutes (500 or 1000)
- Objective
  - Optimize robustness proxy

Used Uncertainty Feature Optimization (UFO)[3] Models

- Use different UFs:
  - IT: maximize total idle time
  - MIT: maximize sum of minimal idle time of each route
  - CROSS: maximize nbr plane crossings
  - PCON: maximize passenger idle connection time
  - MinPCON: maximize minimal PCON

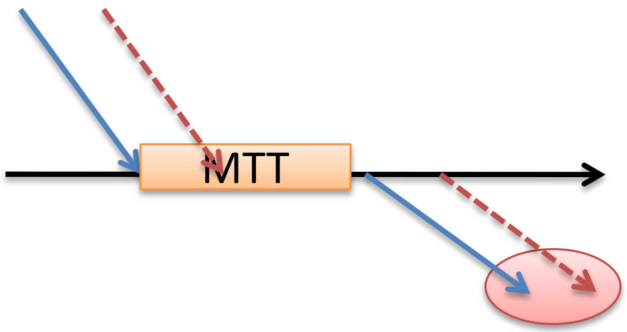
- Solved with CG algorithm (COIN-OR – BCP package)

  (Eggenberg et al., 2010)

[3] Eggenberg et al. (2010b), *Uncertainty Feature Optimization: a implicit paradigm for problems with noisy data* (accepted for publication in Networks in June, 2010)

Robustness in airline scheduling – existing approach

- Robust airline schedules are
  - Operationally more efficient
  - Less sensitive to delay
    - i.e. with reduced delay propagation



Delay Propagation

- 2 types of delays for each flight
  - ***Independent*** delay: generated during a flight
    - At any stage (taxi, runway, landing,…)
  - ***Propagated*** delay
    - Delay due to previously delayed flight
    - Propagation is downstream (possibly to several flights)

- $Del(f) = ID(f) + PD(f)$
- Robustness proxy = expected PD
  - To be minimized

Benchmark

- Models from literature
  - EPD: minimize expected propagated delay (Lan et al., 2006)
    - No retiming
    - Allow only plane swaps
  - EPD2: minimize expected propagated delay (AhmadBeygi et al., 2008)
    - No plane swaps
    - Allow for retiming by ± 15 minutes
    - Total retiming bounded (500 or 1000 minutes)
- Solved with same CG algorithm (COIN-OR – BCP package) (Eggenberg et al., 2010)

Measuring Recoverability: Methodology

- Solve Robust MRP using different robust models
- Simulate different disruption scenarios
  - Differentiate *independent* and *propagated* delay
  - Update propagated delay according to schedule
- Solve the recovery problem
  - Using same recovery algorithm (Eggenberg et al., 2010)
- Evaluation with external recovery cost evaluator
  - Data and cost-evaluator provided by the *ROADEF Challenge 2009* (challenge.roadef.org/2009)

Scenario Generation

- Use historical data of 2 year and separate it by season
  - Winter (October – March)
  - Summer (April – September)

- For each airport, we have arrival and departure delays

- Generate delays for flight f from A to B drawing from empirical distribution by

$$\text{Del} = 0.5 * [\ \text{depDel}(A) + \text{arrDel}(A)\ ]$$

Generated schedules

- UFO solutions are the same for Winter and Summer
  - UFs are non-predictive models
- EPD solutions are different
  - Solution depends on estimated delay distribution
  - Based on average delay of each flight, which is different in Winter and in Summer

Notation for models

- Model of Lan et al., 2006 (minimize expected propagated delay)
  - EPD_W: use average delay of Winter
  - EPD_S: use average delay of Summer
- Model of AhmadBeygi et al., 2008 (minimize expected propagated delay)
  - EPD2_W: use average delay of Winter
  - EPD2_S: use average delay of Summer
- Model name + "_*XXX*"
  - *XXX* is the value of *C* (maximum allowed retiming in min.)

Simulation Overview – UFO solutions

Scenario/Schedules	Winter Schedules	Summer Schedules
Winter Scenarios	NEUTRAL	NEUTRAL
Summer Scenarios	NEUTRAL	NEUTRAL

Simulation Overview – EPD and EPD2

Scenario/Schedules	EPD_W & EPD2_W	EPD_S & EPD2_S
Winter Scenarios	OK	WRONG DISTRIBUTION
Summer Scenarios	WRONG DISTRIBUTION	OK

Comparison Criteria

- Compare a priori AND recovery statistics
- A priori proxies (= objective functions of different models)
  - UF values
  - EPD
- Recovery statistics
  - Recovery costs
  - Aircraft statistics
    - Total aircraft delay
    - Canceled flights
  - Passenger statistics
    - Total / average passenger delay
    - Rerouted passengers
    - Canceled passengers

Used Instance – Derived from instance A01 of the Roadef Challenge 2009

- 608 flights
- 85 aircraft
- 36010 passengers
- 1 day

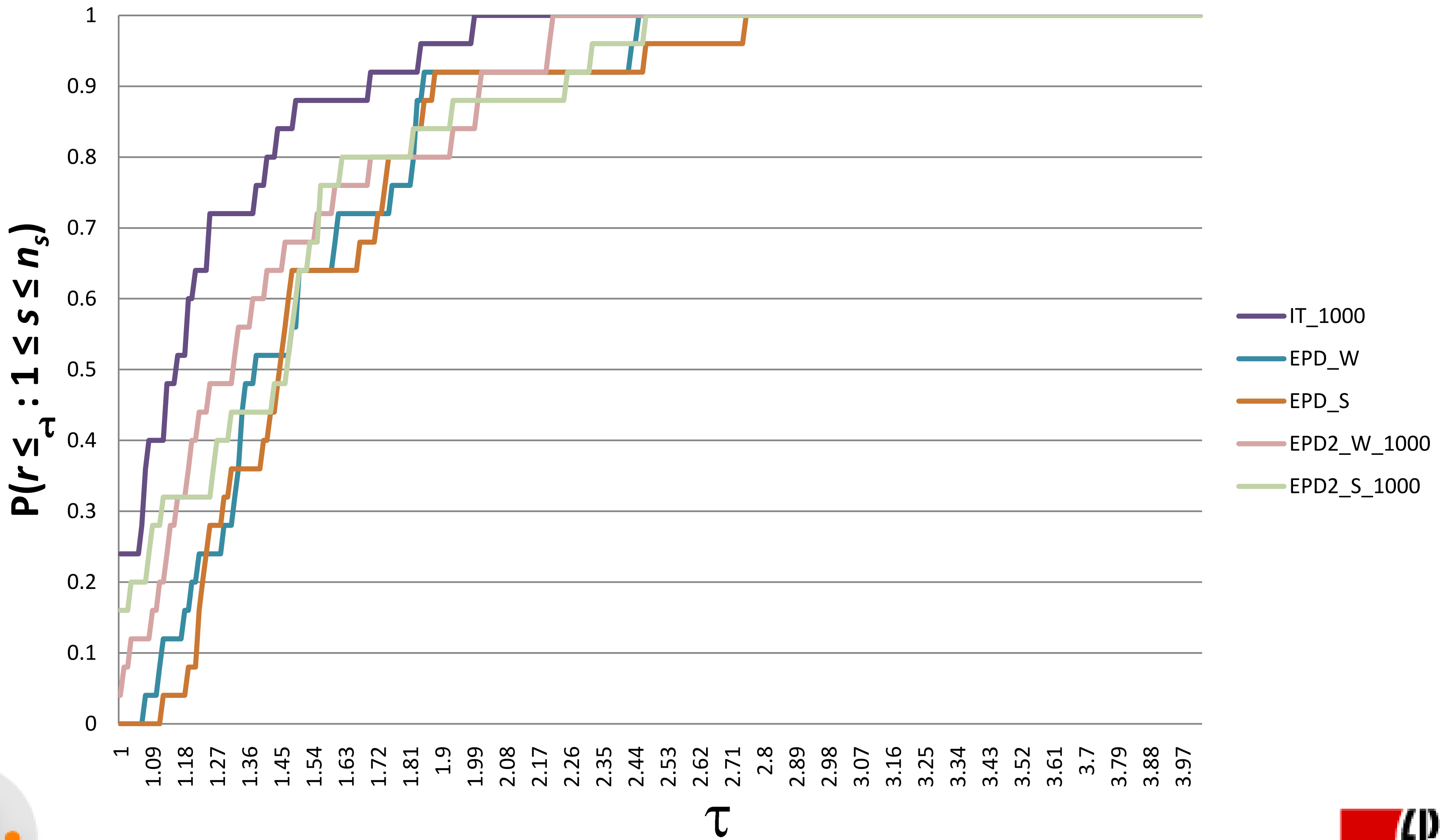
Robustness Proxies: Correlations

WINTER	IT	MIT	PCON	EPD
IT	X			
MIT	**0.293**	X		
PCON	**0.851**	**0.251**	X	
EPD	**-0.318**	**0.458**	-0.04	X

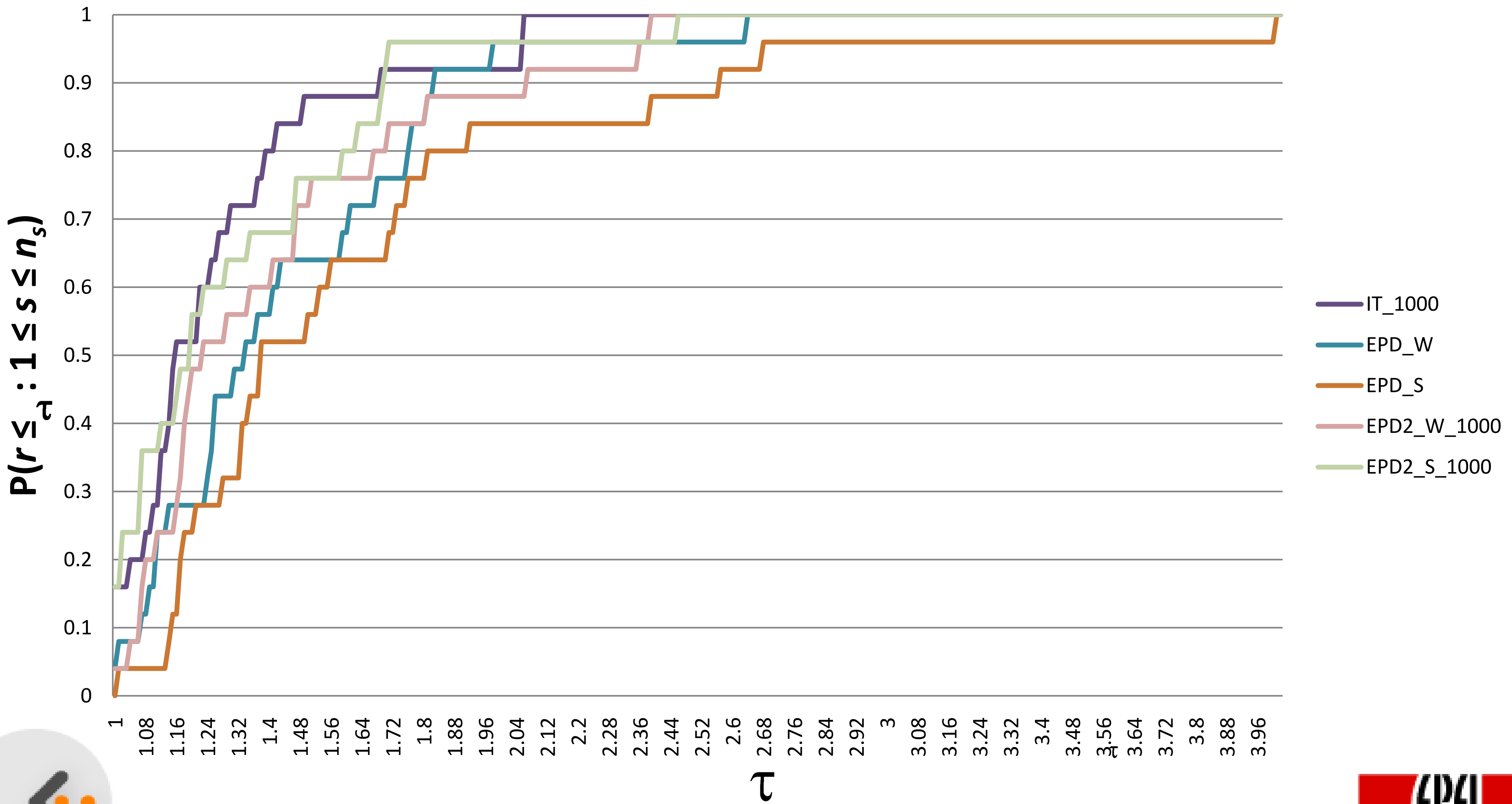
SUMMER	IT	MIT	PCON	EPD
IT	X			
MIT	**0.293**	X		
PCON	**0.865**	**0.248**	X	
EPD	**-0.392**	**0.381**	**-0.082**	X

Bold values are significant with confidence level $\alpha = 0.001$

Performance Profiles
Over all 25 instances (Winter only)



Performance Profiles
Over all 25 instances (Summer only)



Recovery Performance Metrics – Overall (Winter + Summer)

	Original	IT_1000	MIT_500	PCON_1000	EPD2_W_1000	EPD2_S_1000
Rec. Costs [k€]	249.2	**197.4**	241.1	249.6	248.6	239.8
Nbr Canc. Pax	137	**104**	123	137	139	129
Avg. Pax delay [min]	33.42	**31.55**	34.6	33.33	32.97	31.80
Nbr Cancelled Flights	2.98	**2.36**	3.08	2.98	2.84	2.94
Nbr Delayed Flights	53.7	50.6	55.2	53.8	53.1	**45.8**
Propagated Delay [min]	9405	7632	9732	9382	9069	**6108**

Recovery Performance Metrics: Correlations

Overall	Recovery Costs	# Cancelled Pax	Average Pax Delay	# Cancelled Flights	Propagated Delay
Recovery Costs	X				
# Cancelled Pax	**0.961**	X			
Average Pax Delay	**0.683**	**0.621**	X		
# Cancelled Flights	**0.786**	**0.779**	**0.469**	X	
Propagated Delay	**0.548**	**0.467**	**0.815**	**0.427**	X

Bold values are significant with confidence level $\alpha = 0.001$

Recoverability: Correlation between a priori proxies and performance metrics

Overall	Total Slack IT	Minimum Slack MIT	Passenger Connection Time PCON	Expected Propagated Delay EPD
Recovery Costs	**-0.135**	-0.021	**-0.135**	**0.092**
# Cancelled Pax	**-0.135**	-0.016	**-0.134**	**0.082**
Average Pax Delay	**-0.084**	0.058	**-0.086**	**0.137**
# Cancelled Flights	**-0.072**	-0.014	**-0.073**	0.056
Propagated Delay	**-0.155**	**0.171**	-0.152	**0.409**

Bold values are significant with confidence level $\alpha = 0.05$

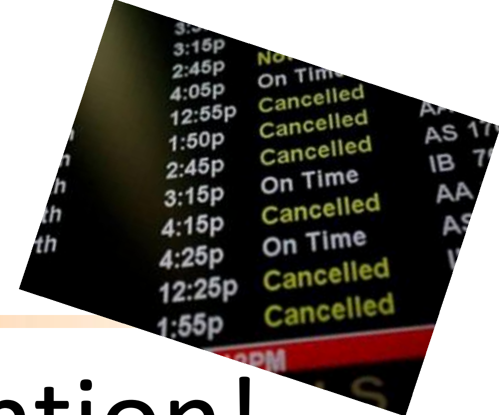
Conclusions

- We propose a methodology to evaluate the relevance of robustness proxies
- We show that these proxies are inter-correlated and indeed improve the ***recoverability*** of the schedule
- We show that expected propagated delay
  - is not a good indicator for recoverability
  - is sensitive to errors in the uncertainty model

Open Research Directions

- Exploit the correlation structure to combine the different robustness proxies
- Explore correlations on wider instance set with disruptions including
  - Imposed flight cancellations
  - Aircraft unavailability periods
  - Airport capacity modifications
- Study other proxies
  - Possible way to partially integrate downstream operational decisions
- Evaluate performances using other recovery algorithms
  - To identify whether correlations are due to the recovery algorithm or if they are globally improving recoverability

The End



Thank you for your attention!