How robust are robust schedules in reality?

N. Eggenberg, M. Salani, M. Bierlaire

Transport and Mobility Laboratory, EPFL, Switzerland

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Introduction

Some numbers

- Huge economical impact
  - Air France-KLM 35 Mio € / day
  - Lufthansa 48 Mio € / day
  - IATA: $200 Mio / day to air sector

- Spill out due to disrupted / blocked passengers

Why robustness appeals for airline scheduling

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

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

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

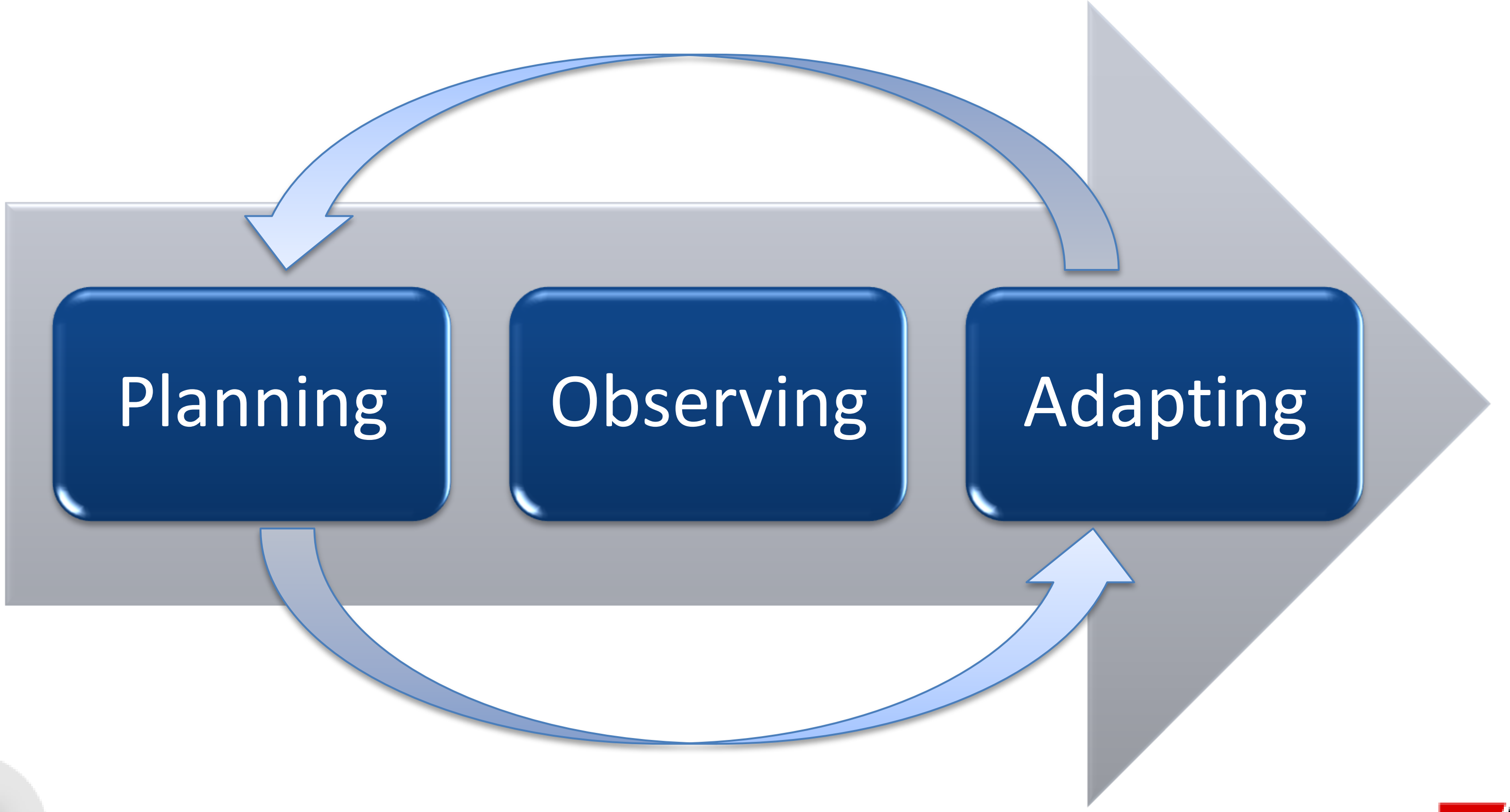
Outline

- 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



Robustness: plan for stability and reliability

- Optimized solutions have
  - Highest “***expected***” revenue/yield/profit
  - Known to be sensitive to noise

- Robust solutions have
  - Lower expected revenue/yield/profit
  - Higher reliability

Definition of robustness

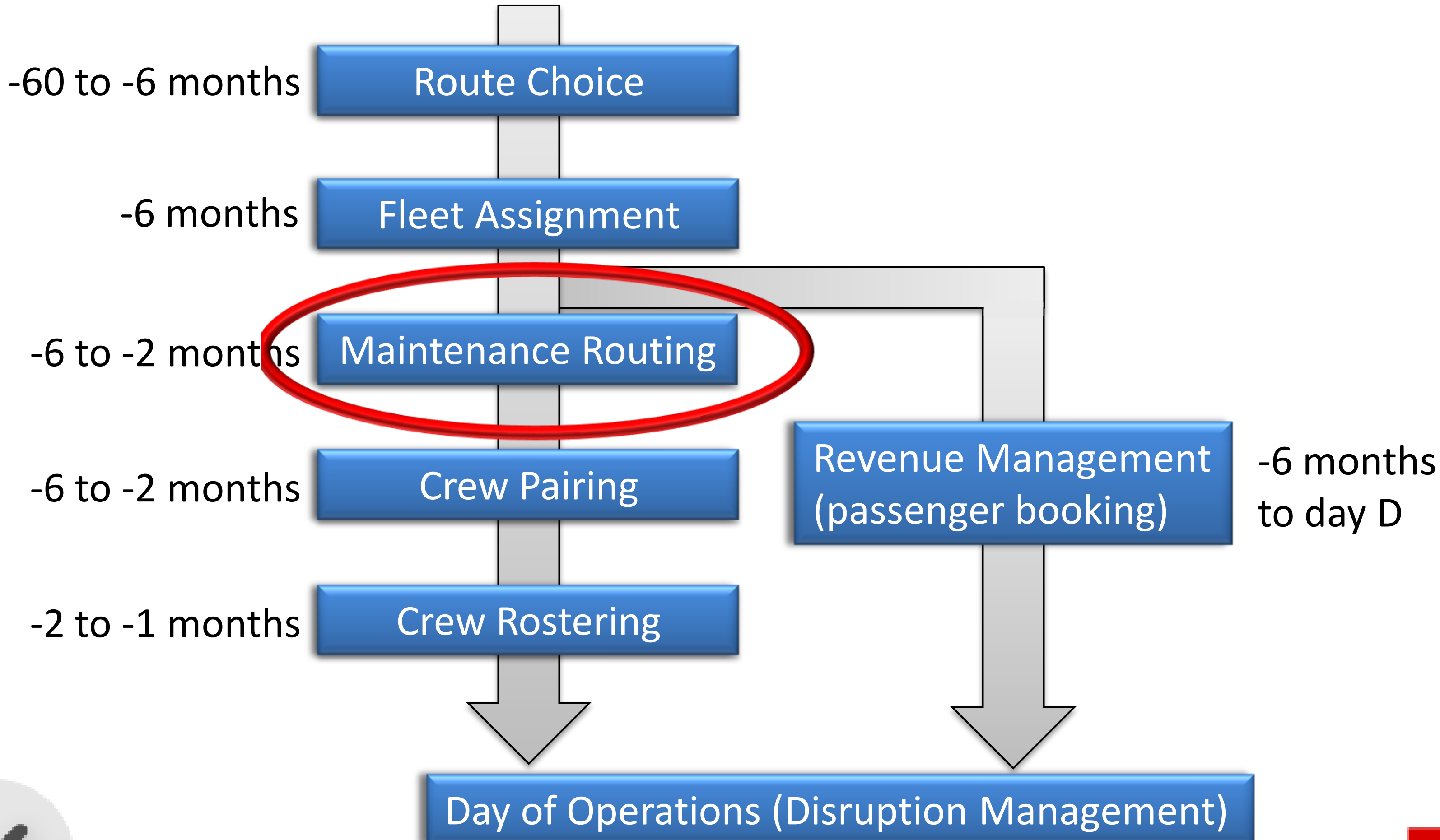
- Unclear in literature
  - For more "***stable***" solutions (that remain feasible)
  - For more "***flexible"*** solutions
  - For solutions with lower "***operational costs"***
- How to determine what "more robust" means?
  - What metric to use?
  - Should it be a priori or a posteriori?

Parallel to Stochastic Programming

- What is the equivalent to robustness
  - Stochastic optimization
  - Stochastic optimization with recourse
  - Risk management / chance constraint programming?

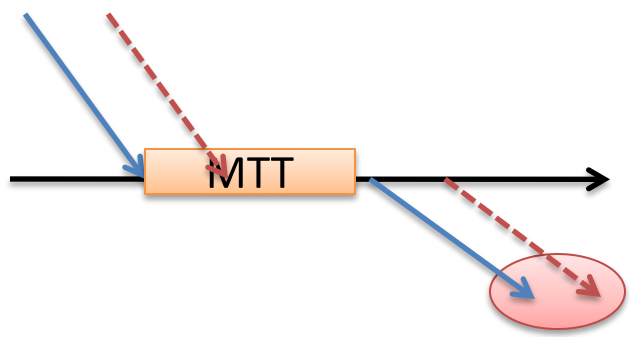
- Or are these robust methods themselves?

Airline Scheduling: An iterative Process



Robustness in airline scheduling

- 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

Other meanings of robustness

- Robustness is also used as a "***flexibility***" measure
  - Facilitates recovery
  - Reduces recovery costs

- We differentiate
  - **ROBUSTNESS** vs **RECOVERABILITY**

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 metric

Used Uncertainty Feature Optimization (UFO) 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)

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)

Measuring Recoverability: Methodology

- Solve Robust MRP using different models
- Apply some disruption scenarios
  - Differentiate *independent* and *propagated* delay
  - Update propagated delay according to schedule
- Solve the recovery problem
  - Using same recovery algorithm
- Evaluation with external recovery cost evaluator
  - Data and cost-evaluator provided by the *ROADEF Challenge 2009*

Scenario Generation

- EPD and EPD2 require expected delay for each flight
  - Generate two distributions using historical data from similar airline (scenarios 1 and 2)
  - Generate several scenarios drawing from each scenario
    - No variability (perfect information)
    - Low variability ($\sigma = 0.1 \hat{\mu}$)
    - High variability ($\sigma = 0.5 \hat{\mu}$)
  - Evaluate solutions on all scenarios and apply recovery algorithm

Generated schedules

- UFO solutions are the same for both scenarios
  - UFs are non-predictive models
- EPD solutions are different
  - Solution depends on estimated delay distribution
- Use two "*realities*" to simulate erroneous predictive models

Simulation Overview – UFO solutions

Scenario/Solution	Solutions Sc. 1	Solutions Sc. 2
Scenario 1	NEUTRAL	NEUTRAL
Scenario 2	NEUTRAL	NEUTRAL

Simulation Overview – EPD and EPD2

Scenario/Solution	Solutions Sc. 1	Solutions Sc. 2
Scenario 1	OK	WRONG DISTRIBUTION
Scenario 2	WRONG DISTRIBUTION	OK

Comparison Criteria

- Compare a priori AND recovery statistics
- A priori
  - UF values
  - EPD
- Recovery statistics
  - Recovery costs
  - Aircraft statistics
    - Total aircraft delay
    - Canceled flights
  - Passenger statistics
    - Total passenger delay
    - Rerouted passengers
    - Canceled passengers

Used Instance

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

A priori robustness statistics (max retiming = 500 minutes)

		Original	IT	MIT	PCON	EPD	EPD2
Scenario 1	EPD [min]	8453	8265	8431	8496	8411	**7953**
	IT [min]	12000	**12185**	12010	12135	12010	12060
	PCON [min]	10815	10950	10860	**11815**	10815	10795
Scenario 2	EPD [min]	7282	7185	7221	7221	7251	**6732**
	IT [min]	12000	**12185**	12010	12135	12065	12110
	PCON [min]	10815	10950	10860	**11815**	10815	10855

Simulation Overview – EPD and EPD2

Scenario	S1	S2
S1	OK	WRONG DISTRIBUTION
S2	WRONG DISTRIBUTION	OK

Average Results (25 scenarios in each “reality”)

		Original	IT	MIT	PCON	EPD	EPD2
Scenario 1	# canc. Flts	13.2	13.2	12.3	11.8	**8.5**	11.2
	P.D. [min]	17,738	17,352	17,692	17,843	17,827	**16,866**
	Rec Cost [€]	872,942	#	#	714,236	**676,273**	866.298
Scenario 2	# canc. Flts	9.9	9.8	9.4	8.1	**6.5**	7.7
	P.D. [min]	14,115	13,973	14,029	14,052	13,967	**13,310**
	Rec Cost [€]	548,194	#	#	**422,551**	423,997	449,128

Simulation Overview – EPD and EPD2

Scenario	S1	S2
S1	OK	WRONG DISTRIBUTION
S2	WRONG DISTRIBUTION	OK

Average Results (25 scenarios in each "reality")

		EPD_S1	EPD_S2	EPD2_S1	EPD2_S2	PCON
Scenario 1	# canc. Flts	8.5	8.6	11.2	11.6	11.8
	P.D. [min]	17,827	17,697	16,866	17,186	17,843
	Rec Cost [€]	676,273	684,246	866.298	915,433	714,236
Scenario 2	# canc. Flts	6.5	6.5	7.9	7.7	8.1
	P.D. [min]	13,971	13,967	13,624	13,310	14,052
	Rec Cost [€]	428,885	423,997	461,774	449,128	422,551

Conclusions

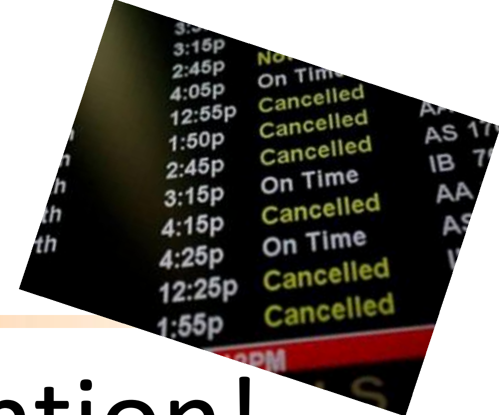
- No absolute meaning of robustness
  - How to measure?
  - How to evaluate?
- Methodology to compare solutions
  - A priori using pre-defined proxies
  - A posteriori using recovery statistics
- Preliminary results show that
  - Proxies are inter-correlated
  - Using evaluation approach allows better understanding of these inter-correlations and their implications

Open Research Directions

- Extend simulations and perform deeper analysis to
  - Better understand relations between proxies
  - Understand correlations between
    - a priori proxies
    - a posteriori proxies (recovery statistics)
    - Structure of the recovery algorithm

- Will this analysis allow to define robustness…
  - … with respect to a given recovery algorithm?
  - … with respect to a chosen proxy?

The End



Thank you for your attention!