Airline Challenges
& Research Opportunities

Bruno F. Santos - b.f.santos@tudelft.nl

SITRAER– Air Transportation Symposium, São José dos Campos, Oct 26th to 28th, 2015

TUDelft

Outline

- The airline industry in Brazil
  - Context
  - Challenges
- Research opportunities (examples)
  - Cost Savings with Big data
  - Reliability in a Dynamic System
  - Planning with Uncertainty
  - Resilience in a Complex System
- Conclusion

TU Delft

Context in Brazil

http://oglobo.globo.com

TU Delft

Context in Brazil

According to IATA statistics (2015), air transport in Brazil:

- contributes $17 billion (2.3%) of Brazil's GDP
- supports 837,000 jobs directly and indirectly
- pays around $1.76 in tax.

The growth and the need for growth

- scheduled passenger traffic was up 6.3% in 2014, to almost 100 million passengers
- it was estimated by IATA that a 10% improvement in connectivity would generate approximately $650 million extra in long-run GDP for the Brazilian economy

Context in Brazil

There are several opportunities:

- airport privatization has generally been welcomed as a potential means to improve the infrastructure
- market growth
  - increase passenger flows' growth (6.7% in Aug 2015)
  - increasing growth of destinations (in Brazil and internationally)
- international collaborations/alliances
- market liberalization
- space for (European-standard) LCC
- new generation fleet and capital investment plans
- strong air transport industry
- jet fuel is currently at low prices

Context in Brazil

But also some threats:

- current economic scenario is adverse
- the high fluctuation and depreciation in R$ (real) — airlines are operating expenses and debts are denominated in US$
- taxation, in one form or another, is a major issue
- high fuel costs, when compared to other regions
    - fuel accounts for 40% of airline costs versus the 30% global average (IATA, 2015)
- lower demand for business passengers and leisure passengers stimulated by promotional fares
- operational revenues are not covering costs
    - Gol has been unprofitable for four consecutive years
    - TAM also has been unprofitable

TU Delft

Airlines Challenges

TUDelft

Airlines Challenges

- Liberalization/deregulation potentialities and threats
- Increased trend from consolidation (alliances)
- Network/service increasing complexity
  - system performance analysis more complex
  - intricate daily operations
- Profitability and cost savings (passenger services, fuel, labor, maintenance)
  - Price war
  - Excessive capacity
  - Resilient operations
- LCC opportunities - penetration in Latin America (LA) below 10%
- Airport privatization - impact on operations
- Environmental performance (new technology, efficient use of the infrastructure and assets, emissions trading)
- Safety performance (in 2014, industry 1:1.5M; LA 1:0.5 M)
- Need for training and R&D - new generation
- Uncertainty — planning flexibility
- Reliable and dynamic costumer-oriented service (inflight and at airports)

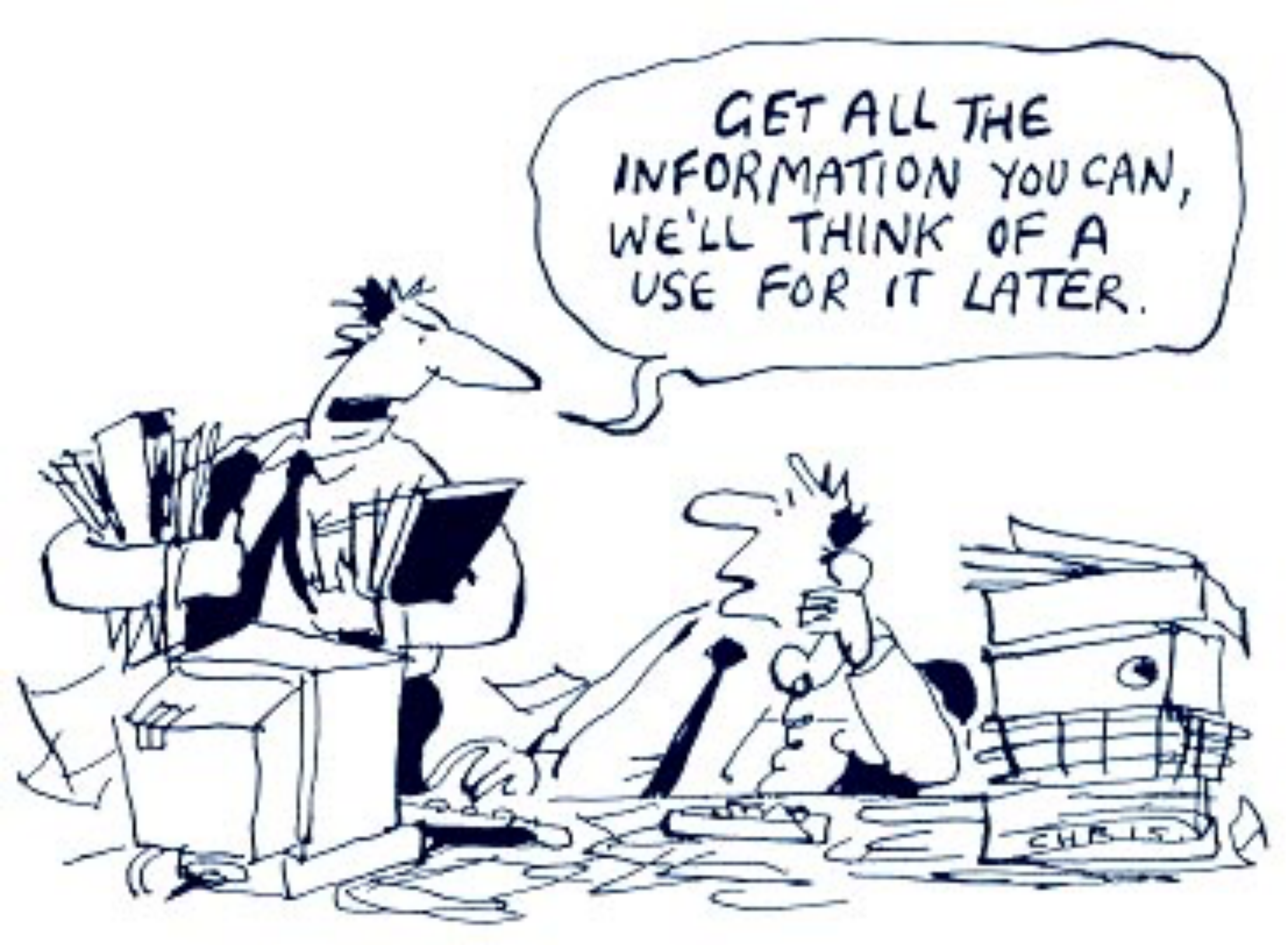
TU Delft

Airlines Challenges

- Liberalization/deregulation potentialities and threats
- Increased trend from consolidation (alliances)
- Network/service increasing **complexity**
  - system performance analysis more complex
  - intricate daily operations
- **Profitability and cost savings** (passenger services, fuel, labor, maintenance)
  - Price war
  - Excessive capacity
  - Resilient operations
- LCC opportunities - penetration in Latin America (LA) below 10%
- Airport privatization - impact on operations
- Environmental performance (new technology, efficient use of the infrastructure and assets, emissions trading)
- **Safety performance** (in 2006, industry 1:1.5M; LA 1:0.5 M)
- Need for training and R&D - new generation
- **Uncertainty — planning flexibility**
- **Reliable and dynamic** costumer-oriented service (inflight and at airports)

TU Delft

Research Opportunities



http://www.zinginsights.com

TUDelft

Air Transport and Operations

TU Delft Delft University of Technology

Prof. Richard Curran
E R.Curran@tudelft.nl

Prof. Henk Blom
E H.A.P.Blom@tudelft.nl

- 8 academic staff (2 full professors)
- 1 supporting staff
- 11 PhD students + 6 (next year)
- 40 new MSc students per year.







TU Delft / Air Transport & Operations
Faculty of Aerospace Engineering
Delft University of Technology
Kluyverweg 1 / P.O.Box 5058
2629 HS Delft / 2600 GB Delft

W www.lr.tudelft.nl/ato
T +31 (0)15 27 82045
E secr-ato-lr@tudelft.nl

Research Challenges

- Cost saving with Big data
- Reliability in a Dynamic System
- Planning with Uncertainty
- Resilience in a Complex System

Cost Saving with Big Data

- Big Data in Maintenance

TU Delft

Big Data in Maintenance

General research objective:

Improve efficiency of maintenance operations by accurate forecasting of component and system remaining useful life

Approach

- Take into account heterogeneous sources of data (operational & maintenance)
- Develop models to enable predictive maintenance:
  - **Diagnostics:** identify component behavior indicating incipient failure
  - **Prognostics:** predict component remaining useful life through simultaneous analysis of big, heterogeneous datasets

TU Delft

Big Data in Maintenance - Prediction

Problem

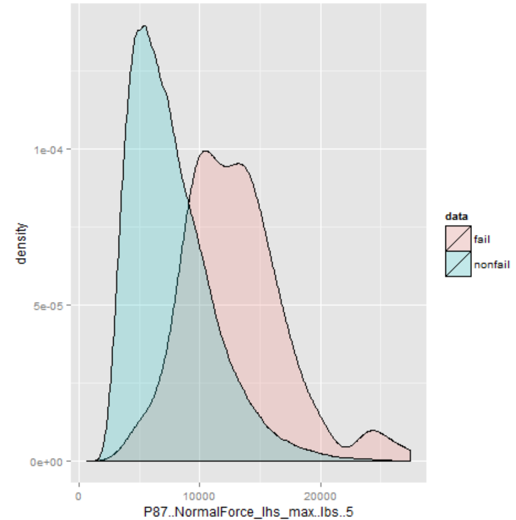
- Unscheduled Removal Rate (URR) of company Dash-8 fleet 175% more than World Wide Fleet (WWF)[1]

Data

- Heterogeneous sources (operations & maintenance)
- Occurrences – landing gear wheel assembly example
  - Complete (Failures): 191
  - Incomplete (Censored): 2891
- > 750 000 Related flights
- > 1 500 Operational factors

Analysis

- Reduce potential flights
  - 1132 to 191
- Identify factors related to component reliability
  - Extreme value analysis (optimization)
  - Maximum difference analysis (statistics)



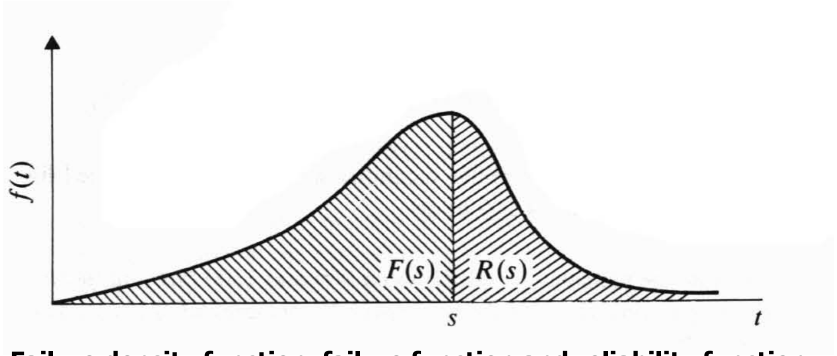
[1]: Annual FRACAS reports, Bombardier

TU Delft

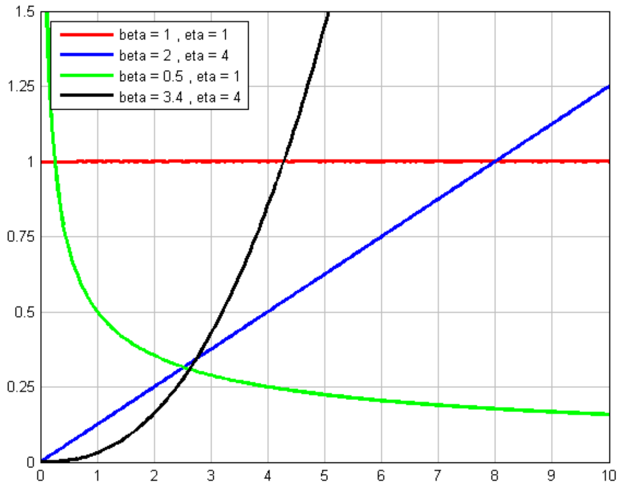
Big Data in Maintenance - Prediction

Reliability Modeling

- Standard
  - reliability models using lifetime distributions (non-repairables) or stochastic processes (repairables);
  - time as only variable.



Failure density function, failure function and reliability function



Hazard rate for different shape and scale parameters of the Weibull distribution

Big Data in Maintenance - Prediction

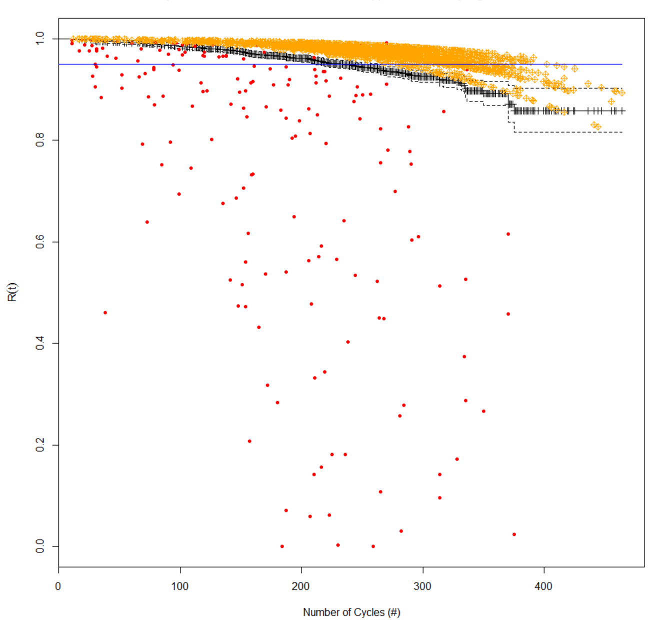
Reliability Modeling

- Improved
  - Proportional Hazard Model (PHM), incorporating influence of operational factors to improve forecast of individual component reliability

1 covariates (operational factors):

- 73.30% of failures below 95% reliability
- 92.67% of scheduled events above 95%

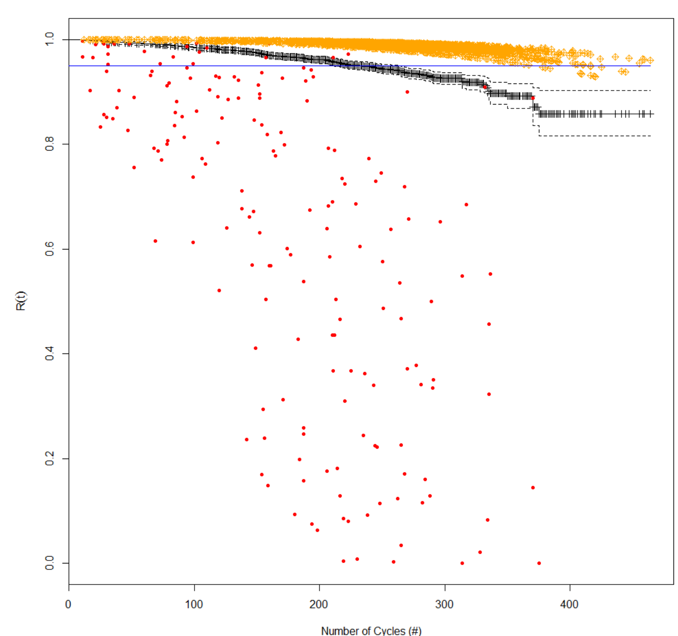
Time independent PHM survival function, R(t), with underlying norm distribution.



3 covariates (operational factors):

- 86.39% of failures below 95% reliability
- 99.52% of scheduled events above 95%

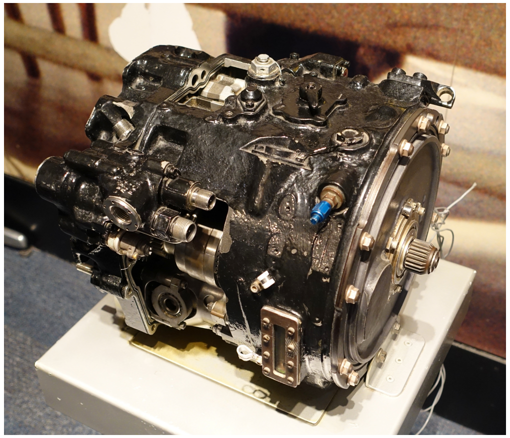
Time independent PHM survival function, R(t), with underlying norm distribution.



Big Data in Maintenance - Diagnostic (& prediction)

Objective

Enable accurate identification of anomalies (diagnostics) and predict time from failure onset to actual failure (prognostics)



Dataset:

- Maintenance data
- Aircraft Condition Monitoring System (ACMS)
- Central Maintenance Computer System (CMCS)

Example – B747 Integrated Drive Generators

- Data size
  - average about 3GB of data for B747 IDG's in June for fleet under consideration
  - dataset incorporates per-second values for five operational variables per IDG, with 4 IDG's on a single B747.
- Methodology
  - accurate identification of anomalies through use of diagnostic algorithms
  - prediction of time to failure using neural network

TU Delft

Reliability in a Dynamic System

- Reliable (Airport) Gate Assignment

Reliable Gate Allocation

General research objective

Improve the reliability of the airport gate allocation by stabilizing the sequence of flights and reducing 'last-hour' gate changes

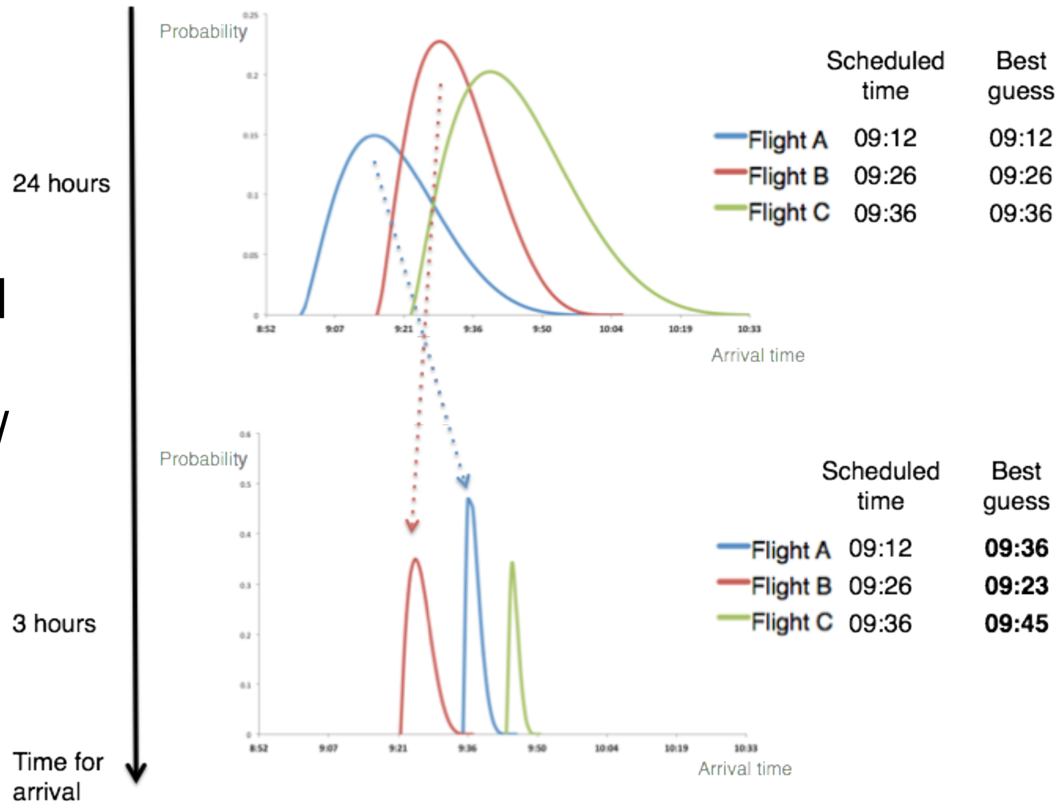
Approach

- Divide the gate planning process in two stages
  - **Planning stage (24h in advance):** allocate flights per group of gates
  - **Reallocation stage (≥1 h before):** allocate (and block) flights to gate within the gate group
- Use historical data to compute arrival estimation errors distributions per different times before the arrival/departure
- Maximize allocations to gate and stability of the flight orders (based on error estimation distributions)

TU Delft

Reliable Gate Allocation

- Errors decrease when getting close to the ETD/ETA
- Last flight information (emitted by the airline) is used to update ETD/ ETA
- ETD/ETA is estimated based on information + error distribution at that period



Reliable Gate Allocation

Problem

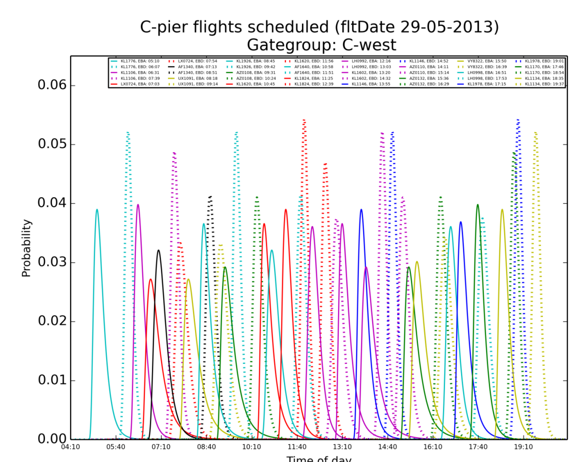
- Almost 40% of flights have at least one gate change
- Around 20% of passengers have a wrong gate on their boarding pass

Data

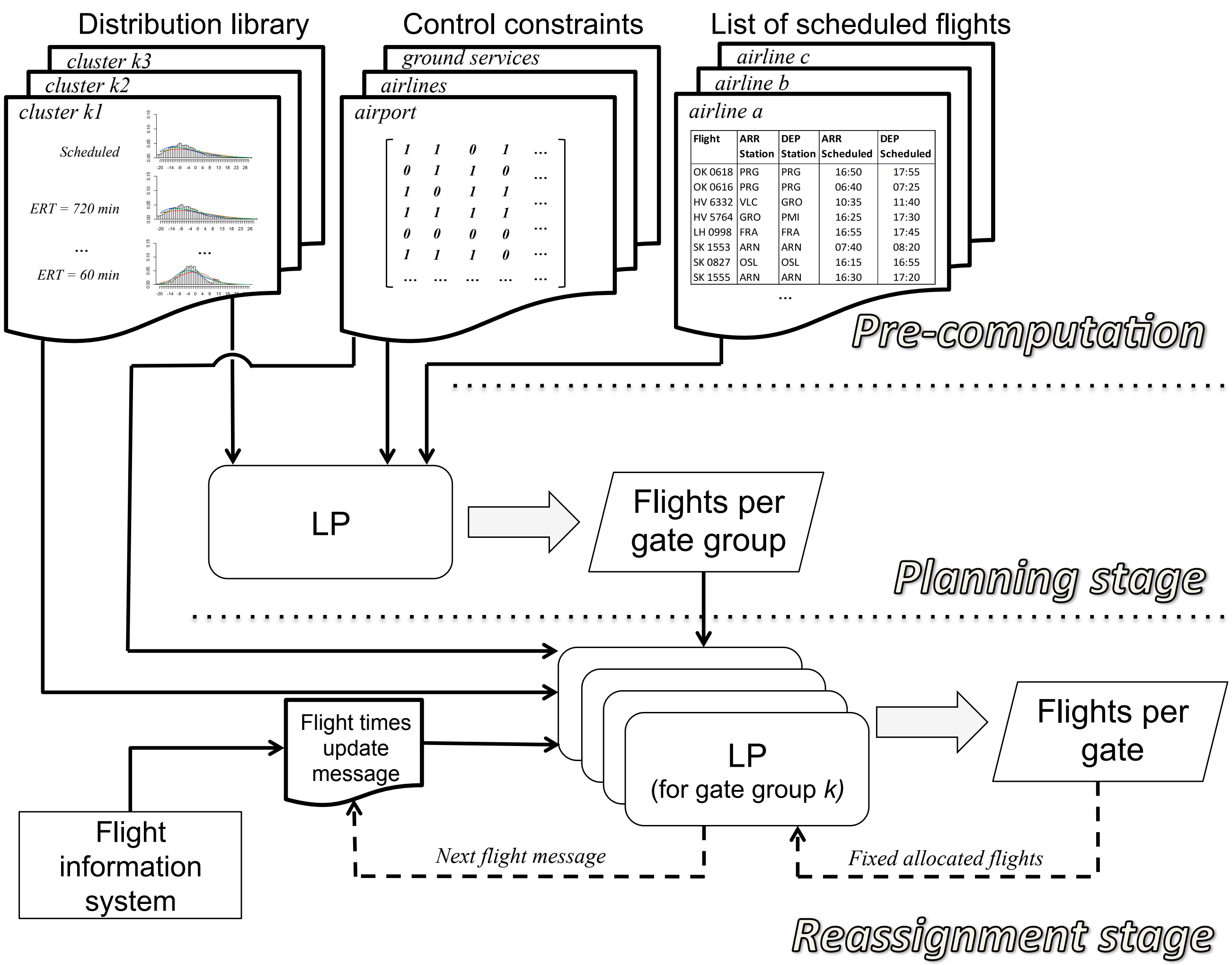
- Flight Information Royal Dutch Airlines (FIRDA)
  - 1st September 2012 and 31st August 2013
  - 10 million communications records
- Pier(s) structure and airlines' preferences

Analysis

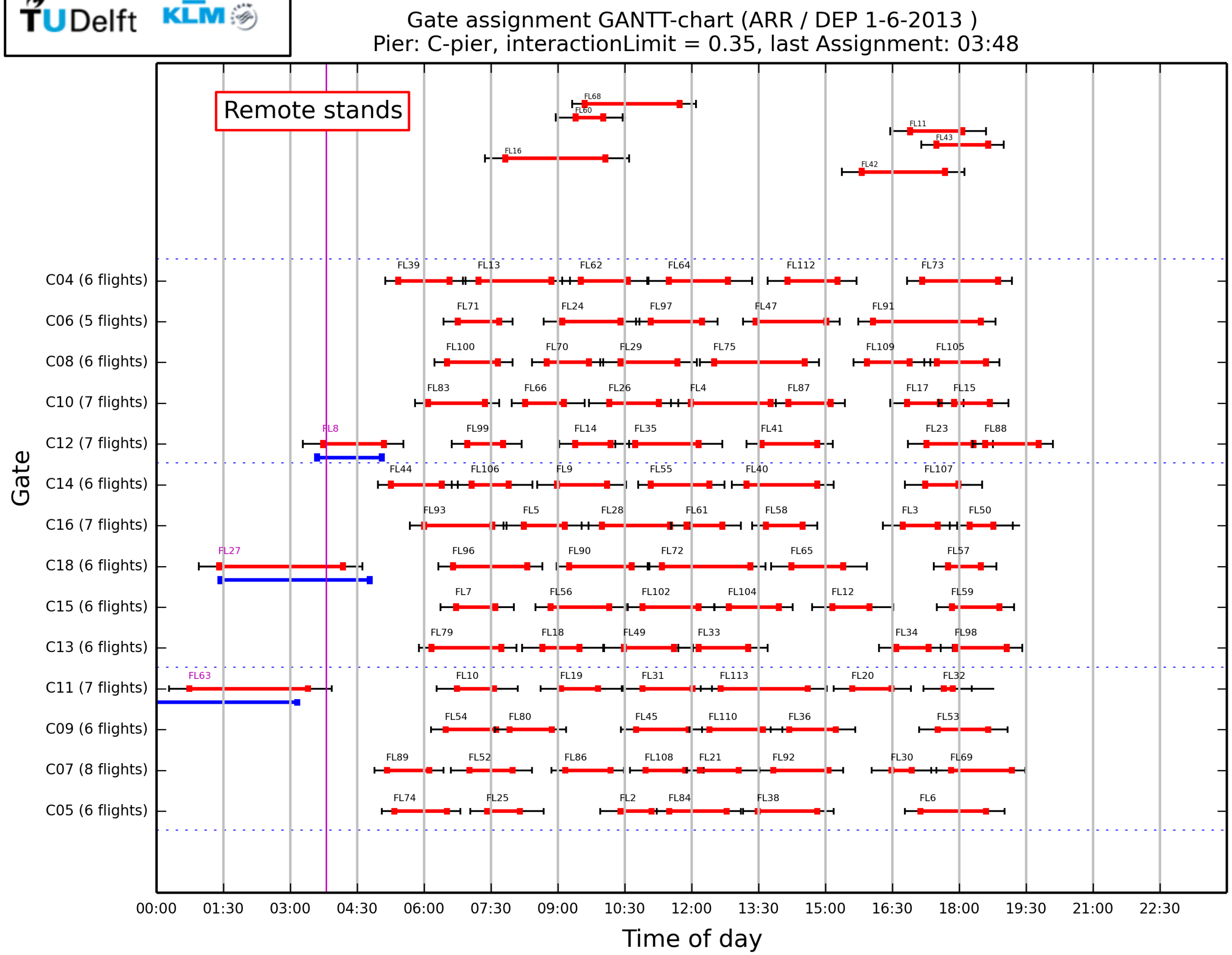
- Stabilize the order of events for a sequence of flights
  - Risk on disturbances is managed for a group of flights
  - Aircraft visits (arrival and departure flights) are considered for a complete sequence



Reliable Gate Allocation



Reliable Gate Allocation



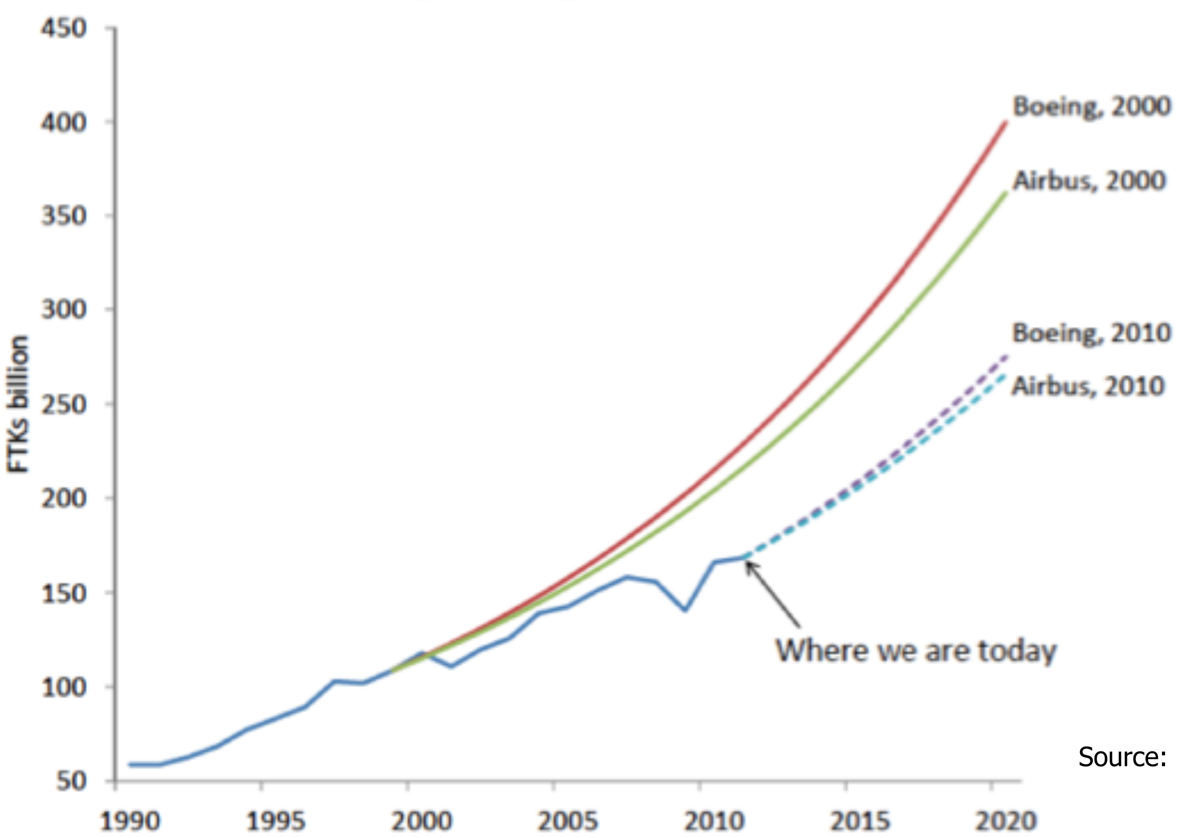
Link for video (click here)

Planning with Uncertainty

- Fleet Planning with Demand Uncertainty

Fleet Planning with Demand Uncertainty

We look to the future with biased assumptions and with the guarantee of having our 'best guess' most likely wrong



Source: IATA - Vision 2050 (2011)

Fleet Planning with Demand Uncertainty

General research objective:

Develop multi-period fleet development plans with demand uncertainty

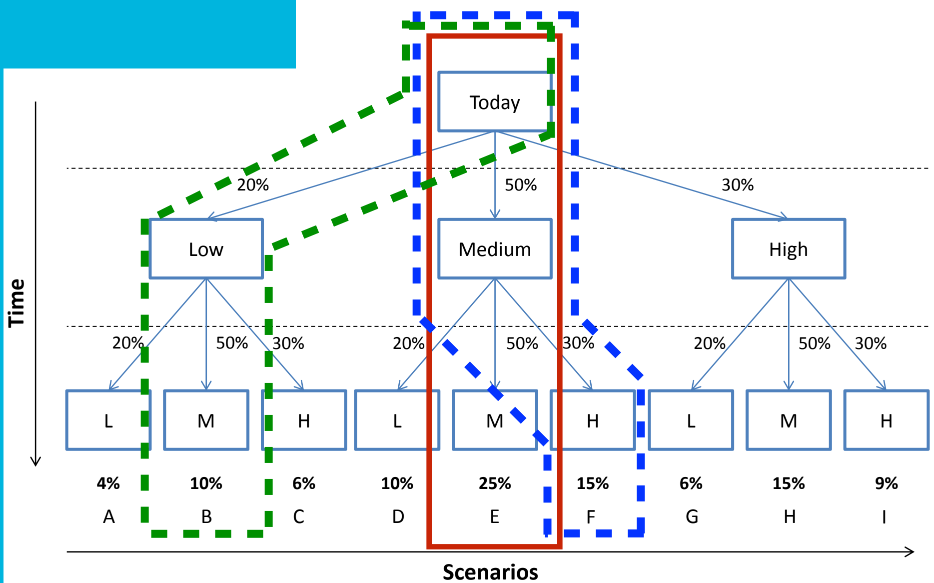
Approach

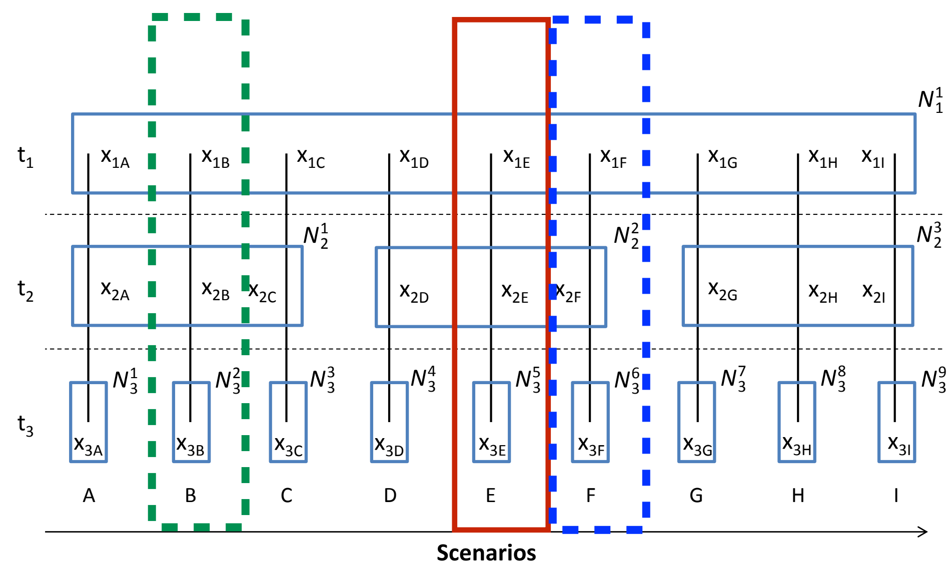
- Scenario tree approach where scenarios are f(demand growth levels, probabilities)
  - Nodes - points of decision in multiple time stages of the planning horizon
  - Branches - demand variation scenarios
- Fleet decision per node and coherent per scenario path (set of nodes linked by branches)

TU Delft

Fleet Planning with Demand Uncertainty

- branches link the decision nodes in consequent time stages and compose scenario paths
- given that some scenario paths share common decision nodes, decisions among scenarios need to synchronized



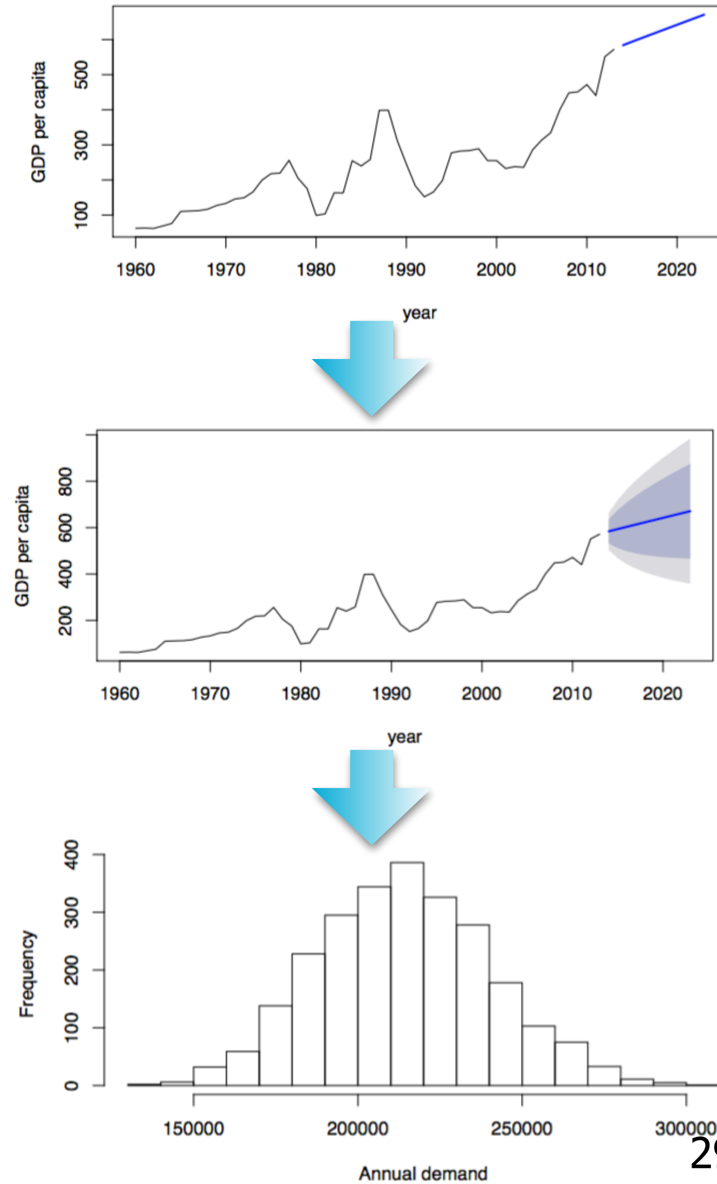


TU Delft

Fleet Planning with Demand Uncertainty

Demand modeling

1. Using socio-economic factors (e.g., GDP, Pop, common language) a prediction model is estimated
2. Input variables are assumed as random and are repetitively generated to forecast future demand values
3. A demand distribution is obtained for each time period in the planning horizon.



Fleet Planning with Demand Uncertainty

Problem

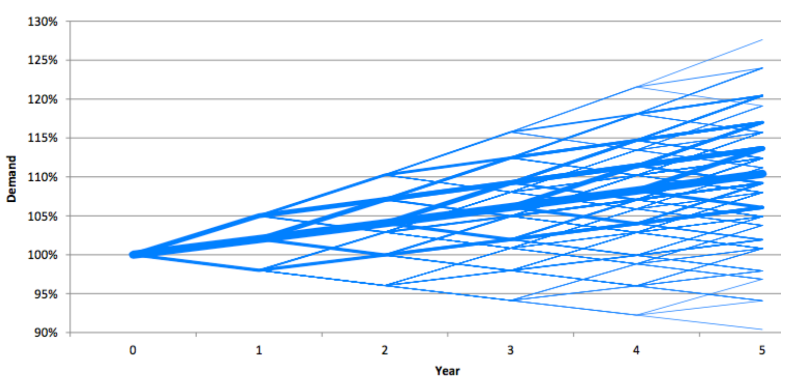
- Planning the transition between generations of aircraft, studying a set of fleet composition options for an H&S airline

Data

- Demand data for the routes served by the airline
  - from 2013 to 2015
  - 12 700 OD pairs
- Socio-economic data per country
  - from 2013 and 2014
- Costs per aircraft type/option and per route

Analysis

- Decisions per node at each point in time
- Fleet composition at multiple periods
- Given the probability of a scenario, fleet composition probabilities for each time-period can be determined



Fleet Planning with Demand Uncertainty

Results example

Decision per time-period and scenario

	Year 0		Year 1		Year 2	
Nodes	*Fleet*	*Buy/sell*	*Fleet*	*Buy/sell*	*Fleet*	*Buy/sell*
0HH	0/6/5	0/0/0	0/6/5	0/+2/0	0/8/5	0/+1/0
0HM	0/6/5	0/0/0	0/6/5	0/+2/0	0/8/5	0/0/+1
0HL	0/6/5	0/0/0	0/6/5	0/+2/0	0/8/5	0/0/0
0MH	0/6/5	0/0/0	0/6/5	0/+1/0	0/6/6	0/0/+1
0MM	0/6/5	0/0/0	0/6/5	0/+1/0	0/6/6	0/0/0
0ML	0/6/5	0/0/0	0/6/5	0/+1/0	0/6/6	+1/+1/0
0LH	0/6/5	0/0/0	0/6/5	+1/0/0	1/6/5	0/+1/0
0LM	0/6/5	0/0/0	0/6/5	+1/0/0	1/6/5	0/+1/+1
0LL	0/6/5	0/0/0	0/6/5	+1/0/0	1/6/5	0/0/0

Fleet per year, per scenario

Stage	Node	Probability	B772	B773	B788	Total
1	-	1.00	0	7	3	10
2	H	0.30	0	7	3	10
2	M	0.50	0	7	3	10
2	L	0.20	0	7	3	10
3	HH	0.09	0	8	4	12
3	HM	0.15	0	8	4	12
3	HL	0.06	0	8	4	12
3	MH	0.15	0	7	3	10
3	MM	0.25	0	7	3	10
3	ML	0.10	0	7	3	10
3	LH	0.06	0	6	3	9
3	LM	0.10	0	6	3	9
3	LL	0.04	0	6	3	9

Fleet probabilities given the scenario tree

Aircraft	*B777-200*	*B777-300*	*B787-8*	Total
0	54%	0%	0%	0%
1	36%	0%	0%	0%
2	9%	0%	0%	0%
3	0%	0%	0%	0%
4	0%	0%	2%	0%
5	0%	0%	51%	0%
6	0%	1%	41%	0%
7	0%	26%	6%	0%
8	0%	44%	0%	0%
9	0%	24%	0%	0%
10	0%	5%	0%	0%
11	0%	0%	0%	0%
12	0%	0%	0%	1%
13	0%	0%	0%	25%
14	0%	0%	0%	42%
15	0%	0%	0%	25%
16	0%	0%	0%	7%

TU Delft

Resilience in a Complex System

- Resilience Analysis with Complex Adaptive Systems Theory

TU Delft

Resilience Analysis

General research objective

Enhance the ability of a system to adjust its functioning prior to, during, or following expected and unexpected disturbances, so that it can sustain required operations

Approach

- By establishing relations between aggregation levels through simulation we examine how resilience emerges through different aggregation levels
- To model resilience we use methods based on integration of hierarchical General Systems Theory (top-down control) and Complex Adaptive Systems Theory (bottom-up self-organization)

TU Delft

Resilience Analysis

We address 3 capacities of resilience of air transport systems

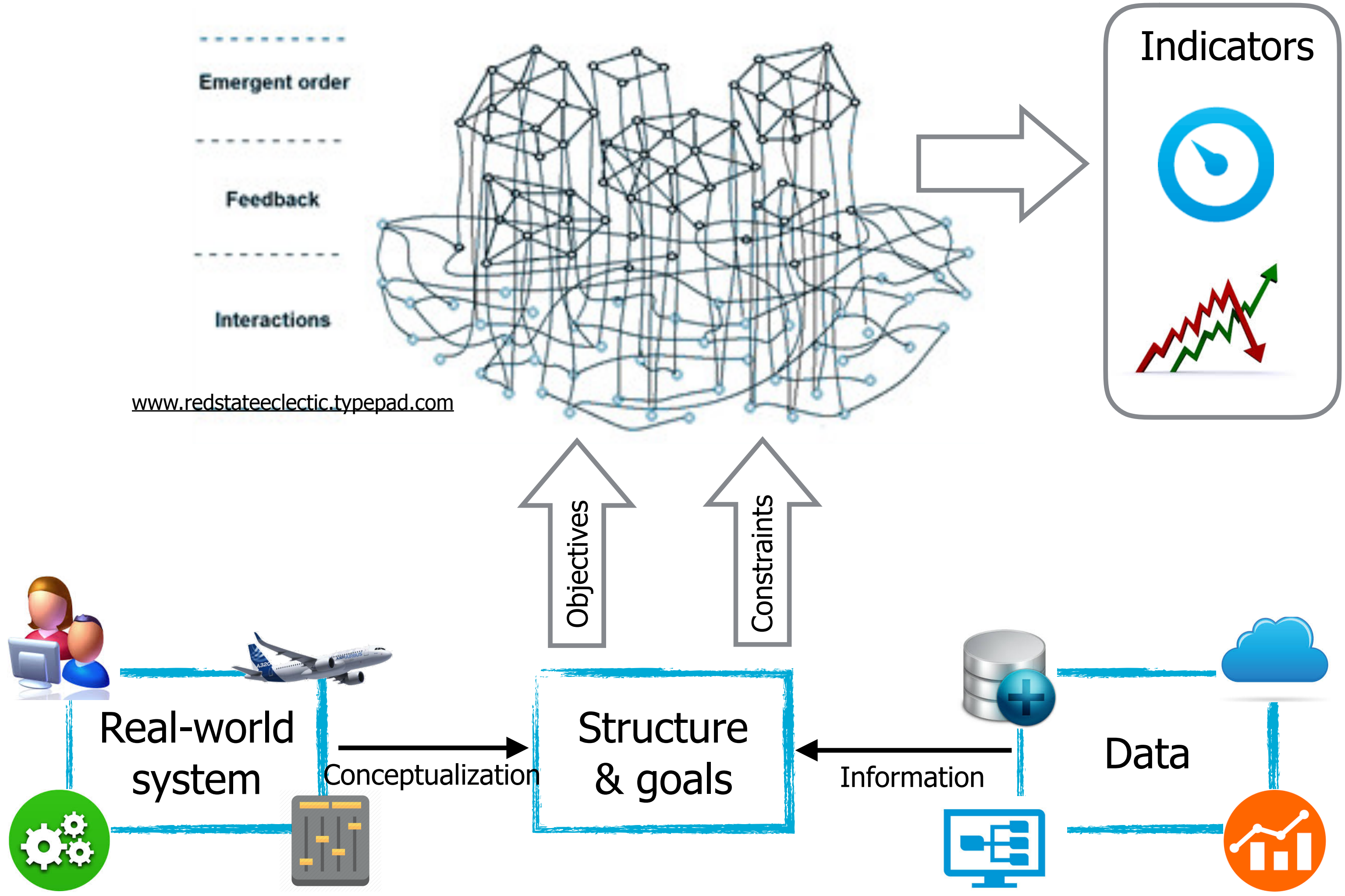
- **adaptive capacity** – the ability of a system to adjust to existing or anticipated undesirable situations by undergoing some changes
- **absorptive capacity** – the degree to which a system can absorb the impacts of system perturbations
- **restorative capacity** – characterized by rapidity of return to normal or improved operations

And we can model resilience at 4 aggregation levels

- individual (e.g., pilot, ATCo)
- team (e.g., pilots-ATCos, platform employees, OCC)
- organizational (e.g., airline, ANSP)
- inter-organizational (e.g., airports interacting with airlines and ANSPs)

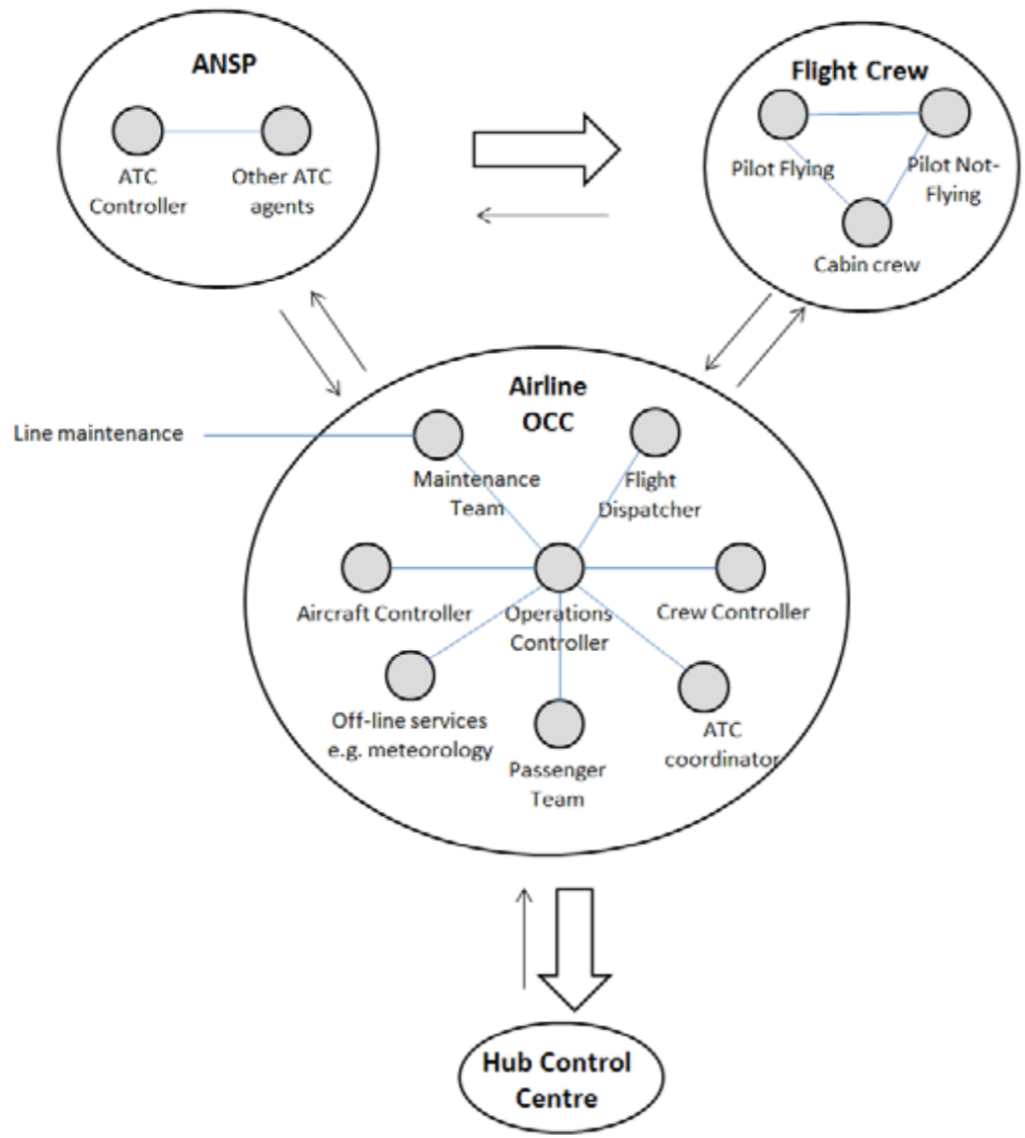
TU Delft

Complex Adaptive Systems



Complex Adaptive Systems

Airline OCC example



Bouarfa et al 2014, AIAA Aviation

http://arc.aiaa.org/doi/pdf/

10.2514/6.2014-3146

TUDelft

Resilience Analysis

Project examples

- data-driven modeling of mechanisms of anticipation of disruptions using Complexity Science methods
- identification of mechanisms of effective coordination in teams comprising humans and technical systems in ATM
- adaptive re-organization of air transport systems to accommodate/recover from major disruptions (e.g., volcano eruptions)
- identifying resilience indicators that reflect dynamics of resilience mechanisms at different aggregation levels (individual, team, organizations, inter-organizational)

Conclusions

Airlines in Brazil are facing challenging times

- liberalization/deregulation of the market
- continuous growth (demand and supply)
- alliances and international reposition
- not healthy operational profitability numbers

Several opportunities and threats emerge from this situation

These challenges demand investment in R&D and create opportunities for research in airlines operations

TUDelft

Conclusions

Future research may focus on one or multiple points:

- System complexity - network effects, multi-agent, multi-time periods
- System dynamics - system status stochastically changes overtime and decisions are made with partial knowledge of the future
- Integrated sub-systems - e.g., integrate maintenance scheduling with fleet management or considering multi aircraft components for condition-based maintenance planning

- Uncertainty - reliability, resilience and flexibility of the system to exogenous and endogenous unpredictability factors
- Big data - use information to generate valuable knowledge and enhance planning capacity

TU Delft

Conclusions

Development of decision-support and analysis tools and not create decision-making tools

- the importance of controllers
- the sense of controllability and the fear of risk

- the goal is to generate questions and explore knowledge

TUDelft

SITRAER 2015
AIR TRANSPORTATION SYMPOSIUM
São José dos Campos, SP, Brazil
October 26 - 28, 2015

Bruno F. Santos
Assistant Professor
TU Delft
Air Transport & Operations
Faculty of Aerospace Engineering
Delft University of Technology

W www.lr.tudelft.nl/ato
E B.F.Santos@tudelft.nl

TUDelft