Assessing ATM Performance Interdependencies through Bayesian Networks

Preliminary results

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ICRAT 2014, Istanbul – 29th May 2014
ALG is part of Indra Business Consulting, the strategy consultancy division of Indra, a global leader in business and technology consulting

- Founded in 1994
- Among the top management consulting firms in Europe and Latin America
- Projects in more than 40 countries
- Ongoing expansion at international level, with 14 Indra Business Consulting offices in Europe, Latin America, Africa, the Middle East and Asia
- Turnover of €66 m and a team of more than 600 professionals

- Integration and development of systems, outsourcing
- Innovative and high technology solutions
- Ticketing systems
- ASP development and e-business solutions
- Centers of technological competence:
  - Customer Relationship Management
  - Supply Chain Management

- Leading Spanish company in IT and Defence systems
- Key programmes for European and international defence
- European leader in surveillance and electronic intelligence
- On the cutting edge of simulation technology and excellence in maintenance systems

- Public sector projects (e.g. Voting machines and election management systems)
- Projects for leading clients in the transport sector (air traffic, terrestrial traffic and public transportation)
- Others: e-ticketing, ATMs, traffic control of high speed trains

Top-tier European consultancy and IT firm
Sales volume > €3,000 million€ (1)
More than 40,000 employees (1)
Presence in more than 115 countries
Growth rate and EBITDA above sector average
ALG is the Transportation and Infrastructure consulting practice

- ALG is the Transportation, Infrastructure and Logistics practice within Indra Business Consulting with:
  - Annual revenue of over 20 million $
  - More than 2,000 projects in more than 50 countries
  - Multidisciplinary team with 140 consultants (40% LatAm, 30% Europe, 15% Middle East & Asia, 15% Africa)
    - Wide knowledge and experience in the complete life cycle of transportation and infrastructure businesses
    - Our professional team combines a multi-disciplinary focus in the key strategic areas (business management, engineering, operations, economics, information systems)

Sector expertise

Transport
- Aviation
- Urban mobility and public transportation
- Ground transportation
- Traffic and tolls

Logistics
- Supply chain
- Maritime transportation
- Railroads
- Logistic platforms
ALG has acquired a strong international experience

We have delivered more than 2,000 projects carried out over the last 25 years
Our work model focuses on the achievement of tangible results, providing comprehensive service offering within the Indra portfolio.

- Technology consulting
- Business Process Outsourcing (BPO)
- Maintenance and Management of Applications
- Outsourcing of distributed Systems and work positions
- Outsourcing of the management of infrastructures and operation

**Top management consultancy**

**Analysis**
- Market and client analysis
- Diagnosis of capabilities and competitive position
- Description of sector trends
- Identification of business opportunities

**Conceptualization**
- Generation of alternative solutions
- Value quantification of alternatives
- Facilitation of decision-making
- Implementation planning

**Implementation**
- Team management
- Internal and external negotiations
- Execution of specific tasks

**Value creation**
- Increasing revenue
- Raising margins
- Developing competitive advantage
- Launching new businesses

- Strategic Planning of Systems and New Technologies
- Diagnosis of the Systems Function
- Selection of technologies and specific solutions
- Implementation of packages commercial solutions of market
- Development of tailored solutions
- Cost modeling

- Understanding of the value creation opportunities
- Design of strategies
- Programme management
- Generation of concrete results
Motivation

State of the art

The model

Use of the model
**Single European Sky & Performance Scheme**

European Commission’s ambitious initiative aiming to meet future ATM capacity and safety needs

- Proposes a legislative approach **Performance Scheme** (Regulation)
- **European Commission** establishes targets in **key areas** to be accomplished by ATM actors: *Safety, Capacity, Cost efficiency and Environmental Flight Efficiency*
Performance regulations in European ATM

- Charges modulation to reflect performance
- Full Cost Recovery principle
- Based on Service provision regulation
- Targets for Capacity, Environment and Cost Efficiency
- Determined Unit Rate
- Risk-sharing mechanisms
- Incentive schemes

2004

(EC) No 219/2007 SESAR JU
(EC) No 1794/2006 Charging Scheme Full Cost recovery

2009

(EC) No 1070/2009 SES II

2013

(EC) No 691/2010 Performance scheme RP1
(EC) No 1191/2010 Charging Scheme Determined cost model

(EC) No 390/2013 Performance scheme RP2
(EC) No 391/2013 Charging scheme Incentives

Motivation

(E) No 549/2004 SES Framework
(EC) No 550/2004 Service provision
(EC) No 551/2004 Airspace
(EC) No 551/2004 interoperability

- Charges modulation to reflect performance
- Full Cost Recovery principle
- Based on Service provision regulation

- Targets for Capacity, Environment and Cost Efficiency
- Determined Unit Rate
- Risk-sharing mechanisms
- Incentive schemes

- Response to the worsen saturation of European airspace and the increase of delays
- Legal basis for the common charging and performance schemes

- Extension of the Regulation’s scope to terminal ANS costs
- Move to a system of binding performance targets with incentives

- Targets for Safety, Capacity, Environment and Cost Efficiency
- Mandatory financial incentive to reach the capacity targets
- Incentives on other targets

Interoperability

Assessing ATM Performance Interdependencies through Bayesian Networks

ICRAT 2014, Istanbul, May 2014
Motivation

KPAs and KPIs defined by SESII

Safety
- Effectiveness of safety management (“maturity”)
- Application of severity classification scheme
- Application of Just Culture
- Runway incursions
- ATM special technical events
- Separation infringements
- Level of occurrence reporting
- Application of automatic data recording for separation minima infringement monitoring
- Application of automatic data recording for runway incursion monitoring

Environment
- En-route ATFM delay
- Arrival ATFM delays
- ATFM Slot adherence
- ATC pre-departure delay
- Additional time in taxi-out phase
- Additional time in arrival sequencing and metering area (ASMA)

Capacity
- Determined Unit Cost (DUC) for En route ANS (Determined Unit Rate DUR in RP1)
- Determined Unit Cost (DUC) for terminal ANS
- Terminal Unit Rate
- Terminal costs
- Costs of EUROCONTROL
- Horizontal flight efficiency of last filed flight plan (KEP)
- Horizontal flight efficiency of actual trajectory (KEA)
- Effectiveness of booking procedures for FUA
- Rate of planning of CDRs
- Effective use of CDRs
- Additional time in taxi-out phase
- Additional time in arrival terminal airspace (ASMA)

Target assigned also for RP1
Assessing ATM Performance Interdependencies through Bayesian Networks

ICRA 2014, Istanbul, May 2014

Motivation

State of the art

The model

Use of the model
## Relevant literature of performance interdependencies in ATM

<table>
<thead>
<tr>
<th>Capacity vs Cost efficiency</th>
<th>Econometric Cost Efficiency study</th>
<th>Capacity vs Cost efficiency</th>
<th>Traffic levels vs Cost effectiveness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assessing the true cost of delay to Airlines*</td>
<td>Econometric Cost-efficiency benchmarking of ANSP*</td>
<td>The Optimum Capacity/Delay trade-off*</td>
<td>A Network Pricing Formulation model*</td>
</tr>
<tr>
<td>- Study of the University of Westminster in collaboration with PRU*</td>
<td>- Estimates a cost function for the provision of ANS</td>
<td>- Future ATM Profile tool for ATFM simulation</td>
<td>- Castelli et. al study the dependencies of ANSP’s revenue as a function of the Unit rate</td>
</tr>
<tr>
<td>- Cost of strategic and tactical delay</td>
<td>- Demonstrates the presence of economies of scale and density in ANS</td>
<td>- Cost model analysis</td>
<td>- Results based on simulations</td>
</tr>
<tr>
<td>- Criteria for re-routing decision</td>
<td>- Assesses the level of ANSP inefficiency</td>
<td></td>
<td>- Criteria for Unit Rate optimization</td>
</tr>
</tbody>
</table>

*Cook, G. Tanner, and Anderson, University of Westminster:*
- “Evaluating the true cost to airlines of one minute of airborne or ground delay”, study for Performance Review Commission (EUROCONTROL), 2004.
- “European airline delay cost reference values”, study for EUROCONTROL Performance Unit, 2011.

*Performance Review Unit Econometric cost-efficiency benchmarking of Air Navigation Service Providers”, May 2011


State of the art

**Capacity vs Cost efficiency**

**Assessing the true cost of delay to Airlines**

- Study performed by the University of Westminster in collaboration with the PRU
- Provides a number of figures useful to quantify the link between the capacity and the cost efficiency

### Airline delay cost

<table>
<thead>
<tr>
<th>Strategic cost</th>
<th>Tactical cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel cost</td>
<td>Primary delay:</td>
</tr>
<tr>
<td>Maintenance</td>
<td>- Fuel</td>
</tr>
<tr>
<td>Fleet</td>
<td>- Crew</td>
</tr>
<tr>
<td>Crew</td>
<td>- Maintenance</td>
</tr>
<tr>
<td>block-hour costs</td>
<td>- Passenger</td>
</tr>
<tr>
<td>Passengers (not considered in the study)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Secondary or reactionary</td>
</tr>
<tr>
<td></td>
<td>- Crew</td>
</tr>
<tr>
<td></td>
<td>- Maintenance</td>
</tr>
<tr>
<td></td>
<td>- Passenger</td>
</tr>
</tbody>
</table>

- Re-routing case → calculate the cost of the flight delay and the alternative route

- Calculated Take-Off Time delay < 15 min
  - Not worth a re-routing

- Calculated Take-Off Time delay > 15 min
  - airborne extension n possibly accepted if CTOT reduction is:
    $$[(1.1n ÷ 1.3n) + 10]min$$
Econometric regression model

### Cobb-Douglas cost function

\[ \log C_{it} = \alpha + \beta \log x_{it} + u_{it} \]

for ANSP “i” and year “t”

<table>
<thead>
<tr>
<th>Variables ((C_{it}, x_{it}))</th>
<th>Definition</th>
<th>Pit &amp; Lee Random effect model</th>
<th>True Random Effects model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Coeff. ((\beta))</td>
<td>Std. errors ((u_{it}))</td>
</tr>
<tr>
<td>C</td>
<td>Total ATM/CNS provision costs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Y</td>
<td>Output measure i.e. number of composite flight-hours</td>
<td>0.57</td>
<td>0.06</td>
</tr>
<tr>
<td>W1</td>
<td>Average employment costs per hour for ATCOs in OPS</td>
<td>0.28</td>
<td>0.02</td>
</tr>
<tr>
<td>W2</td>
<td>Average employment costs for support staff</td>
<td>0.28</td>
<td>0.02</td>
</tr>
<tr>
<td>W3</td>
<td>Price of non-staff operating inputs (index for producer goods)</td>
<td>0.37</td>
<td>-</td>
</tr>
<tr>
<td>W4</td>
<td>Capital input price</td>
<td>0.07</td>
<td>0.02</td>
</tr>
<tr>
<td>VAR</td>
<td>Traffic variability</td>
<td>1.27</td>
<td>0.20</td>
</tr>
<tr>
<td>NET</td>
<td>Network Concentration</td>
<td>-0.34</td>
<td>0.09</td>
</tr>
<tr>
<td>Size</td>
<td>Size of airspace controlled</td>
<td>0.28</td>
<td>0.11</td>
</tr>
<tr>
<td>COMP</td>
<td>Structural traffic complexity</td>
<td>-0.04</td>
<td>0.09</td>
</tr>
<tr>
<td>BUS</td>
<td>Business environment quality</td>
<td>-0.22</td>
<td>0.04</td>
</tr>
<tr>
<td>T</td>
<td>Time trend</td>
<td>-0.02</td>
<td>0.00</td>
</tr>
<tr>
<td>Constant ((\alpha))</td>
<td>ANSP level of inefficiency</td>
<td>4.27</td>
<td>1.45</td>
</tr>
<tr>
<td>Inefficiency</td>
<td>ANSP level of inefficiency</td>
<td>60%</td>
<td>13%</td>
</tr>
</tbody>
</table>
State of the art

Delay, capacity and costs

Costs M€

Capacity / Traffic Volume

Cost of ANS capacity (en route)

Minimise total costs to airspace users

Traffic demand

Cost of ATFM delay (en route)


The Optimum Operating Point represents the best trade-off between the cost of providing capacity and the cost of delay for a particular ACC
State of the art

Traffic levels vs Cost effectiveness

**A Network Pricing Formulation model**

- European ANSP sets its Unit Rate annually, according to EC Regulation (1191/2010)
- Castelli et. al study the dependencies of ANSP’s revenue as a **function of the Unit Rate**

**Route Charge**

\[ RC = l \times w \times T \]

- \( l \) (distance factor): \[ l = \frac{d \text{ (Great Circle Distance)}}{100} \]
- \( w \) (weight factor): \[ w = \sqrt{\frac{MTOW}{50}} \]
- \( T \) (Unit Rate): charge imposed on a flight per 100 km flown in a given charging zone and per 50 metric tonnes of aircraft weight

**Determine the optimal T for both ANSP and Airspace Operator through a Bilevel Programming framework**

**Cost of one flight**

**ANSP Revenue for one simulation**
Methodology approach – Bayesian Networks

**Bayesian Network** - an influence diagram where each node represents a discrete variable, an arc represents a causal influence between the linked variables and the strength of this influence can be quantified using probabilities.

- Graphical model that encodes probabilistic relationships
- Considers dependencies among all variables

**Bayesian Inference (belief update)**
- Calculate posterior probabilities \( P(X|\mathcal{E}) \) with \( \mathcal{E} \) collected evidence

**Marginal probability of A**

<table>
<thead>
<tr>
<th>A</th>
<th>P(A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>0.7</td>
</tr>
<tr>
<td>Moderate</td>
<td>0.2</td>
</tr>
<tr>
<td>Low</td>
<td>0.1</td>
</tr>
</tbody>
</table>

**Conditional probability of B**

| P(B|A) | A    |
|-------|------|
|       | High | Moderate | Low  |
| TRUE  | 0.8  | 0.4      | 0.1  |
| FALSE | 0.2  | 0.6      | 0.9  |

**Marginal probability of B**

<table>
<thead>
<tr>
<th>B</th>
<th>Computation</th>
<th>P(B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRUE</td>
<td>0.8<em>0.7+0.4</em>0.2+0.1*0.1</td>
<td>0.65</td>
</tr>
<tr>
<td>FALSE</td>
<td>0.2<em>0.7+0.6</em>0.2+0.9*0.1</td>
<td>0.35</td>
</tr>
</tbody>
</table>
Strengths and Weaknesses of Bayesian Networks

**Strengths**

- Intuitive representation of the cause-effect relationships among involved variables
- Uncertainty about problem domain can be encoded in a probabilistic interaction model
- White box model permitting different possible analysis: independence analysis, sensitivity analysis, value of information
- Allows building knowledge from historical data in a quantitative way
- Many efficient algorithms to learn Bayesian Network from data and fuse with expert knowledge

**Weaknesses**

- Requires an extensive set of data to derive both structure and parameters
- Uses a large number of probabilities in numerical form
- Computational complexity grows exponentially with the number of nodes
Motivation
State of the art
The model
Use of the model
High level ANS system – the economic view

Inputs/Outputs relationships in the provision of ANS

- **Economies of scale:**
  - Larger ANSPs tend to have lower unit costs
- **Economies of density:**
  - Additional traffic can be absorbed using same resources

**The Model**

- **Cost of ANS production**
- **Revenue**
- **Capacity of ANS production**
- **Demand for ANS**
- **ANS-related delays**
- **Demand-capacity balancing**
- **Financial sustainability**
Building a Bayesian Network – Preliminary BN

Data driven process

- Dataset
- Learn New Structure
- Preliminary Bayesian Network
- Expert judgment
- Knowledge from literature
- Structure Rules
- Final Bayesian Network

Model refinement

The Model

Controlled IFR traffic
Traffic density*structural index
Flight Hours / ATCO hours on-duty

Local factors

ANSP

ATFM Delay/fl-hr

ANSP Size

Area of airspace in km²

ATCO productivity

Adjusted ATCO Cost/fl-hr

PPP adjusted hourly ATCO cost / Flight Hours

Power Constructor algorithm
[Cheng, 1998]

based on independence tests
Building a Bayesian Network – Final BN

Model refinement

- Expert judgement – added value from team expertise
- Knowledge from literature - gained from analysing the background of the project
- Structure rules – absence of cycles and minimal number of variable’s parents to limit computational complexity
The Model

Scope of the model

Geographical scope: 27 ANSPs – En-route airspace only

<table>
<thead>
<tr>
<th>Air Navigation Service Providers</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Aena</td>
<td>IAA</td>
</tr>
<tr>
<td>ANS CR</td>
<td>LFV</td>
</tr>
<tr>
<td>Austro Control</td>
<td>LPS</td>
</tr>
<tr>
<td>Avinor</td>
<td>LVNL</td>
</tr>
<tr>
<td>Belgocontrol</td>
<td>MATS</td>
</tr>
<tr>
<td>BULATSA</td>
<td>M-NAV</td>
</tr>
<tr>
<td>Croatia Control</td>
<td>MUAC</td>
</tr>
<tr>
<td>DCAC Cyprus</td>
<td>NATS</td>
</tr>
<tr>
<td>DFS</td>
<td>NAV Portugal</td>
</tr>
<tr>
<td>DSNA</td>
<td>NAVIAIR</td>
</tr>
<tr>
<td>EANS</td>
<td>ROMATSA</td>
</tr>
<tr>
<td>ENAV</td>
<td>Skyguide</td>
</tr>
<tr>
<td>HCAA</td>
<td>Slovenia Control</td>
</tr>
<tr>
<td>HungaroControl</td>
<td></td>
</tr>
</tbody>
</table>

Temporal scope: 9 years

Annual values for 2003 - 2011

Performance data availability

<table>
<thead>
<tr>
<th>Variable (Values per year and per ANSP)</th>
<th>Data source</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATFM Delay</td>
<td>Performance Review Report</td>
</tr>
<tr>
<td>Traffic Complexity</td>
<td></td>
</tr>
<tr>
<td>Flight hours</td>
<td></td>
</tr>
<tr>
<td>En Route ATCO hours on-duty</td>
<td></td>
</tr>
<tr>
<td>En Route ATCO cost per hour adjusted by PPP</td>
<td>ATM Cost Efficiency report</td>
</tr>
</tbody>
</table>
Probabilistic model - Discretization

**Definition**

- Discretization → Convert continuous variables into discrete ones

**Example – Flight Hours node**

3 States

Equivalent number of observations

States' limits

States distribution

Observation frequency

Greater sample dispersion for High State

<table>
<thead>
<tr>
<th>Method</th>
<th>Uniform Counts</th>
<th>Bin count</th>
<th>3</th>
<th>Prefix</th>
</tr>
</thead>
<tbody>
<tr>
<td>From</td>
<td>To</td>
<td>Count</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low State</td>
<td>152485</td>
<td>81</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium State</td>
<td>315942</td>
<td>81</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High State</td>
<td>315942</td>
<td>81</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5 biggest ANSPs in Europe

- AENA
- ENAV
- DFS
- NATS
- DSNA
Motivation

State of the art

The model

Use of the model
Use of the model – analyze and predict

1 Behavioral analysis of past performance
   • Getting insights on the complex relationships among factors affecting performance, by applying Bayesian inference

   Bayesian inference – computing the impact of observing values of a subset of the model variables on the probability distribution over the remaining variables.

   - Inputs are set as evidence for the desired nodes
   - The remaining variables, with no evidence set, are Outputs

2 Predictive model
   • Assess the probabilities of compliance with the performance targets imposed by the Performance Scheme Regulation at:
     • European level
     • National level
Use of the model

Presence of economies of density and scale

Adjusted ATCO cost/fl-hr probability of occurrence

- > 82.24 €/fl-hr
- 62.45 - 82.24 €/fl-hr
- < 62.45 €/fl-hr

<table>
<thead>
<tr>
<th>Flight hours in ANSP Size</th>
<th>P(High costs) ↓</th>
<th>P(High costs) ↑</th>
<th>P(High costs) ↑</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 152465 fl-hr</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>152465 - 315942 fl-hr</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; 315942 fl-hr</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flight hours in ANSP Size</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 92800 km²</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>92800 - 389895 km²</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; 389895 km²</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Traffic ↑
- Small ANSPs
- Medium ANSPs
- Large ANSPs

ICRAF 2014, Istanbul - May 2014
Use of the model

**Traffic complexity vs number of Flight Hours**

<table>
<thead>
<tr>
<th>Traffic Complexity in ANSP Size</th>
<th>Flight hours probability of occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 92800 km²</td>
<td>&lt; 2.8</td>
</tr>
<tr>
<td>92800 - 389895 km²</td>
<td>2.8 - 5.8</td>
</tr>
<tr>
<td>&gt; 389895 km²</td>
<td>&gt; 5.8</td>
</tr>
</tbody>
</table>

- **Small ANSPs**
- **Medium ANSPs**
- **Large ANSPs**

Use of the model

**Traffic Complexity ↑**

**P(High Traffic) ↑**

<table>
<thead>
<tr>
<th>Traffic Complexity in ANSP Size</th>
<th>Flight hours probability of occurrence</th>
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<tbody>
<tr>
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<td>&gt; 3.8</td>
</tr>
<tr>
<td>152465 - 315942 fl-hr</td>
<td>2.8 - 5.8</td>
</tr>
<tr>
<td>&lt; 152465 fl-hr</td>
<td>&lt; 2.8</td>
</tr>
</tbody>
</table>
Traffic complexity vs ATFM delay

Use of the model
Traffic complexity vs ATFM delay and Adjusted ATCO costs

**Scenario 1**
High flight hours and **High ATCO productivity**
Small variation in costs
Big increase in Delays

**Scenario 2**
High flight hours and **Low ATCO productivity**
Big increase in costs
Moderate increase in Delays
Use of the model

Traffic complexity vs ATFM delay and Adjusted ATCO costs per ANSP size

Presence of economies of scale:

1. Similar probabilities for delays BUT Higher probabilities of High costs for low complexity
2. Probabilities of high costs reduce as complexity increases
Predictive use of the model – new structure

Aim of this second application of the model → assess the probabilities of compliance with the **Performance Scheme targets**

Align the model with the performance indicators: **ATFM Delay/flight** and **Unit Rate**

**Original structure**
- Flight Hours
- ATFM Delay/flight

**New structure**
- Flights
- ATFM Delay/flight
- Unit Rate

**New variable**
- ANSP Size
- Flights
- Traffic Complexity
- ATCO productivity
- Adjusted ATCO Cost/fl-hr
- Unit Rate

ATFM Delay/flight

Unit Rate
Performance Scheme targets for the second Reference Period (2015-2019)

Performance Scheme

Establishes the targets to be accomplished by the European Members in the areas of:

- Safety
- Capacity
- Cost efficiency
- Environmental flight efficiency

<table>
<thead>
<tr>
<th>KPA</th>
<th>KPI</th>
<th>Union wide targets for RP2 (2015-2019)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity</td>
<td>Average En-route ATFM delay</td>
<td>0,5 minutes per flight to be reached for each calendar year</td>
</tr>
<tr>
<td>Cost-efficiency</td>
<td>DUC (Determined Unit Cost)</td>
<td>2015</td>
</tr>
<tr>
<td></td>
<td></td>
<td>56,64</td>
</tr>
</tbody>
</table>

New discretization

Change the discretization according to the target values in order to determine their probability of compliance

3 States
- High
- Medium
- Low

ATFM Delay/flight Unit Rate

2 States
- High
- Low

ATFM Delay/flight
Low ≤ 0,5 min/flight < High Unit Rate
Low ≤ 49,10 €/SU < High Unit Rate
Assessing ATM Performance Interdependencies through Bayesian Networks

ICRAT 2014, Istanbul - May 2014

Use of the model

Probabilities of compliance with both targets

General European level

Targets seem to be ambitious:
38% probabilities of compliance with both targets

National level

Notable differences among ANSPs
Conclusions and next steps

The use of Bayesian Networks in ATM performance analysis allows:

- Building knowledge from historical data in a quantitative way
- An intuitive representation of the cause-effect relationships among involved variables
- Dealing with the stochastic nature of the underlying system in a natural and direct way
- Supporting decision making under uncertainty, e.g. when configuring resources for an ANSP
- Predicting future behavior based on past observations

Overcoming the current limitations:

- Increasing variables’ discretization levels trading off model complexity
- Adding more variables to comprehensively represent all influences
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