A Distributed Approach to Integrated and Dynamic Disruption Management in Airline Operations Control

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SUMMARY

1. Problem and Motivation
2. The Vision
3. A New Approach to Disruption Management
4. Prototype Demonstration
Problem and Motivation

From the set of possible solutions given certain time restrictions, what is the best solution to solve this unexpected event, with the minimum impact on passengers and with the minimum operational costs?

## Typical AOC Problem

**Consequences of this disruption if nothing is done:**
- A departure delay of the subsequent flight
- Possible departure delays on other flights due to crew delay
- Possible violations regarding labor rules
- Loss of passenger goodwill (disrupted and LIS pax)
- Some passengers will miss the connections to other flights
**CURRENT APPROACH**

Approach Used to Solve a Disruption (typically also used in AOCQ)

- Imposes an order of importance to each dimension

The best solution should be selected from the SET of INTEGRATED solutions and NOT built from a sequential process where some dimensions are more important than others.

**MOTIVATION**

Irregular operations can cost between 2% and 3% of the airline annual revenue  
(Chen 2010, IE&EM – Crew scheduling models in airline disruption management)

A better recovery process could result in cost reductions of at least 20% of its irregular operations  
(Irrang 1996, Air Transport Association of America – The Handbook of Airline Economics)

Current tools to optimize schedules and delays do not take into account passengers’ view of journey disruptions  
(Rose 2013, PhoCuswright, Amadeus Group – Passengers First: Re-thinking irregular operations)
The Vision

Future Airline Operations Control Centres should be **Automatic, Autonomous** and include **Learning** capabilities. **Monitoring** the operation, **Detecting** Problems that might affect the operation, **Finding** solutions to the problems, **Choosing** the best solution, **Updating** the operational plan accordingly and increase **Robustness** of future plans, should be done **Without** or with the **Minimum Human Intervention.**
**THE VISION**

**Automation:**
- Repetitive tasks:
  - Monitoring, Detecting, Finding, Updating...

**Autonomy:**
- Decision:
  - When to consider an event as a problem
  - Choose the best solution

**Learning:**
- Solving similar problems
- Increase robustness by avoiding repetitive problems

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**IS THIS VISION AN UTOPIA?**

B707 – 50, 60, 70’s – 3 Crew

L1011 – 1968 ... - 3 Crew
**IS THIS VISION AN UTOPIA?**

A330 – 1994 ... – 2 Crew  
A350 – 2013 - 2 Crew

How are they doing it?  
- Computers perform tasks that were done by humans  
- More than one computer to perform the same task  
- When two computers disagree a third makes the final decision

Very soon (according to Airbus) one man crew!
A New Approach to Disruption Management

NEW APPROACH DISRUPTION MANAGEMENT

1. Main Terminal
2. Flight Dispatch
3. Aircraft Manager
4. Engine
5. Cargo Manager
6. Handling Services
7. Maintenance Services
8. Passenger Manager
9. Crew Manager
10. Link
11. Cabin
12. ARP
13.aints
**SYSTEM ARCHITECTURE**

- **Distribution (functional, spatial and physical)**
- **Multiple-instances and Scalability**
- **Generalizable**

**LEVELS OF NEGOTIATION**

1. **Manager Agents Level**
   - *Agents cooperate* (by exchanging information) to *find* an *integrated solution* (one that considers the impact on the three dimensions problem)
   - Select the *best candidate solutions* with *lowest Total Operational Costs*

2. **Specialist Agents Level**
   - Each *agent* has a *specific expertise* (different resolution algorithm)
   - *Run in parallel* trying to *find* the *best candidate solutions*
   - *Total Operational Cost* is the criteria
• Multi-Attribute:
  – Each with a set of preferred values and domains
• Qualitative Feedback:
  – Organizer agent classifies the values of each attribute and gives feedback
• Several Rounds
• Inter-agents negotiation:
  – Respondent agents negotiate in each round to be able to complete their knowledge and present a proposal
• Learning:
  – Agents adapt their strategy during proposal formulation
• Multiple agent types and roles:
  – Organizer, Respondent. Initiator, Participants.
• Suitable for competitive and cooperative environments

**GQN Characteristics**

**GQN Applied MASDIMA**

3 agents
One for each dimension

Cooperate with each other

Propose integrated solutions

Compete win negotiation

Monitor

Send problem

Ask approval

Receives feedback

SEVERAL ROUNDS

1: CFP

2: PROPOSE
  CS1 = ps1 + ps12 + ps13

2: PROPOSE
  CS2 = ps2 + ps21 + ps23

2: PROPOSE
  CS3 = ps3 + ps31 + ps32

3: FEEDBACK

4: ACCEPT-PROPOSAL

AVC Manager

Crew Manager

Pax Manager

Get local solution ps1

Get local solution ps2

Get local solution ps3

INTER-MANAGER NEGOTIATION

REG ps1

INF ps12

REG ps1

INF ps13

REG ps2

INF ps21

REG ps2

INF ps23

REG ps3

INF ps31

INF ps2

INF ps3
**Costs Used to Search for Solutions**

**Operational cost:**
\[ OC = DC + \beta \times QC \quad \beta \in \mathbb{R}, \quad \beta \geq 0 \]

**Direct cost:**
\[ DC = FC + CC + PC \]

**Flight cost:**
\[ FC = \sum_{i=1}^{\left| F \right|} (TkoF_j + Land_i + Park_i + Maint_i + Air_i + Fuel_i) \]

**Crew cost:**
\[ CC = \sum_{i=1}^{\left| F \right|} \sum_{j=1}^{\left| C \right|} (Salary_{i,j} + ExTime_{i,j} + Perdiem_{i,j} + Hotel_{i,j} + Dhe_{i,j}) \]

**Pax cost:**
\[ PC = \sum_{i=1}^{\left| F \right|} \sum_{d=1}^{\left| P \right|} (Meals_{i,j} + Hotel_{i,j} + Comp_{i,d}) \]

**Quality cost:**
\[ QC_f = \alpha \sum_{p=1}^{\left| PP \right|} (P_p \times C_p) \quad P_p = (\gamma \times pl + tp) \]

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**Quality Costs – Generic Approach**

1. Define the existing classes of passenger profiles in the flight.
2. Define a delay cost for each passenger in a class.
3. Calculate \( QC \) using equations below.

\[ QC_f = \alpha \sum_{p=1}^{\left| PP \right|} (P_p \times C_p) \]

\[ P_p = (\gamma \times pl + tp) \]

\( p \)= a class of passenger profiles.  
\( P \)= number of pax in class \( p \).  
\( C \)= Delay Cost (m.u.) of each passenger in \( p \).
### SPECIALIST AGENTS: PROBLEM SOLVING

<table>
<thead>
<tr>
<th>Aircraft</th>
<th>Crew</th>
<th>Passenger</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sol_{ac} = {&lt;a_i, f_j&gt;,..., }</td>
<td>Sol_{cw} = {&lt;cw_i, as_j&gt;,..., }</td>
<td>Sol_{px} = {f_i, ..., f_n}</td>
</tr>
<tr>
<td>Delay(Sol_{ac})</td>
<td>Delay(Sol_{cw})</td>
<td>Delay(Sol_{px})</td>
</tr>
<tr>
<td>Cost(Sol_{ac})</td>
<td>Cost(Sol_{cw})</td>
<td>Cost(Sol_{px})</td>
</tr>
<tr>
<td>Penal(Sol_{ac})</td>
<td>Penal(Sol_{cw})</td>
<td>Penal(Sol_{px})</td>
</tr>
<tr>
<td>Min (Delay(Sol_{ac}) + Cost(Sol_{ac}) + Penal(Sol_{ac}))</td>
<td>Min (Delay(Sol_{cw}) + Cost(Sol_{cw}) + Penal(Sol_{cw}))</td>
<td></td>
</tr>
<tr>
<td>Simulated Annealing</td>
<td>Simulated Annealing</td>
<td></td>
</tr>
</tbody>
</table>

### SUPERVISOR AND MANAGER AGENTS

\[
U_{a/c} = 1 - \left( \frac{w_1 \left( \frac{ad}{\max(ad)} \right) + w_2 \left( \frac{ac}{\max(ac)} \right)}{w_1 + w_2} \right) \quad (7.15)
\]

\[
U_{\text{crew}} = 1 - \left( \frac{w_3 \left( \frac{cd}{\max(cd)} \right) + w_4 \left( \frac{cc}{\max(cc)} \right)}{w_3 + w_4} \right) \quad (7.16)
\]

\[
U_{\text{pax}} = 1 - \left( \frac{w_5 \left( \frac{pr}{\max(pr)} \right) + w_6 \left( \frac{pc}{\max(pc)} \right)}{w_5 + w_6} \right) \quad (7.17)
\]

\[
U_{\text{sup}} = 1 - \left( \alpha_1 \left( \frac{ad}{\max(ad)} \right) + \alpha_2 \left( \frac{ac}{\max(ac)} \right) + \alpha_3 (\ldots) + \alpha_5 (\ldots) \right) \quad (7.18)
\]

with

\[
\sum_{i=1}^{5} \alpha_i = 1 \text{ and } \sum_{j=1}^{5} v_j = 1
\]
Human-in-the-Loop

- Human operators have control over the final decision and have the possibility to provide feedback during the resolution process.
- Human operators are also essential to provide information and to contact passengers and crew members.
- We are replacing some repetitive processes by autonomous software agents with decision capabilities.
- We are not taking out the human operators from the process.
Thank you for your attention

http://masdima.com
E-mail: acastro@masdima.com

http://www.flytap.com
E-mail: ancastro@tap.pt
Prototype Demonstration

EXPERIMENTS: SCENARIO AND METRICS

Scenario

• TAP Portugal September 2009 Operational Plan.
• 49 problems selected randomly from the operational plan.

Metrics

• 14 related to the Air Transport domain.
• 4 related to the Solution Quality.
• 7 related to the Negotiation Outcome.
• 5 related to the Protocol Performance.
**EXPERIMENTS: APPROACHES**

<table>
<thead>
<tr>
<th>Approach</th>
<th>Type</th>
<th>Learning</th>
<th>CS</th>
<th>Dom Op</th>
<th>Strategy</th>
<th>Filter</th>
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<tbody>
<tr>
<td>TAP-AOC</td>
<td>Manual</td>
<td>Historical Data from TAP</td>
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<td>TSA</td>
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<td>No</td>
<td>---</td>
<td>No</td>
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<td>10</td>
<td>Yes</td>
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<td>No</td>
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<tr>
<td>Q10-Best-V2</td>
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<tr>
<td>Q20-Best-V2</td>
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<td>QL Improved</td>
<td>20</td>
<td>No</td>
<td>Best Util.</td>
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**EXPERIMENTS: MAIN RESULTS (COSTS)**

- Even with TSA: 8.62%
- With GQN approaches: 17.82% to 58.45%
- In accordance with Irrang (1996) studies.
EXPERIMENTS: MAIN RESULTS (DELAYS)

- TSA better than existing manual process.
- TSA has higher costs than the others.
- GQN approaches are better, specially the last four.

EXPERIMENTS: UTILITIES

Agent’s Utilities and $\Delta$ (optimal)
Benefits

- The possibility of reducing the costs with irregular operations between 17% and 58%.
- Even if we only get it right 10% of our conclusions about the cost savings, there is the potential for TAP to have a annual cost reduction between 0.8M and 2.8M Euros.
- Integrated solution:
  - Passenger point-of-view is included.
  - Proactiveness regarding the passenger disruptions.
- Systems and human integration:
  - Better information ---> increases the change to make better decisions.
WHAT DO WE NEED?

• Data regarding costs:
  – Flight/Aircraft.
  – Crew.
  – Passengers (Direct + Quality + flight costs for TAP)
• Data regarding (or access to) schedules:
  – Aircraft/Flight
  – Crew
  – Passengers (booking + flights network)
• Information regarding events:
  – Events affecting aircraft.
  – Events affecting crew.
  – Events affecting passengers.
• Good communication channels:
  – From/to aircraft.
  – From/to crew members.
  – From/to passengers.

CHALLENGES

• Availability of data:
  – Integration with other systems (see new approach image)
  – Realtime availability
• Accuracy of data:
  – Match the real world information