Strategic Cross-Border Capacity Planning Under Uncertainty

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University of Belgrade Faculty of Transport and Traffic Engineering
WHU Otto Beisheim School of Management
Hochschule Worms University of Applied Sciences
EUROCONTROL
Universitat Politècnica de Catalunya BarcelonaTech

Presenters: Radosav Jovanović, Arne Strauss and Nikola Ivanov

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Introduction

- This research is a part of the SESAR H2020 project Advanced Capacity and Demand Management for European Network Performance Optimization – **CADENZA**

- **Problem addressed**: recurring ATFM delays (e.g. summer 2018/19) caused by demand-capacity imbalances (e.g. variable demand, "rigid" capacity)

- **Proposed approach**: Advanced Demand-Capacity Balancing (ADCB) acting simultaneously on three levers: *capacity* (in time and space), *demand in time* (departure slot) and *demand in space* (flight routes/profiles)

- **Goal of the CADENZA** is to define and evaluate different options for demand-capacity balancing to **improve overall network performance**

Concept

- Different options to establish demand-capacity balance

Capacity management	Demand management	Network performance optimisation	DCB phase
Flexibility in time	Administrative	Local-oriented	Strategic
Flexibility in space	Economic incentives	Network-oriented	Pre-tactical
Combined	Hybrid	“In between”	Tactical

Newsvendor Problem:
Expectation is hard to evaluate

We seek to minimize expected displacement and capacity cost:

where $$\min_{\boldsymbol{h}} \boldsymbol{E}[G(S|\boldsymbol{h})] + \gamma^T \boldsymbol{h}$$

- $h = (h_a)_{a \in A}$ is the vector of sector hours ordered for each airspace a
- $\gamma = (\gamma_a)_{a \in A}$: vector of unit costs of one sector hour for each airspace a
- S: random variable containing all information on materialization of uncertain effects (number of flights, trajectory choices, disruptions)
- NP-hard! $G(S|\boldsymbol{h})$: minimum displacement cost to accommodate flights in scenario S under capacity budget $\boldsymbol{h}$ – involves both flight-to-route assignments and sector opening scheme optimization

Deterministic approximation

1. Generate sample scenarios $S_1, \dots, S_K$
2. Obtain best budget vector for a given scenario $k = 1, \dots, K$

$$S_k \rightarrow \boldsymbol{h}^*(S_k) = \mathrm{argmin}_{\boldsymbol{h}} G(S_k|\boldsymbol{h}) + \gamma^T \boldsymbol{h}$$

3. Select budget vector from K solutions $\boldsymbol{h}^*(S_k)$ according to some heuristic rule

Starita et al. Air Traffic Control Capacity Planning Under Demand and Capacity Provision Uncertainty. **Transportation Science** 54(4), pp. 855-1152 (2020)

Approach adapted to allow for cross-border effects through definition of airspace configurations.

Assumption: central pool of cross-border capacity

Deterministic approach:
Obtain best budget for fixed scenario

Cost of running configuration c in airspace a for one time unit

$$\min_{\mathbf{y},\mathbf{z}} \sum_{a\in A}\sum_{c\in C^a}\sum_{u\in U} \gamma_{ac} z_{acu} + \sum_{f\in F^S}\sum_{r\in R_f} d_{fr} y_{fr}$$

Minimize capacity cost and displacement cost

$$\text{s.t.} \sum_{f\in F^S}\sum_{r\in R_f} b_{frpu} y_{fr} z_{acu} \leq \kappa_p^S z_{acu} \quad \forall a \in A, c \in C^a, p \in P^c\, u \in U$$

Traffic in sector p is constrained by sector capacity κ_p^S

$$\sum_{r\in R_f} y_{fr} = 1 \quad \forall f \in F^S$$

Each flight f needs to be assigned to a route r

$$\sum_{c\in C^a} z_{acu} = 1 \quad \forall a \in A, u \in U$$

Each airspace a at time u needs to have exactly one configuration c

$$z_{acu} \in \{0,1\} \quad \forall a \in A, c \in C^a, u \in U$$

Decision to run configuration c in airspace a at time u

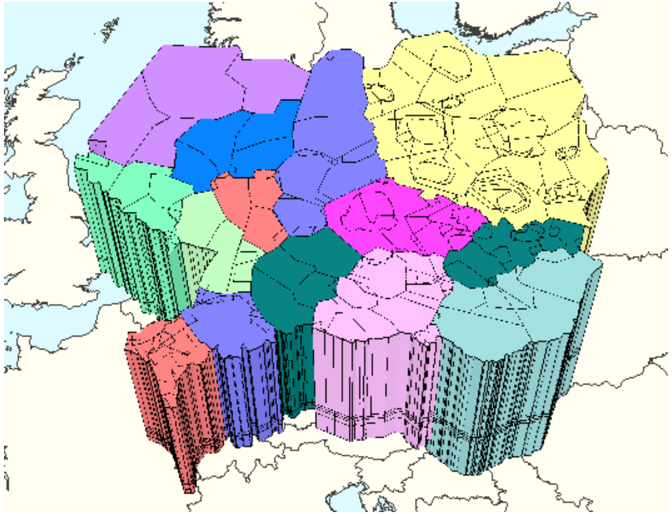
$$y_{fr} \in \{0,1\} \quad \forall f \in F^S, r \in R_f.$$

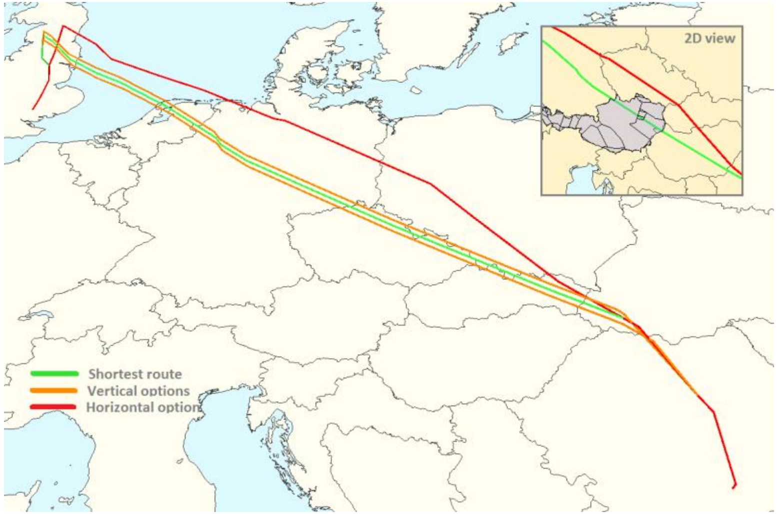
Decision to assign flight f to route r

Results from a small-scale case study

8 ANSPs
15 ACCs/sector groups
173 configurations

1400 flights (1200 scheduled and 200 non-scheduled)

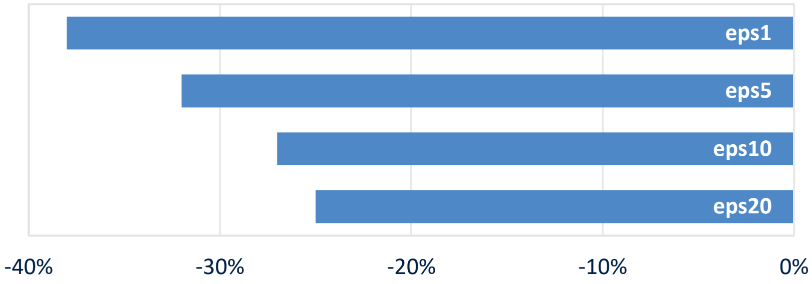




Results from a case study

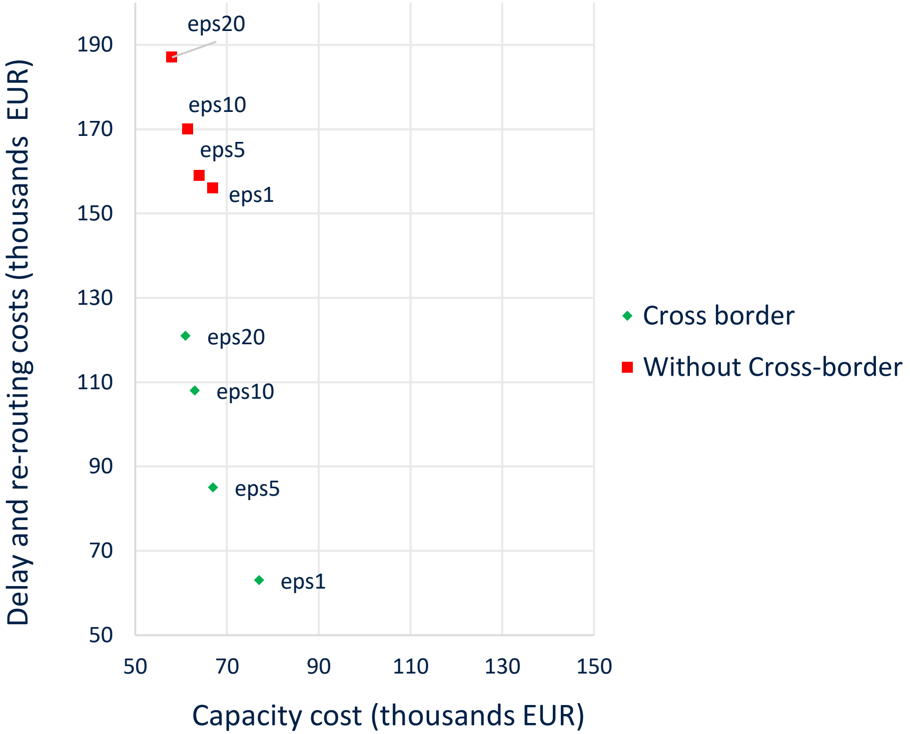
- Total cost reduction across different policies with cross-border capacity provision "enabled"
- The more risk-averse the policy, the higher the savings: this is because cross-border provision acts as an insurance against disruptions

% reduction of average total cost with *vs* without cross-border capacity provision



Results from a case study

- Cross-border capacity provision increases cost of capacity provision, but reduces cost of delays and re-routings, thus improving total cost efficiency
- Also improved:
- More direct routings
- Number of flights with longer delays



Conclusions and outlook

- Network-oriented capacity planning with cross-border capacity provision offers potential to improve network performance across different indicators based on a small-scale case study
- Stochastic solution approach
- “Regional” cross-border capacity provision
- Medium- to large-scale case studies

Advanced Capacity and Demand Management for European Network Performance Optimization

https://cadenza-project.eu/

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