



Maximizing ATM cost-efficiency by flexible provision of airspace capacity

Dr Stefano Starita

University of Warwick – Warwick Business School

Joint work with:

University of Belgrade (Dr Radosav Jovanović, Nikola Ivanov)

University of Warwick (Dr Arne Strauss)

Hochschule Worms (Prof. Frank Fichert)

SESAR Innovation Days

Technical University of Delft 8th – 10th November 2016



Founding Members



Project Motivation

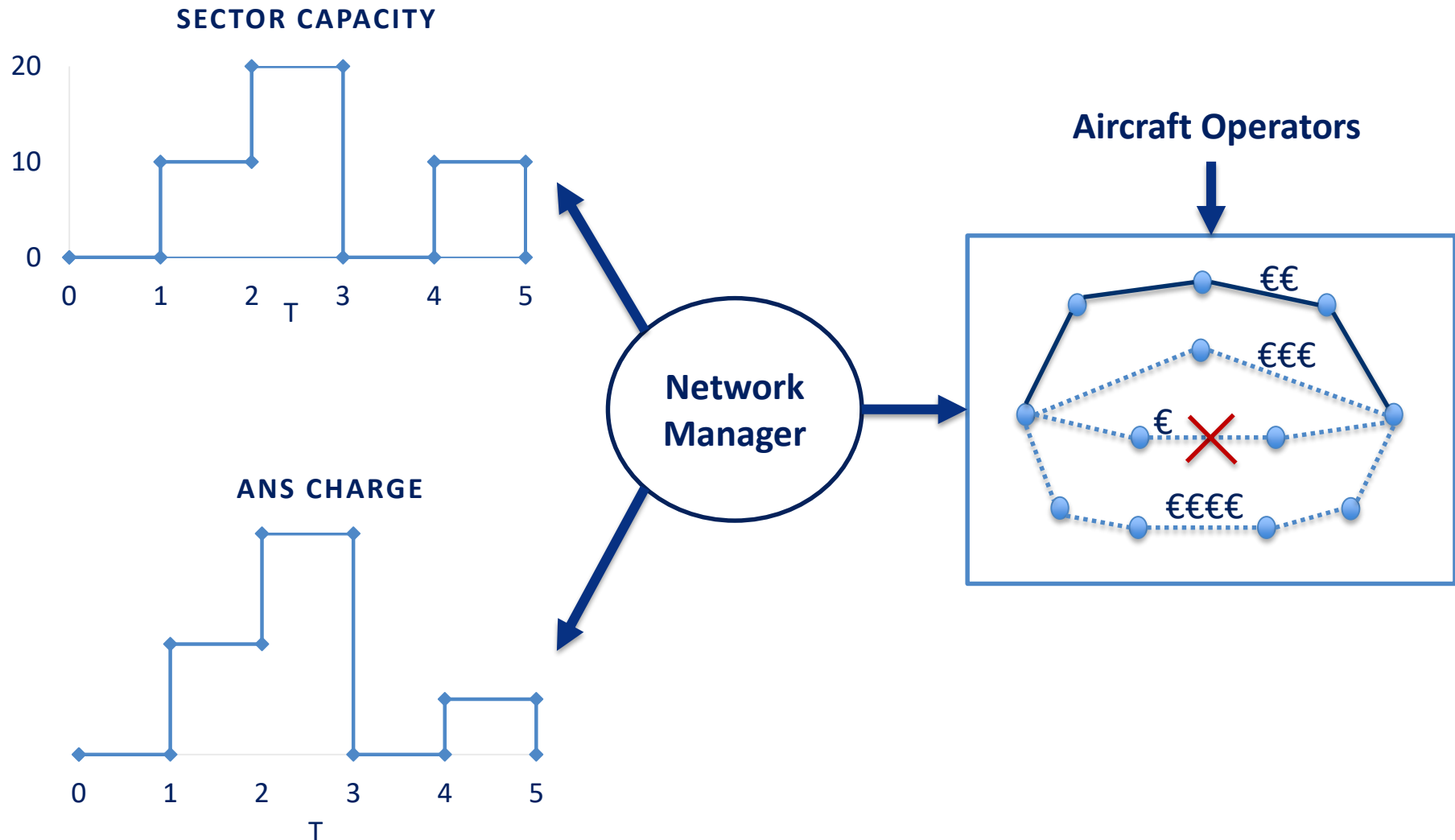


ANSPs have to plan their capacity provision several weeks in advance, while Aircraft Operators (AO) prefer flexibility and tend to make their route choice decisions at rather short term.

This **‘divorced’ planning horizon** sometimes leads to overcapacity or capacity shortages, i.e. in both cases extra cost to users.

The estimated cost of en-route and airport ATFM delay in 2015 was more than 1 billion EUR (EUROCONTROL PRC, 2016)

Model assumptions



Optimization model (1)



Minimize: Total Aircraft Operators' costs, i.e. the sum of route prices and displacement costs

Subject to:

- Flights in sector/time unit $\leq$ sector capacity
- ANS revenue $\geq$ cost of capacity provision

Decisions:

- ANS charges
- Sector capacity levels

Optimization model (2)



$$[\text{RPLC}] \quad \min \sum_{f \in F} \sum_{r \in R^f} y_r^f \left(d_r^f + \sum_{s \in S} \sum_{u \leq U} a_{rsu} p_{su} \right) \quad (1)$$

$$\text{s.t.} \quad \sum_{r \in R^f} y_r^f = 1 \quad \forall f \in F \quad (2)$$

$$\sum_{l \leq L} z_{slu} = 1 \quad \forall s \in S, u \leq U \quad (3)$$

$$\sum_{f \in F} \sum_{r \in R^f} a_{rsu} y_r^f \leq \sum_{l \leq L} k_{sl} z_{slu} \quad \forall s \in S, u \leq U \quad (4)$$

$$\sum_{f \in F} \sum_{r \in R^f} a_{rsu} y_r^f p_{su} \geq \sum_{l \leq L} c_{slu} z_{slu} \quad \forall s \in S, u \leq U \quad (5)$$

$$\sum_{f \in F} \sum_{r \in R^f} y_r^f \sum_{s \in S} \sum_{u \leq U} a_{rsu} p_{su} \geq \sum_{s \in S} \sum_{l \leq L} \sum_{u \leq U} c_{slu} z_{slu} \quad (6)$$

$$y_r^f, z_{slu} \in \{0, 1\}; \quad p_{su} \geq 0.$$

Optimization model (2)

$$[\text{RPLC}] \quad \min \sum_{f \in F} \sum_{r \in R^f} y_r^f \left(d_r^f + \sum_{s \in S} \sum_{u \leq U} a_{rsu} p_{su} \right) \quad (1)$$

$$\text{s.t.} \quad \sum_{r \in R^f} y_r^f = 1 \quad \forall f \in F \quad (2)$$

$$\sum_{l \leq L} z_{slu} = 1 \quad \forall s \in S, u \leq U \quad (3)$$

$$\sum_{f \in F} \sum_{r \in R^f} a_{rsu} y_r^f \leq \sum_{l \leq L} k_{sl} z_{slu} \quad \forall s \in S, u \leq U \quad (4)$$

$$\sum_{f \in F} \sum_{r \in R^f} a_{rsu} y_r^f p_{su} \geq \sum_{l \leq L} c_{slu} z_{slu} \quad \forall s \in S, u \leq U \quad (5)$$

$$\sum_{f \in F} \sum_{r \in R^f} y_r^f \sum_{s \in S} \sum_{u \leq U} a_{rsu} p_{su} \geq \sum_{s \in S} \sum_{l \leq L} \sum_{u \leq U} c_{slu} z_{slu} \quad (6)$$

$$y_r^f, z_{slu} \in \{0, 1\}; \quad p_{su} \geq 0.$$

Minimize sum of route
prices and
displacement costs

Optimization model (2)

$$[\text{RPLC}] \quad \min \sum_{f \in F} \sum_{r \in R^f} y_r^f \left(d_r^f + \sum_{s \in S} \sum_{u \leq U} a_{rsu} p_{su} \right) \quad (1)$$

$$\text{s.t.} \quad \sum_{r \in R^f} y_r^f = 1 \quad \forall f \in F \quad (2)$$

$$\sum_{l \leq L} z_{slu} = 1 \quad \forall s \in S, u \leq U \quad (3)$$

$$\sum_{f \in F} \sum_{r \in R^f} a_{rsu} y_r^f \leq \sum_{l \leq L} k_{sl} z_{slu} \quad \forall s \in S, u \leq U \quad (4)$$

$$\sum_{f \in F} \sum_{r \in R^f} a_{rsu} y_r^f p_{su} \geq \sum_{l \leq L} c_{slu} z_{slu} \quad \forall s \in S, u \leq U \quad (5)$$

$$\sum_{f \in F} \sum_{r \in R^f} y_r^f \sum_{s \in S} \sum_{u \leq U} a_{rsu} p_{su} \geq \sum_{s \in S} \sum_{l \leq L} \sum_{u \leq U} c_{slu} z_{slu} \quad (6)$$

$$y_r^f, z_{slu} \in \{0, 1\}; \quad p_{su} \geq 0.$$

Every flight f must be assigned to a route

Optimization model (2)

$$[\text{RPLC}] \quad \min \sum_{f \in F} \sum_{r \in R^f} y_r^f \left(d_r^f + \sum_{s \in S} \sum_{u \leq U} a_{rsu} p_{su} \right) \quad (1)$$

$$\text{s.t.} \quad \sum_{r \in R^f} y_r^f = 1 \quad \forall f \in F \quad (2)$$

$$\sum_{l \leq L} z_{slu} = 1 \quad \forall s \in S, u \leq U \quad (3)$$

$$\sum_{f \in F} \sum_{r \in R^f} a_{rsu} y_r^f \leq \sum_{l \leq L} k_{sl} z_{slu} \quad \forall s \in S, u \leq U \quad (4)$$

$$\sum_{f \in F} \sum_{r \in R^f} a_{rsu} y_r^f p_{su} \geq \sum_{l \leq L} c_{slu} z_{slu} \quad \forall s \in S, u \leq U \quad (5)$$

$$\sum_{f \in F} \sum_{r \in R^f} y_r^f \sum_{s \in S} \sum_{u \leq U} a_{rsu} p_{su} \geq \sum_{s \in S} \sum_{l \leq L} \sum_{u \leq U} c_{slu} z_{slu} \quad (6)$$

$$y_r^f, z_{slu} \in \{0, 1\}; \quad p_{su} \geq 0.$$

Every sector s must operate at one capacity level l at any given time u

Optimization model (2)

$$[\text{RPLC}] \quad \min \sum_{f \in F} \sum_{r \in R^f} y_r^f \left(d_r^f + \sum_{s \in S} \sum_{u \leq U} a_{rsu} p_{su} \right) \quad (1)$$

$$\text{s.t.} \quad \sum_{r \in R^f} y_r^f = 1 \quad \forall f \in F \quad (2)$$

$$\sum_{l \leq L} z_{slu} = 1 \quad \forall s \in S, u \leq U \quad (3)$$

$$\sum_{f \in F} \sum_{r \in R^f} a_{rsu} y_r^f \leq \sum_{l \leq L} k_{sl} z_{slu} \quad \forall s \in S, u \leq U \quad (4)$$

$$\sum_{f \in F} \sum_{r \in R^f} a_{rsu} y_r^f p_{su} \geq \sum_{l \leq L} c_{slu} z_{slu} \quad \forall s \in S, u \leq U \quad (5)$$

$$\sum_{f \in F} \sum_{r \in R^f} y_r^f \sum_{s \in S} \sum_{u \leq U} a_{rsu} p_{su} \geq \sum_{s \in S} \sum_{l \leq L} \sum_{u \leq U} c_{slu} z_{slu} \quad (6)$$

$$y_r^f, z_{slu} \in \{0, 1\}; \quad p_{su} \geq 0.$$

The sum of the flights using sector s at time u must be less or equal than sector's capacity

Optimization model (2)

$$[\text{RPLC}] \quad \min \sum_{f \in F} \sum_{r \in R^f} y_r^f \left(d_r^f + \sum_{s \in S} \sum_{u \leq U} a_{rsu} p_{su} \right) \quad (1)$$

$$\text{s.t.} \quad \sum_{r \in R^f} y_r^f = 1 \quad \forall f \in F \quad (2)$$

$$\sum_{l \leq L} z_{slu} = 1 \quad \forall s \in S, u \leq U \quad (3)$$

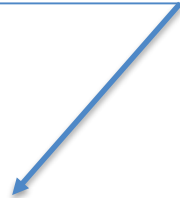
$$\sum_{f \in F} \sum_{r \in R^f} a_{rsu} y_r^f \leq \sum_{l \leq L} k_{sl} z_{slu} \quad \forall s \in S, u \leq U \quad (4)$$

$$\sum_{f \in F} \sum_{r \in R^f} a_{rsu} y_r^f p_{su} \geq \sum_{l \leq L} c_{slu} z_{slu} \quad \forall s \in S, u \leq U \quad (5)$$

$$\sum_{f \in F} \sum_{r \in R^f} y_r^f \sum_{s \in S} \sum_{u \leq U} a_{rsu} p_{su} \geq \sum_{s \in S} \sum_{l \leq L} \sum_{u \leq U} c_{slu} z_{slu} \quad (6)$$

$$y_r^f, z_{slu} \in \{0, 1\}; \quad p_{su} \geq 0.$$

Capacity provision cost of a sector s at time u is equally split among flights using that sector



Optimization model (2)

$$[\text{RPLC}] \quad \min \sum_{f \in F} \sum_{r \in R^f} y_r^f \left(d_r^f + \sum_{s \in S} \sum_{u \leq U} a_{rsu} p_{su} \right) \quad (1)$$

$$\text{s.t.} \quad \sum_{r \in R^f} y_r^f = 1 \quad \forall f \in F \quad (2)$$

$$\sum_{l \leq L} z_{slu} = 1 \quad \forall s \in S, u \leq U \quad (3)$$

$$\sum_{f \in F} \sum_{r \in R^f} a_{rsu} y_r^f \leq \sum_{l \leq L} k_{sl} z_{slu} \quad \forall s \in S, u \leq U \quad (4)$$

$$\sum_{f \in F} \sum_{r \in R^f} a_{rsu} y_r^f p_{su} \geq \sum_{l \leq L} c_{slu} z_{slu} \quad \forall s \in S, u \leq U \quad (5)$$

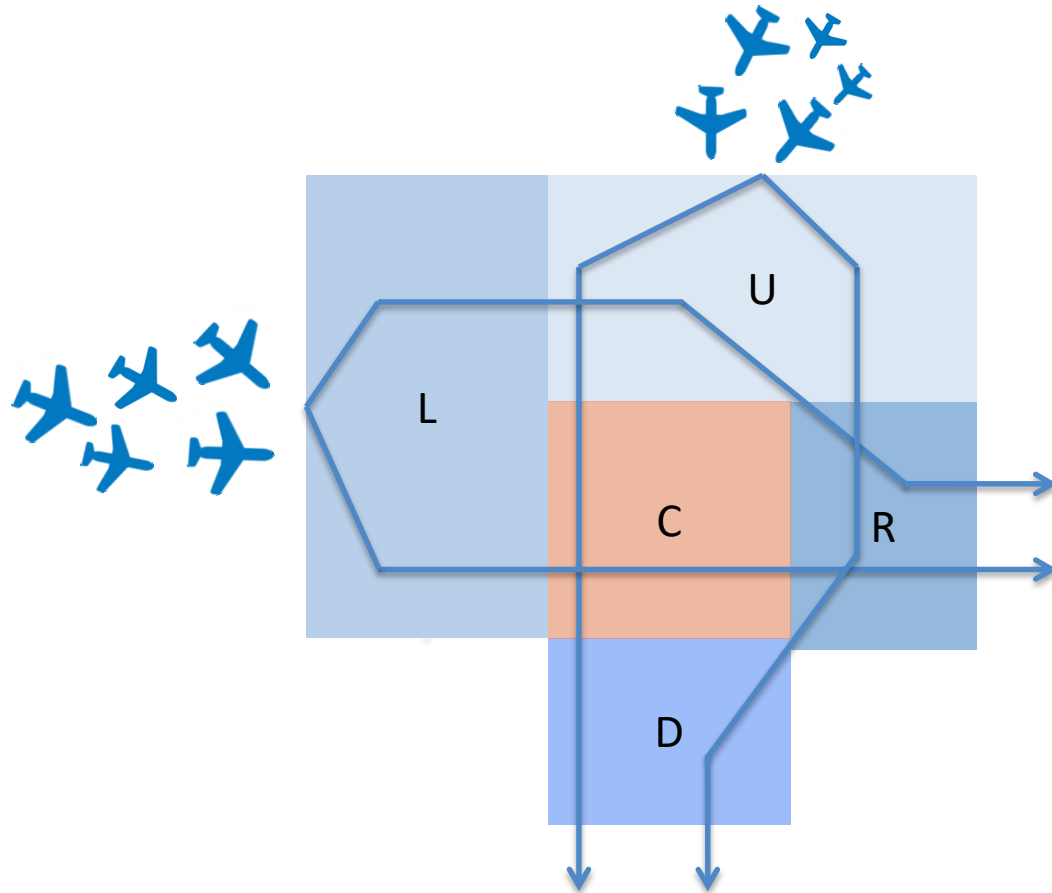
$$\sum_{f \in F} \sum_{r \in R^f} y_r^f \sum_{s \in S} \sum_{u \leq U} a_{rsu} p_{su} \geq \sum_{s \in S} \sum_{l \leq L} \sum_{u \leq U} c_{slu} z_{slu} \quad (6)$$

$$y_r^f, z_{slu} \in \{0, 1\}; \quad p_{su} \geq 0.$$

Total revenue must
fully recover capacity
provision costs

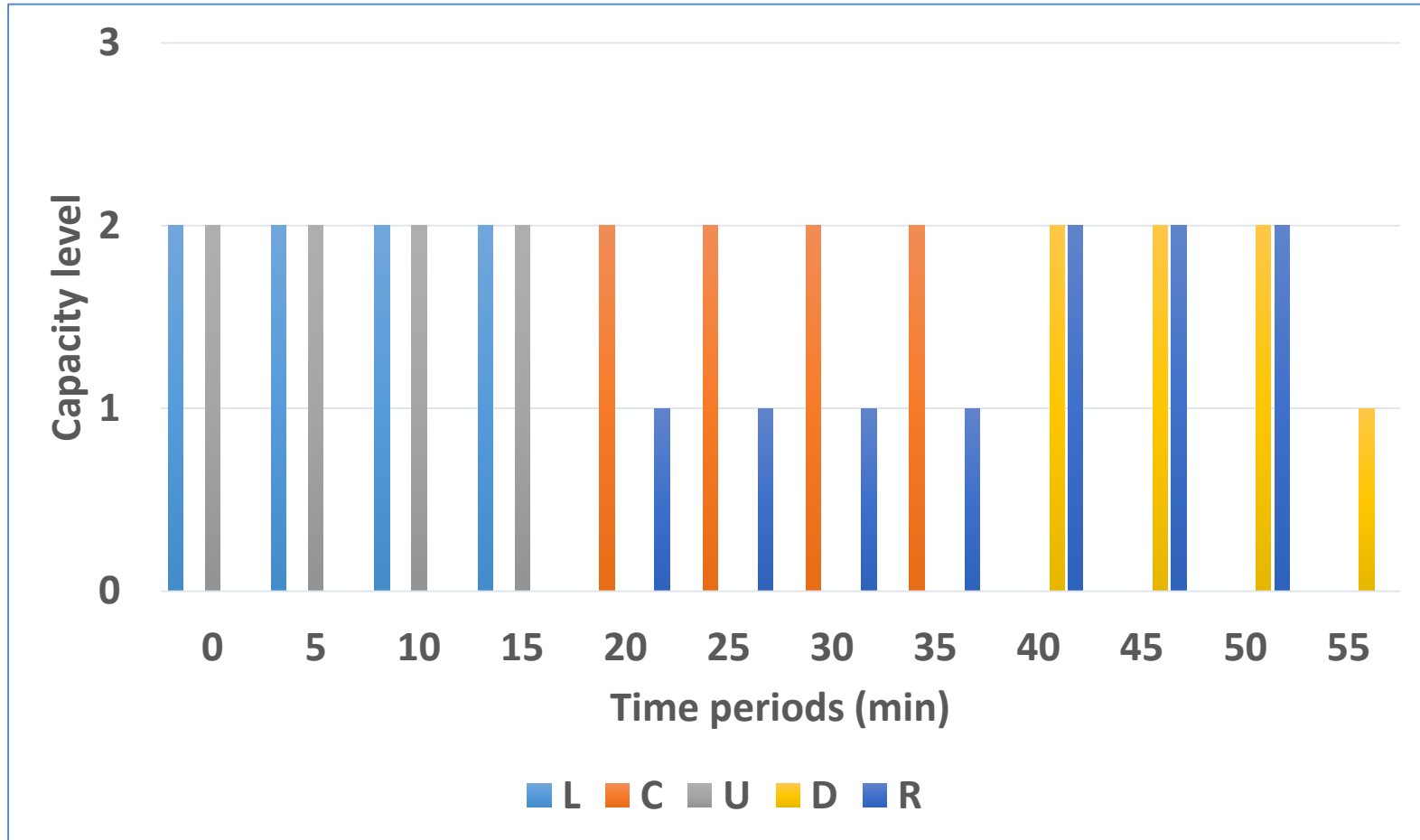


Case study network

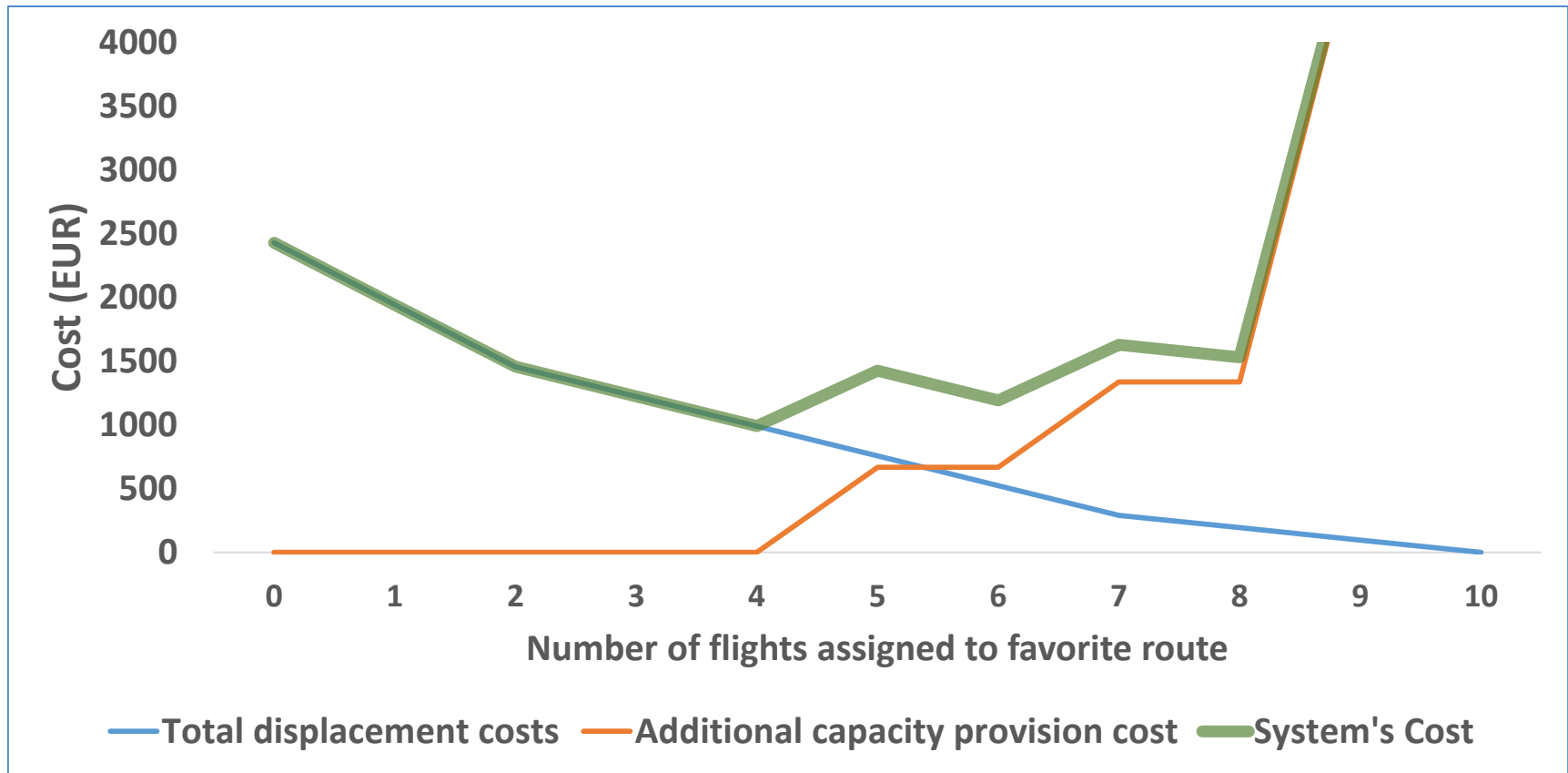


-  Boeing 777-200 (B772)
-  Airbus 321 (A321)
-  Embraer 145LR (E145)

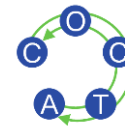
Optimal capacity levels



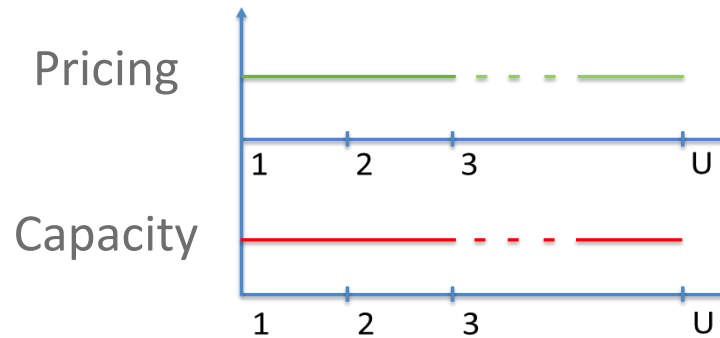
Trade-off between displacement and capacity costs



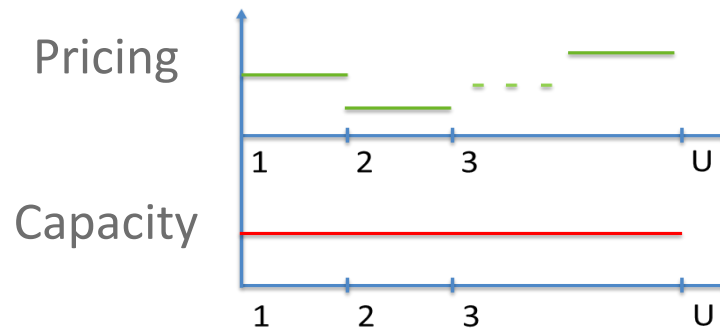
Policies comparison



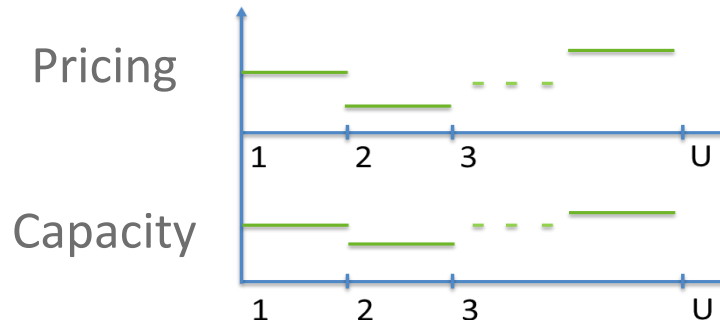
Static Pricing
Fixed Capacities
(SPFC)



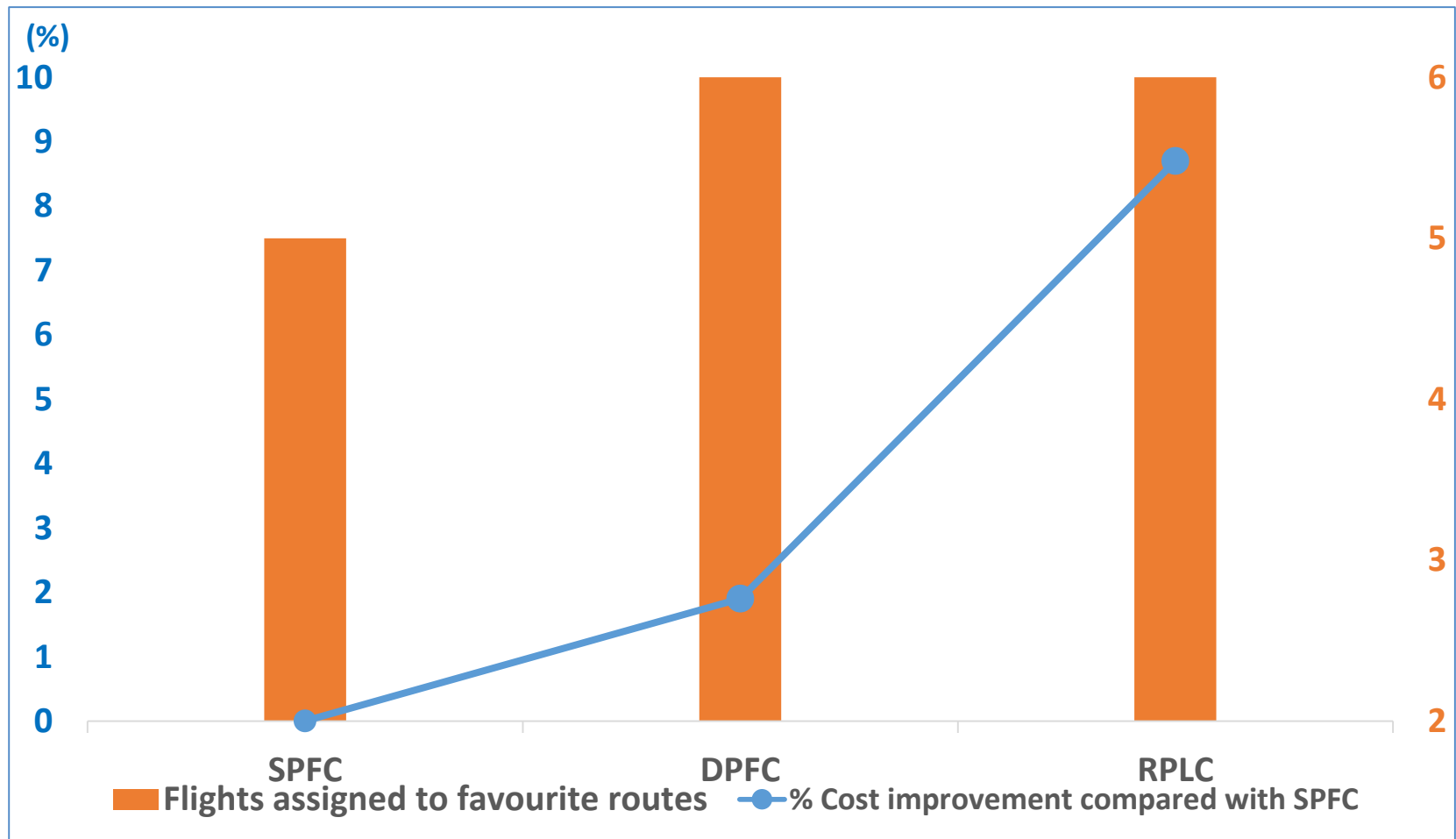
Dynamic Pricing
Fixed Capacities
(DPFC)



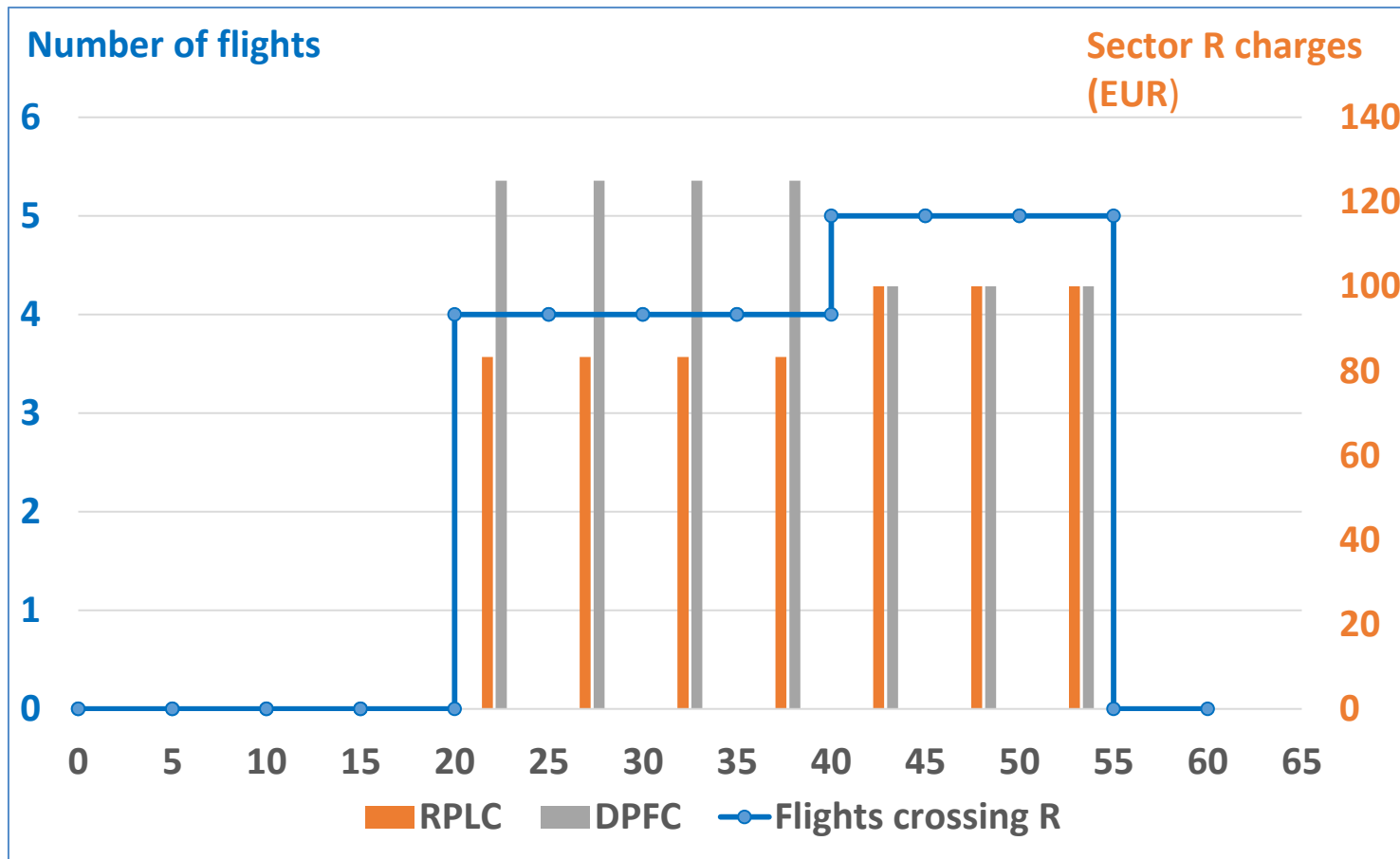
RPLC



Policies comparison: Results



Sector charges

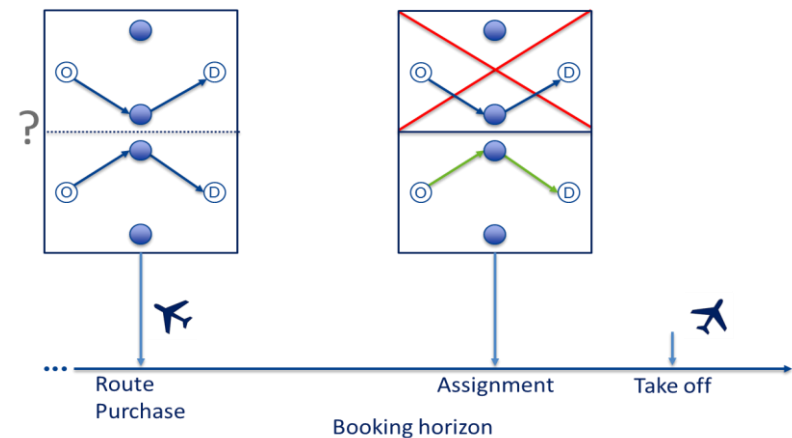
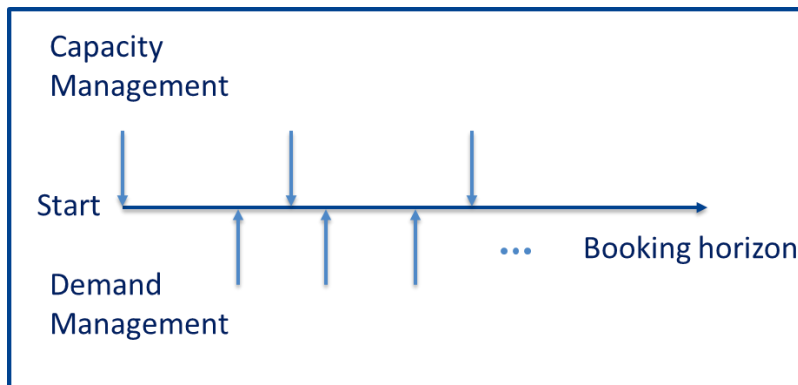


Conclusions and future research

Results look promising: Allowing the NM to set variable prices and capacities results in more flights assigned to their favourite routes and an overall cost reduction.

Future steps:

- Test the model with a realistic case-study
- More sophisticated choice models to represent AOs' behaviours
- Introducing other performance indicators in the objective function
- Develop efficient solution algorithms





Maximizing ATM cost-efficiency by flexible provision of airspace capacity

Thank you very much for your attention!



This project has received funding from the SESAR Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under grant agreement No [699326]



Founding Members



The opinions expressed herein reflect the author's view only.

Under no circumstances shall the SESAR Joint Undertaking be responsible for any use that may be made of the information contained herein.