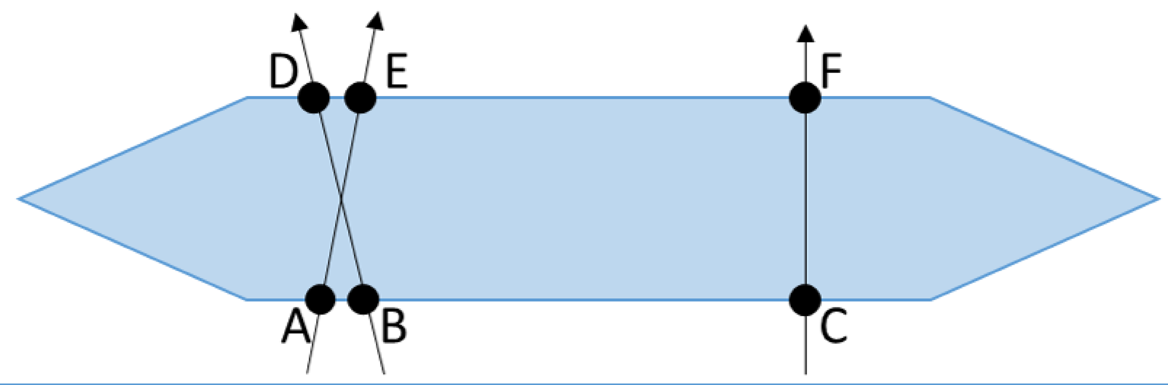
Enhanced Demand and Capacity Balancing based on Alternative Trajectory Options and Traffic Volume Hotspot Detection

Introduction

- The European air traffic increased regularly before the COVID-19 pandemic. For instance, air traffic increased by **3.8%** in 2018 and the network generated a total of 19.1 million minutes of en-route delay (a **105%** more with respect 2017).
- Demand and Capacity Balancing (**DCB**) models should be improved.
- Current Air Traffic Flow Management measures are based on **Ration-by-Schedule** (RBS) algorithm.
- Regulations are applied at **traffic volume** level.
- Flight planning based on the Route Availability Document (**RAD**).

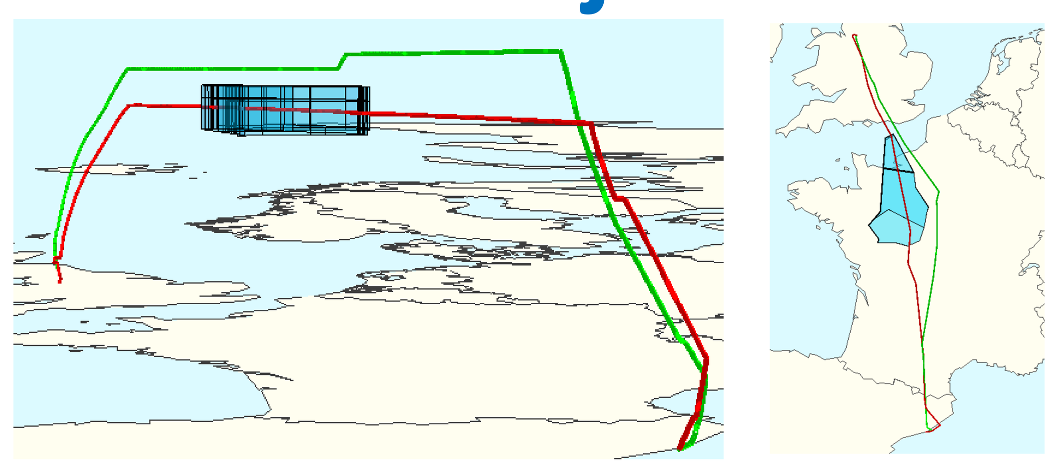


Objective

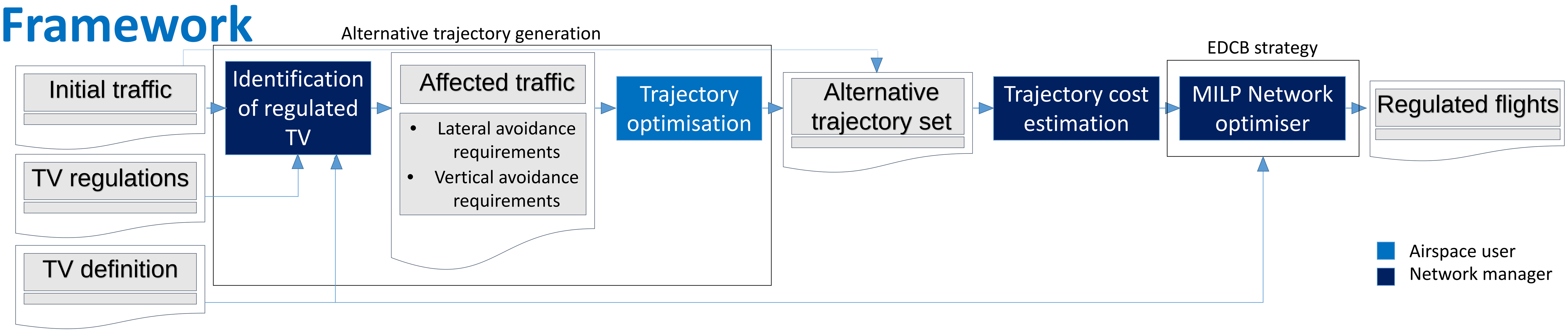
A novel Enhanced Demand and Capacity Balance (**EDCB**) model that:

- Uses **historical regulations** in order to identify **hotspots** at **TV** level.
- Considers either **ground delay** and **reroute options**.
- Allows the AU to provide alternative trajectories with **relaxation** in the **RAD** constraints.
- Optimises to obtain the best **global solution**.

Alternative trajectories



Framework



Demand and Capacity balancing

Decision variables

- Which trajectory is used per each flight?

$$z_m = \begin{cases} 1, \textit{if trajectory } m \textit{ is chosen for flight } f \\ 0, \quad \textit{otherwise} \end{cases}$$

- How much delay is applied?

$$x_{m,t}^l = \begin{cases} 1, \textit{if trajectory } m \textit{ arrives at traffic volume } l \textit{ by time } t \\ 0, \quad \textit{otherwise} \end{cases}$$

Objective function

$$\min J = \min(C_{\Delta F} + C_D + C_{\Delta R})$$

$$C_{\Delta F} = \sum_{f \in \mathcal{F}} \sum_{m \in \mathcal{M}_f} \delta_m \cdot (F_m - F_f) \cdot z_m^f$$

$$C_{\Delta R} = \sum_{f \in \mathcal{F}} \sum_{m \in \mathcal{M}_f} (R_m - R_f) \cdot z_m^f$$

$$C_D = \sum_{f \in \mathcal{F}} \sum_{m \in \mathcal{M}_f} \alpha_m \cdot GH_m$$

$$GH_m = \sum_{t \in T_m^l, l = P(m,1)} (t - r_m^l) \cdot (x_{m,t}^l - x_{m.t-1}^l)$$

Constraints

- One trajectory and only one must be selected:

$$\sum_{m \in \mathcal{M}_f} z_m^f = 1 \;\; \forall f \in \mathcal{F}$$

- Constraints for applying the “by” time technique:

$$x_{m,\underline{T}_m^l - 1}^l = 0 \qquad \forall f \in \mathcal{F}, \forall m \in \mathcal{M}_f, \forall l \in \mathrm{P}_m$$

$$x_{m,\overline{T}_m^l}^l = z_m^f \qquad \forall f \in \mathcal{F}, \forall m \in \mathcal{M}_f, \forall l \in \mathrm{P}_m$$

$$x_{m,t}^l - x_{m,t-1}^l \geq 0 \qquad \forall f \in \mathcal{F}, \forall m \in \mathcal{M}_f, \forall l \in \mathrm{P}_m, \forall t \in T_m^l$$

- Only ground holding is allowed:

$$x_{m,t+r_m^{l+1}-r_m^l}^{l+1} - x_{m,t}^l \geq 0 \qquad \forall f \in \mathcal{F}, \forall m \in \mathcal{M}_f, \forall l \in \mathrm{P}_m, \forall t \in T_m^l$$

- The demand can not exceed the remaining capacity:

$$\sum_{m \in \mathcal{M}_f} \sum_{l \in \mathrm{P}_m} \sum_{t \in T_m^l \cap T(\tau)} (x_{m,t}^l - x_{m,t-1}^l) \leq C_l(\tau) \qquad \forall f \in \mathcal{F}, \forall \tau \in \mathrm{T}$$

Results

		CASA	EDCB	Δ
Cost	Total regulation cost [€]	40,732,688	35,979,664	-11.7%
	Fuel cost [€]	28,611,400	27,388,050	-4.3%
	Delay cost [€]	4,748,382	1,423,575	-70.0%
	Route Charges [€]	7,372,907	7,168,040	-2.8%
Delay	Total delay [min]	58,622	17,575	-70.0%
	Delayed flights	3,518	855	-75.7%
	Max. delay [min]	139	355	155.4%
	Average delay [min]	16.66	20.56	23.4%
	Median delay [min]	14.00	10.00	-28.6%
	Standard dev. [min]	11.5	32.87	185.8%
Trip data	Total fuel [Tn]	47,686	45,647	-4.3%
	Total distance [NM]	6,237,291	6,212,292	-0.4%
	Total trip time [min]	896,153	884,732	-1.3%
Traj. options	Original	6,389	3,382	-
	Lateral	0	1,900	-
	Vertical	0	1,104	-

Conclusions

- A reduction of the **70.0%** in the delay is achieved. This delay reduction, together with the saving in terms of fuel and route charges, reduces the cost of the regulations by **11.7%**.
- A **fairness** problem has been identified, so a few flights are affected by a big amount of delay.

Marc Melgosa