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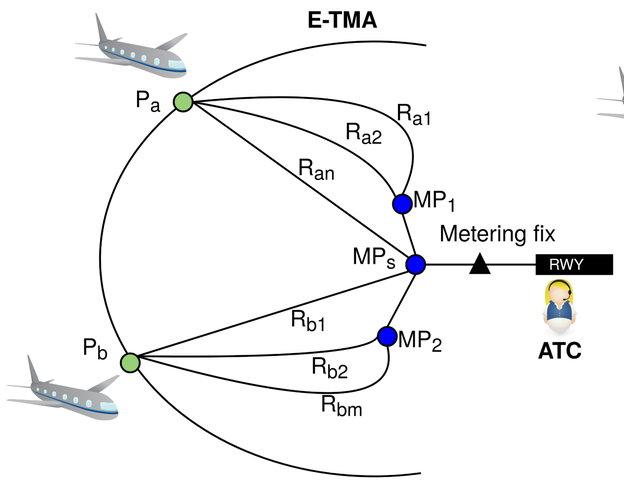
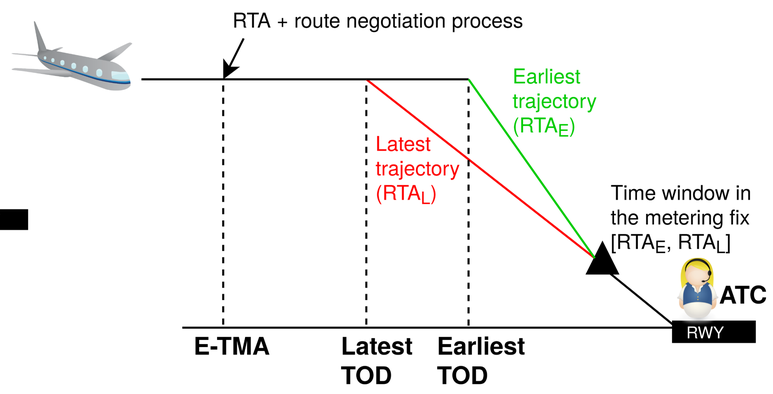
Enabling Continuous Descent Operations in Trombone Sequencing and Merging Procedures: An Implementation Study for Frankfurt Airport

Introduction

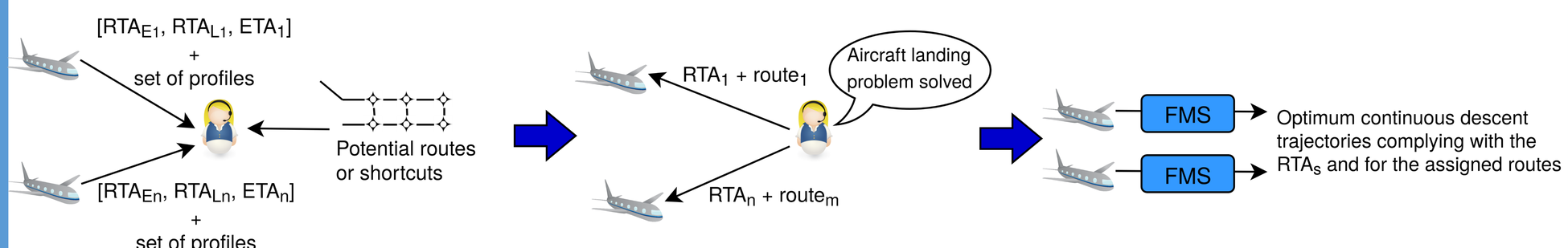
- **Continuous descent operations** (**CDOs**) allow aircraft to follow an **optimum flight** path that delivers major **environmental** and economic benefits
- Less **predictability** → **Separation buffers** issued by ATC + **Open loop** instructions + **Limiting STARs** → CDOs not possible
- Solution: **enhanced trombone** procedure with **4D trajectory negotiation** and **synchronization** (**RTA** + **closed-loop** instructions)

Concept of Operations



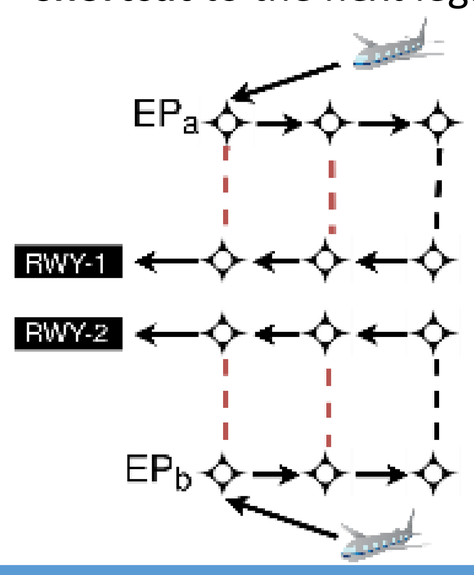


- **RTA** and **route negotiation** starts at **E-TMA entry** point
- A route and RTA is assigned to each aircraft so that the **delay** is **minimized** and a **separation** is ensured in the **whole procedure**



Tromboning

- **Tromboning** is a trombone-shape **RNAV** (area navigation) procedure
- A set of **parallel legs** composed of **multiple waypoints**, in which ATCOs may give a **shortcut** to the next leg.



Input Data

- **Frankfurt airport arrival procedures**: obtained from the German AIP (Aeronautical Information Publication)
- **Historical flight data**: Eurocontrol's DDR2 M3 files (actual flown trajectories)

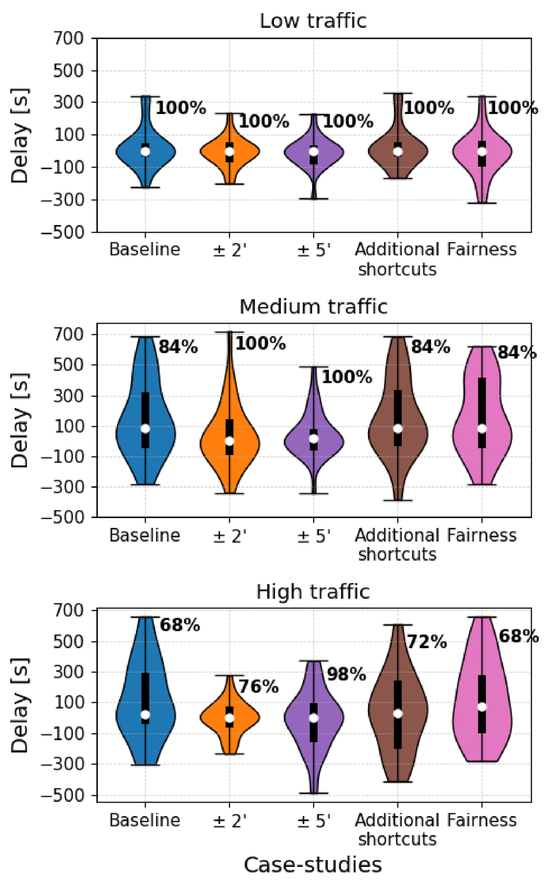
Trajectory generation and a/c landing problem

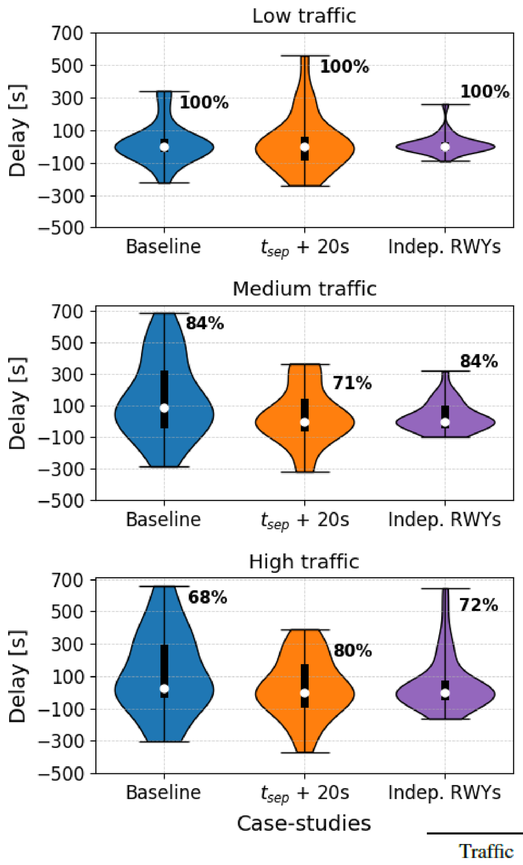
- An **optimal control problem** is solved to generate the **CDOs**
- A **mixed integer linear** problem is formulated and solved in order to **optimally assign** an **RTA** and a **route** that **minimize** the **total delay**

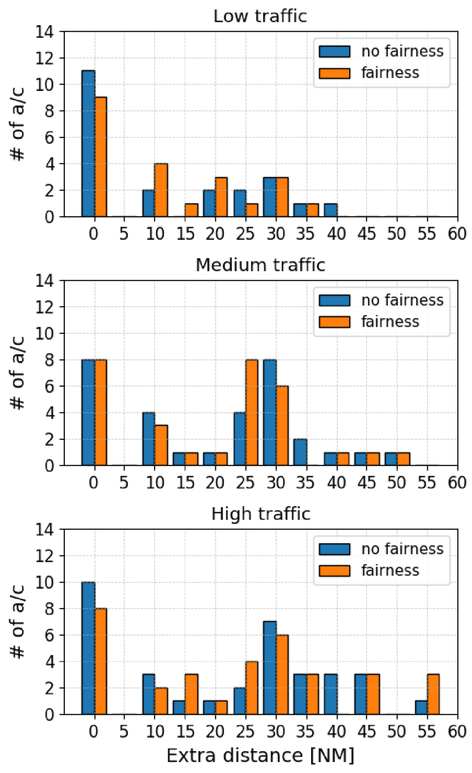
Technical enabler towards a TBO environment

Reduction in fuel consumption and ATC workload

Results







- Different scenarios are analyzed: **(1)** different levels of traffic; **(2)** different E-TMA entry times ; **(3)** Additional tromboning shortcuts; **(4)** Fairness in the delay assignment; **(5)** Independent runways
- The **number** of **aircraft scheduled** and the **delay distribution** is computed for each scenario

Traffic case-study	Enhancement case	% a/c scheduled	Avg. delay (seconds)	Max. delay (seconds)
Low	baseline	100%	75	341
Low	± 2'	100%	58	234
Low	± 5'	100%	53	296
Low	additional shortcuts	100%	70	355
Low	Fairness	100%	89	340
Low	$t_{sep} + 20s$	100%	113	556
Low	indep. runways	100%	29	259
Medium	baseline	84%	213	685
Medium	± 2'	100%	142	721
Medium	± 5'	100%	101	488
Medium	additional shortcuts	84%	209	685
Medium	Fairness	84%	222	622
Medium	$t_{sep} + 20s$	71%	123	364
Medium	indep. runways	84%	64	317
High	baseline	68%	203	657
High	± 2'	76%	77	277
High	± 5'	98%	137	488
High	additional shortcuts	68%	150	558
High	Fairness	68%	222	657
High	$t_{sep} + 20s$	60%	142	389
High	indep. runways	72%	99	643