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Impact of trajectory restrictions onto fuel and time-related cost efficiency

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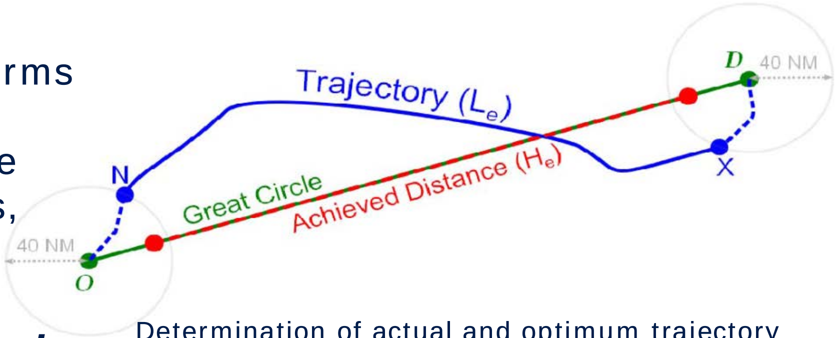
DRESDEN concept
Exzellenz aus Wissenschaft und Kultur

Motivation (1) – SES Performance Scheme

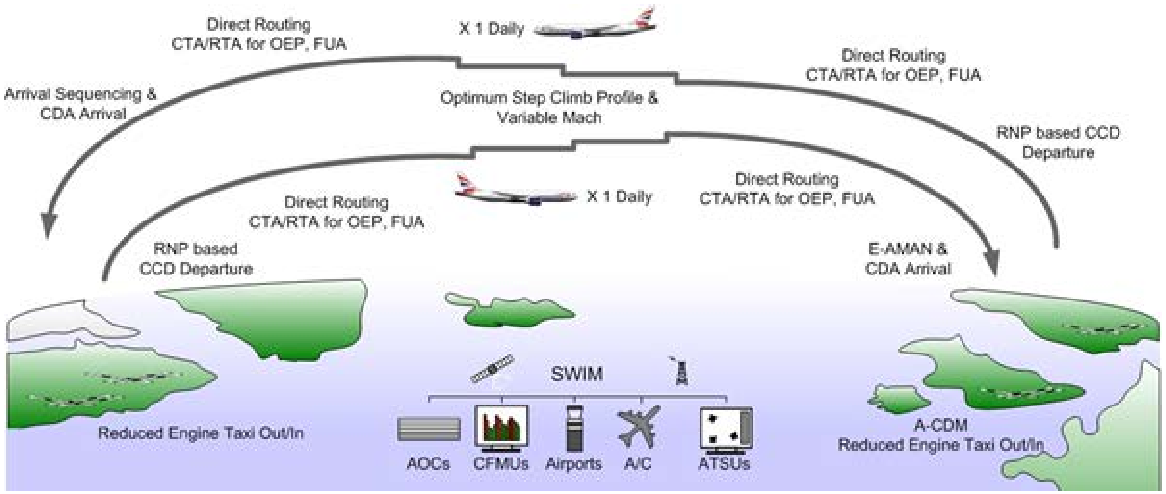
- Performance Review Report 2012: "Inefficiencies are the result of complex interactions between airspace users, ANSPs and the European Network Manager. ***More research is needed to better understand the exact drivers*** in order to identify and formulate strategies for future improvement."
- The "***Average horizontal en route flight efficiency***" is one of the performance indicators of the SES Performance Scheme, defined as "the difference between the length of the en route part of the actual trajectory and the optimum trajectory".
- somehow simple quantification in terms of comparison between the actual trajectory length and the great circle distance (supported by assumptions, e.g. neglecting wind),
- However, does not allow for an assessment of the ***effects of vertical and speed restrictions as well as delays*** on efficiency



Determination of actual and optimum trajectory based on the "achieved distance" principle
[Performance Review Body: "Horizontal Flight Efficiency – Achieved distances", May 2013]

Motivation (2) – Flight Efficiency Initiatives

Example: TOPFLIGHT project ("Sustainable Transatlantic Optimised Flight Demonstrations", runtime: 2012 – 2014)



Research Context at TU Dresden

TUD research focus in flight efficiency & environment domain:

- Development and application of a **methodology to assess flight efficiency**
- **Flight performance** modeling for modern civil aircraft
- Estimation of the **climate impact** of a single flight event
- Minimizing flight emissions while sustaining guaranteed operational safety

Related presentations at ICRAT from the beginning:

- 2004: Investigation on the Effects of Airport ATFM Restrictions
- 2006: Potential of Speed Control on Flight Efficiency
- 2010: Flight Profile Variations due to the Spreading Practice of Cost Index Based Flight Planning

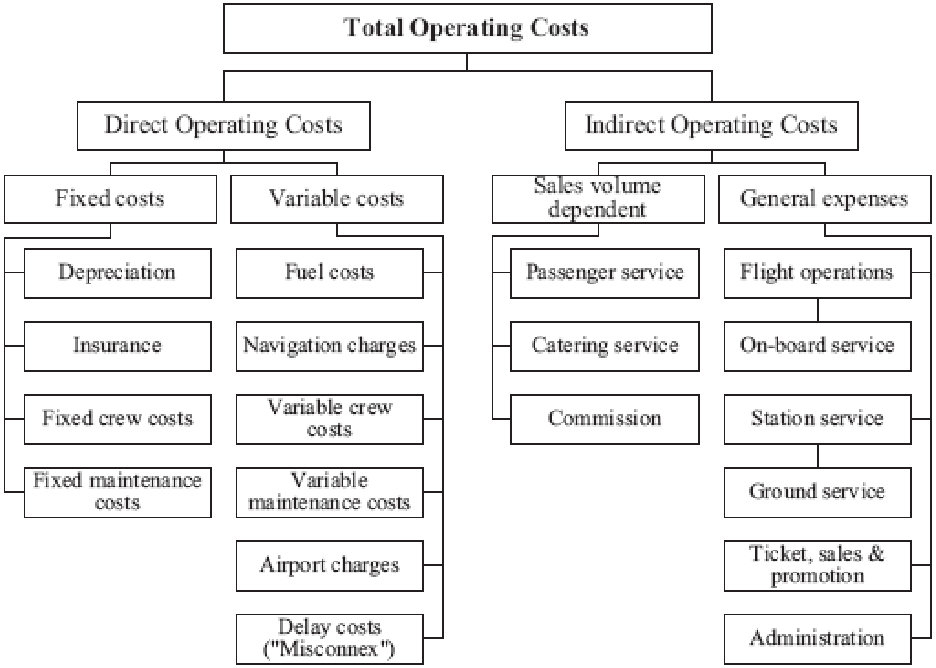
Key objectives / focus of current paper

Enable consistent efficiency assessment based on metrics that are applicable for the complete range of inefficiency reasons

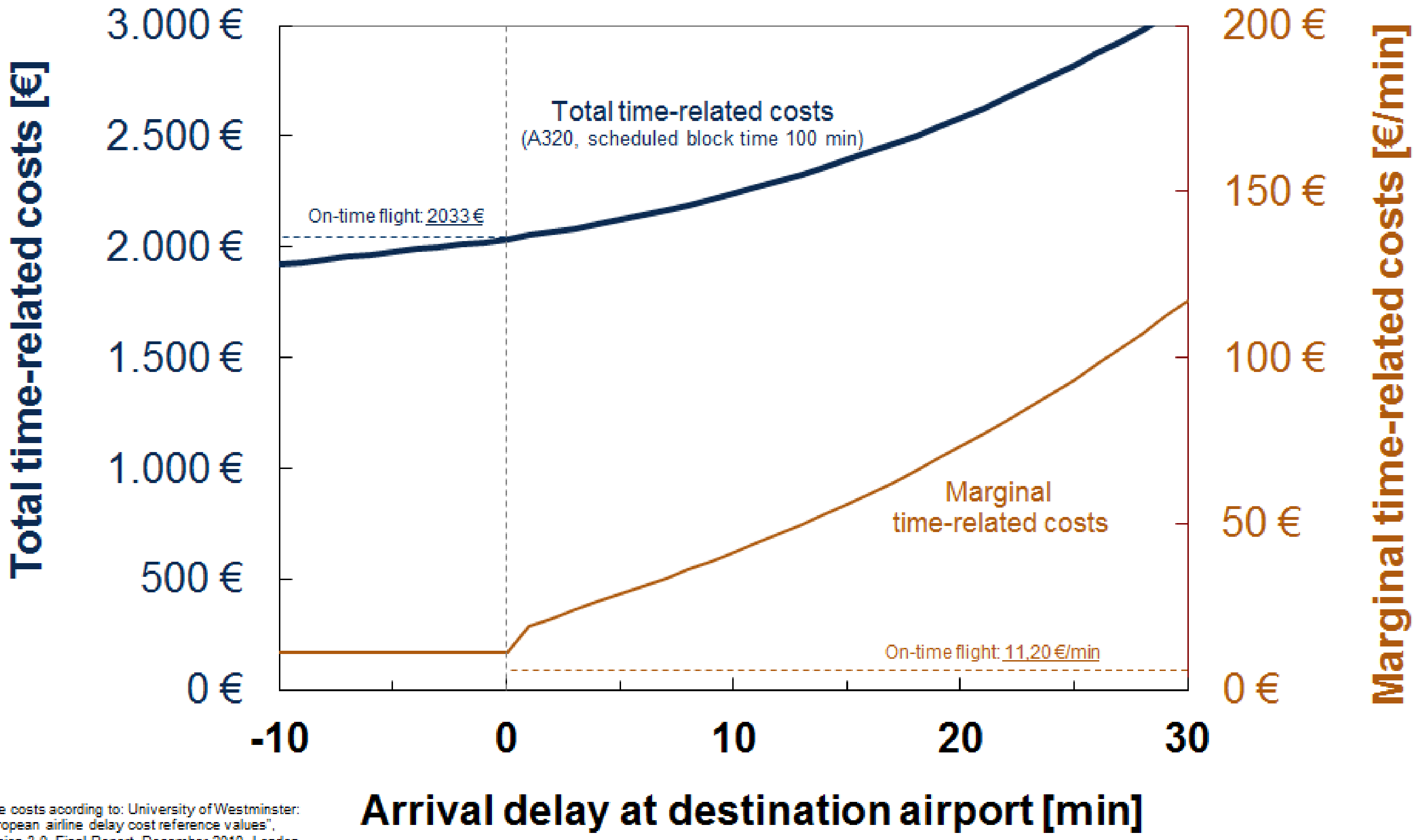
Better cover airspace user expectations by considering both fuel and time-related costs and referring to the cost index (CI) concept

Airline Operating Costs

- variable direct operating costs can be grouped into
  - ***fuel costs***,
  - ***time-related costs*** (includes crew, maintenance, and delay costs),
  - ATC charges (not considered as addressed by the ICAO KPI Cost-Effectiveness),
  - Airport charges (not considered as independent from trajectory)



Impact of delay onto time-related costs



Time costs acording to: University of Westminster: "European airline delay cost reference values", Version 3.0, Final Report, December 2010, London. (A320, base scenario)

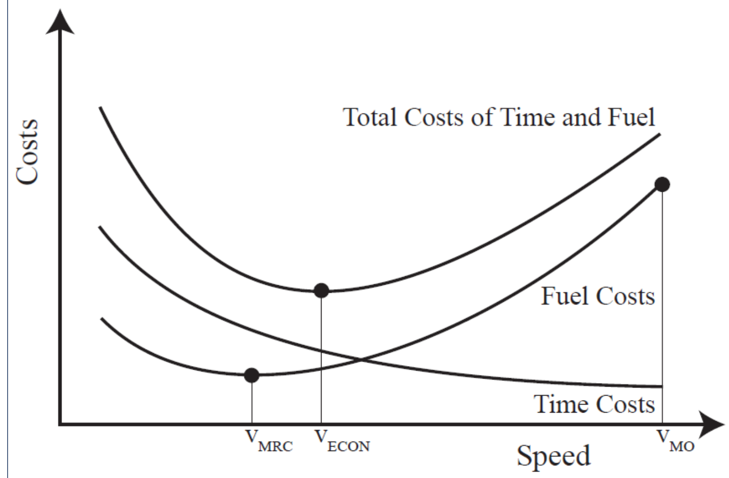
Cost Index

- Cost Index (CI) defined as the ratio between time-related costs and costs of fuel the cost
- key input value for the calculation of the speed and the vertical trajectory based on the most economic flight
- balances the time and fuel costs in order to minimize total costs
- theoretical range between:
  - CI = 0 (minimum fuel): ECON speed (v_{ECON}) is equal to Maximum Range Cruise (v_{MRC})
  - CI = 99 or 999 (minimum time): ECON speed is equal to Maximum Operating Speed (v_{MO})

$$CI = \frac{C_t}{C_f}$$

with

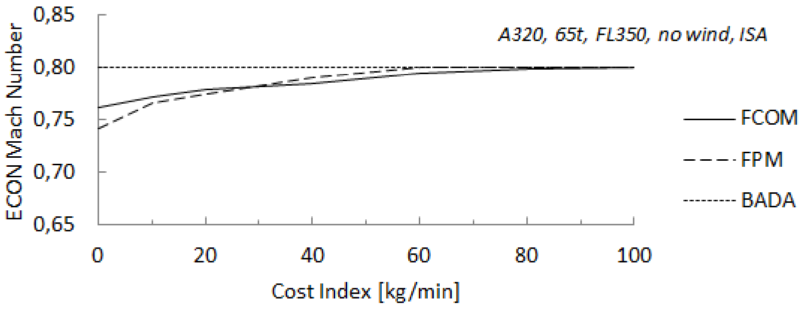
CI	cost index	$[kg/min]_{Airbus}$ $[100lb/h]_{Boeing}$
C_t	specific time costs	
C_f	fuel price	

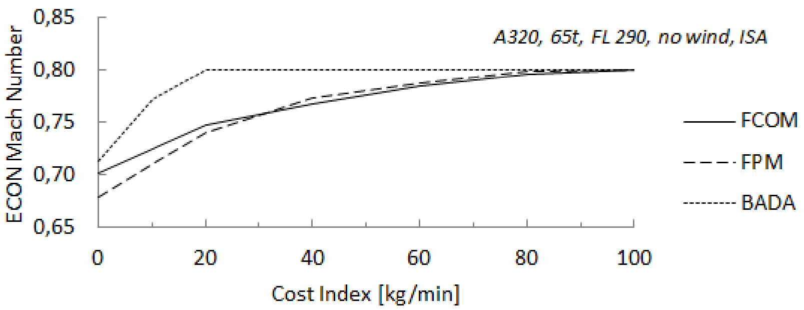


Cost index definition and impact of speed on costs

Trajectory Model (Flight Profile Model, FPM)

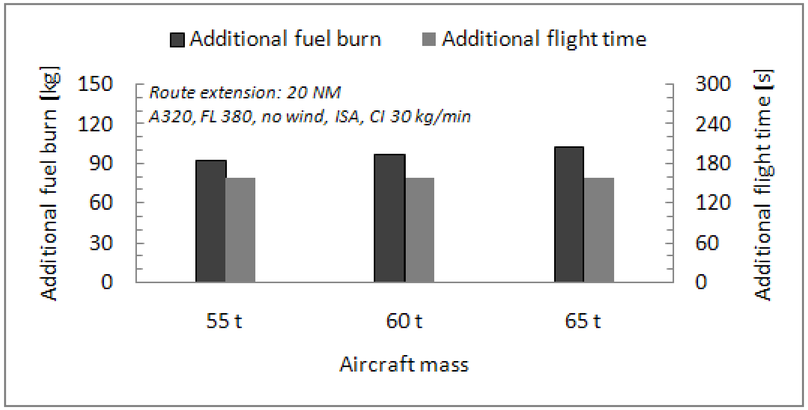
- The trajectory model is based on the Base of Aircraft Data (Version 3.6), but incorporates modifications, incl.:
  - drag model was enhanced to take into account the ***compressibility effect***
  - optimization model to enable ***CI-based trajectory planning*** (for both speed and vertical profile optimization)
- Analysis done exemplarily for an Airbus A320 (no wind, no deviation from ISA conditions)
- validated using A320 Flight Crew Operating Manual (FCOM) tables

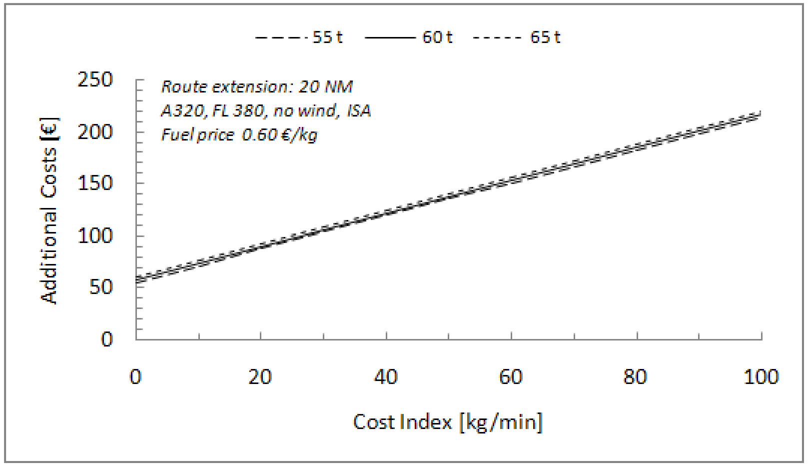




Example 1: Lateral Trajectory Restrictions

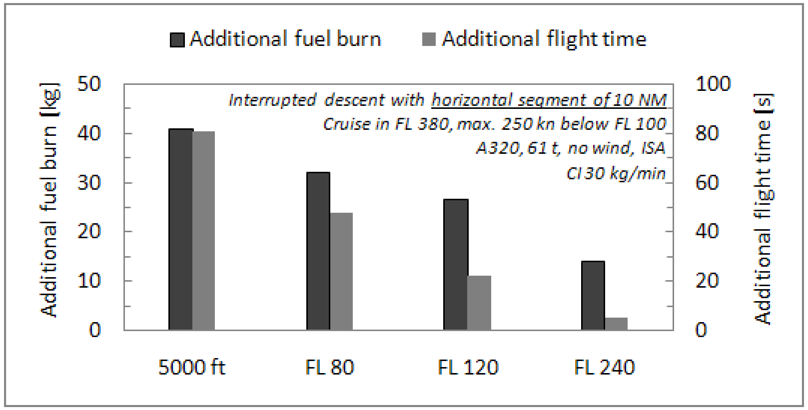
- Lateral trajectory inefficiencies are currently expressed as route extensions, indicated in NM or as a percentage value compared to the great circle distance
- To enable comparison with other trajectory restrictions, diagrams express inefficiencies as ***additional fuel burn, time and total costs***
- total additional costs increase significantly with increasing cost index (higher time-related costs)
- impact of the aircraft mass on the additional costs is very low compared to the impact of the CI

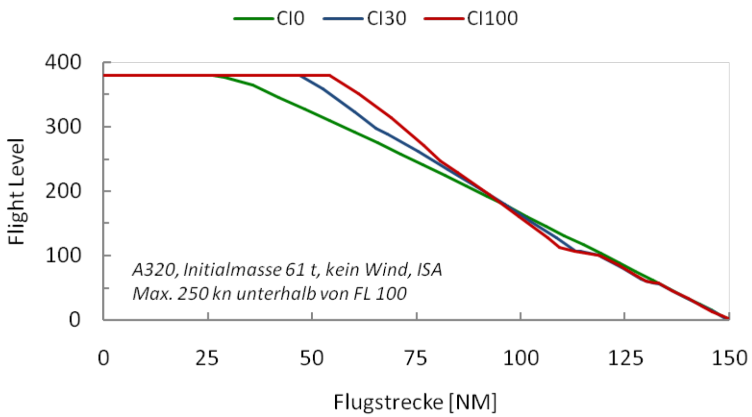


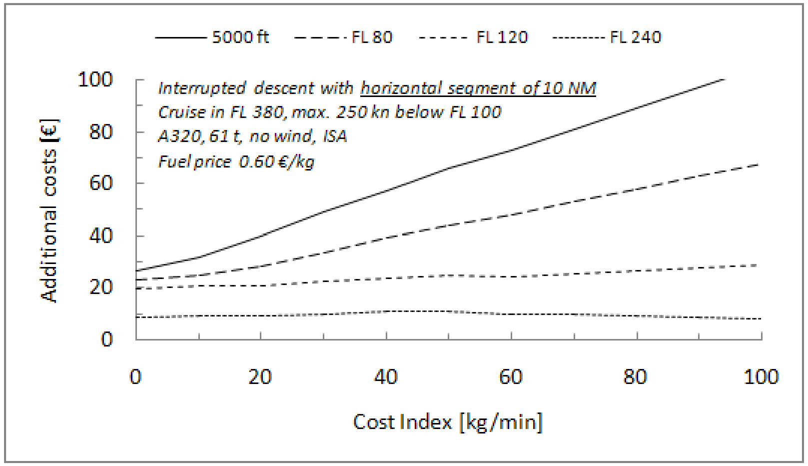


Example 2: Interrupted Descent

- Interrupted descents cause both additional fuel burn and flight time
- due to lower speeds in low altitudes additional costs significantly increase with CIs (however, note that interrupted descents are often used to merge arrival traffic)

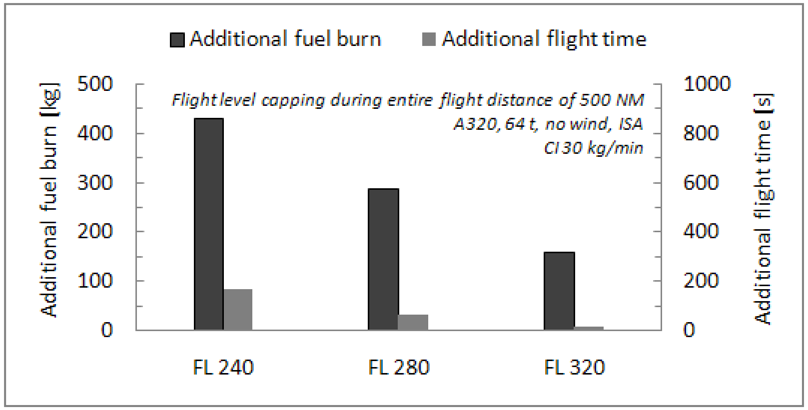


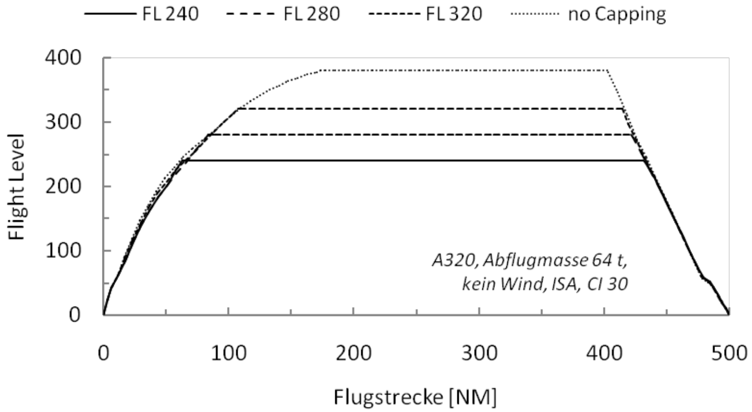


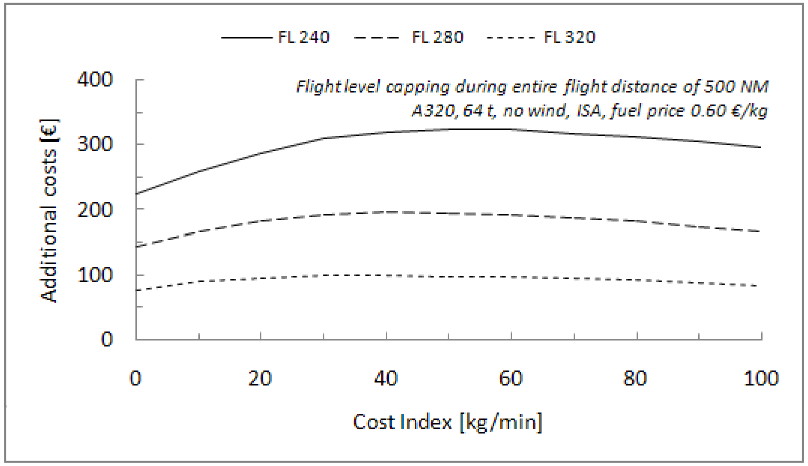


Example 3: Flight Level Capping

- about 12 % of flights in Europe are affected by flight level cappings (as defined in the RAD)
- especially in case of a level capping in FL 240, the caused costs are high compared to other presented trajectory restrictions

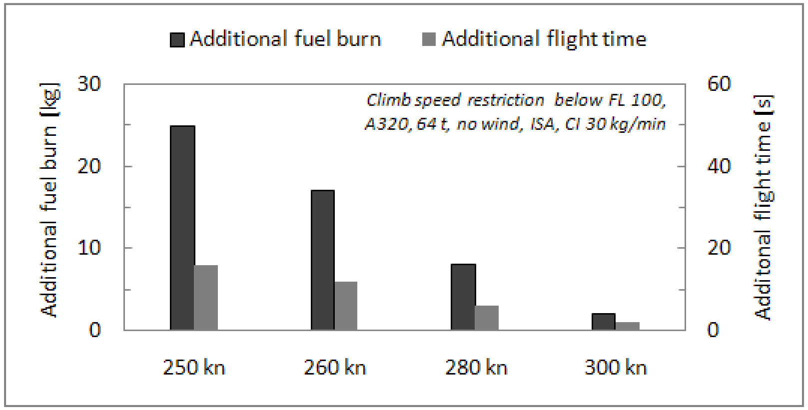


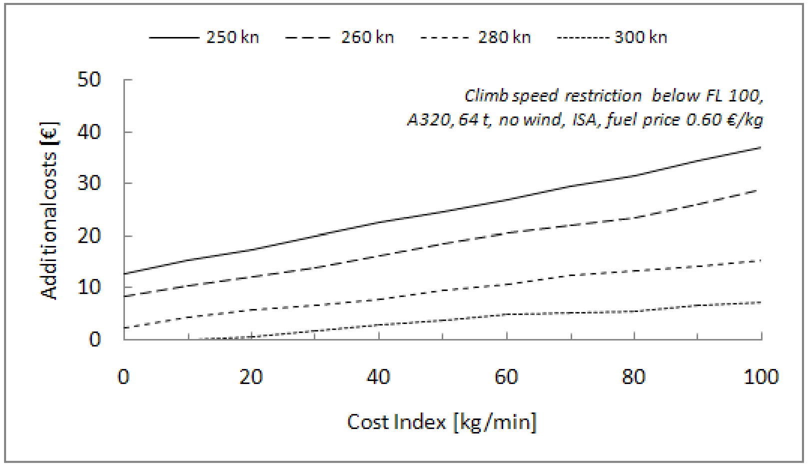




Example 4: Speed Restriction below FL100

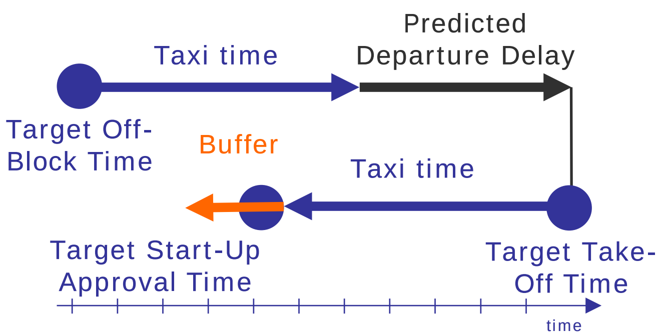
- For flights below FL 100 maximum speed of ***250 kn IAS*** is defined in the ICAO Annex 11 (airspace classes D & higher and VFR in class C)
- With it, for example turn radiuses are limited supporting ATC to manage traffic in high density airspaces
- However, especially during climb this causes a significant deviation between actual and optimal speed profiles (for instance, in case of a CI of 30 kg/min, the ECON climb speed is 310 kn IAS)
- additional costs increase significantly with higher CIs (increasing difference between optimum and limited speed)

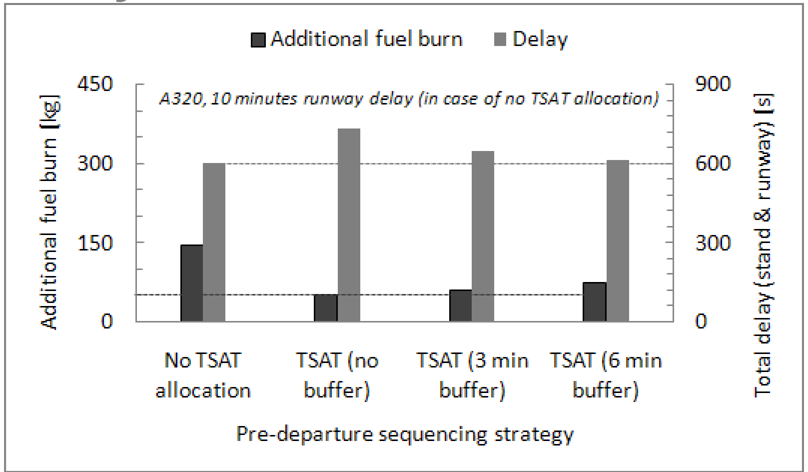


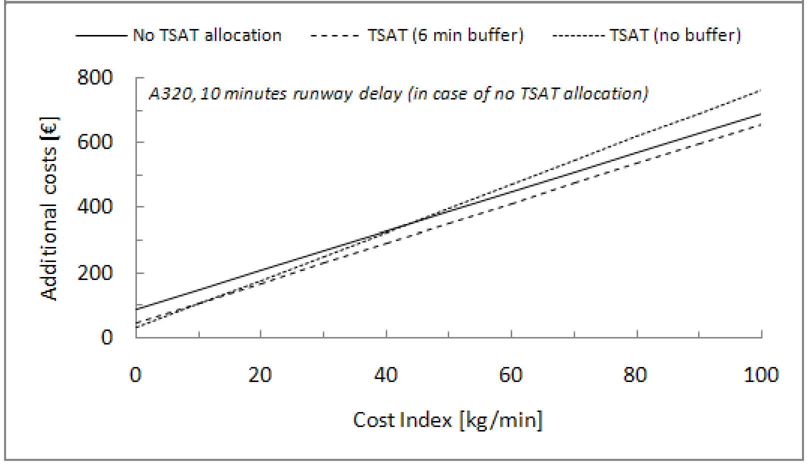


Example 5: Departure Delays

- pre-departure sequencing (US term: departure metering) is one element of Airport CDM concept
- due to uncertainties in the push-back and taxi-out process it is not recommended to absorb the complete delay at the stand (queue buffers are required) to increase efficiency



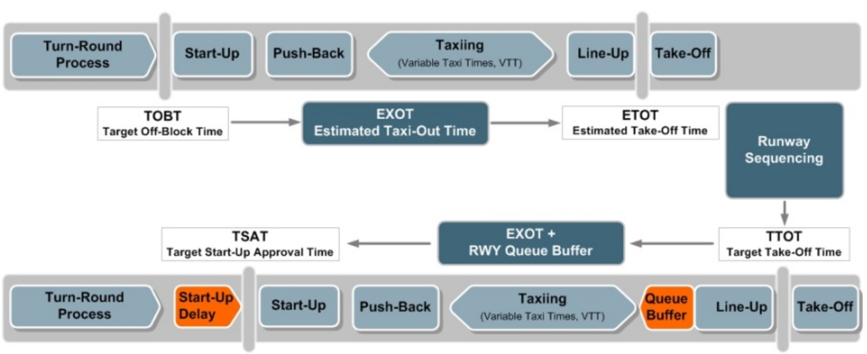


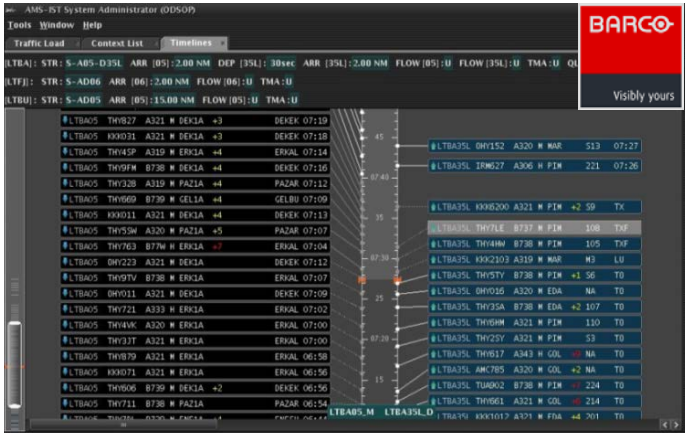


Local example: AMAN / DMAN for Istanbul

Arrival-/Departure Manager is currently implemented at Istanbul Atatürk Airport:

- AMAN/DMAN sequences arrivals & departures in order to improve
  - Predictability (e.g. Estimated Landing Times, Departure Planning Info)
  - Capacity (efficient runway capacity utilization, e.g. gaps for departures)
  - Efficiency (en-route delay absorption, reduced line-up queues)
- DMAN planning (TSAT calculation) takes into account **configurable queue buffers to maximize efficiency**





Summary and Conclusion

A quantification of the additional costs caused by several trajectory restrictions was given.

Thereby, identical efficiency metrics (additional fuel burn, additional flight time and additional costs) have been used for all kinds of restrictions, including horizontal, vertical and speed profile restrictions as well as delays.

May support decision making process in all planning phase (from airspace planning, air traffic flow management to air traffic control) to identify restrictions fulfilling the operational requirements (e.g. maximized utilization of capacities) and thereby causing the lowest costs to airspace users.