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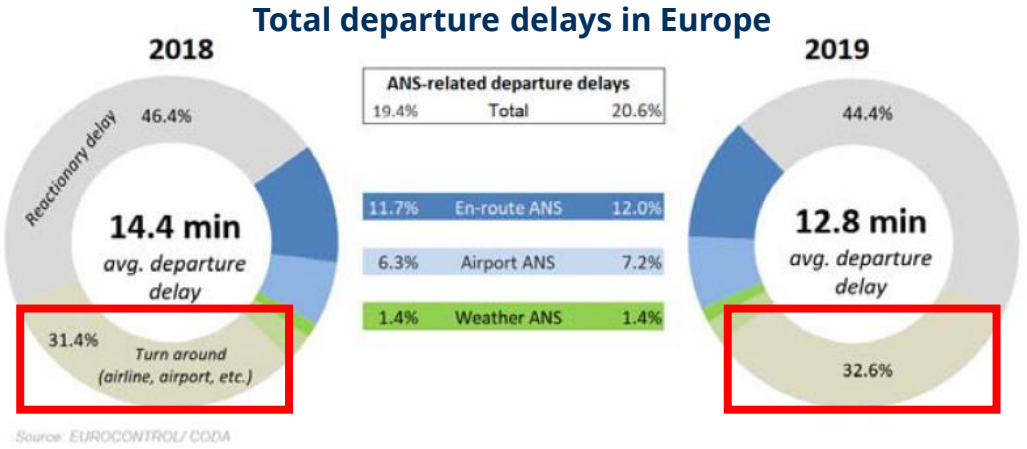
Resource-Constrained Airline Ground Operations: Optimizing Schedule Recovery under Uncertainty

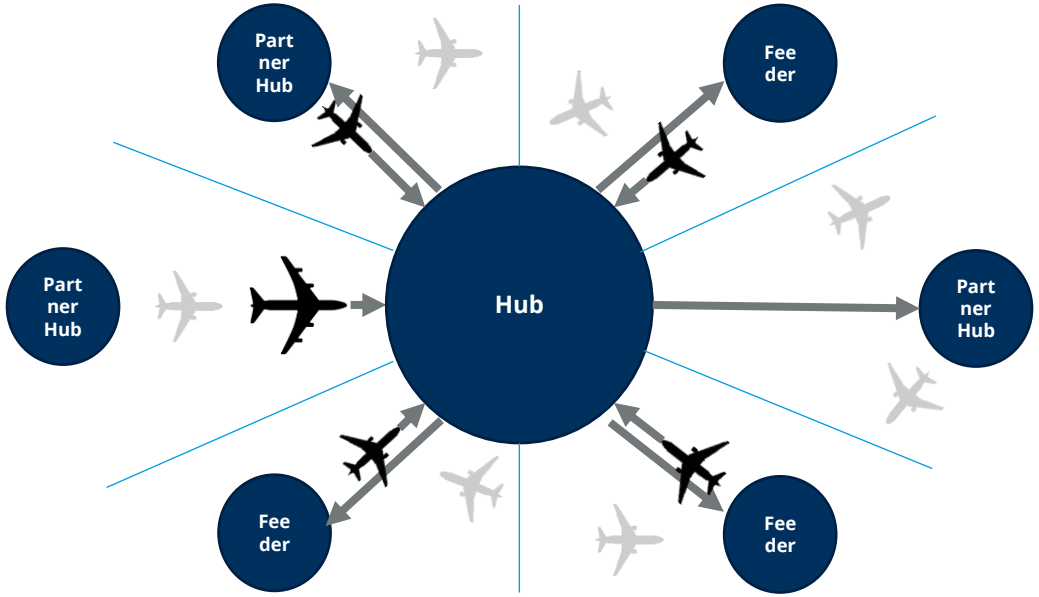
SESAR Summer School 2021

02 September 2021

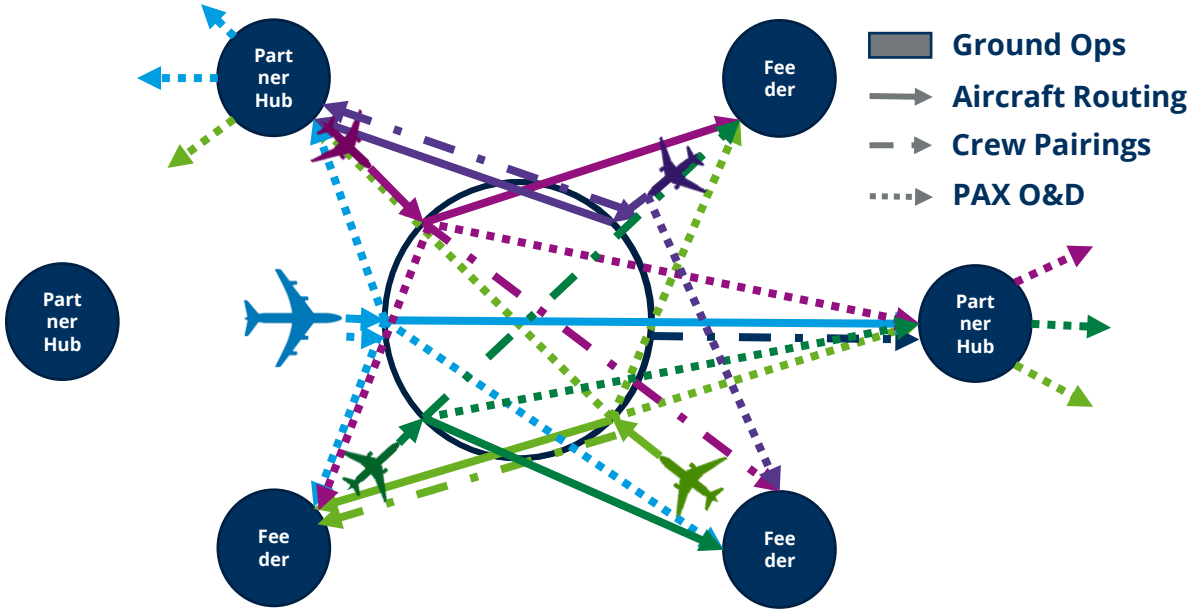
Motivation

- Ground operations are the largest primary delay contributor
- Hypothesis: lack of ATFM-airline cooperation/ coordination





… for **ATFM**, each flight is equal



… for **Airlines**, each flight is unique

Engage PhD Project Agenda

Milestone	Schedule	Content
Step 1.1	Jun19 – Nov19	Set Up Integrated Turnaround Recovery Model
Step 1.2	Dec19 – Feb20	Validation of Model Set Up (2 Articles)
Step 2.1	Mar20 – Aug20	Expand Recovery Model with Stochastic Delay Cost
Step 2.2	Sep20	Validation of Stochastic Delay Cost (1 Article+)
Step 3.1	Oct20 – Mar21	Expand Recovery Model with Tactical Slot Swapping
Step 3.2	Apr21 – May21	Validation of Slot Swapping Mechanism (1 Article+)
Step 4	Jun21 – Feb22	Implementation and Analysis Dissertation Scenario
Step 5	Mar22 – May22	Final Validation and PhD Submission

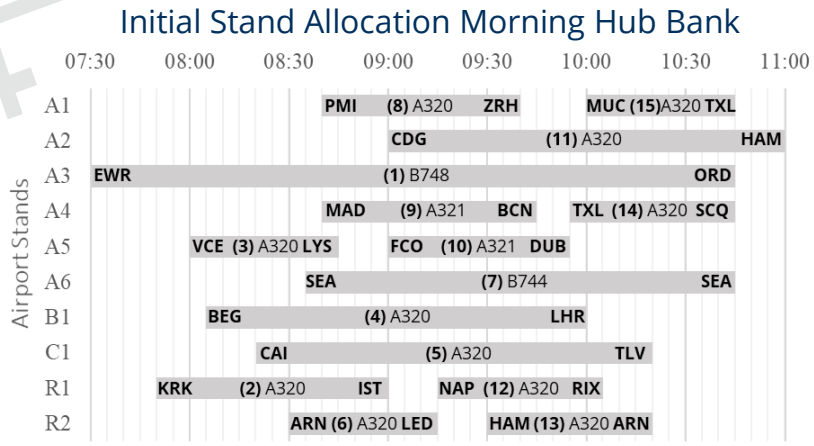
Research Question 1 – see Evler et al. (2021)

RQ1: Which tactical recovery options are the most efficient for the airline when all options are integrated with each other and uncertainty is considered in the optimization process?

Extract from Lufthansa network around hub Frankfurt

Scenario Scope:

En-Route Sector Constraints
(some flights to FRA delayed)



Research Question 1 – see Evler et al. (2021)

RQ1: Which recovery options are the most efficient when all options are integrated with each other and uncertainty is considered in the optimization process?

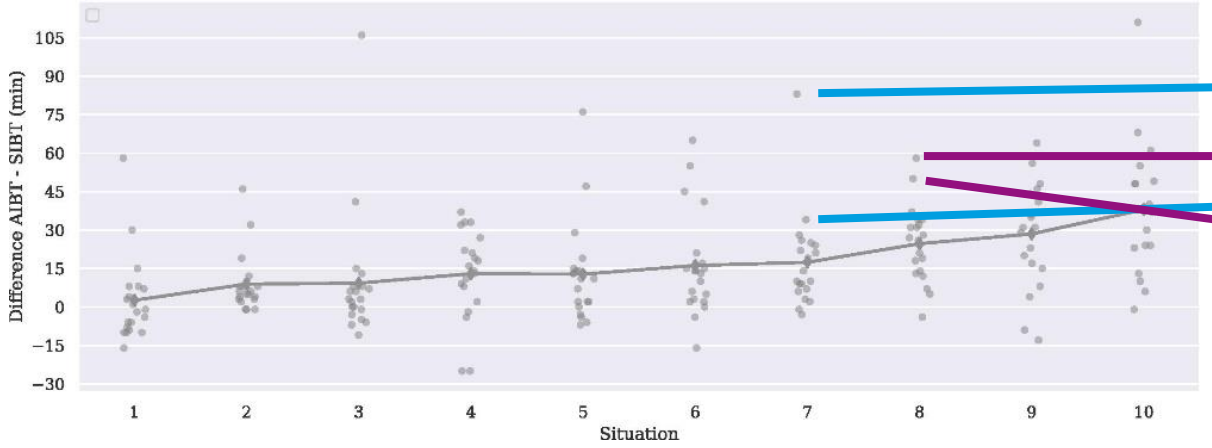
Scenario Scope:

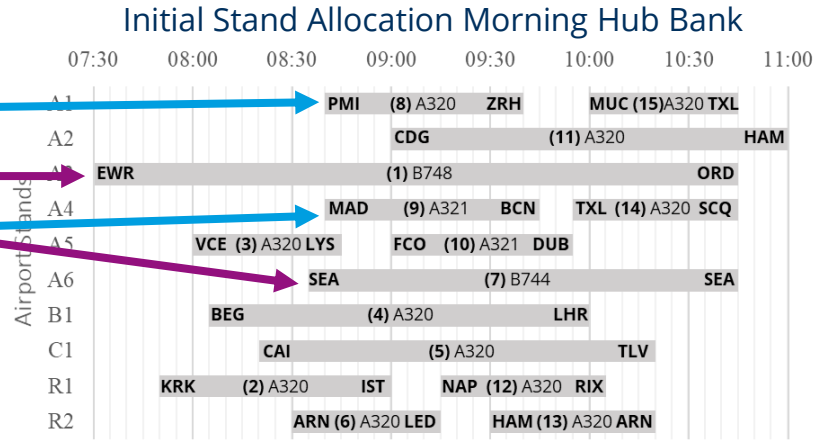
En-Route Sector Constraints
(some flights to FRA delayed)

Disruption Intensity:

Low Arrival Delay
(Mean: <20min)

Med. Arrival Delay
(Mean: ~40min)





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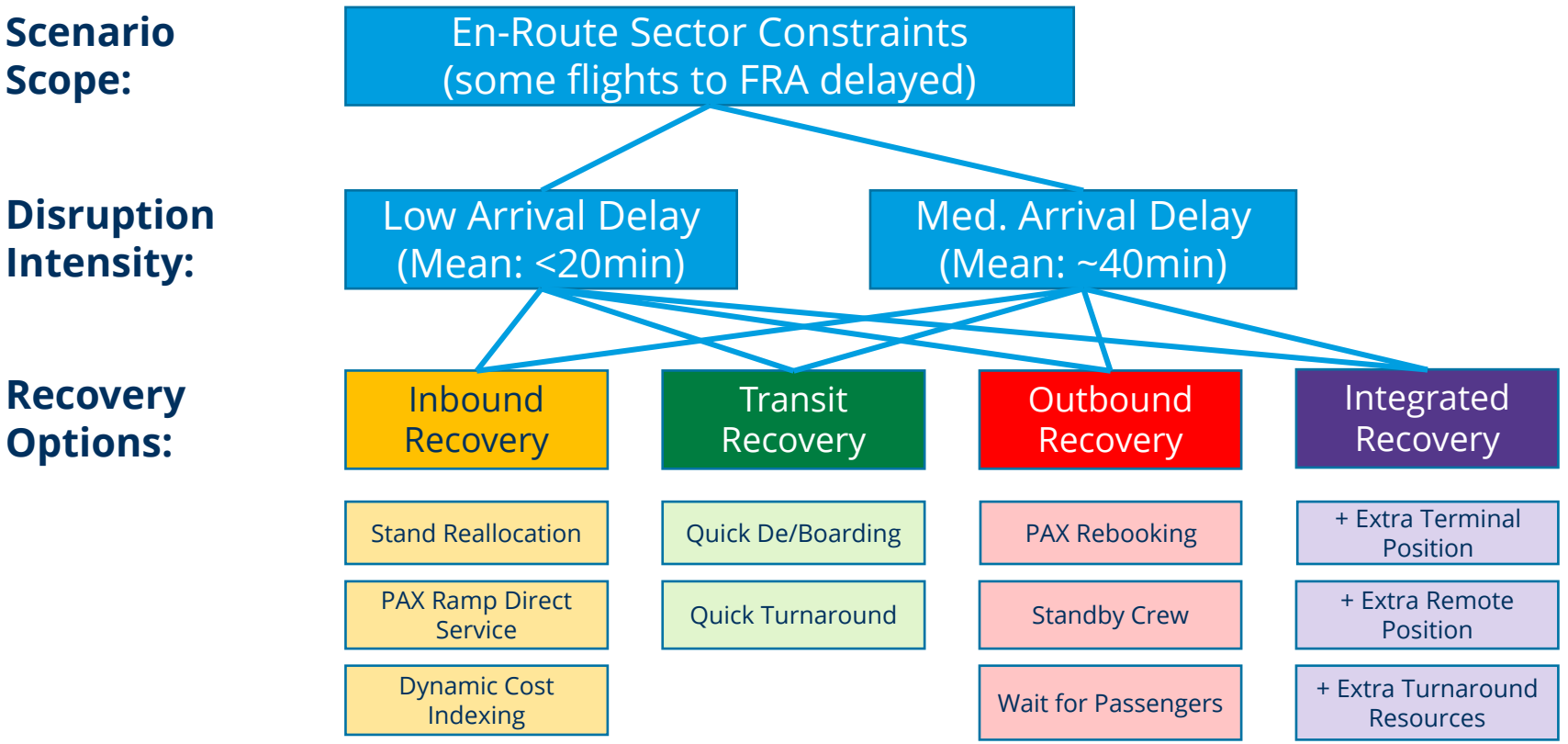

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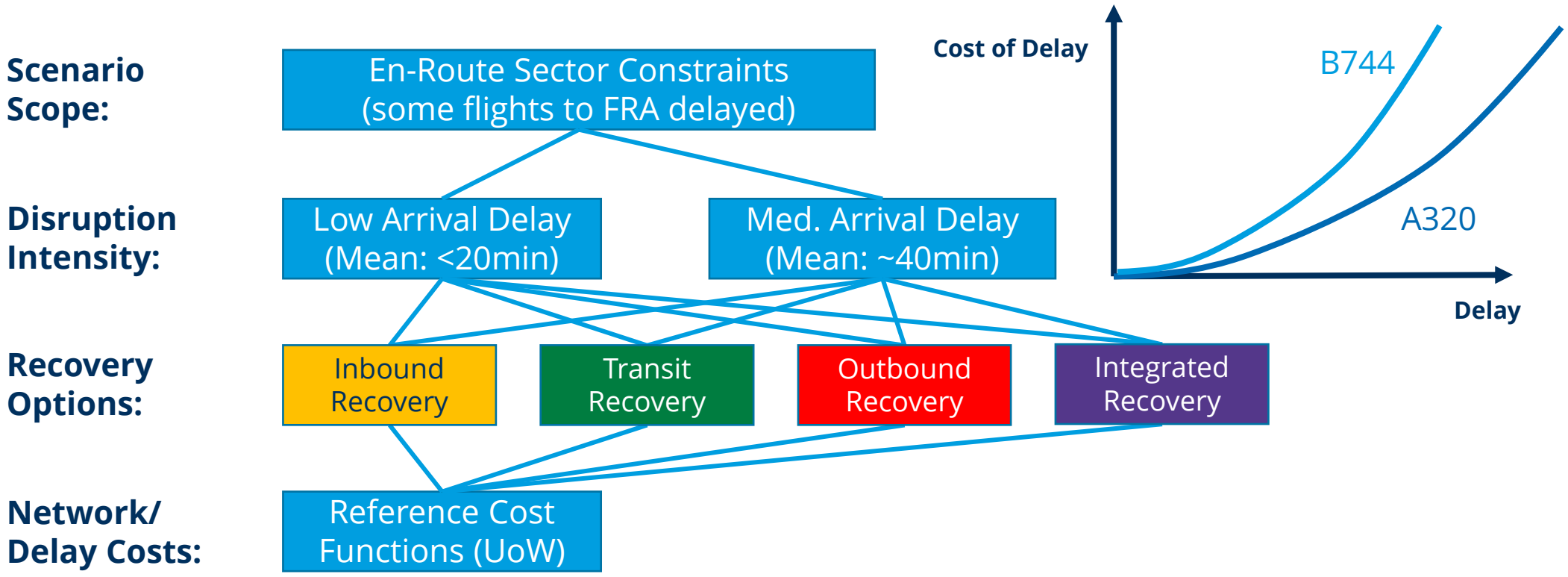

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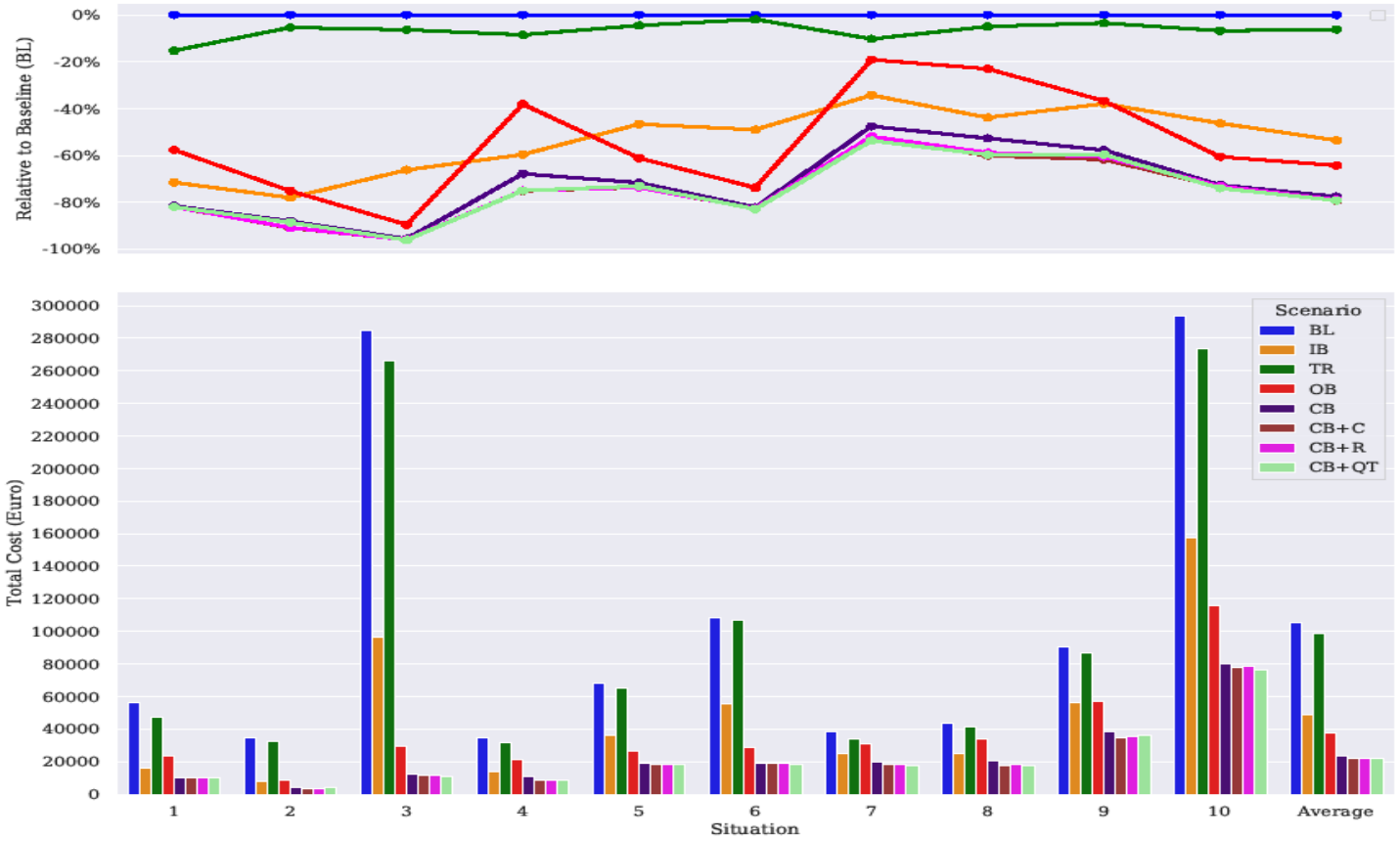


Conclusion for individual recovery categories:

- **Inbound recovery best:**
  - passengers transfers are maintained
  - At least 40% cost reduction even with higher average inbound delays
  - cost reduction is less volatile than outbound recovery

General conclusion:

- Integrated recovery (CB) compensates the weaknesses of individual categories

Research Question 2 – see Evler et al. (2020)

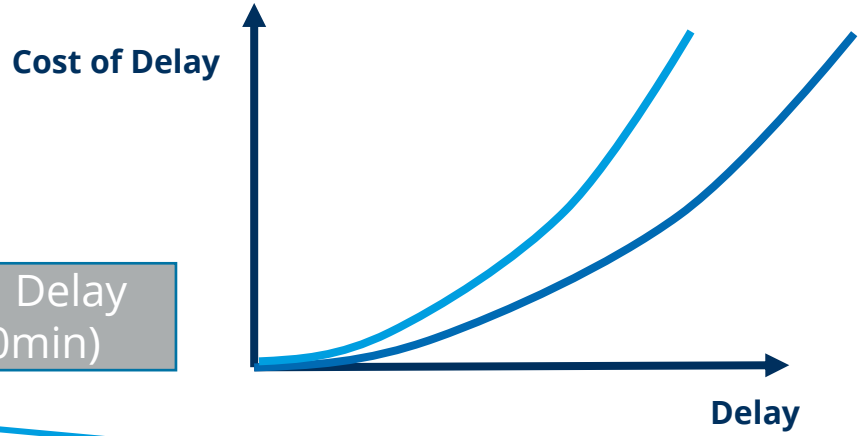
RQ2.1: How can flight-specific delay cost functions be defined, such that they include downstream network dependencies, scheduled slack and active recovery potential?

Scenario Scope: En-Route Sector Constraints (some flights to FRA delayed)

Disruption Intensity: Low Arrival Delay (Mean: ~20min) | Med. Arrival Delay (Mean: ~40min)

Recovery Options: Inbound Recovery | Transit Recovery | Outbound Recovery | Integrated Recovery

Network/ Delay Costs: Reference Cost Functions (Cook)



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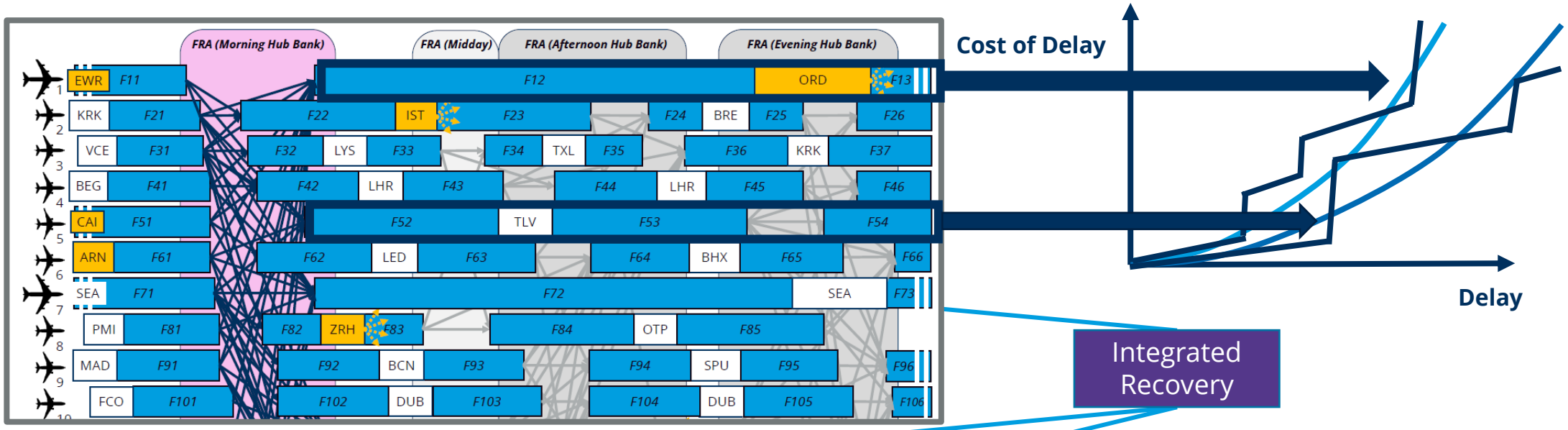


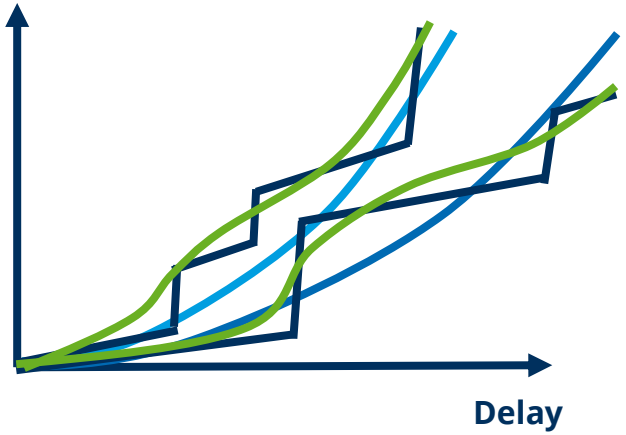
+ Sensitivity Analysis

Research Question 2 – see Evler et al. (2020)

RQ2.1: How can flight-specific delay cost functions be defined, such that they include downstream network dependencies, scheduled slack and active recovery potential?
RQ2.2: How does uncertainty about downstream delays and costs **influence the shape** of such delay cost functions **and the output** of the schedule recovery model?

Scenario Scope:
- En-Route Sector Constraint (some flights to FRA delayed)

Disruption Intensity:
- Low Arrival Delay (Mean: ~20min)
- Med. Arrival Delay (Mean: ~40min)



Recovery Options:
- Inbound Recovery
- Transit Recovery
- Outbound Recovery
- Integrated Recovery

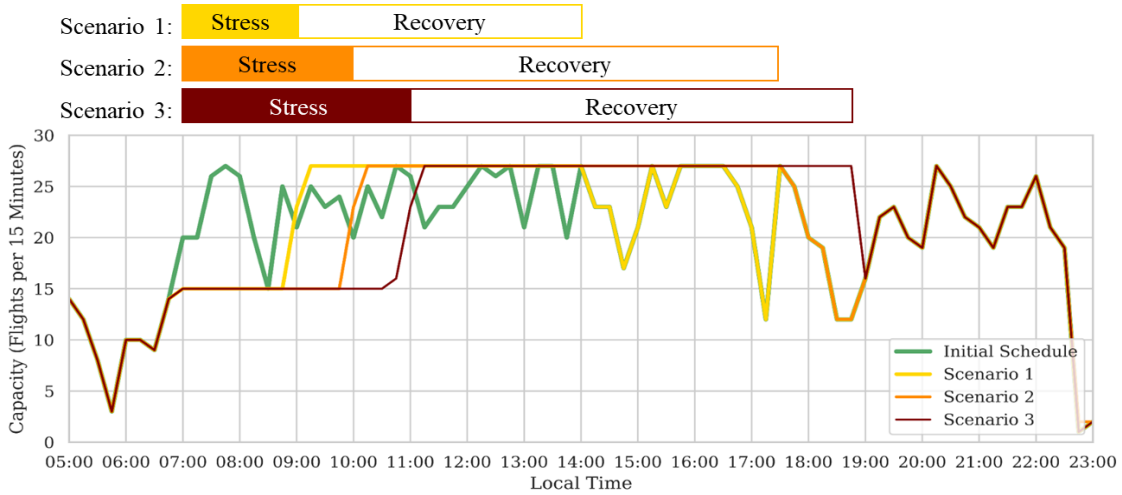
Network/ Delay Costs:
- Reference Cost Functions (Cook)
- Step Cost Functions
- Stochastic Cost Functions

Research Question 3 – see ATM Seminar Paper 2021

RQ3: How can airline-internal flight priorities be defined and coordinated with external stakeholders while respecting data confidentiality and limited resource availability?

Scenario Scope:

En-Route Sector Constraints (only flights in that sector delayed)	Airport Constraint (all flights in FRA delayed)



Research Question 3 – see ATM Seminar Paper 2021

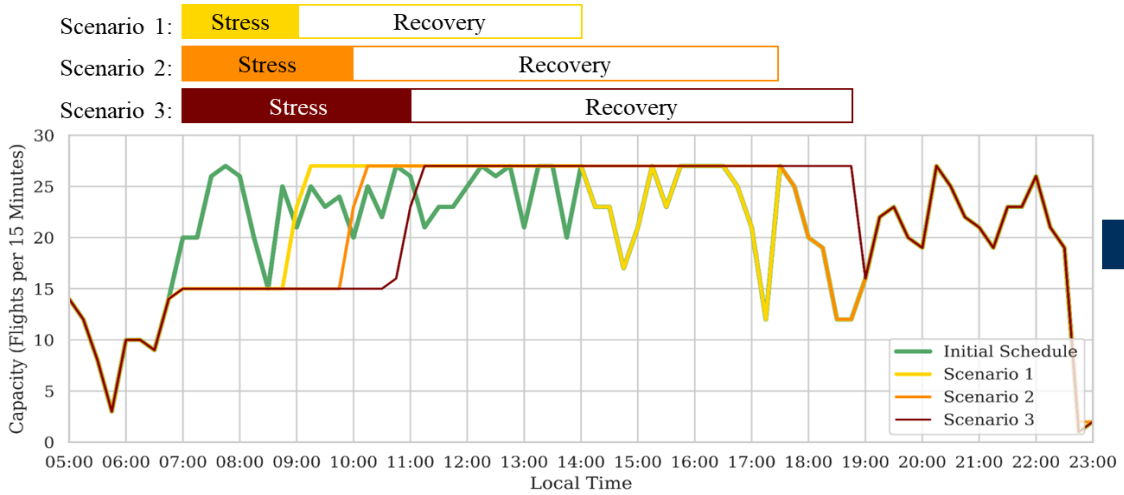
RQ3.1: How can airline-internal flight priorities be defined and coordinated with external stakeholders while respecting data confidentiality and limited resource availability?

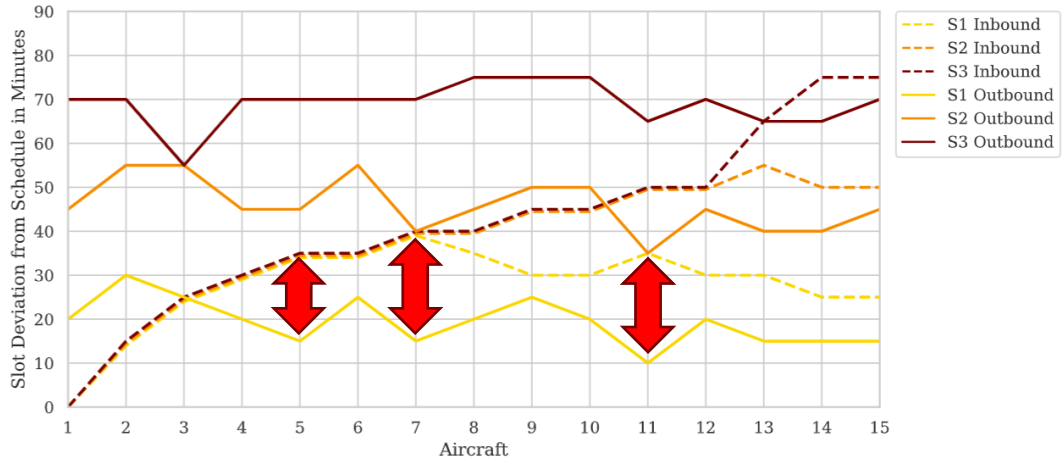
Scenario Scope:

- En-Route Sector Constraints (only flights in that sector delayed)
- Airport Constraint (all flights in FRA delayed)

Disruption Intensity:

- Low Arrival Delay (Mean: ~20min)
- Med. Arrival Delay (Mean: ~40min)
- High Arrival Delay (>60min)





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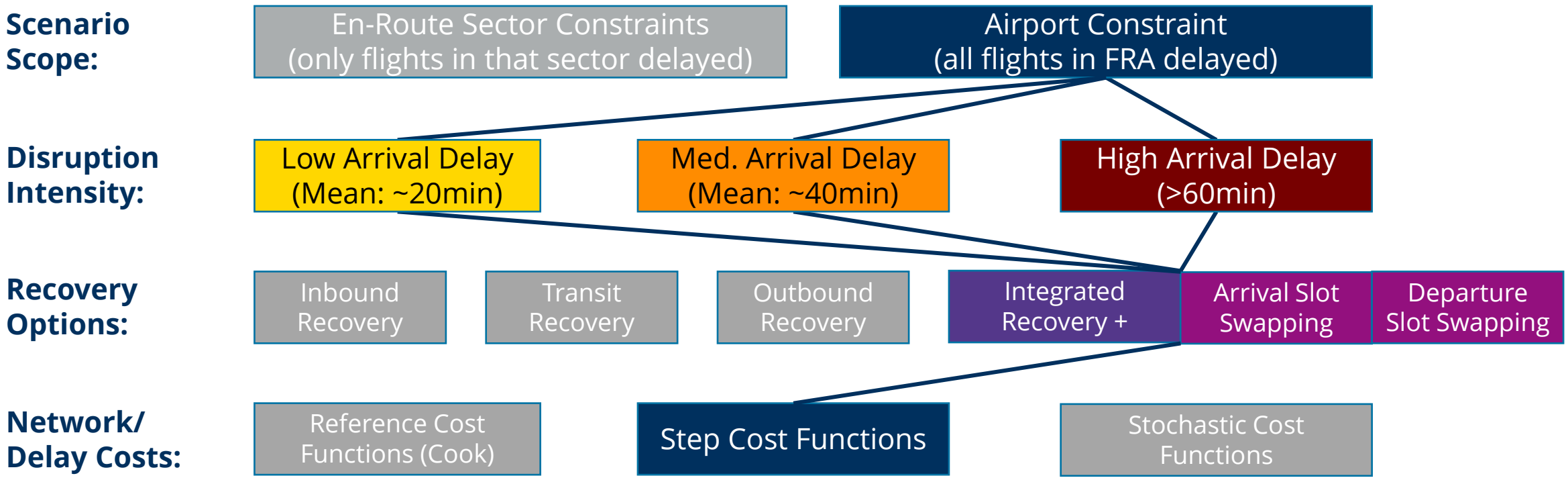
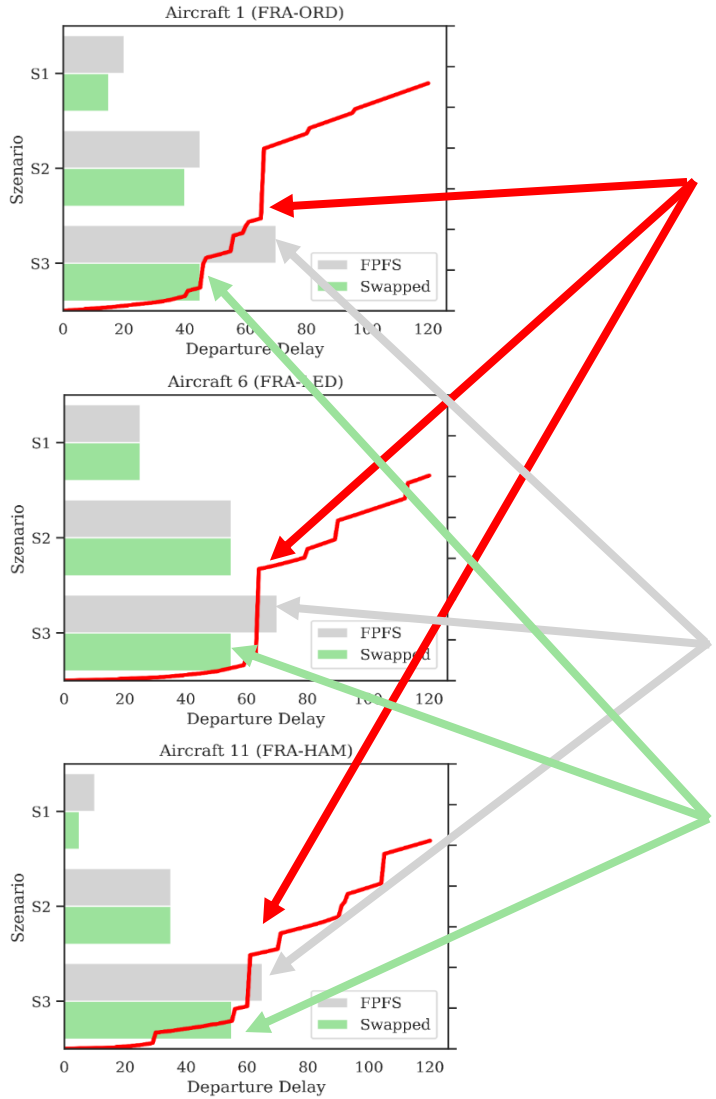
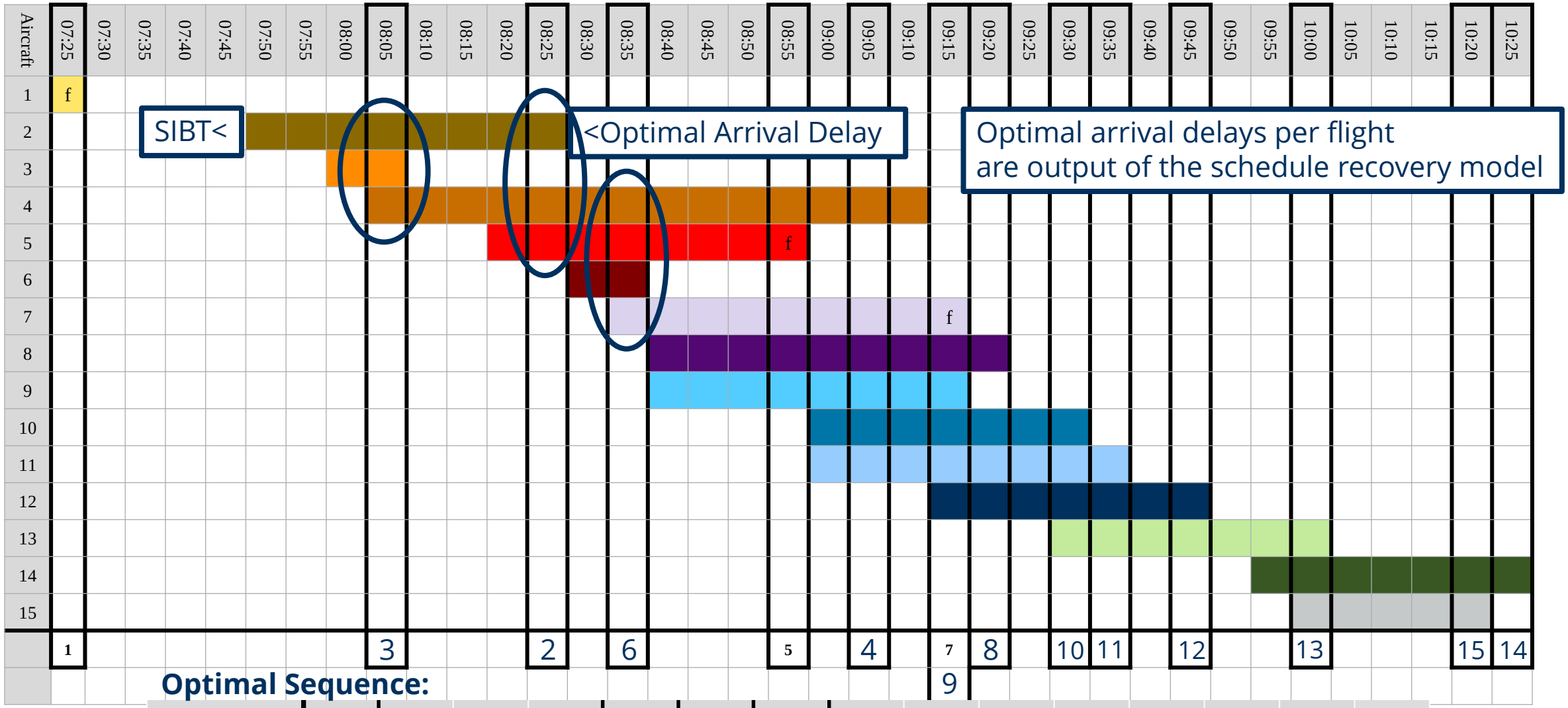


Analysing the Efficiency of Arrival AND Departure Slot Swapping



- Departure delay cost functions have critical cost steps around 60min threshold
- Assigned departure delays in S1 and S2 rarely incur high delay costs, but delays in S3 go beyond 60min
- Impact on efficiency if departure slots are fixed in S3, as critical cost steps cannot be avoided
- Higher number of swaps among departure slots in S3 (if allowed) to reallocate delays before critical thresholds
  - 3 flights are deprioritized (one by 185min)
  - 10 flights are prioritized

Flight Priorities: Assign slot to applicable flight with least delay margin

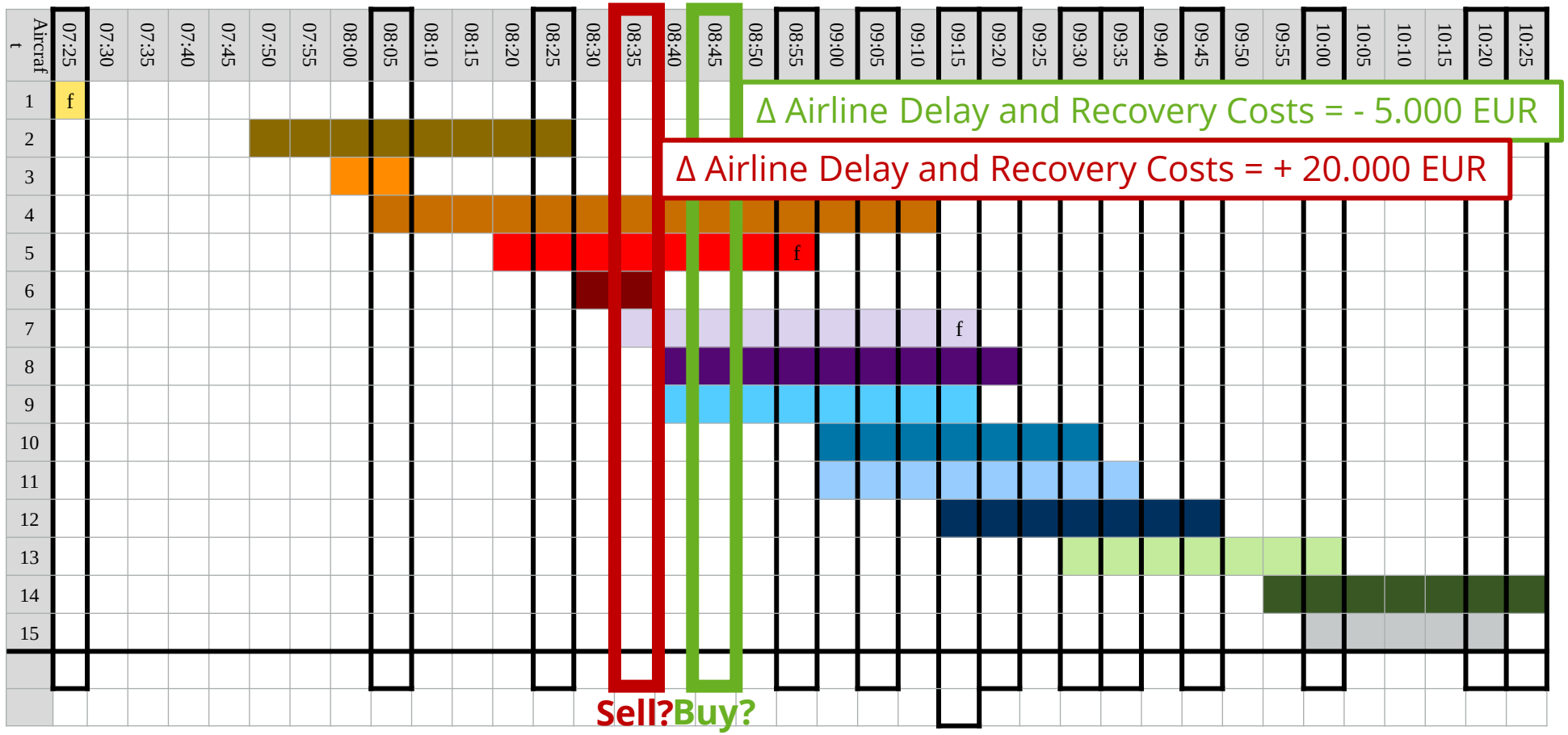


Optimal Sequence:

Scenario 1	7:25	8:05	08:25	08:35	08:55	09:05	09:15	09:15	09:20	09:30	09:35	09:45	10:00	10:20	10:25
Arrival Slot Swapping															

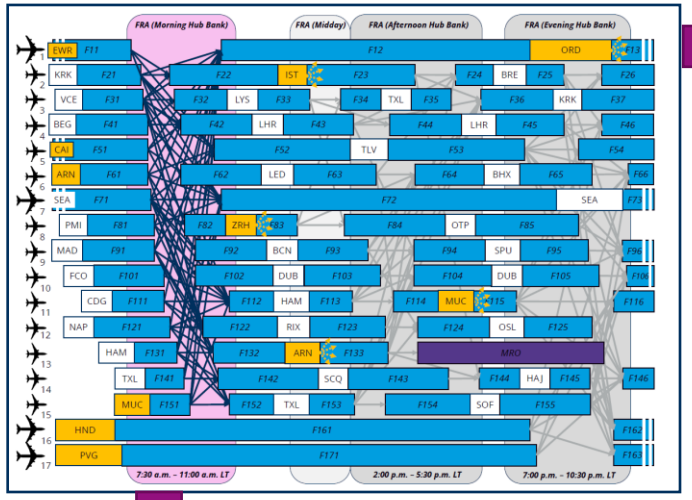
Research Question 3 – ATM Seminar Paper 2021

RQ3.1: How can airline-internal flight priorities be defined and coordinated with external stakeholders while respecting data confidentiality and limited resource availability?
RQ3.2: What is the value of particular slots for an airline and which factors influence this value?



Research Design Final Dissertation

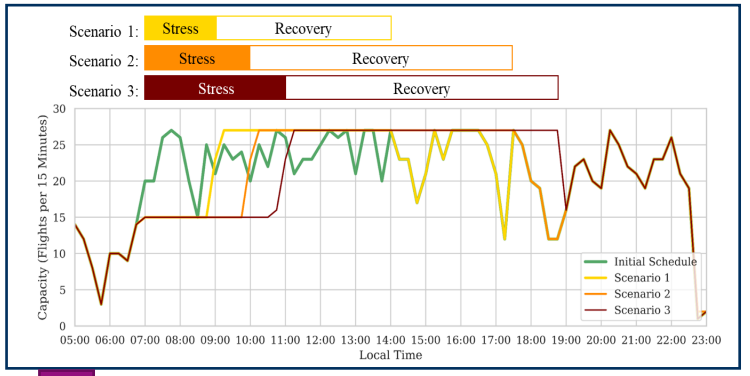
Case Study Airline Network



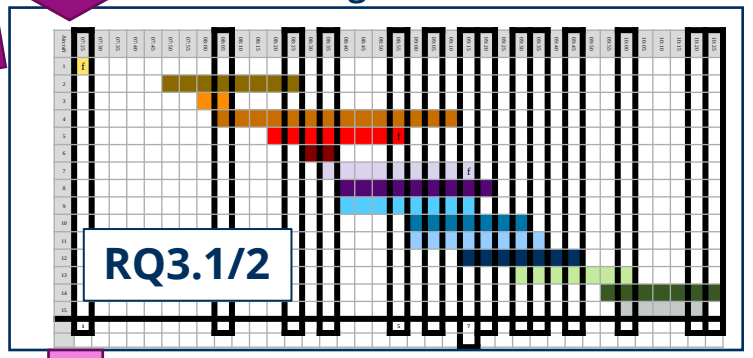
Flight-Specific Delay Costs

Stochastic Delay Costs

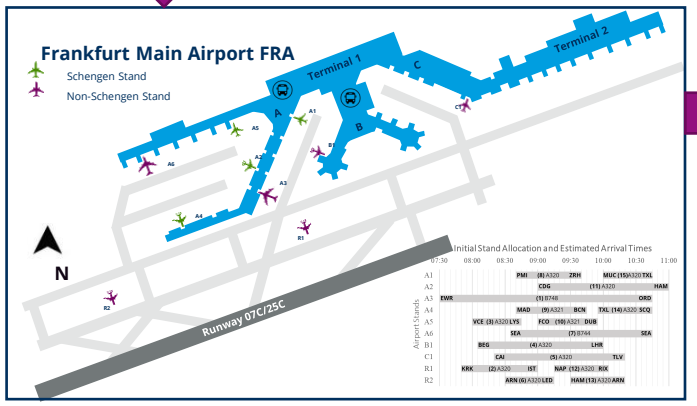
Disruption Scenarios: Airport Constraint 2h/3h/4h



Definition Flight Prios and Slot Values



Focus on Morning Hub Bank



Integration of Recovery Options

Combined Recovery (CB) with Variations

Inbound Recovery (IB)	Transit Recovery (TR)	Outbound Recovery (OB)
Stand Reallocation	Quick De-Boarding	PAX Rebooking
PAX Ramp Direct Service	Quick Turnaround	Standby Crew
Cruise Speed Control	RQ1	Departure Delay
Arrival Slot Swapping		Departure Slot Swapping

Dissertation Analysis:

- Scenario Scope: Airport Constraint (all flights)
- Disruption Intensity: Low/Medium/High
- Recovery Options: Inbound vs. Combined
- Network: Reference vs. Stochastic Delay Costs

= 12 Scenarios

Outlook onto Possible Applications

Tactical Airline Operations Control

1) Comparison of results between current AOCC working procedures and integrated turnaround recovery model in shadow mode with real airline data/ constraints
2) Apply modelling approach within different airline networks (for different business models)

ATFM and Airline Cooperation (UDPP)

Apply model to different airline business models which are impacted by real airport capacity constraint:

1) analyse how their network strategy influences their delay cost functions and recovery decisions
2) analyse if trading slots based on internal value estimations helps to improve recovery performance

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Thank you for the nomination.

Find more details:

- *"Stochastic control of turnarounds at hub-airports"* (2018) SESAR Innovation Days, Salzburg
- *"Integrated operations control at hub-airports with uncertain arrival times"* (2020) ICRAT, Best Paper Award
- *"Future aircraft turnaround operations considering post-pandemic requirements"* (2020) JATM 89
- *"Development of stochastic delay cost functions"* (2020) SESAR Innovation Days
- *"Airline ground operations: Optimal schedule recovery with uncertain arrival times"* (2021) JATM 92
- *"Airline ground operations: Schedule recovery optimization approach with constrained resources"* (2021) TRC 128
- *"Flight Prioritization and Turnaround Recovery"* (2021) ATM R&D Seminar
- *"Integration of Turnaround and Aircraft Recovery to Mitigate Delay Propagation in Airline Networks"* (2022) CAOR 138

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 783287. The opinions expressed herein reflect the authors' view only. Under no circumstances shall the SESAR Joint Undertaking be responsible for any use that may be made of the information contained herein.