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Integrated Instead of Sequential Optimization

A novel approach to solving the multi-hub network planning and scheduling problem

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Speakers

Ralf Schneider is a senior data scientist, software architect and developer with more than 20 years experience in aviation. He has in-depth knowhow in **demand modelling, optimization and AI technologies** combined with a solid understanding of network planning and scheduling business needs.

Judith Semar has extensive experiences in **commercial & operational airline processes**. She is passionate about using modern technologies to improve business processes. Her current focus is the development of **predictive applications and optimization solutions**.

Marius Radde is a data scientist at Lufthansa Systems. He holds a Master of Science degree in Transport Engineering. The current focus of Marius' work is **data science and operations research to facilitate new forecast and optimization features**.

Peter Lietz is an expert for discrete optimization at Lufthansa Systems. He holds a **PhD in Mathematics**. Throughout his career he has applied optimization methodology in the areas of multistage switching networks, cash logistics and – finally – **airline schedule development**.

Lufthansa Group Research Project

NOV2019 – APR2020

The novel optimization approach, now called ‘HubDesigner’, was initially developed in a research project together with **Lufthansa Group**

The objective is to optimize aircraft schedules **within one and across several hubs simultaneously** to avoid cannibalization effects

Designed as holistic, green-field optimization integrating **time and frequency optimization, destination selection, fleet assignment & rotation building** in **one** optimizer

Designed as an end-to-end service in the cloud to facilitate **simple, cost-efficient and scalable use**

Network design & optimization for strategic analysis and for day- to-day planning and scheduling tasks

Data Requirements

Market information
- Market demand data
- Schedules (own and competition)
- Market model parameters

Cost and Revenue information
- Market yields
- Operating costs

Operational and commercial constraints
- Slots & curfews
- Aircraft ranges & restrictions
- Minimum ground & connection times
- Commercial requirements
- …

O&D Network Optimization

Design Schedule from Zero

Optimize Existing Schedule

Business Application and Use Cases

Strategic network planning
- Multi-Hub-Network Design
- Group wide hub focus optimization
- Bank Design of (multiple) hubs
- Fleet Studies

Dynamic scheduling
- Selective schedule adjustments to demand & competitive situation of few markets
- Comprehensive network redesign in case greater schedule adjustments are needed

Special cases
- Fleet Assignment
- Frequency optimization
- Connectivity optimization

Our Concept Architecture Iteratively Creates High-Quality Solutions

Schedule Evaluation	During optimization, the optimizer **evaluates the validity and quality of the latest solution** in each iteration. Valid solutions are feasible aircraft schedules, i.e. schedules without constraint violations. Their quality is determined by calculating the overall network profitability.
Schedule Modification	To improve the latest solution, the optimizer modifies the solution. The complete set of schedule modification options is available (i.e. **flight timings, fleet assignment, frequencies, destinations**).
Optimization Strategy	The interaction between evaluation and modification of a solution is **steered by an overarching strategy**, so that high-quality solutions are generated as a result of the process.

Evaluation of a Schedule

All intermediate and final results of optimization runs are aircraft schedules. How does the optimizer evaluate aircraft schedules?

Check operational as well as commercial constraints related to minimum ground times, frequencies, slots, aircraft ranges etc.

Calculate the un-constrained demand for the previously built itineraries based on market demand data, competition supply and itinerary attractivity.

Based on the passenger mix, sum up all revenues and subtract costs of operating the schedule to **determine profitability**.

CONSTRAINT CHECKER → CONNECTION BUILDER → UNCONSTRAINED DEMAND → OPTIMIZE PASSENGER MIX → PROFIT

Build the supply for passengers, i.e. **direct services and itineraries via the hubs** based on minimum connection times, travel times and maximum acceptable detour factors.

Using a mixed integer program, align demand and capacity and **optimize the onboard passenger mix** to focus on high-yield markets and, thereby, maximum revenues.

Details on Commercial Level Evaluation Modules

Connection Builder

- In addition to direct connections, we build up all **single-connect online itineraries** via the specified hub stations
- We apply a **similar procedure for the competitor itineraries**, where we consider all single-connect online itineraries via their respective hubs

$$itins_{hub} = flights_{In} \times flights_{out}$$

- Built itineraries are reduced by those
  - exceeding max. elapsed times
  - undercutting min. connect times
  - taking too large detours

Market Model

Each itinerary gets a utility score based on its attractiveness. Its market share is determined by its own utility and the utilities of competing itineraries applying a **logit model**.

Utility related to travel time and no. of stops

$$u_{base} = \beta_{elap} * \ln(elap) + \beta_{nstops} * nstop$$

Timing Related Utility

$$u_{time} = \beta_{dep} * STD + \beta_{arr} * STA + \beta_{time_comp} * STD_{density}$$

Total Exp-Utility

$$u = \exp(u_{base} + u_{time})$$

Unconstrained demand

$$u_demand_j = \frac{u_j}{\sum_{i=1}^{n} u_i} * msize$$

Passenger Mix Model

Maximize total revenues (tr), i.e. the sum of revenues generated by both local and connect passengers:

$$\sum_{f} (PL_f * YL_f - C_f) + \sum_{(f,g)} PC_{f,g} * YC_{f,g}$$

local PAX # connect PAX

while considering the following constraint for all flights f:

$$PL_f \leq \frac{u_{m,d}}{u_m} * D_m$$

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Modification of a Schedule

Aircraft schedules can be modified with regard to different aspects

Time Shifting

The optimizer creates new connections at the hub station and offers more profitable itineraries.

Flight Adding/Removing

The optimizer schedules new profitable flights, removes unprofitable ones and adjusts frequencies.

Fleet/Tail Assignment

The optimizer matches demand and supply in a more profitable way.

Destination Swapping

The optimizer shifts the supply to more profitable markets.

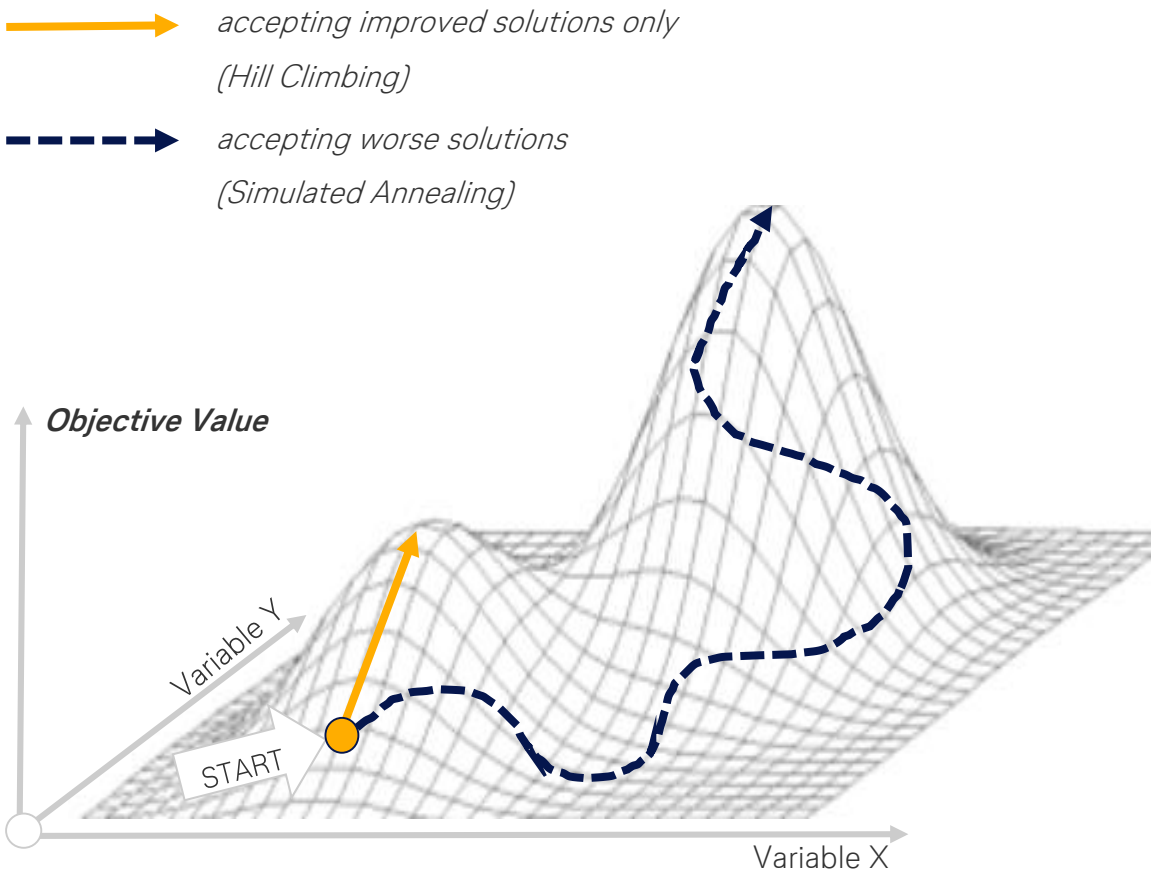
Aircraft Rotations

Each of the above shown schedule modification options will only be implemented if they result in fully feasible aircraft rotations. An according evaluation is performed by the **Constraint Checker** module.

- All schedule modifications are implemented via so-called **operators**: these operators are methods that actually perform a specific schedule change on data level.
- The operators are key to the optimization strategy, as they also build up the **neighborhood** to an existing solution.
- The optimizer works with all operators simultaneously or **any desired subset** of operators (e.g. only time shifting).

Optimization Strategy – How We Ensure Improved Schedules

- **Very Large-Scale Neighborhood Search** is a heuristic optimization strategy that
  - in each step generates neighbors to the current solution and
  - by *usually* accepting only improved neighbors as new solutions steers the process towards local/global optima.
- In a multi-hub network planning problem, any given solution comes with millions of neighbors, so that the underlying search space cannot be explored exhaustively.
- Nonetheless, the optimizer is implemented in a way that it is capable of evaluating hundreds of millions of solutions in one optimization run.
- Even though randomness is part of the process, the variance of the solution quality is very small for repeated runs on the same input data.



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Computational Performance is Key

All intermediate and final results of optimization runs are aircraft schedules. How does the optimizer evaluate an aircraft schedule?

Evaluation of a schedule

CONSTRAINT CHECKER	CONNECTION BUILDER	UNCONSTRAINED DEMAND	OPTIMIZE PASSENGER MIX	PROFIT
0.03 ms	+ 6 ms	+ 1.5 ms	+ 3 ms	~ 10.5 ms

During optimization, evaluations will be cancelled here if new constraint violations are found.

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Case Studies

Study 1: Initial Research Project with Lufthansa Group

- Latest **feasibility study** on an integrated network optimization across Lufthansa Group hub airports
- Several studies conducted before did not yield satisfying results
- Four teams (internal and external to LHG) tried to tackle the problem using different approaches
- Measurement of success based on Lufthansa Group Summer 2019 input data

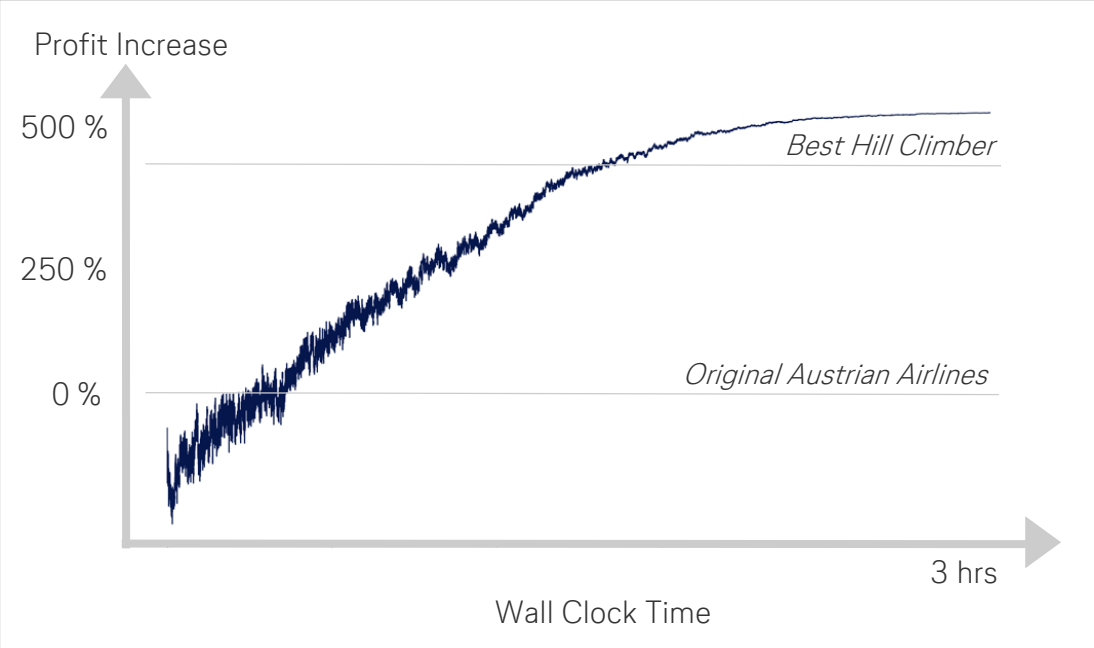
Study 2: Application of HubDesigner during low-demand COVID period

- Examine profitability improvement potentials during the COVID-induced aviation crisis
- Find appropriate bank structure for Lufthansa Group hub aiports
- Evaluate the potential of different setups and configurations:
  - 1. use only time shifts, 2. add fleet assignment, 3. use all options

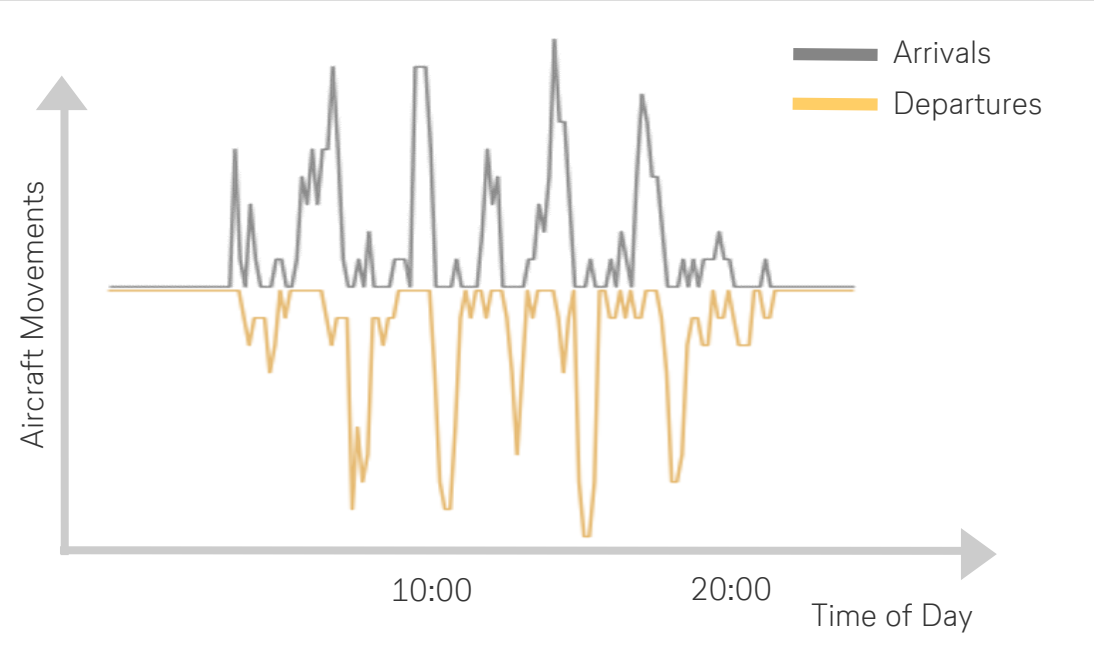
Optimization Results (1)

Case Study 1: Single-hub optimization results for Lufthansa Hub VIE*

Optimization progress



Newly created banks at VIE



- Optimization based on published September 2020 Lufthansa Group Schedule.
- The optimizer starts **from scratch** and creates a highly profitable schedule with a well balanced bank structure at the hub.
- It massively increases production (**410 vs. 510 flights**) and aircraft utilization (**7.7 vs. 6.3 legs per rotation** for short/medium haul fleet).
- The optimized solution fulfills all operational requirements, resulting in **0 constraint violations**.

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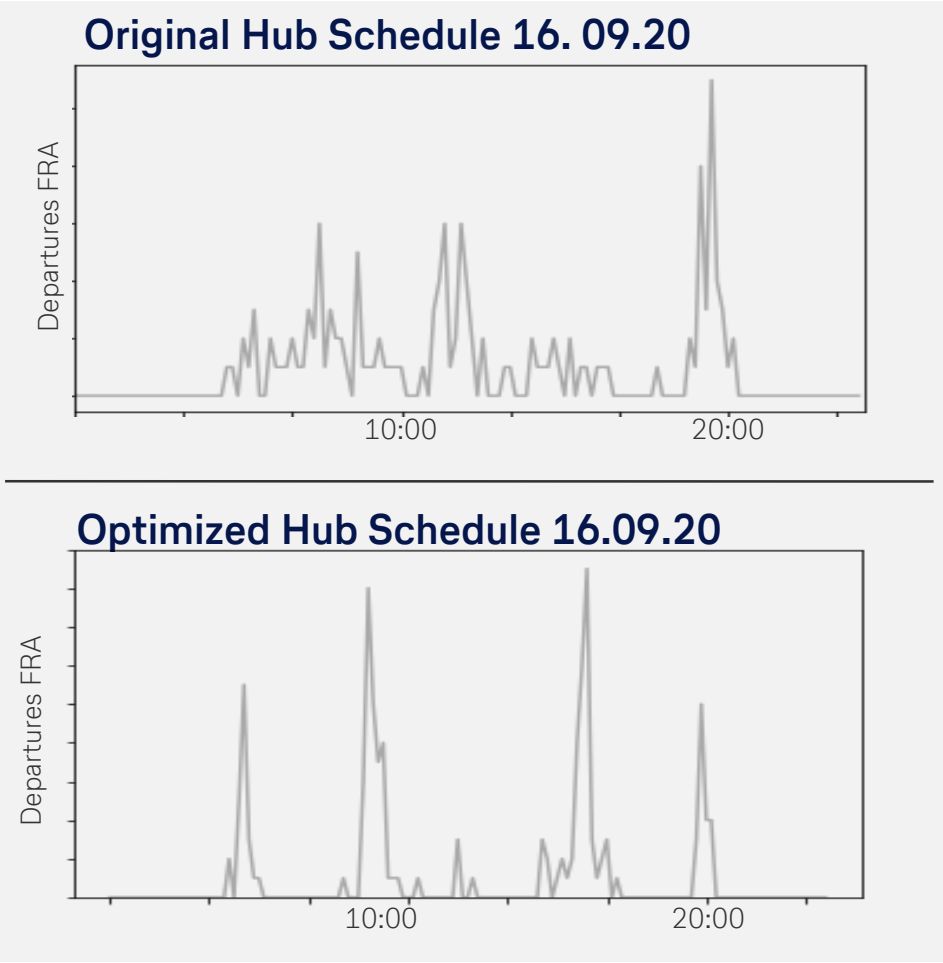
Optimization Results (2)

Case Study 2: Multi-Hub optimization of a low-demand Lufthansa Group schedule*



- Revenue increase by **improving intercontinental itineraries by providing better connectivities and adding additional European feeder flights** (e.g. Europe to HKG, ICN, PVG, YVR, SIN)
- Additional **European leisure demand exploitation** by increasing frequencies to Mediterranean destinations (e.g. PMI, MLA, SKG, HER)
- Cost reduction by **capacity reduction on European flights** (e.g. TXL, BRU, GRZ, CDG)

Schedule KPIs	Original Schedule*	Optimized Schedule	Change
Flights	688	801	+ 16%
Short Haul			
• Legs/rotation	4.8	5.8	+ 21%
• Load factor	62%	87%	+ 25%
Long Haul			
• Legs/rotation	1.8	1.7	- 6%
• Load Factor	22%	44%	+ 22%
Revenue Increase			**+ 64%**

* Optimization based on published Lufthansa Group Schedule September 2020
** Published Lufthansa Group Revenue ASK 2019 (Annual Report 2020) & generic cost information

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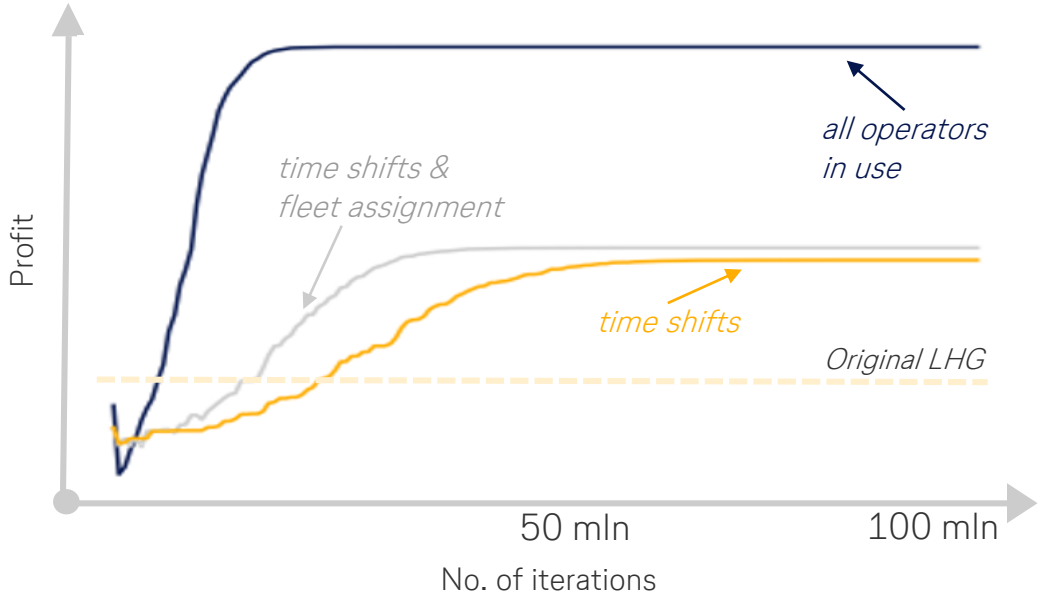
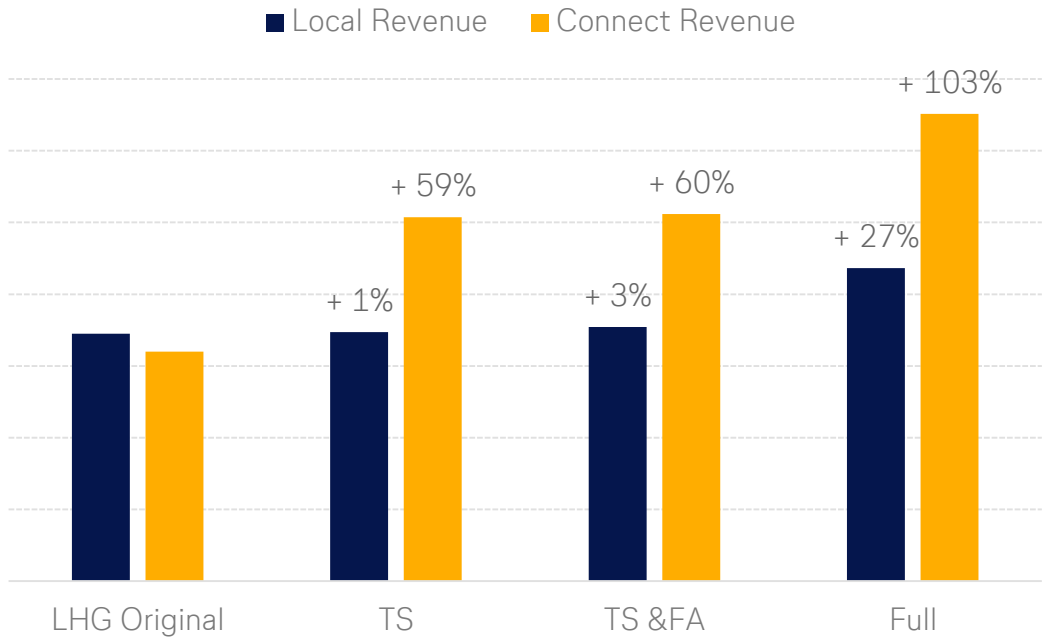
Optimization Results (3)

Case Study 2: Performance with different sets of operators

Optimization progress



Revenue gains by operator subset



- **The more operators are used, the faster** the optimization will jump into high quality regions of the search space.
- Run times are **between 4 hours and 7 hours** depending on configuration.
- The full options run increases **both local and connect** revenue by scheduling an optimized set of flights on **high-yield markets**.

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What Makes This Network Planning and Scheduling Optimization Approach Unique?

1. The optimizer supports **integrated optimization** by applying time shifting, fleet assignment and destination selection in **a single optimization run.**
2. It enables **network optimization across hubs,** thus preventing competition within multi-hub networks.
3. All this is possible, as its highly **efficient computational implementation** offers attractive run times.
4. The ability to **efficiently react to market changes**, be it adjustments to decreased demand or the exploitation of opportunities.
5. Flexibility to extend the optimizer by additional constraints, model features and operators.

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Thanks a lot for your attention!

We are looking forward to answering your questions.

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