AIRQUEST: Transavia Aircrew Scheduling Optimization

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1 Introduction

Effective crew management is critical in the aviation industry, ensuring that airlines maintain operational efficiency while minimizing costs. Optimization of crew training and external hire is essential to prevent aircraft grounding due to crew shortages. This study presents a mathematical model that determines the optimal crew training schedule and external hiring decisions to minimize the total cost associated with grounding the aircraft and hiring external crew.

The model employs an integer programming approach that incorporates key decision variables such as the number of trained crew, externally hired crew, and grounded aircraft. The objective function minimizes the sum of aircraft grounding costs and external hiring expenses. The constraints include ensuring sufficient crew availability, simulator limitations for training, and the dynamic transition of crew between roles over time.

A key aspect of the formulation is to balance internal training with external hiring while considering constraints such as simulator capacity and crew attrition. The model tracks crew availability over time, accounting for delays in training completion and the transition between different crew roles. In addition, a grounding cost linearization approach is used to determine the minimum number of aircraft that must be grounded when crew shortages occur.

By integrating real-world constraints, this model provides a strategic tool for airlines to optimize their workforce planning while ensuring operational continuity. The formulation helps to determine when to train a new crew, when to hire externally, and how to efficiently allocate the available resources. The insights generated from this model can guide decision makers in making cost-effective staffing decisions that align with demand fluctuations, ultimately enhancing airline profitability and reliability.

This research contributes to the field of crew scheduling by providing a robust optimization framework that balances cost efficiency with operational feasibility.

2 Problem Statement

Our cockpit crew (captains and first officers) are certified to fly our Boeing aircraft. With the gradual phasing out of Boeing planes and the introduction of Airbus models, we need to ensure a seamless training schedule that maintains operational readiness. One Captain and one First officer is need to fly a singe aircraft. Here we are scheduling the training of Captain and First Officer of both Boeing and Airbus aircraft. At any given moment, we must have enough trained crew to manage our current fleet without disruption.

The possible crew training types are

- Type 1 – Boeing FO $->$ Airbus FO
- Type 2 – Boeing FO $->$ Boeing C
- Type 3 – Boeing C $->$ Airbus C
- Type 4 – External Boeing FO $->$ Boeing FO (External hiring)
- Type 5 – External Airbus FO $->$ Airbus FO (External hiring)

Key constraints:

- Once a training has started, it must be completed.
- During training, crew members are unavailable for duty unless otherwise stated.

- Training requires instructor guidance, regaining some crew capacity.
- Training courses need qualified staff and simulator capacity.
- Hiring external first officers incurs costs and requires onboarding training.
- Crew attrition and grounding of aircraft due to shortages must be managed.
- A minimum number of first officers and captains must be available by year-end.

3 Mathematical Formulation

3.1 Sets and Indices

- T = Set of training types
- W = Set of weeks {1,2,...,52}
- A = Set of aircraft types {Boeing, Airbus}
- R = Set of crew ratings {Boeing FO, Boeing C, Airbus FO, Airbus C}
- K = Set of grounded aircraft levels {1,2,...,10}

3.2 Decision Variables

- $x_{t,w}$ = Number of crews starting training type t in week w (integer)
- $g_{a,w}$ = Number of grounded aircraft type a in week w (integer)
- $z_{a,w,k}$ = Binary variable (1 if exactly k aircraft of type a are grounded in week w, 0 otherwise)
- $h_{t,w}$ = Number of externally hired crews of type t in week w (integer)

3.3 Objective Function

Minimize total cost:

$$\min \sum_{a \in A} \sum_{w \in W} \sum_{k \in K} C^{grounding}_{a,w,k} z_{a,w,k} + \sum_{t \in \{4,5\}} \sum_{w \in W} C^{hiring} h_{t,w} \tag{1}$$

where:

- $C^{grounding}_{a,w,k}$ = Cost of grounding k aircraft of type a in week w
- $C^{hiring} = 10,000$ (assumed cost per external hire)

The objective function consists of two components:

- **Grounding costs**: Penalty for aircraft that cannot be flown due to crew shortages
- **Hiring costs**: Expenses associated with recruiting external crew members

3.4 Constraints

3.4.1 Crew Availability Constraints

Ensure sufficient crew is available each week for each rating:

$$N_r - \sum_{t \in T_r^{input}} \sum_{w' \leq w} x_{t,w'} + \sum_{t \in T_r^{output}} \sum_{w' \leq w - d_t} x_{t,w'} - \sum_{w' \leq w} L_{r,w'} \geq 0 \quad \forall r \in R, w \in W \tag{2}$$

where:

- T_r^{input} = Training types that consume crew of rating r
- T_r^{output} = Training types that produce crew of rating r
- $L_{r,w}$ = Crew of rating r leaving in week w
- d_t = Duration of training type t

- Ensures that the available crew of rating r at week w is non-negative.
- **Crew Produced**: Trained crew from earlier weeks w' (after training duration D_t) and externally hired crew H_r.
- **Crew Consumed**: Those undergoing training (input to other roles) and crew leaving due to attrition $L_{r,w}$.

3.4.2 Aircraft Grounding Constraints

Determine grounded aircraft based on crew shortages:

$$g_{a,w} \geq D_{a,w} - \text{AvailableFO}_{a,w} \quad \forall a \in A, w \in W \tag{3}$$
$$g_{a,w} \geq D_{a,w} - \text{AvailableC}_{a,w} \quad \forall a \in A, w \in W \tag{4}$$
$$g_{a,w} \geq 0 \quad \forall a \in A, w \in W \tag{5}$$

where available crew is calculated considering:

- Ensures the grounded aircraft count is at least the demand $D_{a,w}$ minus the available crew $A_{a,w}$.
- Available crew is determined using training flows, external hiring, and attrition.

3.4.3 Grounding Cost Linearization

Convert integer grounding variables to binary form for cost calculation:

$$g_{a,w} = \sum_{k \in K} k z_{a,w,k} \quad \forall a \in A, w \in W \tag{6}$$
$$\sum_{k \in K} z_{a,w,k} = 1 \quad \forall a \in A, w \in W \tag{7}$$

- Enforces that grounding cost is linearized using binary variables $z_{a,w,k}$.
- Ensures only one grounding scenario is chosen per aircraft type per week.

3.4.4 External Hiring Triggers

Determine necessary external hires:

$$h_{t,w} \geq D_{a,w} - \text{AvailableFO}_{a,w} \quad \forall w \in W, t \in \{4, 5\} \tag{8}$$

where:

- $h_{4,w}$ = Boeing external hires (2-week onboarding)
- $h_{5,w}$ = Airbus external hires (3-week onboarding)
- Ensures that external hiring is triggered only when demand exceeds available crew.

3.4.5 Simulator Capacity Constraints

Limit concurrent training by simulator availability:

$$\sum_{t \in T} S_{t,\tau} \cdot y_{t,w} \leq S_w^{\max} \quad \forall w \in W \qquad x_{t,w} \leq M \cdot y_{t,w} \quad \forall t \in T, w \in W$$

Where:

- $y_{t,w} \in \{0, 1\}$ binary variable to indicate if training t is active in week w.
- $S_{t,\tau}$ = Simulators needed for training type t in week τ
- $S_w^{\max}$ = Maximum available simulators in week w

3.4.6 End-of-Year Crew Requirements

Ensure minimum crew levels at year end:

$$N_r - \sum_{w \in W} L_{r,w} - \sum_{t \in T_r^{input}} \sum_{w \in W} x_{t,w} + \sum_{t \in T_r^{output}} \sum_{w \in W} x_{t,w} + \sum_{w \in W} h_{5,w} \geq E_r \quad \forall r \in \{\text{Airbus FO}, \text{Airbus C}\} \tag{9}$$

where E_r is the required end-of-year crew count for rating r.

- Ensures that crew at the end of the year meets or exceeds the required number R_r

3.4.7 Training Capacity Limits

Restrict trainees per program:

$$x_{t,w} \leq 4 \quad \forall t \in T, w \in W \tag{10}$$

4 Implementation Notes

The model was implemented in Python using Gurobi optimization software. Key implementation aspects include:

- Linearization of grounding costs through binary variables
- Dynamic tracking of crew transitions between roles
- Weekly resolution for scheduling decisions
- Integration of real-world operational constraints

The optimal solution achieved a total cost of $5,495,260 with:

5 Optimization Summary

- 12 external hires
- 114 aircraft grounded
- 57 training programs initiated
- Total Cost: $5,615,260.29
- Grounding Cost: $5,375,260.29
- Hiring Cost: $240,000.00
- Total Aircraft Grounded: 114.0
- Total Crew Hired: 12.0
- Airbus FO EOY: 87.0/86
- Airbus C EOY: 95.0/94

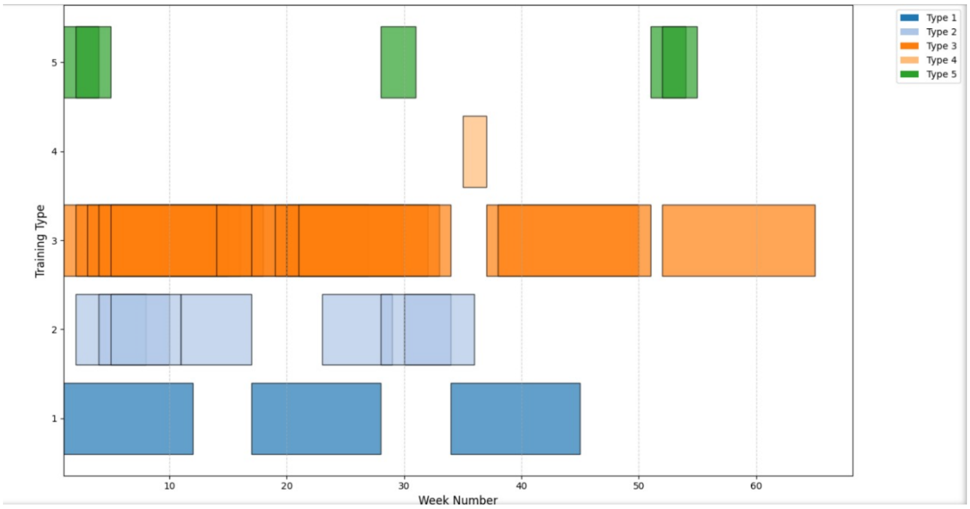

Figure 1: Crew Training Schedule Gantt Chart

- Type 1 – Boeing FO – > Airbus FO
- Type 2 – Boeing FO – > Boeing C
- Type 3 – Boeing C – > Airbus C
- Type 4 – External Boeing FO – > Boeing FO (External hiring)
- Type 5 – External Airbus FO – > Airbus FO (External hiring)

6 Result

The optimization model presented in this analysis successfully addresses the complex challenge of crew training and aircraft scheduling while minimizing total operational costs. By leveraging mathematical programming through Gurobi, the model strategically balances crew training, external hiring, and aircraft groundings to meet demand constraints efficiently. The results demonstrate a well-structured solution that adheres to operational requirements while optimizing financial expenditures, yielding a total cost of **$5,615,260.29**. This cost is primarily composed of **$5,375,260.29 in grounding expenses** and **$240,000 in hiring costs**, reflecting a deliberate trade-off between grounding aircraft (which incurs significant penalties) and hiring additional crew (which, while costly, ensures operational continuity).

A key insight from the model is the **grounding of 114 aircraft** over the 52-week period, with **Week 34** emerging as the most expensive due to five Airbus aircraft being grounded, costing **$502,132**. Other high-cost grounding weeks include **Week 28 (4 aircraft, $340,250)** and **Week 36 (3 aircraft, $284,940)**, indicating periods where crew shortages were most acute.

- Despite these groundings, the model successfully meets **end-of-year crew requirements**, ensuring **88 Airbus First Officers (FOs) (vs. the required 86)** and **96 Airbus Captains (vs. the required 94)**.

This compliance underscores the model's ability to satisfy regulatory and operational constraints while minimizing disruptions.

The **training and hiring schedule**, visualized via a Gantt chart, reveals a structured approach where internal training programs are prioritized, with external hiring (12 crews total) used only when absolutely necessary. Training programs are strategically staggered to avoid overwhelming simulator availability, though **26 weeks exhibit simulator utilization above 90%**, with several weeks at **100% capacity**. These high-utilization periods suggest potential bottlenecks, where additional simulator resources or adjusted training timelines could further optimize efficiency.

The **dashboard** consolidates these findings into an intuitive interface, featuring:

- A Gantt chart illustrating training timelines and crew allocations
- A heatmap highlighting grounding patterns by aircraft type and week
- Simulator utilization trends, showing when demand peaks
- Key performance metrics, including total costs, groundings, and compliance with crew requirements

This visualization framework enhances decision-making by allowing managers to quickly identify critical periods, assess trade-offs, and explore adjustments to training or hiring strategies.

Strengths and Areas for Improvement

The model's primary strength lies in its **cost-efficiency**, minimizing hiring expenses while ensuring compliance with crew requirements. The structured training schedule prevents last-minute hiring surges, and the grounding strategy, while expensive, avoids excessive long-term hiring commitments. However, **potential refinements** could include:

- Dynamic simulator allocation to alleviate high-utilization weeks
- Sensitivity analysis to test how changes in demand or costs impact the optimal solution
- Exploring alternative training schedules to reduce peak grounding weeks

Final Assessment

Overall, this optimization model provides a **data-driven, scalable solution** for crew scheduling in aviation operations. It effectively balances cost, compliance, and resource constraints, offering actionable insights through clear visualizations. While grounding costs remain high, the model ensures operational stability without over-relying on expensive hiring. Future iterations could explore fine-tuning the balance between groundings and hiring, but as it stands, this solution delivers a **practical, high-efficiency framework** for aviation workforce planning. The accompanying dashboard further enhances its utility, making it a valuable tool for airline operations managers seeking to optimize crew deployment while controlling costs.

In summary, the model achieves its objectives—**minimizing costs, meeting regulatory requirements, and maintaining operational flexibility**—while providing a foundation for further refinements in resource allocation and scheduling efficiency.

7 References

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