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SIMULATION-BASED AIRCRAFT SPARE PARTS OPTIMIZATION WITH OPERATIONAL OBJECTIVES AND CONSTRAINTS

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ABSTRACT

Despite numerous theoretical and practical advances in aircraft spare parts inventory management, airline operations are still being continuously challenged by elevated numbers of delays and cancellations, driven by part (un)availability. Most available methods consider a static approach, optimizing inventory reorder points based on service level (availability of part at the time of demand). To many carriers' disappointment, these methods tend to disregard the dynamics of their operation, which includes among many the ability to defer maintenance, expedite inventory delivery, and borrow parts and fail to optimize for the ultimate goal of minimizing delays and cancellations. In this work, we introduce a simulation based inventory allocation optimization framework that accounts for the dynamics of airline operations and directly connects part availability to operational impact. We present a real-life case study of a major international carrier that has deployed this simulation-based optimization model.

1 INTRODUCTION

Several advances in aircraft spare parts inventory management have recently taken place. This includes simulation-based inventory optimization approaches, the majority of which have been focused around the simulation of service level and the repair cycle of parts. Even though such methods are undoubtedly useful, they do not account for real operational impact, such as delays and cancellations (D&Cs) and Aircraft-Out-Of-Service (AOS) events. To this end, we have developed a simulation-based optimization model which allows us to model and connect D&Cs and AOS events to part availability. This model works in two stages:

1. We run a high-fidelity simulation that models part-to-aircraft operations and includes, aircraft movement based on the flight schedule, part usage events, maintenance scheduled and unscheduled events, aircraft rest-overnights, part criticalities, purchase orders, repair cycles, expedited deliveries, borrowed events, and other technical aspects of the operation,
2. We run iterative simulation runs to model, assess, and optimize the impact of inventory levels and allocations to D&Cs and AOS for each part at each station. The optimization uses a hill climbing algorithm to achieve the target performance objectives driven by the airlines' operational goals.

AOS performance improvement at a major US carrier demonstrates the potential of the proposed framework.

2 SIMULATION AND OPTIMIZATION MODELING

The model was deployed at a major international carrier and the inventory was optimized for a carrier-mandated AOS target. The carrier operates 700+ aircrafts, is managing inventory at more than 40 domestic and international stations, and completes more than 5000 flights per day. Around 35,000 parts (with sufficient usage data) were optimized, amounting to more than $1B (USD) of inventory value. During the simulation of the airline's operations, its intrinsic operational characteristics are taken into account. The model replicates and accounts for the airline's specific policies, procedures, and operational constraints, thus better approximating its operational performance. This provides a significant modeling advantage in comparison to traditional statistical closed-form approaches.

The simulation is run for a single part and a set of station reorder points, and outputs several operational metrics such as the observed service level and the average monthly AOS, both at the station and network level. Every run executes the future flight schedule which is repeated sufficiently to ensure that the simulation reaches a steady state with a stable solution.

The optimization runs start with an initial condition that depicts a realistic state of the airline's operations and helps increase the convergence speed to the steady state. This includes an initial reorder point (usually set at zero). At each step, the algorithm compares the simulated AOS events (or any other desired operational metric) to the target. The algorithm selects the station with the highest number of AOS events and increases its reorder point. The simulation engine is then run with this new set of station reorder points and the process is repeated until a solution satisfying the target has been achieved.

3 OPTIMIZATION RESULTS

Optimization with the objective of minimizing AOS events while using the existing inventory investment (rebalancing inventory without additional investment) led to a **25% reduction in simulated AOS events** vs. the simulated current state, and an **increase of 10% in simulated service levels.** Optimization with the objective of achieving a target daily AOS target (allowing for both increased and decreased inventory across parts) led to an approximately **12% decrease in total inventory value, 35% reduction in simulated AOS events and 20% increase in simulated service levels.** We estimate that savings from decreased inventory spend going forward can fund investment in understocked parts and bring the entire inventory to the optimized levels. We have deployed the simulation/optimization engine as a web-based application with data pipelines to/from the airline's data warehouse. The application is accessed by the carrier's planners who can view optimization results, run their own scenarios, etc. (see Figure 1).

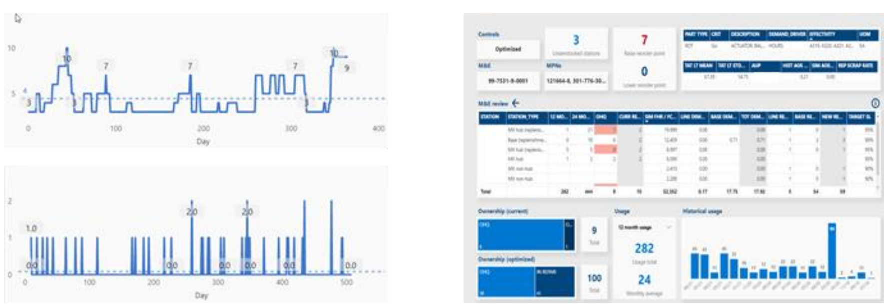

Figure 1: Left: (Top) Simulation of inventory levels, and (Bottom) demand events for a sample part. Right: Visualizations of optimized reorder points and simulated usage along with part specific information.

4 CONCLUSION

We have introduced a simulation-based optimization method for airline spare parts management. Using a real world case study of a major carrier, we have demonstrated that the proposed method can optimize for critical front-line operational targets, accounts for the airlines intrinsic operational constraints, and yields significant improvements in operational and financial metrics.