Flight Disruption Management Optimization

1 Problem Statement

Weather events such as snowstorms, heavy rains, and icy runways pose significant challenges to the airline industry. These disruptions cause flight delays and cancellations, leading to passenger inconvenience and massive financial losses for airlines. For instance, the 2014 Polar Vortex resulted in an estimated $1.4 billion loss in the United States alone.

Given a scenario where a weather event reduces the operational capacity of airports, airlines face the problem of:

- Deciding which flights to cancel or operate.
- Re-routing aircrafts while ensuring operational feasibility.
- Minimizing the total revenue loss from cancelled flights.

We approach this problem by formulating a **Mathematical Optimization Model** that determines the optimal flight schedule post-disruption while adhering to constraints related to aircraft routing and airport capacity.

2 Dataset Description

The dataset is based on real flight operation data from the **ROADEF 2009 Challenge** by Amadeus. It consists of:

2.1 1. Current Flight Plan

- Scheduled flights on the disruption day.
- Fields: `flight`, `aircraft`, `ori` (origin airport), `des` (destination airport), `start_time`, `end_time`, `duration`.

2.2 2. Aircraft Starting & Ending Positions

- Defines where each aircraft should start and end the day.
- Fields: `aircraft`, `airport`.

2.3 3. Passenger Itineraries

- Number of passengers and ticket revenue per flight.
- Fields: `flight`, `n_pass`, `cost`, `total_cost`.

Dataset Insights:

- Flights operate between multiple French airports.
- Aircrafts have fixed initial and final airport positions.
- Passenger revenue data quantifies cancellation impact.

3 Mathematical Model Formulation

3.1 Sets and Indices

N	Set of airports
A	Set of aircrafts
F	Set of flights
F_a	Flights assigned to aircraft a
E_a	Feasible transitions for aircraft a

3.2 Parameters

r_f	Revenue from flight f
o_f, d_f	Origin and destination airports of flight f
C_i^{arr}, C_i^{dep}	Arrival and departure capacities of airport i
α	Level of disruption (0 = full shutdown, 1 = normal operation)

3.3 Decision Variables

$$x_{a,f} = \begin{cases} 1 & \text{if aircraft } a \text{ operates flight } f \\ 0 & \text{otherwise} \end{cases}$$

$$y_{a,f_1,f_2} = \begin{cases} 1 & \text{if aircraft } a \text{ operates flight } f_2 \text{ after flight } f_1 \\ 0 & \text{otherwise} \end{cases}$$

3.4 Objective Function

Minimize total lost revenue due to cancellations:

$$\min \sum_{a \in A} \sum_{f \in F_a} (1 - x_{a,f}) \cdot r_f$$

3.5 Constraints

- **Aircraft Path Continuity (Flow Balance):**

$$\sum_{f' \in \delta^+(source_a)} y_{a,source_a,f'} = 1 \quad \forall a \in A$$
$$\sum_{f' \in \delta^-(sink_a)} y_{a,f',sink_a} = 1 \quad \forall a \in A$$
$$\sum_{f' \in \delta^+(f)} y_{a,f,f'} = \sum_{f' \in \delta^-(f)} y_{a,f',f} \quad \forall f \in F_a, a \in A$$

- **Flight Execution Dependency:**

$$x_{a,f} \leq \sum_{f' \in \delta^+(f)} y_{a,f,f'} \quad \forall f \in F_a, a \in A$$

- **Airport Capacity Constraints:**

$$\sum_{a \in A} \sum_{f \in F_a : d_f = i} x_{a,f} \leq C_i^{arr} \cdot \alpha \quad \forall i \in N$$
$$\sum_{a \in A} \sum_{f \in F_a : o_f = i} x_{a,f} \leq C_i^{dep} \cdot \alpha \quad \forall i \in N$$

4 Results

4.1 Case Study: $\alpha = 0.5$

- **Total Revenue Loss:** \$0.25 million
- **Flights Operated:** 13
- **Passengers Transported:** 738
- **Aircrafts Utilized:** 4 out of 4

Insights:

- Aircraft routing ensures feasibility from start to end positions.
- High-revenue flights are prioritized under capacity restrictions.

5 Sensitivity Analysis

α	Flights Operated	Passengers Transported	Revenue Loss ($M)
1.0	20	1121	0.00
0.75	17	1005	0.06
0.5	13	738	0.25
0.25	7	401	0.55
0.0	0	0	1.12

Observations:

- As α decreases, fewer flights can operate.
- The model optimally reallocates aircraft routes to minimize losses.
- Full shutdown ($\alpha = 0$) leads to a complete loss of daily revenue.

6 Extensions and Future Work

- **Flight Delays & Passenger Rebooking:** Model delay decisions and rebooking passengers onto alternate flights.
- **Additional Operational Costs:** Include maintenance, crew overtime, and fuel costs in the objective.
- **Crew Scheduling:** Model crew assignments and connection requirements post-disruption.

7 References

- ROADEF 2009 Challenge
- Amadeus
- CNBC Polar Vortex Report