Predictive Insights for Flight Delay Mitigation

Leveraging Machine Learning to Enhance Airline and Airport Reliability

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Date: June 2025

Date

Problem Statement:

Flight delays are a persistent challenge in air travel, causing inconvenience for passengers and substantial operational costs for airlines. These delays impact fuel usage, crew management, customer satisfaction, and overall reliabilit.

Project Objective:

This project leverages historical flight data to:

- **Uncover hidden delay patterns** through in-depth EDA
- **Build a two-step predictive model** to forecast both delay occurrence and duration
- **Generate actionable insights** for airlines to proactively mitigate delays and improve operational efficiency

Data Summary & Preprocessing:-

Key Features:-

- **Delay Causes**: carrier_ct, weather_ct, nas_ct, security_ct, late_aircraft_ct
- **Delay Durations**: carrier_delay, weather_delay, nas_delay, security_delay, late_aircraft_delay
- **Other**: arr_flights, arr_del15, arr_cancelled, arr_diverted, arr_delay, month, carrier, airport

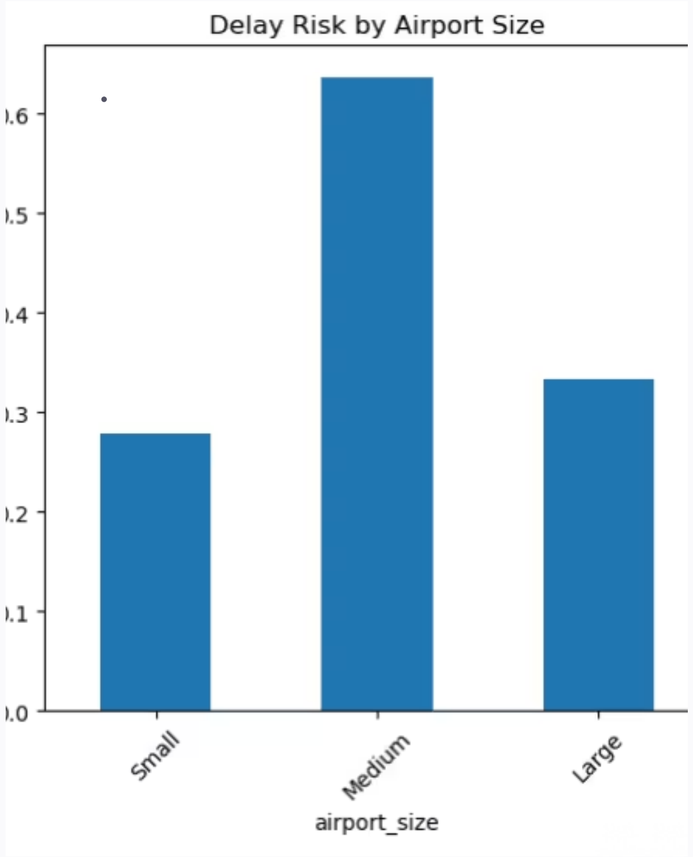
Preprocessing Workflow

- 🔹 **Dropped irrelevant columns**: year, carrier_name, airport_name
- 🔹 **Encoded** airline and airport by frequency (carrier_encoded, airport_encoded)
- 🔹 **Handled missing values**:
  - Common missing rows across multiple columns dropped
  - arr_del15 filled using **median imputation**
- 🔹 **Outlier Treatment**:
  - Z-score method for arr_delay
  - Group-wise **IQR capping** by airport for multiple numerical columns
- 🔹 **Removed sparse airport** (YNG)
- 🔹 **Engineered target metric**:

Operational Adjustability Index (OAI)

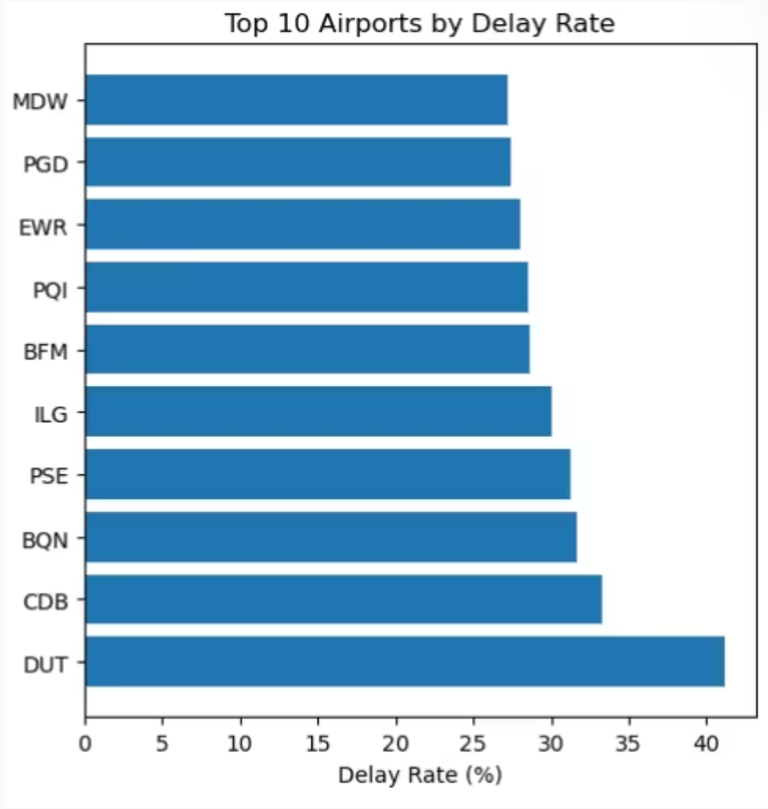
- carrier_encoded, airport_encoded
- delay_rate, delay_prone, OAI

EDA — Delay Distribution & Trends



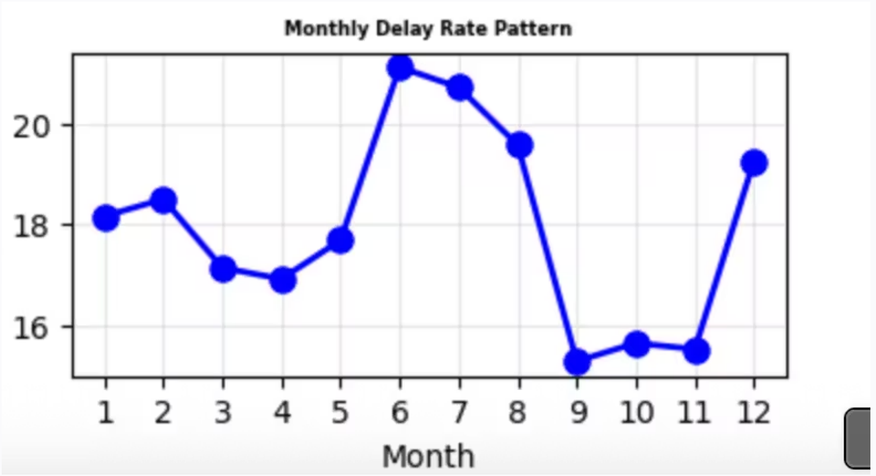
Delay Risk by Airport :-

- Medium-sized airports show the **highest delay risk** (~65%) compared to small and large airports.
- Indicates a potential resource imbalance or traffic congestion at mid-tier airports.



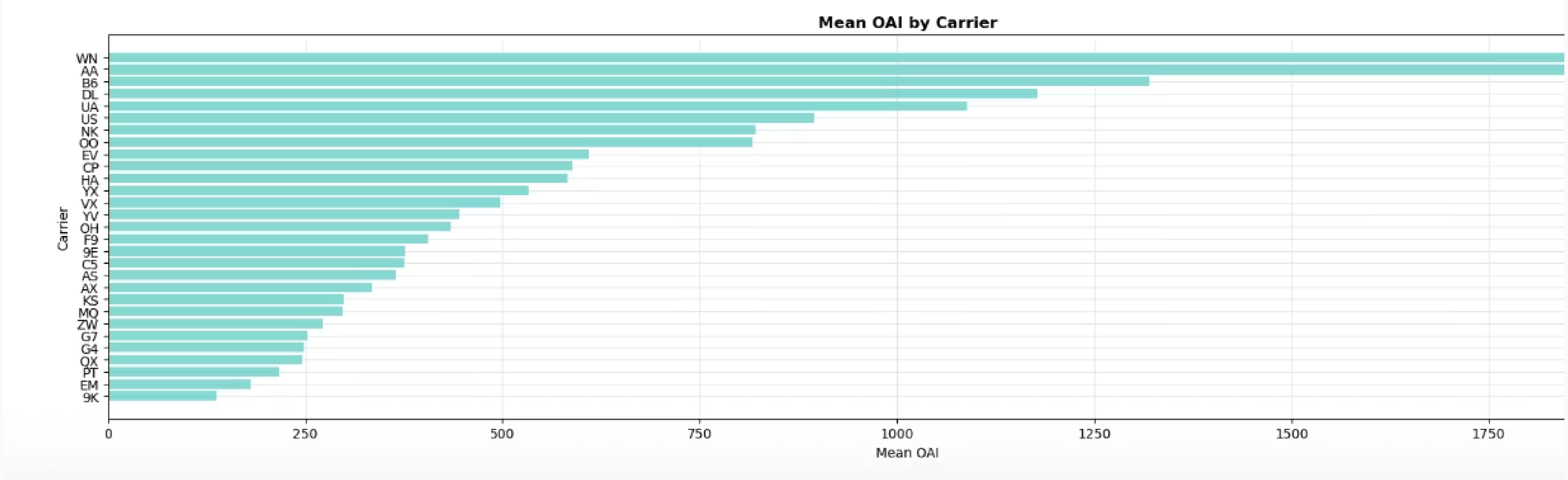
Top 10 Airports by Delay Rate:-

- **DUT tops** the list with a delay rate exceeding 40%.
- Several smaller regional airports dominate the top 10 list — hinting at limited operational buffer capacity.



Monthly Delay Rate Pattern:-

- Peak delay months: **June, July, and August**, suggesting seasonal congestion (likely summer travel surge).
- Delay rates dip in **September–November** indicating operational ease post-peak season.



Controllable delay by Carrier:-

OAI shifts focus from total delay to fixable delay — helping airlines prioritize internal interventions where they can actually make a difference.
Top carriers with highest OAI:
WN, AA, B6, DL, UA have the highest Mean OAI, meaning a large share of their total delay is operationally controllable.
🔁 These airlines have greater potential to reduce delays through internal process improvements (e.g., better turnaround management, staffing, or fleet coordination).
Mid-range OAI carriers (OO, EV, CP, etc.):
These carriers have a mix of controllable and uncontrollable delays. Focused interventions can still yield moderate improvement.
Low OAI carriers:-
Carriers like **EM, PT, 9K** have **low Mean OAI**, meaning most of their delays are due to **factors outside their control**, such as **weather or airspace restrictions**.
🔒 Operational improvements may have **limited impact** on total delay for these airlines.

Insightful Model Overview:-

1. Delay Classification Model (XGBoost Classifier) :-

Objective: Predict whether a flight will be delayed

- F1 Score: 0.8408
- F2 Score: 0.8710 *(prioritises recall for delay events)*
- AUC Score: 0.8757
- Key Features:
  Late Aircraft Ct, NAS Ct, Arr Flights, Carrier Delay, Carrier Ct

> **Insight: Accurately identifies high-risk delay scenarios, supporting timely operational responses.

2. Delay Severity Estimator (XGBoost Regressor) :-

Objective: Predict Operational Delay Impact Score (ODIS) based on controllable delay factors

- MAE: 245.59 minutes
- RMSE: 1091.29 minutes
- R^2 Score: 0.7834 *(strong explanatory power)*
- Top Contributors:
  Carrier Delay, Carrier Ct, Late Aircraft Ct, Weather Delay, NAS Delay

> **Insight: Enables deeper understanding of delay severity to prioritize interventions.

3. Unified Delay Prediction Pipeline :-

Function: predict_flight_delay(input_df, clf_model, reg_model)

- Combines classification (delay or not) and regression (how long, if delayed)
- Predicts delay minutes only if classified as a delay
- Returns precise, interpretable results for each flight

> **Insight: A robust end-to-end tool for real-time flight delay prediction and impact estimation—ready for operational deployment.

Key Insights & Actionable Recommendations:-

- **High Operational Adjustability carriers** (WN, AA, DL) face more controllable delays → prime candidates for operational improvements.
- **Major delay causes**: *Late Aircraft* and *Carrier Delay* dominate across airlines.
- **Low Adjustability carriers** (9K, EM, PT) mainly suffer from uncontrollable delays → limited intervention scope.

Actionable Recommendations & Consulting Insights:-

To mitigate delay occurrences and enhance operational resilience:-

- **Schedule Optimization**:
  Adjust flight schedules for high-delay routes or peak congestion hours to reduce operational strain.
- **Enhanced Ground Operations**:
  Improve turnaround processes through better coordination of baggage handling, fueling, and boarding.
- **Proactive Passenger Communication**:
  Deploy real-time delay alerts and rebooking support to reduce customer frustration and manage flow.
- **Targeted Resource Allocation**:
  Allocate more personnel and equipment at high-risk airports or during adverse weather periods.
- **Collaboration Between Stakeholders**:
  Foster coordination between carriers and airports to address systemic bottlenecks collectively.