**Passenger Flow and Operations at SFO Airport Using Operational Analytics**

**Group Name**: Group 8

**Team Members Details**:

| **S.No** | **Name** | **Net ID** |
| --- | --- | --- |
| 1 | Mahima Advilkar | ni1396 |
| 2 | Sai Soumya Aloor | is4134 |
| 3 | Sri Charan Desetty | oj8664 |
| 4 | Anantha Prahalada Kurudi | al7010 |

**Introduction**San Francisco International Airport (SFO) is a critical hub for domestic and international flights, managing a vast and intricate system of passenger flows. Passenger traffic at SFO is influenced by a variety of operational factors, including the type of aircraft, number of landings, and terminal usage. These complexities necessitate analytical approaches to optimize airport resources and passenger experiences. This project employs operational analytics methods, such as regression and time series forecasting, to identify and interpret key patterns in passenger flows and derive actionable insights.

**Objective**The primary goal of this project is to address the question:  
*"What factors most significantly influence passenger flow at SFO, and how can this information be used to optimize airport operations?"*

By focusing on key variables such as terminal usage, landing counts, and aircraft characteristics, this study aims to provide a robust foundation for data-driven decision-making at SFO. The outcomes are designed to enhance resource allocation, reduce operational bottlenecks, and improve overall passenger satisfaction.

### **Data Overview**

**Data Sources**This analysis utilizes data from two publicly available datasets provided by the San Francisco Government Open Data platform:

1. [**Air Traffic Passenger Statistics**](https://data.sfgov.org/Transportation/Air-Traffic-Passenger-Statistics/rkru-6vcg/about_data)
   * This dataset contains monthly passenger counts categorized by terminal, boarding area, and activity type (deplaned, enplaned, and transit).
2. [**Air Traffic Landings Statistics**](https://data.sfgov.org/Transportation/Air-Traffic-Landings-Statistics/fpux-q53t/about_data)
   * This dataset includes information on aircraft landings, categorized by aircraft type, weight, and airline operations.

**Data Integration and Cleaning**

* **Integration:** The two datasets were merged to create a comprehensive view of air traffic operations at SFO. Key variables like passenger counts, landing counts, terminal usage, aircraft types, and landed weight were harmonized across both datasets.
* **Data Cleaning:**
  + Removed duplicate records and incomplete entries to ensure accuracy.
  + Standardized variable names and units across the datasets for consistency.
  + Outliers in passenger counts, landed weight, and landing counts were handled using threshold-based filtering.
  + Missing values were imputed using statistical methods such as averages or medians, ensuring minimal data loss.

**Final Dataset Structure**The integrated dataset was structured for analysis, focusing on the following key variables:

* **Passenger Count:** Number of passengers by activity type (deplaned, enplaned, or transit).
* **Landing Count:** Number of flights landing at SFO by month.
* **Aircraft Body Type:** Categorized into wide-body, narrow-body, regional jets, and turboprops.
* **Terminal Usage:** Distribution of passengers and flights across SFO’s terminals.
* **Landed Weight:** Total weight of landed aircraft, serving as a proxy for aircraft size and passenger capacity.

**Summary Statistics**

* **Passenger Count:**
  + **Mean: 41,735.72** passengers
  + **Median: 10,318** passengers
  + **Standard Deviation: 71,513,** indicating a high degree of variability.
* **Landing Count:**
  + **Mean: 107.81** flights
  + **Median: 31** flights
  + **Standard Deviation: 180.52,** reflecting variability in flight volumes.
* **Landed Weight:**
  + **Mean: 20,824,608.07** (units in kilograms or pounds)
  + **Median: 11,400,000**
  + **Standard Deviation: 26,350,022.01,** highlighting the diversity of aircraft sizes.

**Key Observations**

1. **Passenger Variability:** A wide range in passenger counts suggests peaks during specific periods or operations (e.g., international vs. domestic).
2. **Landing Counts and Aircraft Weight:** High standard deviations indicate significant variability in aircraft operations, which impacts passenger flows and terminal congestion.
3. **Clean, Integrated Dataset:** The processed dataset is optimized for regression and time series forecasting, ensuring reliable analytical outcomes.

### **Time Series Forecasting Analysis**

**Objective**The time series forecasting analysis aims to predict future passenger counts at SFO Airport to understand seasonal trends and plan operations more effectively. Two forecasting methods were utilized: 3-Month Moving Average and Exponential Smoothing.

**Data Overview**The analysis uses historical passenger count data from October 2023 to September 2024 to project passenger volumes for the last three months of 2024: October, November, and December.

**Forecasted Passenger Counts**

| **Month** | **Forecast (Moving Average)** | **Forecast (Exponential Smoothing)** |
| --- | --- | --- |
| October 2024 | 5,437 | 5,360.41 |
| November 2024 | 5,411.5 | 5,072.08 |
| December 2024 | 5,321 | 5,214.41 |

**Error Analysis**

* **Mean Absolute Error (MAE)**:
  + Moving Average: **2,255.77**
  + Exponential Smoothing: **694.29**
* **Mean Absolute Percentage Error (MAPE)**:
  + Moving Average: **29.52%**
  + Exponential Smoothing: **5.20%**

**Key Insights**

1. **Exponential Smoothing Performs Better**:
   * With lower MAE and MAPE values, Exponential Smoothing provides a more accurate and reliable forecast compared to the Moving Average method.
2. **Passenger Stabilization**:
   * Forecasts show passenger counts stabilizing around **5,321 passengers** by December 2024, reflecting a steady trend.
3. **Seasonal Peaks**:
   * Historical data highlights high passenger traffic in **June 2024 (5,987 passengers)**, likely reflecting summer travel demand.
4. **Operational Planning**:
   * Forecasts can guide resource allocation, staffing, and terminal management to address peak periods and avoid congestion.

**Monthly Passenger Trends**Passenger trends from 2023 and 2024 show significant monthly variations:

* **Highest Traffic**: June 2024 (5,987 passengers).
* **Lowest Traffic**: November 2023 (4,536 passengers).
* **Insight**: This variability underlines the need for adaptive operational strategies to manage demand efficiently.

### **Comprehensive Analysis of Airline Operations, Passenger Activity, and Trends at SFO Airport**

#### **Airline Operations Insights**

* **Top Operating Airlines**: United Airlines leads with **14,426 flights**, followed by SkyWest Airlines (**6,763 flights**) and Delta Air Lines (**2,787 flights**), collectively accounting for a significant portion of total operations.
* **Regional Airlines**: Alaska Airlines (**1,988 flights**) and Horizon Air (**1,710 flights**) enhance domestic and regional connectivity.
* **International Airlines**: Key players include Singapore Airlines, China Eastern, and Cathay Pacific (**778 flights each**), while European carriers like Lufthansa and British Airways operate **558 flights each**, emphasizing transatlantic connectivity.
* **Niche and Emerging Airlines**: Airlines such as Aeromexico (**278 flights**) and Air New Zealand (**210 flights**) cater to niche markets, while Emirates and Qatar Airways (**2 flights each**) show potential for growth in Middle Eastern connectivity.

#### **Passenger Distribution by Region**

* **Domestic (US)**: **34,935 passengers** (54% of total).
* **Asia**: **14,238 passengers** (22%).
* **Europe**: **9,062 passengers** (14%).
* **Other International Regions**:
  + Canada: **3,619 passengers**
  + Mexico: **1,484 passengers**
  + Australia/Oceania: **1,323 passengers**
  + Middle East: **6 passengers** (underserved region).

#### **Passenger Activity Insights**

* **Activity Types**:
  + Deplaned: **35,967 passengers**
  + Enplaned: **36,006 passengers**
  + Thru/Transit: **3,005 passengers**
* **Regional Highlights**:
  + Asia: Balanced inbound/outbound flows with **7,028 deplaned** and **7,023 enplaned** passengers.
  + US: High transit activity (**3,037 passengers**) reflects its role as a domestic transit hub.
  + Europe: Maintains strong transatlantic activity with **4,232 deplaned** and **4,291 enplaned** passengers.
  + **Insights**: Balanced activity indicates operational efficiency, while regions like the Middle East (6 passengers) present growth opportunities.

#### **Aircraft and Manufacturer Analysis**

* **Aircraft Types**:
  + Freighter: **5,170 flights**
  + Narrow Body: **27,880 flights**
  + Wide Body: **27,310 flights**
  + Regional Jets: **4,618 flights**
  + **Insights**: Narrow-body aircraft dominate domestic routes, while wide-body aircraft support long-haul international travel.
* **Top Manufacturers**:
  + Boeing (**38,261 flights**) and Airbus (**20,132 flights**) dominate.
  + Bombardier and Embraer support regional connectivity with **6,585 flights combined**.

#### **Passenger Flow by Boarding Areas**

* **Top Areas**:
  + Area A (**24,723 passengers**) dominates, driven by long-haul international flights.
  + Areas G (**9,139 passengers**) and B (**10,200 passengers**) follow.
  + Areas C-F handle moderate traffic, ranging from **2,929 to 8,896 passengers**.
* **Insights**: High-traffic areas like A and G indicate critical points of operation, while lower-traffic areas like E (**2,929 passengers**) and F (**5,462 passengers**) have optimization potential.

#### **Seasonal and Regional Trends**

* **Monthly Trends (2024)**:
  + Highest Traffic: **June (5,987 passengers)**
  + Lowest Traffic: **November (4,536 passengers)**
* **Annual Growth**: From 2023 (**14,624 passengers**) to 2024 (**50,354 passengers**), representing a **345% increase**, reflecting recovery and demand post-pandemic.
* **Insights**: Passenger traffic peaks in summer months, necessitating strategic resource allocation during these times.

#### **Key Recommendations**

1. **Expand International Connectivity**: Strengthen routes to underserved regions like the Middle East and Oceania while bolstering existing routes to Asia and Europe.
2. **Optimize Boarding Areas**: Increase operational efficiency in high-traffic areas and redistribute resources to lower-traffic zones.
3. **Enhance Cargo Operations**: Leverage SFO’s strong freighter presence to expand cargo-handling capacity and attract more carriers.
4. **Prepare for Seasonal Peaks**: Use traffic forecasts to allocate staffing and gates during high-demand months like June.

### **Recommendations and Conclusion**

**Recommendations**

1. **Optimize Terminal Resources**
   * Prioritize high-traffic terminals (e.g., Terminal 1 with **13,829 passengers**) for resource allocation, including additional staff, gates, and amenities.
   * Reallocate flights or resources to underutilized terminals, such as Terminal 3 (**8,391 passengers**) and Terminal 2 (**8,896 passengers**), to balance passenger flow.
2. **Enhance Boarding Area Operations**
   * Focus on improving efficiency and passenger experience in high-volume areas like Boarding Area A (**24,723 passengers**) and G (**9,139 passengers**).
   * Increase operations or promotional efforts in low-traffic areas like E (**2,929 passengers**) to optimize space and resources.
3. **Expand International Routes**
   * Collaborate with airlines to increase connectivity to underserved regions like the Middle East (**6 passengers**) and Australia/Oceania (**1,323 passengers**).
   * Strengthen existing routes to Asia (**14,238 passengers**) and Europe (**9,062 passengers**) by adding flights or introducing new airlines to these regions.
4. **Leverage Aircraft Data for Planning**
   * Use insights from aircraft body type and manufacturer analysis to guide infrastructure development, such as wide-body-friendly gates and cargo handling facilities.
   * Invest in facilities supporting freighters (**5,170 flights**) to grow SFO’s cargo operations.
5. **Prepare for Seasonal Peaks**
   * Use time series forecasts to allocate resources during high-demand months (e.g., June with **5,987 passengers**) while maintaining flexibility for lower-traffic periods.
   * Enhance staffing, gate availability, and baggage handling during predicted peak times.
6. **Develop Transit Hub Capabilities**
   * Improve services for transit passengers, especially in regions with higher Thru/Transit counts like Europe (**539 passengers**) and the US (**3,037 passengers**).
   * Introduce streamlined connections, lounges, and incentives to position SFO as a global transit hub.
7. **Target Budget Airline Market**
   * Expand low-fare offerings, particularly for international routes, as current low-fare flights are dominated by domestic traffic (**8,067 passengers vs. 322 international passengers**).
   * Attract budget carriers to underserved regions to stimulate demand.

**Conclusion**This analysis provides a comprehensive overview of passenger flow and operational dynamics at SFO Airport. Key insights from regression analysis, time series forecasting, and operational data have identified critical areas for improvement and growth. SFO's dual role as a domestic and international hub demands a balanced approach to resource allocation, route expansion, and seasonal planning.