AIR TRAFFIC FLOW MANAGEMENT OPTIMIZATION

SUBMITTED BY,

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INTRODUCTION:

Air traffic flow management (ATFM) optimization is a critical area in aviation aiming to streamline air traffic movement for efficiency, safety, and cost reduction. Imagine a complex network of airplanes vying for space in the sky. ATFM steps in to ensure this network runs smoothly, especially when demand surpasses available airspace or airport capacity.

OBJECTIVES :

ATFM optimization aims to strategically manage traffic flow to reduce ground delays and airborne holding patterns

This involves strategies like optimized routing to avoid bottlenecks and scheduling arrivals and departures to prevent congestion.

Improved efficiency translates to smoother traffic flow and potentially even increased capacity in the long run.

Optimization strategies consider factors like weather patterns and separation requirements to prevent situations that could lead to mid-air incidents.

predictable flight times and minimized delays, airlines can optimize crew scheduling, fuel planning, and ground handling, leading to overall cost reduction.

system requirements:

The data contained in this dataset has been US Automatic Traffic Recorder Stations Data (kaggle.com)

This comprehensive dataset records important information about Automatic Traffic Recorder (ATR) Stations located across the United States.

The dataset comprises a collection of attributes for each station such as its location details (latitude, longitude), AADT or The Annual Average Daily Traffic amount, classification of road where it's located etc…

Sttnkey: A unique identifier for each station.

NHS: Indicates if the station is part of national highway system.

Location: Describes specific location of a station with street or highway name.

Comment: Any additional remarks related to that station.

Longitude, Latitude: Geographic coordinates.

STPostal: The postal code where a given station resides.

ADT: Annual Average Daily Traffic count indicating average volume of vehicles passing through that route annually divided by 365 days

Year_GEO: The year when geographic information was last updated - can provide insight into recency or timeliness of recorded attribute values

METHODOLOGY:

1. Demand and Capacity Analysis:

Demand Forecasting: Historical data, weather predictions, and airline schedules are analyzed to predict the volume and type of air traffic in a specific airspace or airport.

Capacity Assessment: The available airspace and airport infrastructure are evaluated to determine the maximum number of aircraft they can safely handle. This considers factors like weather limitations, runway configurations, and staffing levels.

2. Strategic Planning:

Flow Management Programs: Based on the demand-capacity analysis, centralized Air Traffic Control (ATC) authorities develop flow management programs (FMPs). These programs might include:

Ground Delay Programs (GDPs): Strategically delaying departures to regulate the number of aircraft entering the airspace.

Ground Stops: Temporarily halting departures from specific airports due to severe congestion or airspace limitations.

Rerouting Strategies: Optimizing flight paths to avoid congested areas or utilize available airspace more efficiently.

3. Real-time Traffic Management:

Tactical Decision Making: Air Traffic Controllers (ATCs) use real-time data on weather, aircraft positions, and potential conflicts to make adjustments to the planned flow. This might involve:

Sequencing Arrivals and Departures: Prioritizing aircraft for landing and takeoff to maintain a safe and efficient flow.

Speed Adjustments: Directing aircraft to adjust their speed to maintain separation and avoid delays.

Holding Patterns: Instructing aircraft to enter holding patterns when necessary to manage traffic flow.

4. Technological Advancements:

Machine Learning and Data Analytics: These technologies are increasingly used to analyze vast datasets and predict traffic patterns with greater accuracy. This allows for more proactive and data-driven optimization strategies.

Advanced Communication Systems: Real-time communication between airlines, ATCs, and other stakeholders is crucial for effective flow management. Advanced data sharing platforms and communication protocols facilitate smoother coordination.

5. Collaboration and Information Sharing:

Airline Cooperation: Airlines play a vital role by providing accurate flight plans and being flexible with scheduling adjustments when requested by ATFM authorities.

International Coordination: For international flights, close collaboration between different air traffic control agencies is essential for seamless flow management across borders.

model EVALUATION

REGERSSION METRICS:

R-squared (R^2): This metric represents the proportion of variance in the target variable (AADT) that can be explained by the linear regression model. It ranges from 0 (no explanatory power) to 1 (perfect fit). A higher R^2 indicates a better fit.

Mean Squared Error (MSE): This metric calculates the average squared difference between the predicted values (y_pred) and the actual values (y_test). Lower MSE signifies a better fit.

Mean Absolute Error (MAE): This metric calculates the average absolute difference between the predicted values and the actual values. MAE is less sensitive to outliers compared to MSE. Lower MAE indicates a better fit.

Median Absolute Error (Median AE): This metric represents the middle value of the absolute errors between predicted and actual values. It's less affected by extreme values compared to MAE. Lower Median AE indicates a better fit.

Ranking Metrics:

Spearman Rank Correlation Coefficient: This metric measures the monotonic relationship between the predicted and actual values, regardless of the magnitude of the differences. It ranges from -1 (perfect negative correlation) to 1 (perfect positive correlation). A value closer to 1 indicates a strong positive ranking relationship.

Kendall Tau Rank Correlation Coefficient: Similar to Spearman's rank correlation, this metric measures the similarity between the ordering of the predicted and actual values. It ranges from -1 (perfect negative correlation) to 1 (perfect positive correlation). A value closer to 1 indicates a strong agreement in ranking between predicted and actual values.

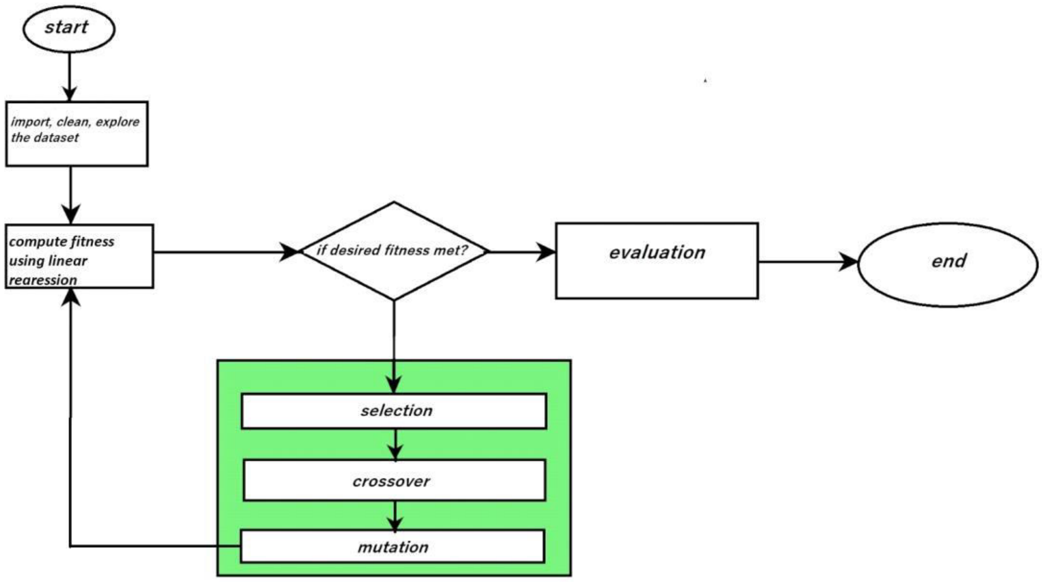
existing work:

A wealth of research exists in ATFM optimization, with advancements in machine learning for traffic prediction, collaborative decision-making tools, dynamic airspace concepts, and optimization algorithms aiming to improve efficiency, while exploring integration with automation for a future of smoother traffic flow and reduced human error.

proposed work :

Proposed work in ATFM aims to leverage cutting-edge technologies like AI and real-time data analysis to develop even more precise traffic forecasting models. This would allow for proactive flow management strategies like dynamic airspace allocation and collaborative decision-making platforms, ultimately leading to smoother traffic flow, reduced delays and emissions, and a more resilient air transport system in the face of emerging challenges like drone integration.

FLOW CHART:



code:

```
import pandas as pd
import seaborn as sns
data =pd.read_csv('Automatic_Traffic_Recorder_ATR_Stations (1) (1).csv')

#The data description are given....
print(data.head())
print(data.tail())
print(data.info())
print(data.describe())

# the null data handling are given....
print(data.isnull().sum())
m = data.dropna()
print(m)


#the data validation are given...
print (data['VERSION'].unique())

#the data reshgaping are given....
transposed_data=data.T
print(transposed_data)
```

```
# the data aggregation are given...
grouped_data = data.groupby('VERSION')
aggregated_data = grouped_data.agg('VERSION')
print(aggregated_data)
print(grouped_data)

#the data viualization are given...

import matplotlib.pyplot as plt
class univariate:
  def hist(self):
    columns = ['LONGITUDE', 'LATITUDE', 'AADT','CTFIPS']
    fig, axes = plt.subplots(nrows=2,  ncols=2,  figsize=(12, 8))
    for i, col in enumerate(columns[:10]):
        num_subplots = len(columns)
        rows, cols = divmod (num_subplots, 2)
        for i, col in enumerate(columns):
            row, col_index = divmod(i, 2)
            axes[row, col_index].hist(data[col], bins='auto')
            axes[row, col_index].set_xlabel(col)
            axes[row, col_index].set_ylabel('CustomerID',)
            axes[row, col_index].set_title(col)
    fig.suptitle("Histogram")
    plt.tight_layout()
    plt.show()



  def bar(self):
    columns = ['LONGITUDE', 'LATITUDE', 'AADT','CTFIPS']
    plt.figure(figsize=(12, 6))
    for i, col_name in enumerate(columns ):
       x_axis = data['LONGITUDE']
       y_axis = data[col_name]
       plt.subplot(1, len(columns), i + 1)
       plt.bar(x_axis, y_axis, label=col_name)
       plt.xlabel(data.columns[0])
       plt.ylabel(col_name)
    plt.suptitle('Bar Chart ')
```

```
    plt.tight_layout()
    plt.show()

a=univariate()
univariate.hist(a)
univariate.bar(a)
print(f"the end of univariate visualization ")

class bivariate:
  def scatter(self):
    columns = ['LONGITUDE', 'LATITUDE', 'AADT','CTFIPS']
    rows = int((len(columns) - 1) / 2) + 1
    cols = min(2, len(columns))
    fig, axes = plt.subplots(rows, cols, figsize=(12, 8))
    col_index = 0
    for i in range(rows):
      for j in range(cols):
       if col_index >= len(columns):
         break;
       ax = axes[i, j]
       x = data['LONGITUDE']
       y = data[columns[col_index]]
       fig.suptitle("Scatter plot",weight='bold')
       ax.scatter(x, y, color='blue', marker='o', edgecolors='black', alpha=0.7)
       ax.set_xlabel('LONGITUDE')
       ax.set_ylabel(columns[col_index] )
       ax.set_title('LONGITUDE vs ' + columns[col_index])
       col_index += 1

    plt.tight_layout()
    plt.show()




b=bivariate()
bivariate.scatter(b)
```

```
print(f"the end of bivariate visualization")
class multivariate:
  def pairplot(self):
    columns = ['LONGITUDE', 'LATITUDE', 'AADT','CTFIPS']
    sns.pairplot(data=data[columns],height=1.5,palette="husl",diag_kind="hist")
    plt.figure(figsize=(12, 6))
    plt.subplots_adjust(left=0.1, bottom=0.1, right=0.9, top=0.9, wspace=1.5, hspace=1.4)
    plt.tight_layout()
    plt.show()
c=multivariate()
multivariate.pairplot(c)
print(f'the end of multivariate')
import plotly.express as px
class interactive:
  def hist(self):

    fig = px.histogram(x=data['LONGITUDE'],y=data['LATTITUDE'],title='Interactive Histogram').update_layout(xaxis_title='LONGITUDE',yaxis_title='LATTITUDE')
    fig.show()



  def scatter(self):
    fig = px.scatter(x=data['LONGITUDE'],y=data['LATTITUDE'],title='Interactive Scatter plot ')
    fig.show()

d=interactive()
interactive.hist(d)
interactive.scatter(d)
print(f'the end of interactive visualization')
```

```
from sklearn.linear_model import LinearRegression
```

```
from sklearn.model_selection import train_test_split, GridSearchCV

from sklearn.metrics import r2_score, mean_squared_error, mean_absolute_error,
median_absolute_error

from scipy.stats import spearmanr, kendalltau

from sklearn.preprocessing import StandardScaler  # Import StandardScaler


# Load your data into a pandas DataFrame

data = pd.read_csv("Automatic_Traffic_Recorder_ATR_Stations (1).csv")  # Replace with
your data file path


# Select features and target variable

X = data[["LONGITUDE", "LATITUDE"]]

y = data["AADT"]


# Split data into training and testing sets

X_train, X_test, y_train, y_test = train_test_split(X, y, test_size=0.2, random_state=42)


# *Data Normalization (Alternative to hyperparameter tuning):*

# Create a StandardScaler object

scaler = StandardScaler()


# Fit the scaler on the training data (learn mean and standard deviation)

scaler.fit(X_train)


# Normalize both training and testing data using the fitted scaler

X_train_scaled = scaler.transform(X_train)

X_test_scaled = scaler.transform(X_test)
```

```
# Define hyperparameter grid for LinearRegression (without 'normalize')
hyperparameter_grid = {
    'fit_intercept': [True, False]  # Whether to fit an intercept term
}

# Create and train the linear regression model with hyperparameter tuning
model = GridSearchCV(LinearRegression(), hyperparameter_grid, cv=5, scoring='r2')
model.fit(X_train_scaled, y_train)

# Get the best model with tuned hyperparameters
best_model = model.best_estimator_

# Make predictions on testing data using the best model
y_pred = best_model.predict(X_test_scaled)

# ... (rest of your code for evaluation metrics)



# Evaluate the model using various metrics
r2 = r2_score(y_test, y_pred)
print("R-squared (Proportion of variance explained):", r2)

mse = mean_squared_error(y_test, y_pred)
print("Mean Squared Error (Average squared difference):", mse)

mae = mean_absolute_error(y_test, y_pred)
print("Mean Absolute Error (Average absolute difference):", mae)
```

```
median_ae = median_absolute_error(y_test, y_pred)

print("Median Absolute Error:", median_ae)


# Ranking Metrics

spearman_rho, _ = spearmanr(y_test, y_pred)  # Spearman's rank correlation coefficient

print("Spearman Rank Correlation Coefficient:", spearman_rho)


kendall_tau, _ = kendalltau(y_test, y_pred)  # Kendall's rank correlation coefficient

print("Kendall Tau Rank Correlation Coefficient:", kendall_tau)


# Print the best hyperparameter configuration

print("Best Hyperparameters:", model.best_params_)

print(f' end of the code')
```

OUT PUT:

```
FID                                              6006
STTNKEY                                      02000802
STTNID                                         000802
NHS                                                 0
LOCATION    RAIG/KLAWOCK/HOLLIS HWY BTW KLAWOCK R. BR. & BAYV
CONFIDENCE                                          3
COMMENT                                   Not on NHPN
LONGITUDE                                 -133.088078
LATITUDE                                    55.550582
STPOSTAL                                           AK
AADT                                             2028
YEAR_GEO                                         2001
FCLASS                                              7
STFIPS                                              2
CTFIPS                                              0
VERSION                                             1

                                                  6    \
index                                               6
X                                          -132.36462
Y                                           56.467185
FID                                              6007
STTNKEY                                      02000803
STTNID                                         000803
NHS                                                 0
LOCATION    RANGELL PTR: ZIMOVIA HWY BTW BENNET & CASE   WRAN
CONFIDENCE                                          3
COMMENT
LONGITUDE                                  -132.36462
LATITUDE                                    56.467186
STPOSTAL                                           AK
AADT                                             2113
YEAR_GEO                                         2001
FCLASS                                              7
STFIPS                                              2
CTFIPS                                            280
VERSION                                             1

                                                  7    \
index                                               7
X                                         -132.951902
Y                                           56.776219
FID                                              6008
```

```
FID                                      6004
STTNKEY                              02000800
STTNID                                 000800
NHS                                         0
LOCATION     AWDEN PTR BTW DOCK & PARK   KETCHIKAN
CONFIDENCE                                  2
COMMENT                           Not on NHPN
LONGITUDE                         -131.640004
LATITUDE                            55.344761
STPOSTAL                                   AK
AADT                                        0
YEAR_GEO                                 2001
FCLASS
STFIPS                                      2
CTFIPS                                      0
VERSION                                     1

                                                       4     \
index                                                  4
X                                            -131.711563
Y                                              55.377654
FID                                                 6005
STTNKEY                                         02000801
STTNID                                            000801
NHS                                                    0
LOCATION     TONGASS BTW S & N JCTS W/SHORELINE DR, KETCHIKAN
CONFIDENCE                                             3
COMMENT
LONGITUDE                                    -131.711563
LATITUDE                                       55.377654
STPOSTAL                                              AK
AADT                                                   0
YEAR_GEO                                            2001
FCLASS
STFIPS                                                 2
CTFIPS                                               130
VERSION                                                1

                                                        5     \
index                                                   5
X                                             -133.088078
Y                                               55.550582
FID                                                  6006
```

```
LOCATION     EST END BADGER LOOP ROAD (NB)
CONFIDENCE                               2
COMMENT          Poor Location Description
LONGITUDE                      -147.565704
LATITUDE                         64.818031
STPOSTAL                                AK
AADT                                 10620
YEAR_GEO                              2001
FCLASS                                  17
STFIPS                                   2
CTFIPS                                  90
VERSION                                  1

                                                        2     \
index                                                   2
X                                             -147.803037
Y                                               64.849282
FID                                                  6003
STTNKEY                                          02000532
STTNID                                             000532
NHS                                                     7
LOCATION     OHANSEN EXPRESSWAY EAST OF UNIVERSITY AVENUE (EB)
CONFIDENCE                                              2
COMMENT
LONGITUDE                                     -147.803037
LATITUDE                                        64.849282
STPOSTAL                                               AK
AADT                                                20866
YEAR_GEO                                             2001
FCLASS                                                 14
STFIPS                                                  2
CTFIPS                                                 90
VERSION                                                 1

                                            3     \
index                                       3
X                                 -131.640005
Y                                   55.344761
FID                                      6004
STTNKEY                              02000800
STTNID                                 000800
NHS                                         0
LOCATION     AWDEN PTR BTW DOCK & PARK   KETCHIKAN
```

```
1         2001     17       2      90        1
2         2001     14       2      90        1
3         2001              2       0        1
4         2001              2     130        1
...        ...    ...     ...     ...      ...
6344      1999              6      95        1
6345      2000              6      95        1
6346      1999              6      95        1
6347      1999              6      95        1
6348      2000     12       6      97        1

[6349 rows x 19 columns]
[1]
                                                     0      \
index                                                0
X                                           -147.799672
Y                                             64.837219
FID                                               6001
STTNKEY                                       02000530
STTNID                                          000530
NHS                                                  3
LOCATION    IRPORT WAY BETWEEN MARKET STREET AND UNIVERSITY A
CONFIDENCE                                           3
COMMENT
LONGITUDE                                   -147.799672
LATITUDE                                      64.837219
STPOSTAL                                            AK
AADT                                             15330
YEAR_GEO                                          2001
FCLASS                                              14
STFIPS                                               2
CTFIPS                                              90
VERSION                                              1

                                  1      \
index                                 1
X                           -147.565705
Y                             64.818031
FID                                6002
STTNKEY                        02000531
STTNID                           000531
NHS                                   0
LOCATION    EST END BADGER LOOP ROAD (NB)
```

```
dtype: int64
      index           X          Y   FID   STTNKEY  STTNID  NHS  \
0         0 -147.799672  64.837219  6001  02000530  000530    3
1         1 -147.565705  64.818031  6002  02000531  000531    0
2         2 -147.803037  64.849282  6003  02000532  000532    7
3         3 -131.640005  55.344761  6004  02000800  000800    0
4         4 -131.711563  55.377654  6005  02000801  000801    0
...     ...         ...        ...   ...       ...     ...  ...
6344   6344 -122.086734  38.242014   996  06043334  043334    1
6345   6345 -122.101213  38.235599   997  06043340  043340    1
6346   6346 -122.101298  38.235561   998  0604334E  04334E    1
6347   6347 -122.101256  38.235580   999  0604334W  04334W    1
6348   6348 -122.714518  38.431792  1000  06044040  044040    3

                                              LOCATION  CONFIDENCE  \
0     IRPORT WAY BETWEEN MARKET STREET AND UNIVERSITY A           3
1                            EST END BADGER LOOP ROAD (NB)           2
2     OHANSEN EXPRESSWAY EAST OF UNIVERSITY AVENUE (EB)           2
3                  AWDEN PTR BTW DOCK & PARK   KETCHIKAN           2
4      TONGASS BTW S & N JCTS W/SHORELINE DR, KETCHIKAN           3
...                                                 ...         ...
6344                        ABERNATHY LANE (WAS 10004W7)           3
6345                                  .5MILEW/ORTE12EAST           3
6346                              .5 MILE W/O RTE 12 EAST           3
6347                              .5 MILE W/O RTE 12 EAST           3
6348                                          JCTRTE12           3

                         COMMENT   LONGITUDE   LATITUDE STPOSTAL    AADT  \
0                                -147.799672  64.837219       AK   15330
1     Poor Location Description -147.565704  64.818031       AK   10620
2                                -147.803037  64.849282       AK   20866
3                    Not on NHPN -131.640004  55.344761       AK       0
4                                -131.711563  55.377654       AK       0
...                          ...         ...        ...      ...     ...
6344                             -122.086733  38.242014       CA       0
6345                             -122.101213  38.235599       CA       0
6346                             -122.101298  38.235561       CA       0
6347                             -122.101255  38.235580       CA       0
6348                             -122.714518  38.431792       CA  105045

      YEAR_GEO FCLASS  STFIPS  CTFIPS  VERSION
0         2001     14       2      90        1
1         2001     17       2      90        1
2         2001     14       2      90        1
```

```
       CONFIDENCE    LONGITUDE     LATITUDE           AADT     YEAR_GEO  \
count  6349.000000  6349.000000  6349.000000    6349.000000  6349.000000
mean      2.830524   -92.207418    39.439932   12501.190581  1995.132777
std       0.437608    15.816166     5.570506   27710.539367    93.802239
min       0.000000  -159.404750    19.502810       0.000000     0.000000
25%       3.000000  -100.126822    36.092894       0.000000  1999.000000
50%       3.000000   -88.076386    39.759902      83.000000  1999.000000
75%       3.000000   -81.196029    42.992022   12071.000000  2000.000000
max       3.000000   -67.370606    64.979661  322369.000000  2005.000000

           STFIPS       CTFIPS  VERSION
count  6349.000000  6349.000000   6349.0
mean     29.542605    71.882659      1.0
std      15.322071    94.834270      0.0
min       1.000000     0.000000      1.0
25%      19.000000    13.000000      1.0
50%      27.000000    49.000000      1.0
75%      41.000000   103.000000      1.0
max      56.000000   820.000000      1.0
index         0
X             0
Y             0
FID           0
STTNKEY       0
STTNID        0
NHS           0
LOCATION      0
CONFIDENCE    0
COMMENT       0
LONGITUDE     0
LATITUDE      0
STPOSTAL      0
AADT          0
YEAR_GEO      0
FCLASS        0
STFIPS        0
CTFIPS        0
VERSION       0
dtype: int64
      index           X          Y   FID   STTNKEY  STTNID  NHS  \
0         0 -147.799672  64.837219  6001  02000530  000530    3
1         1 -147.565705  64.818031  6002  02000531  000531    0
```

```
     STPOSTAL    AADT  YEAR_GEO FCLASS  STFIPS  CTFIPS  VERSION
6344       CA       0      1999              6      95        1
6345       CA       0      2000              6      95        1
6346       CA       0      1999              6      95        1
6347       CA       0      1999              6      95        1
6348       CA  105045      2000     12       6      97        1
<class 'pandas.core.frame.DataFrame'>
RangeIndex: 6349 entries, 0 to 6348
Data columns (total 19 columns):
 #   Column      Non-Null Count  Dtype
---  ------      --------------  -----
 0   index       6349 non-null   int64
 1   X           6349 non-null   float64
 2   Y           6349 non-null   float64
 3   FID         6349 non-null   int64
 4   STTNKEY     6349 non-null   object
 5   STTNID      6349 non-null   object
 6   NHS         6349 non-null   int64
 7   LOCATION    6349 non-null   object
 8   CONFIDENCE  6349 non-null   int64
 9   COMMENT     6349 non-null   object
 10  LONGITUDE   6349 non-null   float64
 11  LATITUDE    6349 non-null   float64
 12  STPOSTAL    6349 non-null   object
 13  AADT        6349 non-null   int64
 14  YEAR_GEO    6349 non-null   int64
 15  FCLASS      6349 non-null   object
 16  STFIPS      6349 non-null   int64
 17  CTFIPS      6349 non-null   int64
 18  VERSION     6349 non-null   int64
dtypes: float64(4), int64(9), object(6)
memory usage: 942.6+ KB
None
             index            X            Y          FID          NHS  \
count  6349.000000  6349.000000  6349.000000  6349.000000  6349.000000
mean   3174.000000   -92.207418    39.439932  3175.000000     2.425894
std    1832.942761    15.816166     5.570506  1832.942761     2.927780
min       0.000000  -159.404750    19.502810     1.000000     0.000000
25%    1587.000000  -100.126822    36.092894  1588.000000     0.000000
50%    3174.000000   -88.076386    39.759902  3175.000000     1.000000
75%    4761.000000   -81.196029    42.992022  4762.000000     7.000000
max    6348.000000   -67.370607    64.979661  6349.000000     9.000000
```

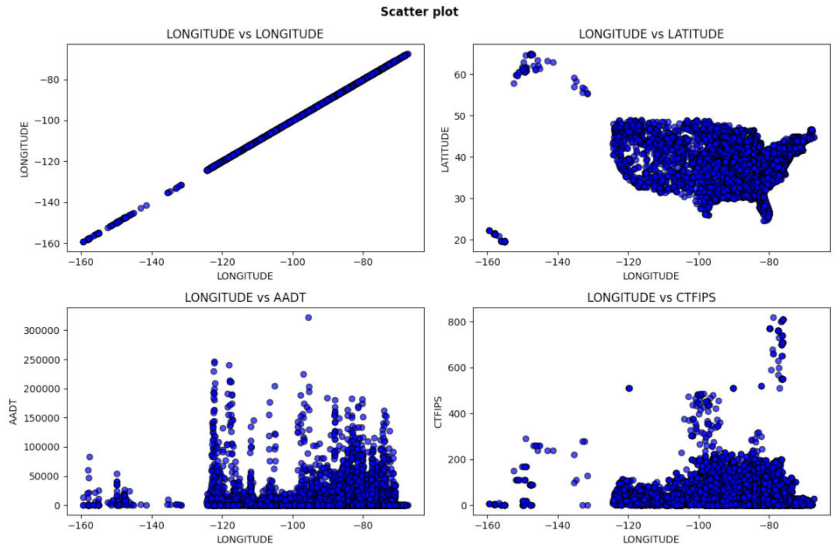
```
   index           X          Y   FID   STTNKEY  STTNID  NHS  \
0      0 -147.799672  64.837219  6001  02000530  000530    3
1      1 -147.565705  64.818031  6002  02000531  000531    0
2      2 -147.803037  64.849282  6003  02000532  000532    7
3      3 -131.640005  55.344761  6004  02000800  000800    0
4      4 -131.711563  55.377654  6005  02000801  000801    0

                                          LOCATION  CONFIDENCE  \
0  IRPORT WAY BETWEEN MARKET STREET AND UNIVERSITY A           3
1                       EST END BADGER LOOP ROAD (NB)           2
2  OHANSEN EXPRESSWAY EAST OF UNIVERSITY AVENUE (EB)           2
3               AWDEN PTR BTW DOCK & PARK   KETCHIKAN           2
4   TONGASS BTW S & N JCTS W/SHORELINE DR, KETCHIKAN           3

                    COMMENT   LONGITUDE   LATITUDE STPOSTAL   AADT  YEAR_GEO  \
0                           -147.799672  64.837219       AK  15330      2001
1  Poor Location Description -147.565704  64.818031       AK  10620      2001
2                           -147.803037  64.849282       AK  20866      2001
3                Not on NHPN -131.640004  55.344761       AK      0      2001
4                           -131.711563  55.377654       AK      0      2001

  FCLASS  STFIPS  CTFIPS  VERSION
0     14       2      90        1
1     17       2      90        1
2     14       2      90        1
3              2       0        1
4              2     130        1
      index           X          Y   FID   STTNKEY  STTNID  NHS  \
6344   6344 -122.086734  38.242014   996  06043334  043334    1
6345   6345 -122.101213  38.235599   997  06043340  043340    1
6346   6346 -122.101298  38.235561   998  0604334E  04334E    1
6347   6347 -122.101256  38.235580   999  0604334W  04334W    1
6348   6348 -122.714518  38.431792  1000  06044040  044040    3

                        LOCATION  CONFIDENCE COMMENT   LONGITUDE   LATITUDE  \
6344  ABERNATHY LANE (WAS 10004W7)           3         -122.086733  38.242014
6345              .5MILEW/ORTE12EAST           3         -122.101213  38.235599
6346        .5 MILE W/O RTE 12 EAST           3         -122.101298  38.235561
6347        .5 MILE W/O RTE 12 EAST           3         -122.101255  38.235580
6348                        JCTRTE12           3         -122.714518  38.431792

     STPOSTAL    AADT  YEAR_GEO FCLASS  STFIPS  CTFIPS  VERSION
6344       CA       0      1999              6      95        1
```

```
FCLASS                                                    7
STFIPS                                                    2
CTFIPS                                                  280
VERSION                                                   1

                                                       7     \
index                                                     7
X                                               -132.951902
Y                                                 56.776219
FID                                                    6008
STTNKEY                                            02000804
STTNID                                               000804
NHS                                                       0
LOCATION    ITKOF HWY PTR, S JCT SCOW BAY LOOP - USFS WAREHOU
CONFIDENCE                                                3
COMMENT
LONGITUDE                                       -132.951902
LATITUDE                                          56.776219
STPOSTAL                                                 AK
AADT                                                   1081
YEAR_GEO                                               2001
FCLASS                                                    7
STFIPS                                                    2
CTFIPS                                                  280
VERSION                                                   1

                                                     8     \
index                                                   8
X                                             -134.733378
Y                                               58.383147
FID                                                  6009
STTNKEY                                          02000805
STTNID                                             000805
NHS                                                     0
LOCATION    LACIER HWY BTW N LENA & AUKE BAY FERRY TERMINAL
CONFIDENCE                                              3
COMMENT
LONGITUDE                                     -134.733378
LATITUDE                                        58.383147
STPOSTAL                                               AK
AADT                                                 2019
YEAR_GEO                                             2001
FCLASS                                                 16
```

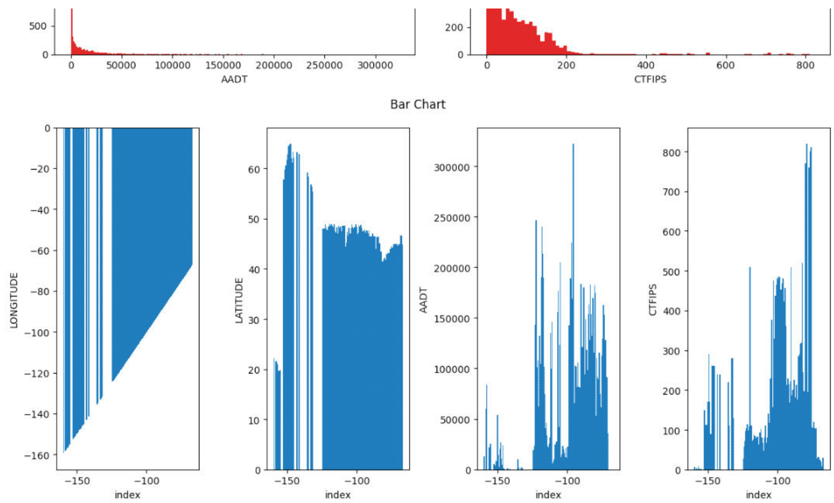
```
                          6345                     6346  \
index                     6345                     6346
X                  -122.101213              -122.101298
Y                    38.235599                38.235561
FID                        997                      998
STTNKEY               06043340                 0604334E
STTNID                  043340                   04334E
NHS                          1                        1
LOCATION    .5MILEW/ORTE12EAST  .5 MILE W/O RTE 12 EAST
CONFIDENCE                   3                        3
COMMENT
LONGITUDE          -122.101213              -122.101298
LATITUDE             38.235599                38.235561
STPOSTAL                    CA                       CA
AADT                         0                        0
YEAR_GEO                  2000                     1999
FCLASS
STFIPS                       6                        6
CTFIPS                      95                       95
VERSION                      1                        1

                               6347        6348
index                          6347        6348
X                       -122.101256 -122.714518
Y                          38.23558   38.431792
FID                             999        1000
STTNKEY                    0604334W    06044040
STTNID                       04334W      044040
NHS                               1           3
LOCATION    .5 MILE W/O RTE 12 EAST    JCTRTE12
CONFIDENCE                        3           3
COMMENT
LONGITUDE               -122.101255 -122.714518
LATITUDE                   38.23558   38.431792
STPOSTAL                         CA          CA
AADT                              0      105045
YEAR_GEO                       1999        2000
FCLASS                                       12
STFIPS                            6           6
CTFIPS                           95          97
VERSION                           1           1

[19 rows x 6349 columns]
```

```
                               6339                     6340        6341  \
index                          6339                     6340        6341
X                       -124.210648              -124.210648 -122.929746
Y                         40.622209                40.622209   39.074249
FID                             991                      992         993
STTNKEY                    0601110N                 0601110S    06017720
STTNID                       01110N                   01110S      017720
NHS                               3                        3           0
LOCATION    JCT RTE 1, SINGLEY RD IC  JCT RTE 1, SINGLEY RD IC  S/OPARKWAY
CONFIDENCE                        2                        2           3
COMMENT
LONGITUDE               -124.210648              -124.210648 -122.929745
LATITUDE                  40.622209                40.622209    39.07425
STPOSTAL                         CA                       CA          CA
AADT                              0                        0       12614
YEAR_GEO                       1999                     1999        2000
FCLASS                                                                 2
STFIPS                            6                        6           6
CTFIPS                           23                       23          33
VERSION                           1                        1           1

                          6342         6343                         6344  \
index                     6342         6343                         6344
X                  -121.045207  -121.328546                  -122.086734
Y                    38.945374     38.33099                    38.242014
FID                        994          995                          996
STTNKEY               06034580     06035010                     06043334
STTNID                  034580       035010                       043334
NHS                          1            7                            1
LOCATION    BOWMAN-PLA-80-R23.43  N/OARNOROAD  ABERNATHY LANE (WAS 10004W7)
CONFIDENCE                   2            3                            3
COMMENT
LONGITUDE          -121.045207  -121.328545                  -122.086733
LATITUDE             38.945374     38.33099                    38.242014
STPOSTAL                    CA           CA                           CA
AADT                     39726        67598                            0
YEAR_GEO                  2000         2000                         1999
FCLASS                       1            2
STFIPS                       6            6                            6
CTFIPS                      61           67                           95
VERSION                      1            1                            1
```

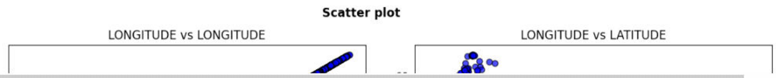
```
the end of univariate visualization
```



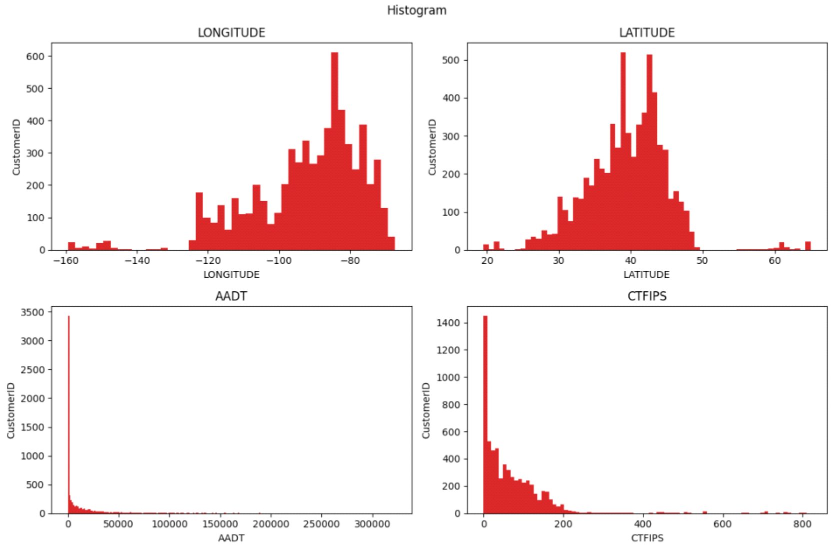

```
the end of bivariate visualization
/usr/local/lib/python3.10/dist-packages/seaborn/axisgrid.py:1513: UserWarning: Ignoring `palette` because no `hue` variable has been assigned.
```

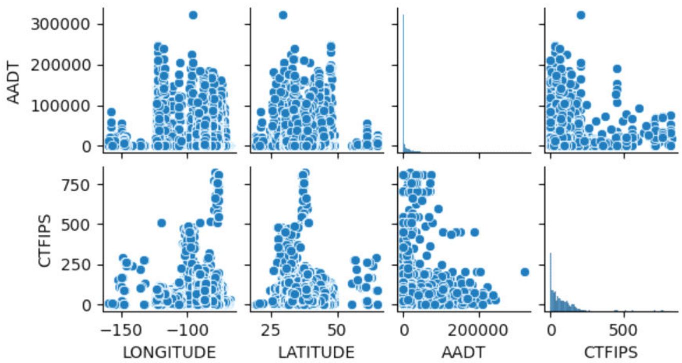



```
the end of univariate visualization
```

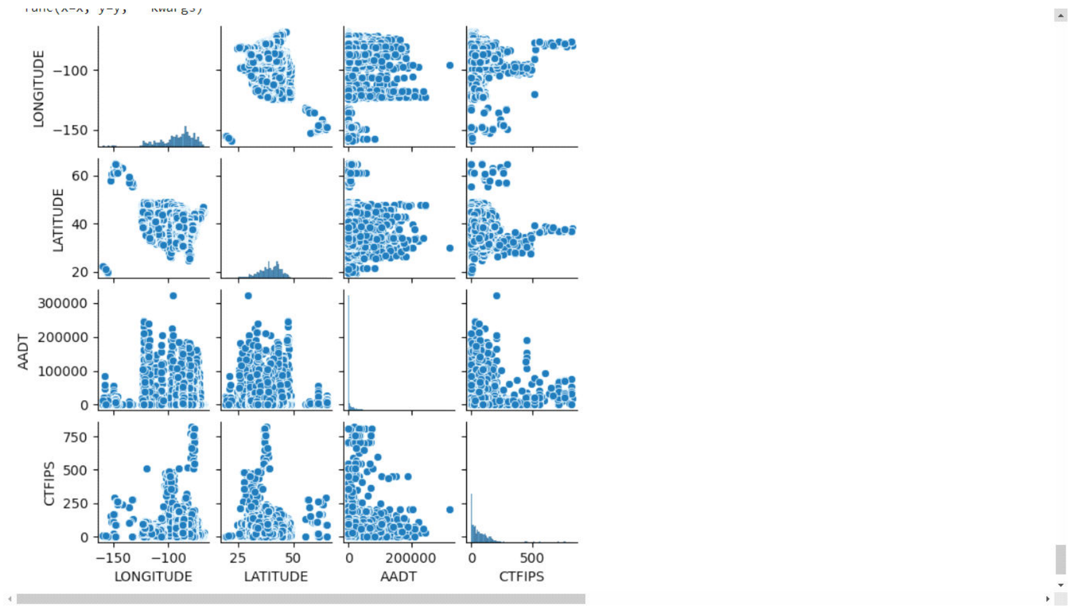


```
<pandas.core.groupby.generic.SeriesGroupBy object at 0x7eea39fc5570>
<pandas.core.groupby.generic.DataFrameGroupBy object at 0x7eea39fc4e80>
```






```
<Figure size 1200x600 with 0 Axes>
the end of multivariate
R-squared (Proportion of variance explained): 0.009399250045855623
Mean Squared Error (Average squared difference): 810056787.4575367
Mean Absolute Error (Average absolute difference): 16197.888074329161
Median Absolute Error: 10978.073010069096
Spearman Rank Correlation Coefficient: 0.11492142786729159
Kendall Tau Rank Correlation Coefficient: 0.08192798553360979
Best Hyperparameters: {'fit_intercept': True}
 end of the code
```



CONCLUSION:

ATFM optimization plays a critical role in ensuring a safe, efficient, and sustainable air transport system. By strategically managing air traffic flow, it aims to minimize delays, reduce fuel consumption and emissions, and maintain safety within airspace limitations.By embracing these advancements and fostering collaboration, ATFM optimization can continue to play a vital role in shaping a resilient and sustainable air transport system for the future.