Months and Days

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This notebook contains analysis on how different months and days of the month compare wrt. delays.

```
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
import dataframe_image as dfi
from helper_functions import group_data_reliability, hhmm_to_hour
```

0.1 Loading the Data

```
# Load data
flights = pd.read_csv("data/filtered_flights.csv")
```

0.2 Delay by Month

This section explores how flight delays vary across different months of the year, examining both average delays and on-time rates.

```
# Defining "on time" threshold as 15 minutes
on_time_threshold = 15

# Creating new variables saying whether a flight was delayed on departure and arrival, respectively
flights["dep_on_time"] = (flights["DEPARTURE_DELAY"] <= on_time_threshold).astype(int)
flights["arr_on_time"] = (flights["ARRIVAL_DELAY"] <= on_time_threshold).astype(int)

# Aggregating by month
summary_performance_month = group_data_reliability(flights, "MONTH")

# Sort by month number
summary_performance_month = summary_performance_month.sort_index()
```

Below is a table showing on time arrivals and departures as well as average arrival and departure delays by month.

```
# Create a formatted table
month_table = summary_performance_month[["n_flights",
                                         "arr_on_time_rate", "dep_on_time_rate",
                                         "mean_arr_delay", "mean_dep_delay"]
                                        ].rename(columns={
                                            "n_flights": "Total Flights",
                                            "arr_on_time_rate": "On Time Arrivals (Rate)",
                                            "dep_on_time_rate": "On Time Departures (Rate)",
                                            "mean_arr_delay": "Average Arrival Delay (Minutes)",
                                            "mean_dep_delay": "Average Departure Delay (Minutes)"
                                        }).reset_index()
```

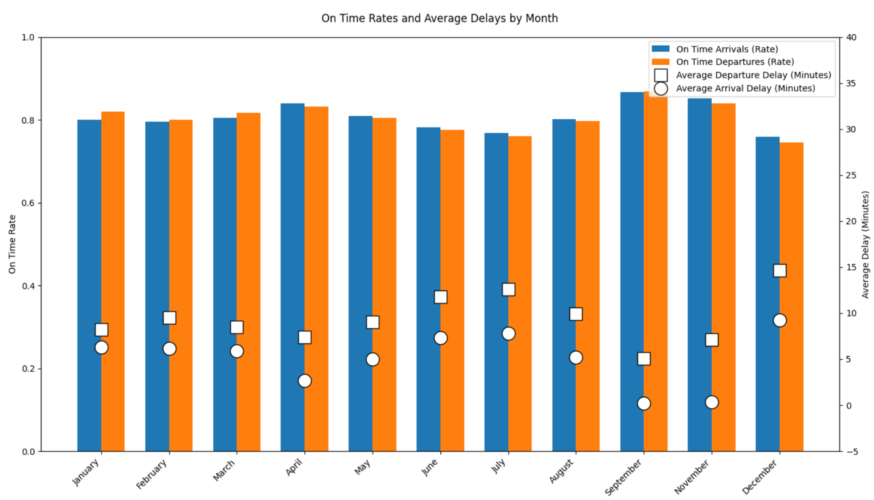
```
# Add month names
month_names = {1: "January", 2: "February", 3: "March", 4: "April",
               5: "May", 6: "June", 7: "July", 8: "August",
               9: "September", 10: "October", 11: "November", 12: "December"}
month_table["Month"] = month_table["MONTH"].map(month_names)
month_table = month_table[["Month", "Total Flights", "On Time Arrivals (Rate)",
                           "On Time Departures (Rate)", "Average Arrival Delay (Minutes)",
                           "Average Departure Delay (Minutes)"]]

dfi.export(month_table, "figures/df_flights_months.png", table_conversion="matplotlib")
month_table
```

	Month	Total Flights	On Time Arrivals (Rate)	On Time Departures (Rate)	Average Arrival Delay (Minutes)	Average Departure Delay (Minutes)
0	January	57331	0.799323	0.820307	6.296069	8.187103
1	February	51887	0.795536	0.799680	6.177883	9.521592
2	March	59381	0.804634	0.816911	5.908526	8.466741
3	April	58122	0.839579	0.832611	2.651358	7.409653
4	May	59821	0.809632	0.804283	5.022416	9.055392
5	June	60412	0.781914	0.775541	7.324353	11.772874
6	July	63052	0.767652	0.760864	7.791537	12.572607
7	August	62791	0.801962	0.797598	5.198773	9.902271
8	September	57850	0.867468	0.868643	0.189811	5.034868
9	November	56536	0.852413	0.839943	0.317161	7.087673
10	December	57767	0.759465	0.744716	9.224019	14.664086

The same thing can be showed in a bar plot, which is easier to interpret and compare across months.

```
# Create bar chart for monthly delays
fig, ax1 = plt.subplots(figsize=(14, 8))

# On Time Rates
width = 0.35
x_pos = np.arange(len(summary_performance_month))
month_labels = [month_names[i] for i in summary_performance_month.index]

ax1.bar(x_pos - width/2,
        summary_performance_month["arr_on_time_rate"], width, label="On Time Arrivals (Rate)")
ax1.bar(x_pos + width/2,
        summary_performance_month["dep_on_time_rate"], width, label="On Time Departures (Rate)")
ax1.set_ylabel("On Time Rate")
ax1.set_ylim(0, 1)
ax1.set_xticks(x_pos)
ax1.set_xticklabels(month_labels, rotation=45, ha="right")

# Average Delays
ax2 = ax1.twinx()
ax2.plot(x_pos,
         summary_performance_month["mean_dep_delay"], marker="s", markersize=15,
         linestyle="None", label="Average Departure Delay (Minutes)",
         markerfacecolor="white", markeredgecolor="black")
ax2.plot(x_pos,
         summary_performance_month["mean_arr_delay"], marker="o", markersize=15,
         linestyle="None", label="Average Arrival Delay (Minutes)",
         markerfacecolor="white", markeredgecolor="black")
```

```
ax2.set_ylim( -5, 40)
ax2.set_ylabel("Average Delay (Minutes)")

# Title
fig.suptitle("On Time Rates and Average Delays by Month")

# Legend
handles1, labels1 = ax1.get_legend_handles_labels()
handles2, labels2 = ax2.get_legend_handles_labels()
ax1.legend(handles1 + handles2, labels1 + labels2, loc="upper right")

plt.tight_layout()

plt.savefig("figures/delays_by_month.png", dpi=300, bbox_inches='tight')

plt.show()
```



The plot shows a seasonal pattern in when flights are on time. On-time arrival and departure rates are highest in spring and early fall, when average delays are also at their lowest. In contrast, the summer months (June and July) and December show worse performance, with lower on-time rates and higher average delays. This indicates that increased demand during peak travel periods reduce reliability significantly, while less busy seasons result in more stable flight performance.

0.3 Delay by Day of Month

This section explores how flight delays vary across the days of the months, examining both average delays and on-time rates.

```
# Aggregating by day of month
summary_performance_day = group_data_reliability(flights, "DAY")

# Sort by day number
summary_performance_day = summary_performance_day.sort_index()
```

Below is a table showing on time arrivals and departures as well as average arrival and departure delays by day of the month.

```
# Create a formatted table
day_table = summary_performance_day[["n_flights",
                                     "arr_on_time_rate", "dep_on_time_rate",
                                     "mean_arr_delay", "mean_dep_delay"]
                                   ].rename(columns={
```

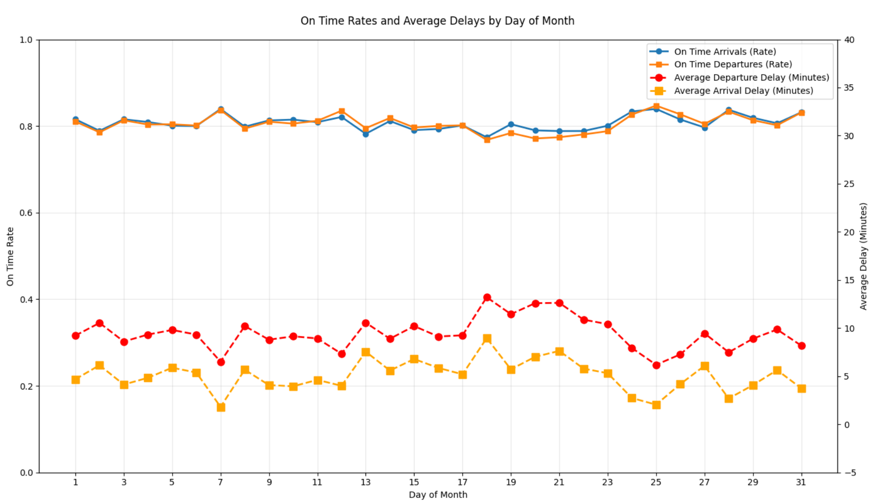
```
                                                "n_flights": "Total Flights",
                                                "arr_on_time_rate": "On Time Arrivals (Rate)",
                                                "dep_on_time_rate": "On Time Departures (Rate)",
                                                "mean_arr_delay": "Average Arrival Delay (Minutes)",
                                                "mean_dep_delay": "Average Departure Delay (Minutes)"
                                            }).reset_index()

day_table = day_table.rename(columns={"DAY": "Day of Month"})
day_table = day_table[["Day of Month", "Total Flights", "On Time Arrivals (Rate)",
                       "On Time Departures (Rate)", "Average Arrival Delay (Minutes)",
                       "Average Departure Delay (Minutes)"]]

dfi.export(month_table, "figures/df_flights_days.png", table_conversion="matplotlib")
day_table
```

	Day of Month	Total Flights	On Time Arrivals (Rate)	On Time Departures (Rate)	Average Arrival Delay (Minutes)	Average Departure Delay (Minutes)
0	1	20900	0.815550	0.810383	4.688888	9.224856
1	2	21739	0.788859	0.785455	6.144059	10.541512
2	3	21449	0.815516	0.813231	4.132903	8.606191
3	4	21165	0.809213	0.803449	4.840499	9.329607
4	5	21052	0.800732	0.803914	5.884538	9.808428
5	6	21171	0.799868	0.801049	5.385201	9.328209
6	7	20627	0.839337	0.837107	1.813376	6.513215
7	8	21371	0.798418	0.794020	5.673279	10.212737
8	9	21470	0.812902	0.809921	4.081258	8.795746
9	10	21348	0.814737	0.805556	3.956448	9.148429
10	11	21119	0.808892	0.812018	4.621480	8.927733
11	12	21084	0.820907	0.835231	4.005019	7.333509
12	13	21604	0.782031	0.794899	7.553473	10.565112
13	14	20779	0.811492	0.818519	5.589374	8.893644
14	15	21228	0.790465	0.796589	6.789313	10.211448
15	16	21685	0.793129	0.800231	5.866164	9.128348
16	17	21558	0.801419	0.801605	5.198297	9.253356
17	18	21241	0.774069	0.767902	8.956549	13.206501
18	19	21364	0.804203	0.783889	5.715881	11.449264
19	20	21732	0.789987	0.771213	7.018854	12.593222
20	21	20922	0.788357	0.774161	7.632650	12.624684
21	22	21367	0.788459	0.780503	5.794012	10.880806
22	23	21501	0.800614	0.788103	5.316145	10.410735
23	24	20870	0.833541	0.826449	2.735091	7.931044
24	25	20780	0.839461	0.847064	2.046190	6.187524
25	26	20658	0.815035	0.826944	4.183471	7.273300
26	27	21359	0.796573	0.804907	6.084735	9.458035
27	28	21178	0.837473	0.833129	2.685166	7.485099
28	29	19785	0.819055	0.813445	4.074434	8.898410
29	30	19781	0.806279	0.801779	5.642501	9.857346
30	31	11063	0.831601	0.831058	3.742337	8.180900

The same thing can be showed in a plot, which is easier to interpret and compare across days.

```
# Create line plot for delays by day of month
fig, ax1 = plt.subplots(figsize=(14, 8))
```

```
# On Time Rates
ax1.plot(summary_performance_day.index,
         summary_performance_day["arr_on_time_rate"],
         marker="o", label="On Time Arrivals (Rate)", linewidth=2)
ax1.plot(summary_performance_day.index,
         summary_performance_day["dep_on_time_rate"],
         marker="s", label="On Time Departures (Rate)", linewidth=2)
ax1.set_ylabel("On Time Rate")
ax1.set_ylim(0, 1)
ax1.set_xlabel("Day of Month")
ax1.set_xticks(range(1, 32, 2))
ax1.grid(True, alpha=0.3)

# Average Delays
ax2 = ax1.twinx()
ax2.plot(summary_performance_day.index,
         summary_performance_day["mean_dep_delay"],
         marker="o", markersize=8, label="Average Departure Delay (Minutes)",
         linestyle=" - -", linewidth=2, color="red")
ax2.plot(summary_performance_day.index,
         summary_performance_day["mean_arr_delay"],
         marker="s", markersize=8, label="Average Arrival Delay (Minutes)",
         linestyle=" - -", linewidth=2, color="orange")
ax2.set_ylim( -5, 40)
ax2.set_ylabel("Average Delay (Minutes)")

# Title
fig.suptitle("On Time Rates and Average Delays by Day of Month")

# Legend
handles1, labels1 = ax1.get_legend_handles_labels()
handles2, labels2 = ax2.get_legend_handles_labels()
ax1.legend(handles1 + handles2, labels1 + labels2, loc="upper right")

plt.tight_layout()

plt.savefig("figures/delays_by_day.png", dpi=300, bbox_inches=’tight’)

plt.show()
```



The plot shows that flight delays are relatively stable across the days of the month, with on-time arrival and departure rates generally being around 80%. However, average delays show clearer fluctuations, with a noticeable increase around the middle of the 18.-21., where both arrival and departure delays are highest. This indicates that while airlines have consistent reliability throughout the month, something happens in the middle of the month that tends to increase delay durations.

0.4 Delay by Day of Week

This section explores how flight delays vary across the days of the week, examining both average delays and on-time rates.

```
# In the original Kaggle flights data, DAY_OF_WEEK is:
# 1 = Monday, 2 = Tuesday, ..., 7 = Sunday

summary_performance_dow = group_data_reliability(flights, "DAY_OF_WEEK")
summary_performance_dow = summary_performance_dow.sort_index()

# Map numeric day of week to names
dow_names = {
    1: "Monday",
    2: "Tuesday",
    3: "Wednesday",
    4: "Thursday",
    5: "Friday",
    6: "Saturday",
    7: "Sunday"
}
```

Below is a table showing on time arrivals and departures as well as average arrival and departure delays by day of the week.

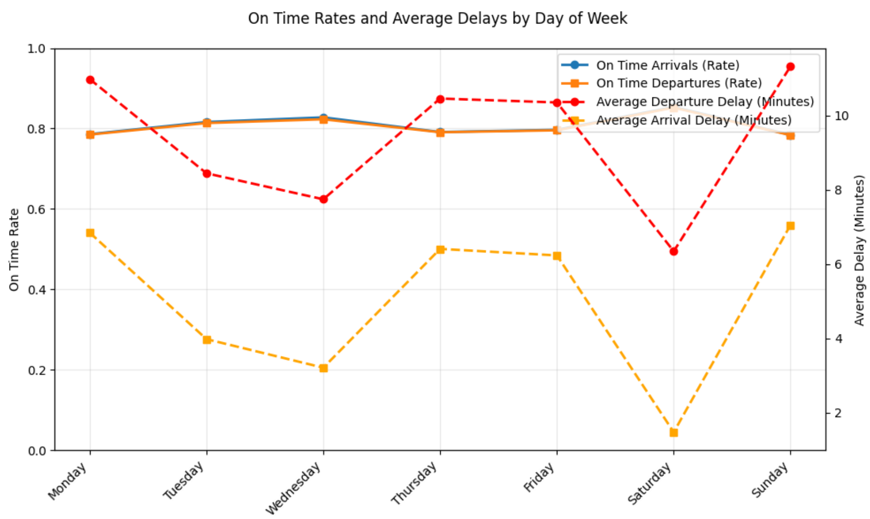
```
dow_table = (
    summary_performance_dow[
        ["n_flights", "arr_on_time_rate", "dep_on_time_rate",
         "mean_arr_delay", "mean_dep_delay"]
        ]
    .rename(columns={
        "n_flights": "Total Flights",
        "arr_on_time_rate": "On Time Arrivals (Rate)",
        "dep_on_time_rate": "On Time Departures (Rate)",
        "mean_arr_delay": "Average Arrival Delay (Minutes)",
        "mean_dep_delay": "Average Departure Delay (Minutes)"
    })
    .reset_index()
)

dow_table["Day of Week"] = dow_table["DAY_OF_WEEK"].map(dow_names)
dow_table = dow_table[
    ["Day of Week", "Total Flights",
     "On Time Arrivals (Rate)", "On Time Departures (Rate)",
     "Average Arrival Delay (Minutes)", "Average Departure Delay (Minutes)"]
]

dfi.export(month_table, "figures/df_flights_dow.png", table_conversion="matplotlib")
dow_table
```

	Day of Week	Total Flights	On Time Arrivals (Rate)	On Time Departures (Rate)	Average Arrival Delay (Minutes)	Average Departure Delay (Minutes)
0	Monday	96629	0.786027	0.784971	6.850157	10.984757
1	Tuesday	94515	0.816241	0.813585	3.983212	8.448567
2	Wednesday	95664	0.827762	0.823037	3.215092	7.749026
3	Thursday	95754	0.791299	0.790724	6.413493	10.461795
4	Friday	94493	0.796768	0.795625	6.237937	10.356115
5	Saturday	77066	0.853463	0.852075	1.479301	6.348848
6	Sunday	90829	0.784309	0.783439	7.056912	11.328469

The same thing can be showed in a plot, which is easier to interpret and compare across days.

```
# Plot: on -time rates and delays by day of week

fig, ax1 = plt.subplots(figsize=(10, 6))

x_pos = np.arange(1, 8)
dow_labels = [dow_names[i] for i in x_pos]

# On time rates
ax1.plot(
    x_pos,
    summary_performance_dow["arr_on_time_rate"],
    marker="o",
    linewidth=2,
    label="On Time Arrivals (Rate)",
)
ax1.plot(
    x_pos,
    summary_performance_dow["dep_on_time_rate"],
    marker="s",
    linewidth=2,
    label="On Time Departures (Rate)",
)
ax1.set_ylabel("On Time Rate")
ax1.set_ylim(0, 1)
ax1.set_xticks(x_pos)
ax1.set_xticklabels(dow_labels, rotation=45, ha="right")
ax1.grid(True, alpha=0.3)

# Average delays
ax2 = ax1.twinx()
ax2.plot(
    x_pos,
    summary_performance_dow["mean_dep_delay"],
    marker="o",
    linestyle=" - -",
    linewidth=2,
    color="red",
    label="Average Departure Delay (Minutes)",
)
ax2.plot(
    x_pos,
    summary_performance_dow["mean_arr_delay"],
    marker="s",
    linestyle=" - -",
```

```
    linewidth=2,
    color="orange",
    label="Average Arrival Delay (Minutes)",
)
ax2.set_ylabel("Average Delay (Minutes)")

fig.suptitle("On Time Rates and Average Delays by Day of Week")

# Combined legend
h1, l1 = ax1.get_legend_handles_labels()
h2, l2 = ax2.get_legend_handles_labels()
ax1.legend(h1 + h2, l1 + l2, loc="upper right")

plt.tight_layout()

plt.savefig("figures/delays_by_dow.png", dpi=300, bbox_inches="tight")

plt.show()
```



Here we see clear differences in flight performance across the days of the week. On-time arrival and departure rates are highest during the middle of the week, indicating more stable operations during these days. Weekends show more mixed performance, where Saturday has relatively comparable on-time rates but the lowest average arrival delays. Mondays also stand out with higher delay times despite moderate on-time rates, probably showing schedule recovery effects from weekend disruptions.

1 Time-of-Day Delay Analysis

This section is about how flight behavior changes throughout the day and analyzing the reliability of flight times. Using a helper function to convert the departure time into an hour of the day, and assuming flights within the same hour are, on average, comparable and that time of day can show us operational constraints like congestion or dispersal of flights, allows us to aggregate performance metrics at an hourly level. This will give us a clear idea of how operational constraints affect flight reliability over the course of a typical day.

```
#Time -of -day delay analysis (using scheduled departure hour)

time_col = "SCHEDULED_DEPARTURE"

#Convert departure time (HHMM) into hour of day (0 -23)
flights["dep_hour"] = flights[time_col].apply(hhmm_to_hour)
```

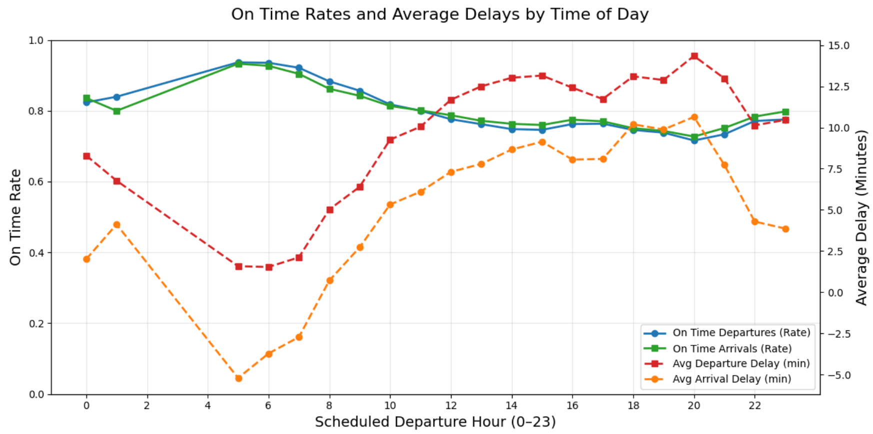
```
#Drop missing values in table
flights_hour = flights.dropna(subset=["dep_hour"]).copy()
flights_hour["dep_hour"] = flights_hour["dep_hour"].astype(int)

#add in performance metric by hour of day
summary_performance_by_hour = (
    group_data_reliability(flights_hour, "dep_hour").sort_index()
)

dfi.export(summary_performance_by_hour, "figures/df_delays_by_hour.png", table_conversion="matplotlib")

summary_performance_by_hour
```

	mean_dep_delay	mean_arr_delay	dep_on_time_rate	arr_on_time_rate	n_flights
dep_hour					
0	8.297591	2.002132	0.823492	0.836024	4708
1	6.772006	4.116883	0.839489	0.799716	704
5	1.578130	-5.209951	0.936592	0.932824	9289
6	1.530847	-3.722909	0.935369	0.926764	50904
7	2.114243	-2.723818	0.921236	0.904097	40082
8	5.020384	0.705051	0.882955	0.862004	47110
9	6.398356	2.725028	0.856498	0.842113	40529
10	9.259322	5.322866	0.817874	0.813380	47846
11	10.046378	6.099747	0.800188	0.800995	37180
12	11.681393	7.305840	0.776018	0.787276	42990
13	12.498396	7.786941	0.762077	0.771567	40988
14	13.020133	8.660192	0.748085	0.763082	34341
15	13.153504	9.137352	0.746077	0.759735	32947
16	12.416274	8.051626	0.762412	0.774754	35570
17	11.725976	8.089649	0.763347	0.770046	34633
18	13.106170	10.191720	0.745789	0.750593	31643
19	12.880871	9.878401	0.738139	0.742998	30669
20	14.341451	10.642752	0.716010	0.727123	26184
21	12.983682	7.732187	0.733401	0.751159	21793
22	10.131139	4.286856	0.771042	0.783517	23406
23	10.455467	3.866843	0.775319	0.797884	11434

The same thing can be showed in a plot, which is easier to interpret and compare across hours.

```
#plot

# plot on -time rates and average delays by time of day
fig, ax1 = plt.subplots(figsize=(12, 6))
hours = summary_performance_by_hour.index.to_numpy()

# On -time rates
ax1.plot(
    hours,
    summary_performance_by_hour["dep_on_time_rate"],
    marker="o",
    linewidth=2,
    color = "tab:blue",
    label="On Time Departures (Rate)",
)
ax1.plot(
    hours,
    summary_performance_by_hour["arr_on_time_rate"],
```

```
    marker="s",
    linewidth=2,
    color = "tab:green",
    label="On Time Arrivals (Rate)",
)

ax1.set_xlabel("Scheduled Departure Hour (023)", fontsize=14)
ax1.set_ylabel("On Time Rate",fontsize=14)
ax1.set_ylim(0, 1)
ax1.set_xticks(range(0, 24, 2))
ax1.grid(True, alpha=0.3)

# Average delays (second y -axis)
ax2 = ax1.twinx()
ax2.plot(
    hours,
    summary_performance_by_hour["mean_dep_delay"],
    linestyle=" - -",
    linewidth=2,
    marker="s",
    color = "tab:red",
    label="Avg Departure Delay (min)",
)
ax2.plot(
    hours,
    summary_performance_by_hour["mean_arr_delay"],
    linestyle=" - -",
    linewidth=2,
    marker="o",
    color = "tab:orange",
    label="Avg Arrival Delay (min)",
)
ax2.set_ylabel("Average Delay (Minutes)", fontsize=14)

# Title and legend and save
fig.suptitle("On Time Rates and Average Delays by Time of Day", fontsize=16)

h1, l1 = ax1.get_legend_handles_labels()
h2, l2 = ax2.get_legend_handles_labels()
ax1.legend(h1 + h2, l1 + l2, loc="lower right")

plt.tight_layout()
fig.savefig("figures/delays_by_hour.png", dpi=300, bbox_inches="tight")
plt.show()
```



Graph Description: The Left Y-axis is the on-time rate which is any flight that is only delayed by 15 minutes or less. The right Y-axis is the average minutes of delay for flights delayed 15 minutes or more. This graph shows how often flights are on time during the day as well as how bad the delays are when they do happen simultaneously. This graph is highlighting reliability and severity.

Graph Patterns: At around 5am, the on-time rates are the highest and the delays are the lowest which suggest that this is the "starting time" for many airports, their staff and travelers. In other words, this would be the begining of the day's flights as if they start from zero and continue on so there is no previous flight to delay them at this time. The later flights after this, can be affected by congestion or delay build ups.

From about 7am to the end of the day, the graph shows that reliability is declining since the on-time departures and arrivals decreases while the average delays increase. This indicates delay propagation in which all the small delays from early morning start to accumulate and lead to longer delays for later flights. The worst performance for reliability and severity is around hour 18 to 21 (6pm to 9pm) in which the average delay reaches almost 15 minutes pass the already set delay definition. In this case, a flight in this time frame could be delayed at least almost 30 minutes from its original departure time.

Overall, the daily pattern is that early morning flights are the most reliable with shortest delays and flights between peak evening hours of 6pm to 9pm are the least reliable with the longest delays for this specific dataset.