**4.2**

The dataset provided information on flights from 17 different carriers along 6,684 unique routes being flown between a combination of 362 airports in the United States (including Alaska and Hawaii and a couple airports in US territories such as Guam). 3,814,366 out of the 10,915,495 flights (~35\%) had some form of arrival delay. A histogram of all arrival delays is shown in \underline{Fig 4.1}. We observe that most “early” flights are not incredibly early compared to the frequency at which late flights can become “significantly” delayed, say more than 30 minutes. Clearly, the data is strongly right-skewed. To correct the skewness (to meet assumptions for our analysis), a cube-root transformation was performed, but subsequent Shapiro-Wilk tests provided strong evidence against normality for this transformation, so we turned to other methods, as will be discussed in chapter 5. To heuristically assess dependence between covariates and late arrivals, we examined various conditional distributions, as follows.

4.2.1 Geographic

In \underline{Fig 4.21}, the routes that have various average intervals of delay time are shown. Note straight lines are drawn for simplicity; the actual flight most likely flew a non-linear path toward the destination. Also, early arrivals are given a delay time of 0 in the computation of the mean. We observe many things. Almost all routes have an average delay that is positive. This spotlights the nature of this project: to focus on remedying delays to improve customer satisfaction and increase airline revenue. For the routes with a mean delay between 30 and 45 minutes, most of the delays are clustered on the eastern US with most of the routes either beginning or ending in the San Francisco, New York, or southern Florida regions. For more severe delays of 45+ minutes, these routes encompass more cross-country flights. Furthermore, it can be seen that an airport in the northeast, most likely JFK in New York, is involved in a lot of severe flight delays. Next, in \underline{Fig 4.22}, the average delays at certain airports is depicted. We see further evidence that the more problematic delays are centered in bigger cities, particularly those on the east and west coast. \underline{Fig 4.23} illustrates the relationship between the popularity of an airport and the amount of delays. As expected, airports that crank out more flights have a higher average delay time. This raises the question: Does more flights simply give airports a higher probability of having delays (by random chance), or does an increase in flights also bring in other factors that \textit{cause} an increase in flight delays. In more broad terms, what factors correlate with delays, and which ones can be controlled by the airlines?

4.2.2 Temporal

\underline{Fig 4.31}, \underline{Fig 4.32}, \underline{Fig 4.33}, and \underline{Fig 4.34} display the distribution of flight delays for quarter, month, day of the week, and time of day, respectively. Note that because our data contained a year and a half’s worth of observations, the frequency of delays for, say quarter 1, are higher than other time periods that were not recorded twice. The histograms appear roughly symmetric with a slight right-skew. Specifically, early arrivals appear to follow a normal distribution while it transitions to an exponential distribution once delays become positive. We will explore this specific observation in the first section of our next chapter. Regardless, the distributions across these time factors do not change significantly. This produces an initial assumption that time of the flight is independent of delay time. To further investigate this hypothesis, we conduct \textit{John talk about coplots and stuff here}.

4.2.3 Weather

This most obvious factor that most likely affects flight delays is the weather. Therefore, we analyzed the conditional distributions of flight delays given average temperature, precipitation, and the presence of various rare weather events. These are described in \underline{Fig 4.41}, \underline{Fig 4.42}, and \underline{Fig 4.43}, respectively. In the scatterplot depicting rain, we see a lack of evidence that more extreme temperatures correlate with increased delays. This would be evident if the scatterplot showed a parabolic pattern, which is not seen. Surprisingly, we see the same idea in the scatterplot of precipitation. Contrary to intuition, as the amount of precipitation increase, there is no visual subsequent increase in the delay time. Lastly, \underline{Fig 4.43} demonstrates that some dangerous weather events have a slightly bigger effect on delay times than others. For example, the distributions of “ice, sleet and hail” and “blowing or drifting snow” have more area in their right-tails. This is indicative of more occurrences where these events caused more significant delays. Besides these difference in tail-density, the overall shape remains very similar.

4.2.4 Carrier

Next, looking at delays by carrier would provide us with insight as to whether some carriers are better at mitigating delays. \underline{Fig 4.5} shows us that the distribution across carriers stays roughly the same. Apart from the differences in frequencies (with some airlines being more popular or providing more flight routes), the shape of the distribution is basically homogenous, especially when compared to the other conditional distributions of other factors. This means that delays across carriers \textit{behave} in the same manner. To analyze if the average delay time (as opposed to distribution) differs across airlines, we conducted ANOVA (analysis of variance). Specifically, we used Tukey’s HSD to make multiple comparisons across each combination of carriers to see what carriers differed from one another. A plot of the resultant 95% confidence intervals for the mean difference between airport delays is show in \underline{Fig 4.6}. We see that the majority of the intervals constructed do not fall within 0. Thus for those that didn’t, we conclude that they do indeed have a difference in mean arrival delays. All in all, we observe that the \textit{distribution} across carriers is similar, but the \textit{quantitative amount of delays} across carriers is different.

4.2.5 Airport

\underline{Fig 4.7} displays the histograms of delays for some of the most popular airports. As has been the trend thus far, the distribution across the airports does not change much save for the changes in frequency. Thus, we can conclude the behavior and process of flight delays is pretty universal and can be modeled with an explicitly defined distribution, as we will dive into in the next chapter.

4.2.6 | Making Up Lost Time En Route

One last thing we wanted to explore was the ability for pilots to make up lost time as a result of a departure delay. We presumed that a longer flight, distance-wise, would allow for more opportunity for a flight delay to be alleviated. In the air, harnessing favorable air currents or taking shortcuts can remedy the lost time they left the ground with. Surely, in \underline{Fig 4.8}, we see that flights over a longer distance have, on average, less arrival delays. Similarly, the shorter the flight, the more severe the arrival delay is. These observations support our hypothesis stated above. Of course, correlation does not imply causation, so more substantive knowledge on how pilots navigate the flight route would provide more clarification on this.

**LOGISTIC REGRESSION**

The majority of the models in data science can be put into three bins: regression, classification, and clustering. As we came to realize that our linear regression model was not useful enough, we turned to a classification method. In particular, we chose binary logistic regression to predict whether or not a flight would be delayed or not given certain pre-departure covariates. In retrospect, our motivation for pursuing logistic regression was two-fold. For one, we wanted to improve on the accuracy of our predictive model, so by moving away from regressing on a continuous variable, we shifted our focus to predicting a binary success or failure. Secondly, our conditional density estimates illustrate that given certain covariate levels, the shape of our distribution changes more than the mean (location) of our distribution. Thus, regressing on the parameter p from our Bernoulli random variable from our mixed distribution would help us explain these observed changes in our conditional density estimates. The marginal distribution of U in our model changes how thick-tailed our distributions become on either side of 0.

Using the \textit{glm()} function in R, we fit a generalized linear model using the logit function as the link function and the binomial distribution family as the probability distribution. A 5\% subset of our data frame was taken to shorten computation time. Even more, 80% of our data was allotted for training and 20% for testing. The summary of our fit model is show in \underline{Fig X.X}. Our covariates included various factors on the time as well as weather phenomena in the departure and arrival airport. We interpret our logistic regression output in two separate ways for numerical and categorical data. For numerical data, the specific factor level’s coefficient can be interpreted as the change in the log-odds of the “success” occurring – in our case a delay. Exponentiating these values gives you a more interpretable estimate. For example, from our model output, we can say that for every additional millimeter of snow, the odds of a delay occurring (versus not occurring) increases by a factor of e^0.1283 = 1.013. For categorial data, the interpretation is a little different. We illustrate by example. In our case, flying in April as opposed to January lowers one’s chances of having a flight delayed by a factor of e^-0.2646 = 0.767. Furthermore, we see that the majority of our coefficients are statistically significant as indicated by the asterisks next to each line. These significant predictors are thus being utilized in our model, as desired.

Since our logistic regression model outputted a \textit{probability} that a delay will occur, we needed to determine the optimal probability threshold to determine whether or not a delay will take place. We thus improved our model by plotting an ROC curve, or a “Receiver Operating Characteristics” curve (\underline{Fig X.X}. By maximizing the area under the curve, we are able to increase our accuracy. The y-axis gives the true positive rate while the x-axis gives 1 minus the true negative rate. Thus, by altering the probability threshold, we can then predict with better accuracy. Using this ROC curve and various functions, we found that the optimal probability threshold was 0.39. This means that any predictions that output the probability of a delay as being over 0.39, we say that a delay will occur.

Finally, after validating our model on the testing data, we generated a confusion matrix and other measures of performance as shown in \underline{Fig X.X}. Our accuracy was 67.62% where out of our testing set of 92,667 observations, it correctly predicted 62,187 of them. Observe from the confusion matrix that we have significantly more false positives than false negatives. Thus, we interpret this as our model is more on the pessimistic side and is more likely to forecast a delay when in reality there is not one.

**EXECUTIVE SUMMARY**

2.1 Problem and Approach

Ever since the first commercial airline flight was flown in 1914, the air transportation industry has played an integral part in both boosting the global economy as well as connecting people from all over the ever-interconnected world. On occasion, flights can be delayed from their scheduled times, and this results in lost revenue and irritated customers. The goal of our analysis was to not only model flight delays but also create predictive models to forecast future late arrivals, specifically for the third quarter of 2019. We dove into this project by first gathering and tidying up our data, performing exploratory data analysis, then fitting and assessing unique predictive models. By gathering substantive knowledge about airlines we then interpreted and applied our results with the intent to provide airlines with detailed areas to focus on to mitigate delays. Given a limit on resources, our goal was to uncover trends and pinpoint factors that can be controlled to help alleviate untimely arrivals. Intentional and thorough analysis was out driving force since quantitative evidence is what best drives changes in businesses.

2.2 Data Preprocessing

In addition to the datasets provided to us, we worked to gather historical weather information for all 11 million flights at both the origin and destination airport by fetching pertinent data from the NCDC (National Climate Data Center) API. After all data was gathered, we ensured our data was “tidy” by combining all flight, weather, airfare, route, airport, and geographical data into one data frame with each observation as a row and column as a covariate. Moreover, we changed appropriate covariates to categorical variables, replaced all missing values with reasonable entries, and experimented with transformations of variables. For subsequent models, data were further reorganized to fit the nature of the problem. For example, for one of our models we formatted the data to resemble longitudinal panel data.

2.3 Exploratory Analysis

During the exploratory phase, we produced various plots and summary statistics to learn about the distribution and nature of flight delays. By using numerous packages in R along with connection to the Google maps API, we were able to produce numerous revealing plots. Among these, we were able to assess the geographic, temporal, carrier, and weather-based patterns of flight delays, to name a few. Through the construction of conditional density estimates and other tests, the main takeaway from our exploration was that flight delays are not a purely random event and that they behave very predictably across a myriad of factors. This motivated us to pursue the models that we did.

2.4 Model Creation & Assessment

\textit{John, talk briefly about MLE and distribution stuff here\\}

\textit{John, talk briefly about OLS here\\}

As we found that modeling the binary variable of whether or not a delay would occur was beneficial, we trained a logistic regression model. By splitting our data into training and testing sets, we regressed on the now-binary arrival delay response on a variety of other pre-departure factors such as weather conditions. We when generated a Receiver Operating Characteristics curve as well as a confusion matrix to further optimize our model and maximize its accuracy.

\textit{John, talk briefly about dynamic regression model here\\}

2.5 Applications and Conclusions

**BUSINESS RECOMMENDATIONS**

**7.1 Diﬀerences Between Carriers**

As we saw in our analysis of variance in our data exploration, the average delay times across carriers do differ. More popular carriers such as American Airlines do incur more delays than say, a lesser known airline such as Pinnacle Airlines. For large carriers, Alaska Airlines and Delta do a very solid job of alleviating delays. It is also evident the more flights an airport hosts, the more chance there is at a delay occurring. From a customer’s point of view, one could simply avoid flying with the most popular airlines if the cost and quality level of another airline is more tolerable. From this same perspective, flying during less delay-prone times such as leaving late at night, flying during the months of October and November, or leaving on a Saturday would help families and the like minimize their chances of experiencing delays.

**7.2 Important Variables to Keep an Eye On**

As a result from playing around so much with our covariates, we have a solid idea of what does and what doesn’t go into predicting a flight delay. Surprisingly, weather has a minimal affect on delays. Even more, drastic weather events are rare in the grand scheme of things, and so they would not be the best factor to predict a future delay. The time of the flight (when in the year, when during the week, and when in the day) does indeed tend to be highly correlated with late flights. Airlines should schedule flights as to avoid propagation of delays throughout the day. Delay propagation occurs when a delayed flight early on in the day creates a ripple effect of increasingly delayed flights as the day progresses. In a sense, a delay becomes contagious as it is quite literally spread across the country and different airports. Thus, it is advantageous to commit resources to ensuring early flights do not get delayed. As the number of flights that take off toward the evening and into the night decreases, the airlines can catch-up during these phases to start fresh the next day. Survey data conducted on a random sample of customers could provide airlines with information regarding passengers’ willingness to fly early in the morning or late in the evening. Thus, data on clusters of flyers could be analyzed to move certain flights to different time blocks while maximizing the amount of people who would be willing to purchase tickets for these. Delays simply comes down to business of the airport. The more balls are thrown into the air, the more likely one will slip the hand and fall to the ground.