Report Draft

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Title

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Abstract

The purpose of this report is to develop short-term and long-term projections on the outlook of air transportation and to produce recommendations for the direction of NASA aviation research.

Introduction

State of the US Air Transportation Industry pre-2020

Industry Overview

The United States air transportation system is large and complex, carrying 889 million passengers in 2018, more than any other country (ICAO World Bank data). Aviation is a multi faceted industry, with multiple sectors including: passenger travel, cargo travel, manufacturing, and management of the National Airspace System. The various sectors of aviation influence the US economy in many ways, including revenue from passenger aircraft fares, price of manufactured aircraft parts, the operating costs of aviation, and spending by visitors that travel by air transportation. (FAA Civil Aviation Economic Impact Report) The industry's economic impact is huge: combined with its connected sectors (related goods and services), civil air transportation represents approximately 5.2% of the US's GDP, contributes about 1.8 trillion dollars in total economic activity and supports 10.9 million jobs each year. (FAA Civil Aviation Economic Impact Report). Civil aircraft manufacturing was also the US's largest net export in 2016 (FAA Civil Aviation Economic Impact Report). Each year, the industry expands, and airlines generate more revenue than the year before. In 2018, US airlines gained revenue for the 10th year in a row (FAA 2019 Aerospace Forecast). And there has been consistent growth in total revenue passenger miles (RPMs) of US airlines (domestic and international) since 2002, despite a decrease in RPMs into 2008 and 2009 due to the recession. (Bureau of Transportation Statistics)

Over the last few decades, air transportation has become a necessity in American daily life. Air transportation allows passengers to visit new places, attend business meetings, see loved ones, deliver e-commerce packages, keep retail stores stocked, and more (FAA Civil Aviation Economic Impact Report). However, though airline revenue remains high and operations increase each year, the average passenger experience on commercial flights is debatably decreasing. More and more passengers are being fit into each aircraft, with US airlines having a load factor of about 85% in 2019 (a 15% increase for domestic flights and 7% increase for international flights since 2002) (Bureau of Transportation Statistics). In addition, the number of seats per aircraft is increasing, with new trends of large widebody aircrafts, like the Airbus A380 and Boeing 747 models. In the 10 years between 2008 and 2018, seats per aircraft rose 28% (FAA 2019 Aerospace Forecast). Airlines also are heavily dependent on the use of ancillary revenues, charging passengers for services that used to be included in the traditional ticket fare (FAA 2019 Aerospace Forecast). This has allowed the airlines to gain revenue each year, but leaves passengers with growing dissatisfaction.

The aviation industry continues to adapt to the challenges of the expanding air transportation system and to handle demand as it increases each year. However, actions like the major mergers and acquisitions of US airlines in recent years, and new methods of generating revenue, have allowed the industry and airlines to continue their profit (FAA 2020 Aerospace Forecast).

Previous Industry-wide Disruptions

9/11

Great Recession

Passenger Travel

Leisure Travel

Business Travel

Cargo Operations

Urban Air Mobility

Manufacturing

NAS

The US National Airspace System (NAS) is the largest and most complex air transportation system on the globe. It manages about 29,000,000 mi.² of aerospace, handling about 44,000 flights and 2.6 million passengers each day, and about 5000 aircraft in the sky at any given time. ([NextGen: Where are we now?]) Due to the scope of the system, efficiency and growth management are large challenges.

Prior to 2020, operations at FAA and contract tower airports reached their fifth consecutive year of positive growth, growing the largest amount in more than 20 years. ([2020-2040 FAA Forecast]) Air traffic management had been modernized and redefined in recent years, with increasing use of automated technology to carry out the system's main goals: to increase the safety, efficiency, and predictability of air travel. ([Modernization of US Airspace]). NextGen, the FAA's widespread project to modernize the US Air Transportation System, was part way through a multi-year plan to innovate all aspects of the NAS.

While the updates may not be noticeable to passengers, air traffic control facilities have been modernized and some even replaced by automated systems, redefining the role of an air traffic controller. ([FAA ATC Automation]) Tracon radar and radio facilities, which guide aircraft at higher altitudes than air traffic controllers (FAA: Tracon), were in the process of being modernized, one of many programs to alleviate pressures off air traffic controllers. Newly implemented data communication services between pilots and controllers have allowed air traffic controllers to handle about 30% more traffic (DoT: ATC Modernization). Similarly, the FAA concluded its En Route Automation and Modernization program in 2015, which ambitiously replaced the previous air traffic control system that controlled aircrafts while in flight, improving air traffic management and adding flexible routing and other advanced technological features (FAA: ERAM). Between infrastructure upgrades at airports, air traffic control towers, Tracon terminals, and en route sites, various modernization projects have greatly changed the air traffic management system of the NAS.

Congestion and delays are still common at many US and global airports, though various programs have taken pressure off of air traffic controllers. In 2017, the Department of Transportation estimated that flight delays and congestion cost the economy more than $20 billion each year, with an expected 50% increase in passengers over the next two decades. (DoT: Beyond Traffic 2045)

Environment

The aviation industry has an enormous impact on the environment. About 2% of all CO2 emissions in 2019 were produced by the global aviation industry, producing 915 million tonnes (or more than a billion US tons) of CO2. (ATAG - Facts and Figures) About 1/4 of CO2 emissions from global passenger air transport came from flights departing from the US and its territories (The International Council on Clean Transportation - CO2 Emissions from Commercial Aviation, 2018). Aviation emissions are increasing each year, despite a slow increase in overall greenhouse gases (FAA - Aviation Emissions, Impacts & Mitigation: A Primer), and actions to decrease emissions and decarbonize other industries (Transport and Environment - Growing aviation emissions). Fuel efficiency of the current aircrafts are more than 70% more efficient than the first aircrafts in the 1960s (FAA - Aviation Emissions, Impacts & Mitigation: A Primer). However, the increasing operations of the industry and long time use of aircrafts have made for slow overall improvement in aviation emissions.

The aviation industry has identified a few core environmental concerns, including aircraft noise, air quality, climate change, and water quality. (FAA - Environment and Energy - In the Operation) Airline manufacturers, NASA aeronautics, and private public partnerships aim to create technologies that will decrease these environmental concerns, hoping to innovate on various parts of the aviation system, including fuel combustion, aircraft aerodynamics, aircraft operation efficiency, fuel consumption, airport infrastructure, and more. NASA's aeronautics research mission directory includes the "transition to low-carbon propulsion” as one of its main areas of research, and is an industry leader paving the way for sustainable aviation.

The industry has set a variety of environmental goals that aim to reduce the massive and detrimental impacts of the aviation industry on the globe as the realities of climate change increase. The ICAO, or International Civil Aviation Organization, created a carbon dioxide standard for the aviation industry in 2016. Its goal is to “reduce fuel burn and carbon emissions by 650 million metric tons or more between 2020 and 2040” (equivalent to taking 140 million cars off the road). (FAA - Environment and Energy - In the Operation) By 2050, the Air Transportation Action Group aims to cut net aviation carbon emissions to half of what they were in 2005 (Air Transport Action Group - Facts and Figures). Another large goal of the industry is carbon neutral growth from 2020 onwards. (FAA - Environment and Energy - In the Operation)

The current effects of COVID-19 on US air transportation

Industry Overview

Months into the COVID-19 pandemic, it is clear this health crisis has greatly impacted every country and every sector across the globe. The United States has already had more than 130,000 deaths and about 3 million confirmed cases of COVID-19. Globally, there have been 500,000 fatalities and more than 11 million total confirmed COVID-19 cases (WHO 7/7 Covid Report). The widespread effects of the pandemic have been unprecedented, leading the country into a recession in addition to a public health crisis. The United States employment rate is above 13% (Department of Labor News Release), the highest in the country's recent history, much greater than during the great recession from 2007 to 2009, and comparable to unemployment rates during the great depression (Pew: Unemployment Rates: Covid vs Great Recession).

The pandemic has had a massive effect on air transportation and the travel industry, with some calling this the "Great Travel Depression”. The virus has caused a massive decline in airline operations, with the number of passengers going through US TSA checkpoints reaching a low of 88,000 passengers on April 14, compared to 2.2 million on the same day in 2019 (Only 4% of 2019 levels) (TSA checkpoint travel numbers). Aircrafts have been grounded across the country, and flights canceled.

Many airlines have either temporarily or permanently laid off staff, responding to the drastic decrease in demand (NYT: Airlines Cancel Flights, Lay Off Workers). The travel industry as a whole has experienced more than 8 million jobs lost (by the end of April), 38% of all jobs lost through April, with the overall travel industry having an employment rate of about 50% (US Travel Association - The Great Travel Depression).

Passenger Travel

Leisure travel

Business travel

Cargo Operations

Urban Air Mobility

Manufacturing

NAS

Like every other sector of aviation, COVID-19 had a massive impact on aviation operations, drastically decreasing overall operations and creating new logistical challenges.

At the start of the pandemic, airlines and airports experienced mass cancellations of scheduled flights, leading to many near-empty flights, logistical rescheduling of passengers, and lost fees from commitments to the airports to lease gates, services, and more. (NY Mag: Empty flights) With the decline in demand, aircraft have been temporarily taken out of use and parked across the globe. Delta airlines announced in March that they would park more than 600 of their aircraft, parking them at the airline's hub airports and various aircraft service facilities across the country. (Delta News Release)

In addition, the FAA announced at the end of April that they would adjust the operating hours of 100 control towers across the country, after seeing a massive reduction in operations due to the COVID-19 pandemic. (FAA press release, List of towers) While the towers are closed, the FAA will be monitoring the facilities from various radar facilities. (FAA press release) These reduced aviation operations make us consider whether just how many people should be employed, and what the role of automation should play in air traffic management once the pandemic ends.

Environment

COVID-19 has greatly reduced airline operations, reducing the industry's environmental emissions for the year, but has also shifted the focus of the industry away from becoming more sustainable. Research shows that when the economy declines, environmental concerns get pushed aside, and environmental policies/actions are less likely to be prioritized. (Report - Environmental Concern and the Business Cycle: The Chilling Effect of Recession) In the current state of chaos due to COVID-19, the industry is focusing on its recovery, regaining passengers and increasing operations to generate revenue. In fact, this year's emissions are being disregarded for the CORSIA (Carbon Offsetting and Reduction Scheme for International Aviation) program (ICAO: CORSIA Adjustment COVID-19), potentially allowing airlines to pay reduced carbon offset prices in future years (Reuters: UN backs changes to aviation emissions scheme in boost for airlines), in a time where environmental standards are being temporarily loosened and across the globe under the rationale of the COVID-19 pandemic (EPA Enforcement during COVID).

Global airline bailouts also present an interesting potential environmental impact on aviation, as airlines across the globe are expected to get billions of dollars in bailouts to cover the extreme losses in revenue due to COVID-19, and environmental lobbyists are pushing for climate agreements in bailout deals. Various European governments, such as the French government and Dutch government, have discussed environmental conditions and restrictions that will come with the bailouts of airlines Air France and KLM. (Fortune: Bailout Climate Conditions, Reuters KLM bailout) Environmentalists claim that government bailouts must force a green transition of the industry, and that the industry cannot return to its state pre-2020 where it had massive emissions, tax exemptions, and very few pollution laws. (Transport and Environment - European Airline Bailouts) However, very few bailout agreements currently include these "green strings", with US airlines expected to get $25 billion in bailouts without any environmental conditions (NYT - Crippled Airline Industry to Get $25 Billion Bailout).

The outlook of US air transportation

Model

Introduction

We created a model to help answer two questions: *to what extent has covid-19 impacted domestic air travel,* and *what are some possible outlooks for domestic air travel demand in the short term.* To answer these questions, we developed 4 models. Each model uses Revenue Passenger Miles(RPMs) to measure domestic air travel demand. The first 3 models are predictive models that implement an Artificial Neural Network to give us an idea of what the next few months may look like for domestic aviation. The three models each account for a different scenario: the pessimistic model predicts what RPMs may look like in the case of a large surge of new coronavirus cases in the fall/summer, the baseline model predicts what RPMs may look like in the case of a surge of new coronavirus cases in the fall/summer, but not as severe as the pessimistic scenario, and the optimistic model predicts what RPMs may look like in the case that coronavirus cases briefly surge in July and then return to decreasing through the fall[1]. The fourth model implements a counterfactual multiplicative time series decomposition to predict what would demand would have looked like had the covid-19 outbreak not occurred. Note that the counterfactual model's only purpose is to serve as a reference to determine the extent that covid-19 has impacted domestic air travel. The data used to train the three predictive models is similar to the data used to train this model that analyzes the impact of 9/11 on domestic air travel demand.

Results

The results after training the model are shown in Table 1 and displayed in Figure 1. If you want to look more closely at the performance of the model and some potential limitations, read the Validation section of Appendix A. For the purposes of this section however we will only discuss the results of the model. Figure 2 shows the percent change of the historical[2] post covid-19 RPMs data as well as the RPMs prediction data in comparison to the counterfactual reference model. The exact percentages are shown in Table 2.

[1] This section of the report only briefly summarizes the methodology for the predictive models, to view the full methodologies read the methodology section of Appendix A

[2] Historical RPMs data for April, May, and June estimated from percent decreases given by A4A in their covid-19 updates

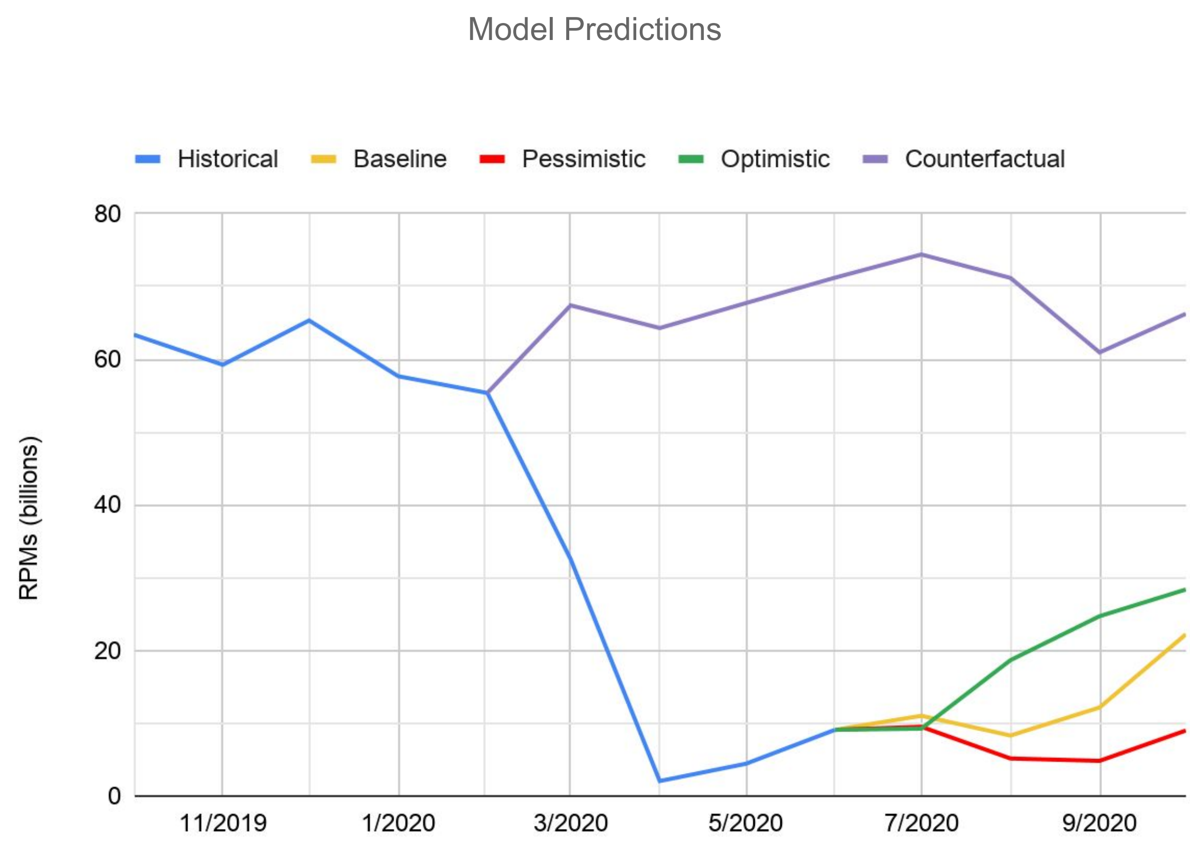

Figure 1.

Model Predictions

Date	Historical	Baseline	Pessimistic	Optimistic	Counterfactual
10/2019	63393387515				
11/2019	59253230565				
12/2019	65346264617				
1/2020	57685825985				
2/2020	55382246128				
3/2020	32536517473				67420192977
4/2020	2062326017				64305392035
5/2020	4441051791				67737827247
6/2020	9105190130				71229626797
7/2020		11025619360	9519224875	9258157794	74411367247
8/2020		8315106271	5160126269	18668740756	71189248837
9/2020		12168713658	4835580366	24711683401	60959193777

10/2020		22218041780	9003937883	28379643947	66262443952

Table 1.

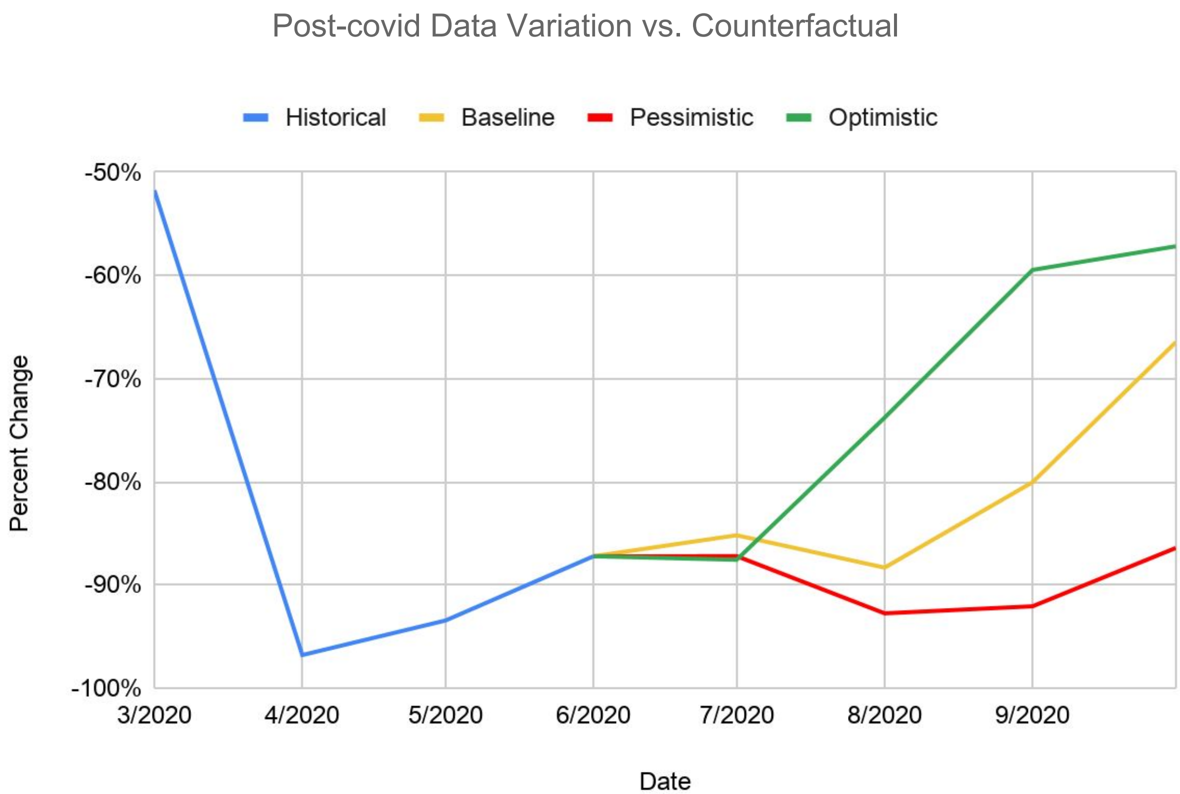

Figure 2.

Post-covid Data Variation vs. Counterfactual

Date	Historical	Baseline	Pessimistic	Optimistic
3/2020	-51.74069365			
4/2020	-96.79291899			
5/2020	-93.44376404			
6/2020	-87.21713065			
7/2020		-85.18288298	-87.20729745	-87.55814046
8/2020		-88.31971624	-92.75153713	-73.77589866
9/2020		-80.03793537	-92.0675126	-59.46192548
10/2020		-66.46963128	-86.4117027	-57.17084633

Table 2.

Discussion

In this section we will analyze the three different projections being made. To further understand how the model came about those projections, read Appendix A. As seen in Figure 1, all three projections more or less agree with what will happen in July, and then diverge after.

The optimistic scenario shows a similar nike-swoosh shaped recovery that has already been seen not only in the US domestic air travel demand from April to June but also in other regions of the world (IATA, Eurocontrol). Interestingly however, the optimistic scenario is predicting growth to slow down during October. One reason that could explain this is that although as cases continue decreasing generally speaking more people will feel comfortable flying again, as cases start to flatten out and approach zero there will most likely be a significant portion of the population that will not be willing to fly as long as covid-19 is still circulating.

The pessimistic scenario shows a dip in RPMs from its June levels for the remainder of the summer that starts recovering again in September. In this scenario, we would be looking at only a 1.01% increase in RPMs from June to October. This second wave and the resulting four month stalling of the recovery process could prove disastrous for many airlines, which are already facing enormous financial strain because of the lack of demand.

In the baseline scenario, recovery would stall through August but demand would only experience a dip 1.03% dip in comparison to the June levels, much better than the pessimistic scenario's 5.58% decrease. Additionally the baseline scenario shows a promising path to recovery during the fall, with a 21.87% increase from August to October.

Conclusion

The covid-19 pandemic has already resulted in unprecedented blows to the air travel industry. At its worst, demand was down 96.79% than what it would have been had the pandemic not occurred. The pandemic has additionally brought a lot of uncertainty to the industry, and with this model we hope to provide some guidance as to what the following months may look like. Throughout the rest of this report we will refer back to the model when making predictions on the outlook of the air industry, and contrast the predictions being made with what other industry experts are saying.

Industry Overview

There are many unknowns when thinking about the future of US air transportation. The COVID-19 pandemic has disrupted every aspect of the industry, and completely shaken up the global economy and the lives of people across the globe. A variety of factors will affect the recovery of air transportation, including economic stability, the state of the virus, a potential vaccine, forced quarantines and travel bans, and other social factors. The national and global recession is expected to continue through 2020, with an expected 6.1% decrease in the US economy in 2020, and a 5.2% overall decrease in the global economy. (World Bank: Global Recession) This leaves a potential for a long-term decrease in aviation passengers and airline revenue due to the decrease in disposable income of potential passengers (Report: Covid-19 impact on air transport). The continuation of travel bans and forced quarantines will also extend the period of decreased passengers.

Passenger Travel

Leisure Travel

Business Travel

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NAS

Before the COVID-19 pandemic began, the FAA estimated that airline operations would consistently increase in the next 2 decades, with activity at FAA facilities and contract towers estimated to increase at about 0.9% each year from 2020 to 2040, increasing from 53.3 million total operations in 2019 to a total of about 64.6 million operations in 2040. (2020-2040 FAA Forecast) Though current aviation operations are far reduced from that of 2019, and significantly decreased operations are projected through 2020, the demand for aviation will return with time, and it is likely that operations will continue to grow once the pandemic ends.

We can expect to see the continuation of prior infrastructure modernization projects in the post COVID-19 world. After receiving government funding from the CARES act, the FAA declared that they will increase funds to the airport improvement program as airports face challenging financial circumstances (FAA: CARES for airports). However, besides funding, programs to modernize infrastructure experienced more challenges before the pandemic including project length and concerns about various environmental factors, so it is still unclear whether the efforts will be prioritized in the post-covid environment.

The FAA must also take great strides to integrate commercial space flight, UAS, and other NextGen additions to the national airspace system without compromising those in the current system. Significant research and development in software and automation capabilities will be needed to ensure this safe integration. (FAA: NextGen: Future of the NAS) Automated systems will ensure the safe integration of unmanned aircraft systems and commercial aircrafts with the current airspace system (FAA: NextGen: Future of the NAS).

Automation has a huge role in all future projects and programs. Automated systems will also prioritize the core goals of the NAS: efficiency, consistency/dependability, safety, and the environment.

We can also expect a change in employment in the aviation system management sector:
For decades, experts have warned of the changes to the job of an air traffic control specialist as automated systems are implemented (FAA: Selection of Air Traffic Controllers for Automated Systems). There has been evident change in the role of an air traffic controller over the years, with new automated technologies being said to "reduce the traffic complexity and cognitive workload" of air traffic controllers (FAA: NextGen: Future of the NAS). As the number of automated systems increase, the role of the air traffic controller will be heavily focused towards understanding the automated platform, and there is potential for the continuation of the current unemployment of air traffic controllers during the covid-19 pandemic.

Environment

It is unclear how much of an impact COVID-19 will have on the future environmental progress of the aviation industry. Green strings attached to airline bailouts will increase the attention and emphasis on electrifying aviation, while the loosening of environmental restrictions, focus on returning regaining revenue, and cancellation of electric aircraft projects will be setbacks for the industry's environmental progress. In the next few years, airlines will prioritize regaining revenue and ensuring that they survive the long-term challenges of COVID-19. However, though environmental restrictions may be loosened and environmental concerns may be pushed to the back burner, it is of the utmost importance that airlines and the industry continue to take large strides towards decarbonizing aviation.

The future of aviation is sustainable aviation. Climate change has been slowly increasing for decades, and we have reached a turning point where the effects of climate change on the globe are irreversible, causing disastrous conditions and dangerous extreme weather patterns. The UN has declared that we have 10 years left before the effects of climate change are irreversible. (UN: 11 years to prevent irreversible climate damage) In contrast, the aviation industry continues to increase its emissions, and is on track to triple its emissions by 2050, where aviation may account for 25% of global carbon emissions. (The International Council on Clean Transportation - CO2 Emissions from Commercial Aviation, 2018)

Despite progress in fuel efficiency, aircraft system design, aerodynamic changes, optimization strategies, and other retrofits and innovations to current aircraft technologies, it is clear that advancing conventional technologies will have limited potential for a future sustainable improvement. (IATA: Aircraft Technology Roadmap to 2050) Instead, the industry must direct its focus towards the development of revolutionary aircraft, aiming to produce aircraft much more environmentally friendly than any conventional technology. NASA aviation research and aviation industry leaders must invest in the production of these future aircraft, and put significant time and funds into various airframe configurations, aircraft structure and materials, and future propulsion technology. Though the progress of electric and hybrid electric aircraft took a hit during the COVID-19 pandemic when the Airbus E-Fan X was discontinued (Airbus: Beyond E-Fan X), it is clear that research and development towards hybrid electric aircraft will be a necessity in the near future. The industry cannot just offset their emissions through programs like CORSIA, but must develop revolutionary aircraft that will re-define aviation.

Outlook conclusions

NASA’s Aviation Research

The state of NASA’s Aviation Research pre-2020

NASA has a long history of developing revolutionary aviation technology since its creation in 1958. NASA has always looked towards the future and has taken on monumental challenges that seemed impossible at the time, from war planes, helicopters, to the passenger jet. Now, in the 21st-century, NASA's aeronautic flight teams focus on tackling the monumental challenges of the next generation of aviation, with the Aeronautics Research Mission Directorate detailing efforts in “Safe, Efficient Growth in Global Operations”, “Innovation in Commercial Supersonic Aircraft”, “Ultra-Efficient Commercial Vehicles”, “Transition to Low-Carbon Propulsion”, “In-Time System-Wide Safety Assurance”, “Assured Autonomy for Aviation Transformation”. (Source)

NASA is committed to the development of supersonic technology, working through the many challenges that block practical commercial supersonic flight: sonic boom, noise, emissions and fuel efficiency, integration with current aerospace operations and more (NASA - Commercial Supersonic Technology (CST) Project Technical Challenges). NASA aviation research also works to develop NextGen technology, researching the safe and efficient management of the national airspace system (NASA - Airspace Operations and Safety Program (AOSP)). Various other large projects within NASA Aeronautics include the development and integration of unmanned aircraft systems into the national airspace system to seamlessly work with current aeronautic flight technologies, and other research in revolutionary aircraft technologies (revolutionary vertical lift technology, advanced composite materials, fixed wing aerodynamic design, and more). Though NASA's environmentally responsible aviation project concluded in 2015 (NASA: End of an ERA), research continues to be done on producing efficient and environmentally conscious aircraft and aviation system technology, including recent progress on the X-57 Maxwell, NASA's first all electric x-plane (X-57 Maxwell Recent Progress).

Effects of COVID on NASA's Aviation Research

Recommendations for NASA's Aviation Research

Final Conclusions

Appendix A: Predictive Models

This appendix will rigorously discuss how the predictive models work, and go over the model's performance and some potential limitations.

Methodology

As previously stated in the report, the predictive models implement an Artificial Neural Network. The network is trained on various economic, seasonal, and covid-19 historical data[3], and it also takes into account several major events that have disrupted the air industry. The model then makes predictions by feeding economic and covid-19 projections, as well as the appropriate seasonal variables into the network. It is important to note that there are many similarities between these predictive models and the analytical model developed by Ito and Lee.

Data

In this section we will go over the data that is used to train and make predictions with the neural network. All the data that is used to train the model is monthly and spans from January 1990 to

[3] Initially we were also using the same supply side variables used by Ito and Lee, but decided to drop them because when we removed those variables from the model because we did not find any predictions for the supply side variables, which complicated making projections because we would have to come up with our own predictions for these variables to feed into the model. Additionally, when we removed these variables model accuracy did not decrease.

June 2020. Prediction data used to make projections with the model is also monthly and spans from July 2020 to October 2020.

Economic Features

The air travel industry has been known to be heavily dependent on economic cycles. The model takes into account the state of the economy by considering monthly total nonfarm payrolls[4] and the monthly unemployment rate[5]. Historical total nonfarm payrolls and unemployment data is sourced from the BLS and both are seasonally adjusted. The total nonfarm payrolls data is shown in figure 3 and the unemployment rate data is shown in figure 4.

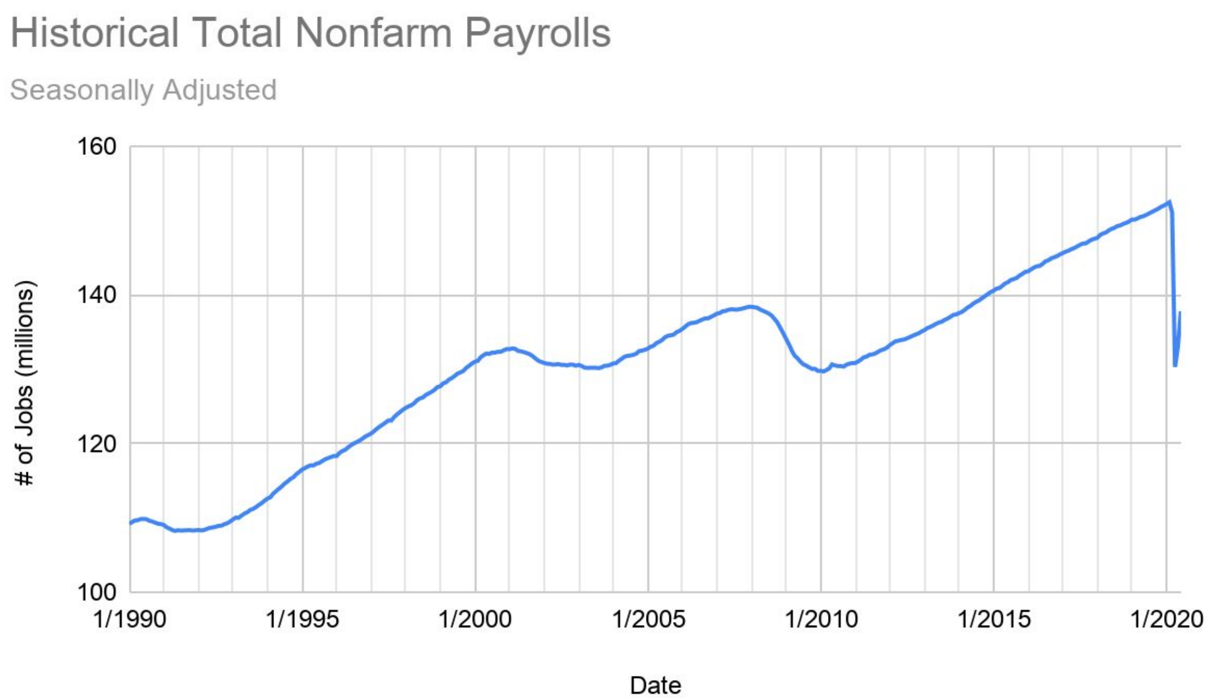

Figure 3.

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[4] Initially we were using total labor force instead of total nonfarm payrolls, however we switched over because we found that there were available predictions for total nonfarm payrolls and none for total labor force, and when switching over we did not find any noticeable changes in model accuracy.

[5] Although GDP is the standard for metric for determining the state of the economy, GDP data is only available on a quarterly basis and for our model we need monthly data.

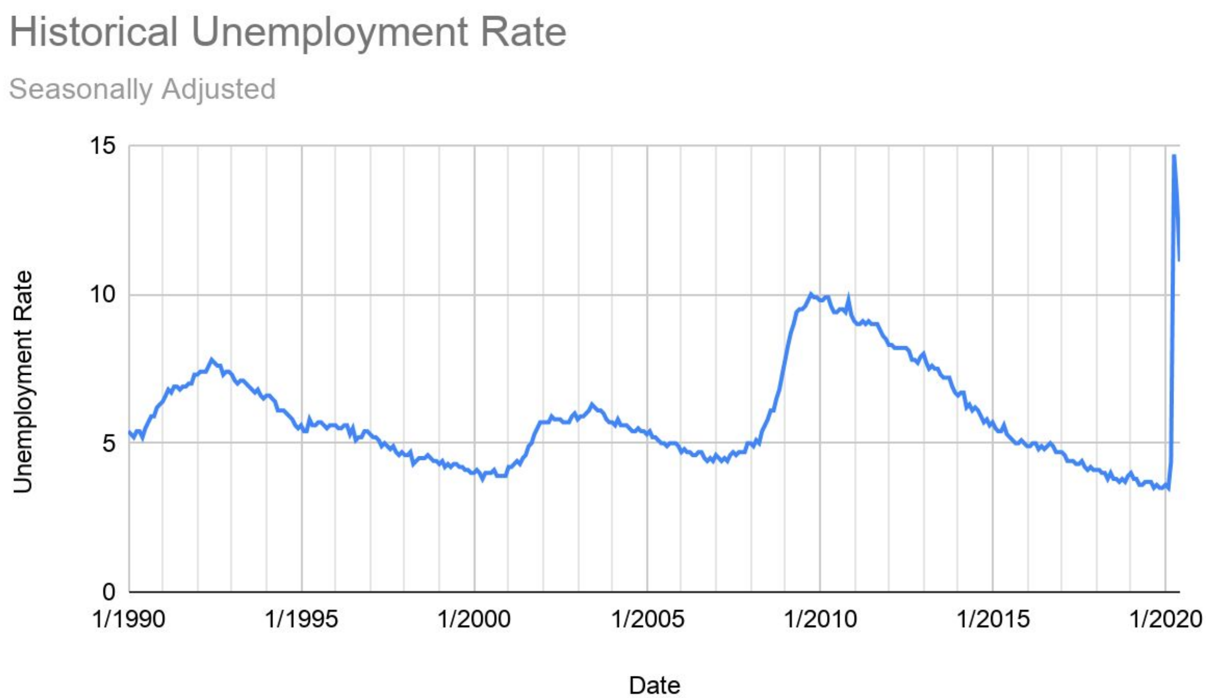

Figure 4.

The total nonfarm payrolls and unemployment rate predictions used to make projections are sourced from The Financial Forecast Center and are seasonally adjusted. The predictions for total nonfarm payrolls are shown in Figure 5, and the predictions for unemployment rate are shown in Figure 6.

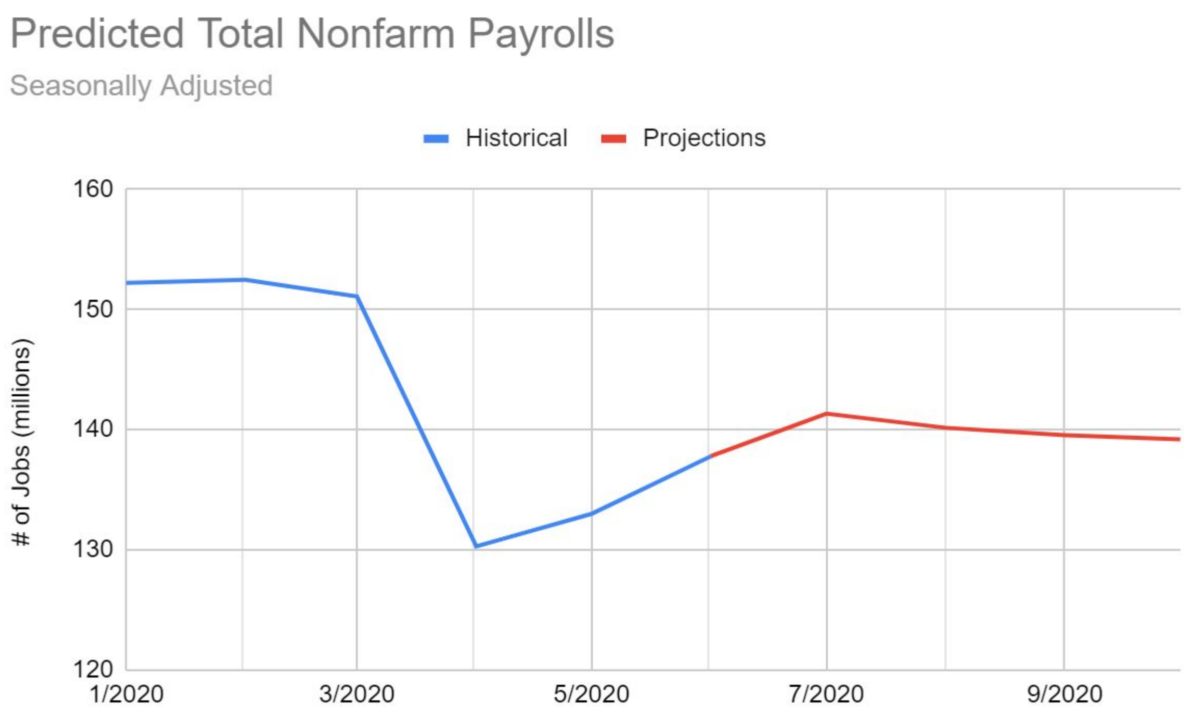

Figure 5.

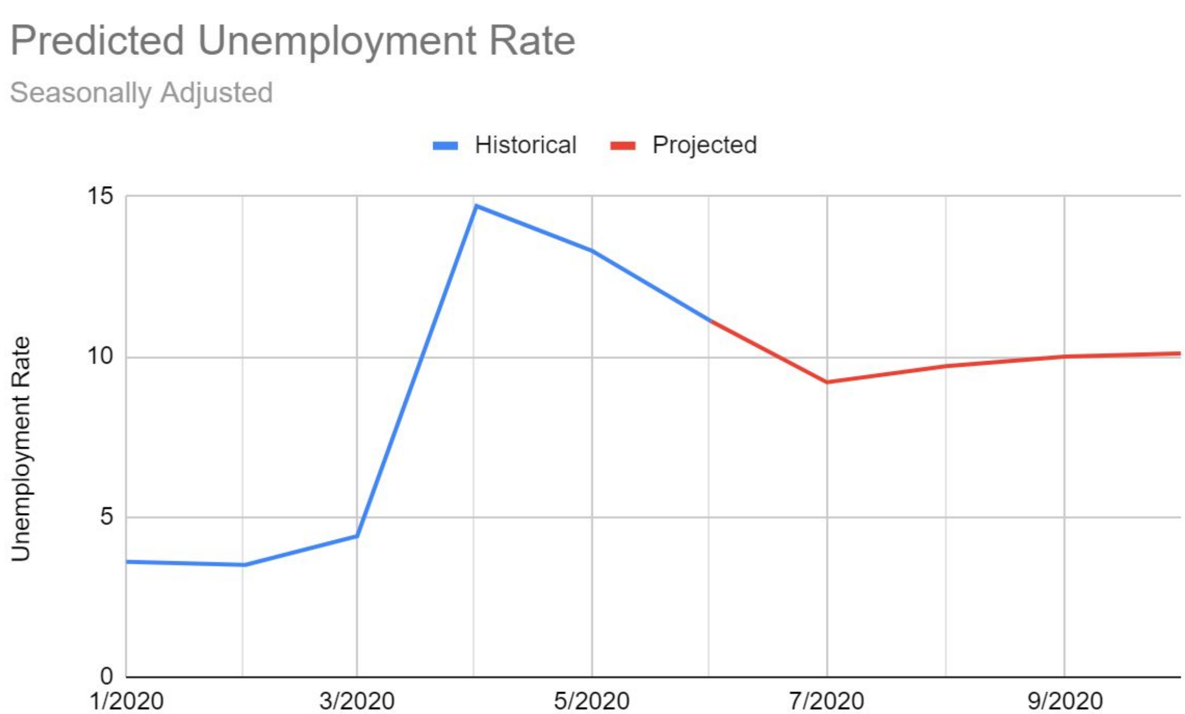

Figure 6.

Seasonal Features

Demand for air travel is heavily dependent on multiple seasonal factors. To capture these seasonal factors, the model uses 15 variables:

To account for monthly fluctuations in demand, the model uses 12 one hot encoded variables, each representing a separate month.

The Sunday after Thanksgiving generally results in a surge of air travel demand as people are flying back home from visiting their relatives. However, some years the Sunday after Thanksgiving falls in November and some years it falls in December. To account for this increase in demand, the model has two one hot encoded variables: one variable takes a value of 1 when it is November and the Sunday after Thanksgiving is in November, and the other takes a value of 1 when it is December and the Sunday after Thanksgiving is in December.

Since in leap years February has an extra day, this results in February during leap years having more relative demand than February when it is not a leap year. Because of this, we added a one hot encoded variable that takes the value of one when it is a February during leap year.

Industry Disruption Features

Although seasonal and economic variables are good indicators of the air travel industry, there are certain events that have caused a large decrease of demand that can not be solely explained by economic and seasonal factors. For this reason, the model has 6 variables to account for anomalies in demand. These variables are:

- A one hot encoded variable that takes a value of 1 during the Gulf War
- A one hot encoded variable that takes a value of 1 in September 2001
- A variable that represents the squared inverse[6] of the number of months elapsed since October 2001[7]
- A one hot encoded variable that takes a value of 1 during the Iraq War
- A one hot encoded variable that takes a value of 1 during the SARS outbreak
- A one hot encoded variable that takes a value of 1 during the Great Recession

Covid-19 Features

The covid-19 pandemic has brought unprecedented challenges to the air travel industry. Because it is unprecedented, it is hard to understand the relationship between the state of the pandemic and an increase or decrease in air travel demand. However, some patterns have

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[6] The variable uses an inverse square relationship because Ito and Lee found that this equation was a good estimation of the decay of the impact of 9/11 on air travel demand over time

[7] The variable starts counting from October and not September because there is already a variable accounting for the transitory shock that 9/11 had on air travel demand, and this variable accounts for the permanent downwards shift that 9/11 had on air travel demand.

been seen during the first few months of the pandemic, and thus the model attempts to capitalize on these patterns.

The first pattern that has been observed not only in the United States(A4A) but also in other regions of the world ((IATA, Eurocontrol), is that generally, as countries experience decreases in cases and deaths, air travel demand slowly recovers in a shape resembling that of a nike swoosh. For the model to determine the relationship between cases and deaths and a change in demand, the model is fed 3 variables: average daily deaths, estimated average new daily cases, and estimated average active cases[8]. The data for these three variables is sourced[9] from COVID-19 Projections, one of the models used by the CDC. Their model provides a lower, baseline, and upper range for their projections, which is where we get the pessimistic, baseline, and optimistic scenarios for our RPMs predictions from. The three scenarios for deaths, new cases, and active cases can be seen in Figure 1, Figure 2, and Figure 3 respectively.

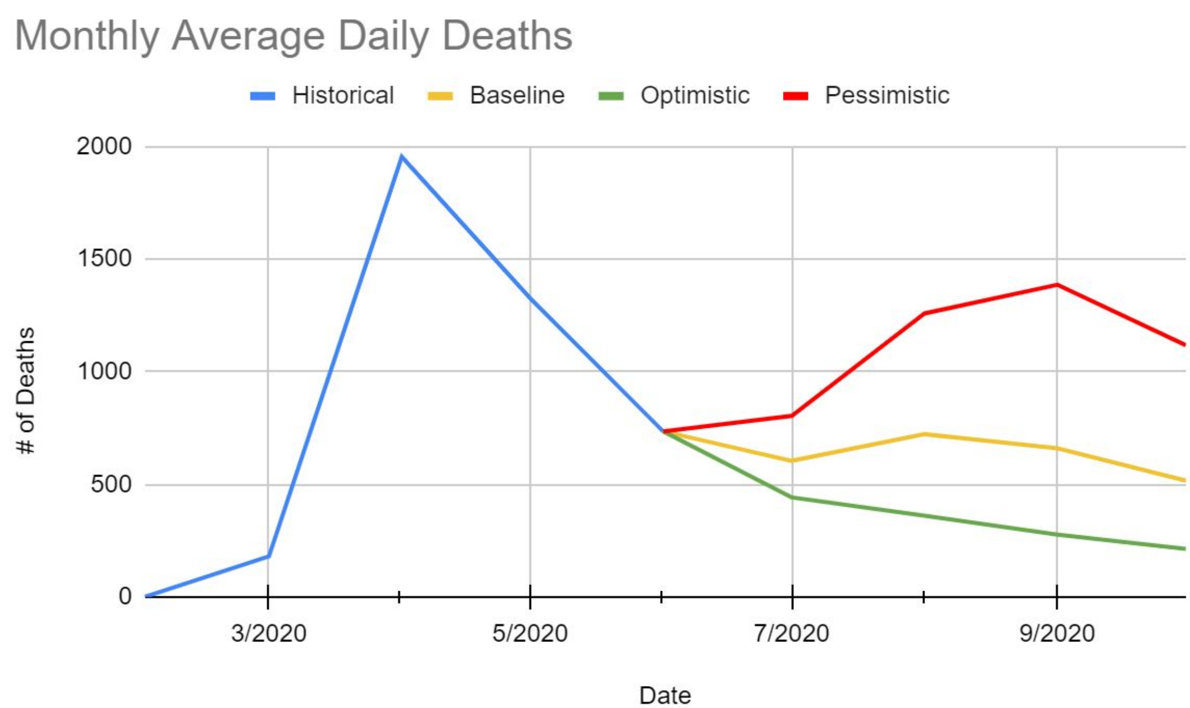

Figure 7.

[8] It is important to emphasize that these variables are the *estimated* average new daily cases and the *estimated* average active cases, not the actual cases that are being detected
[9] Data sourced on July 8th 2020

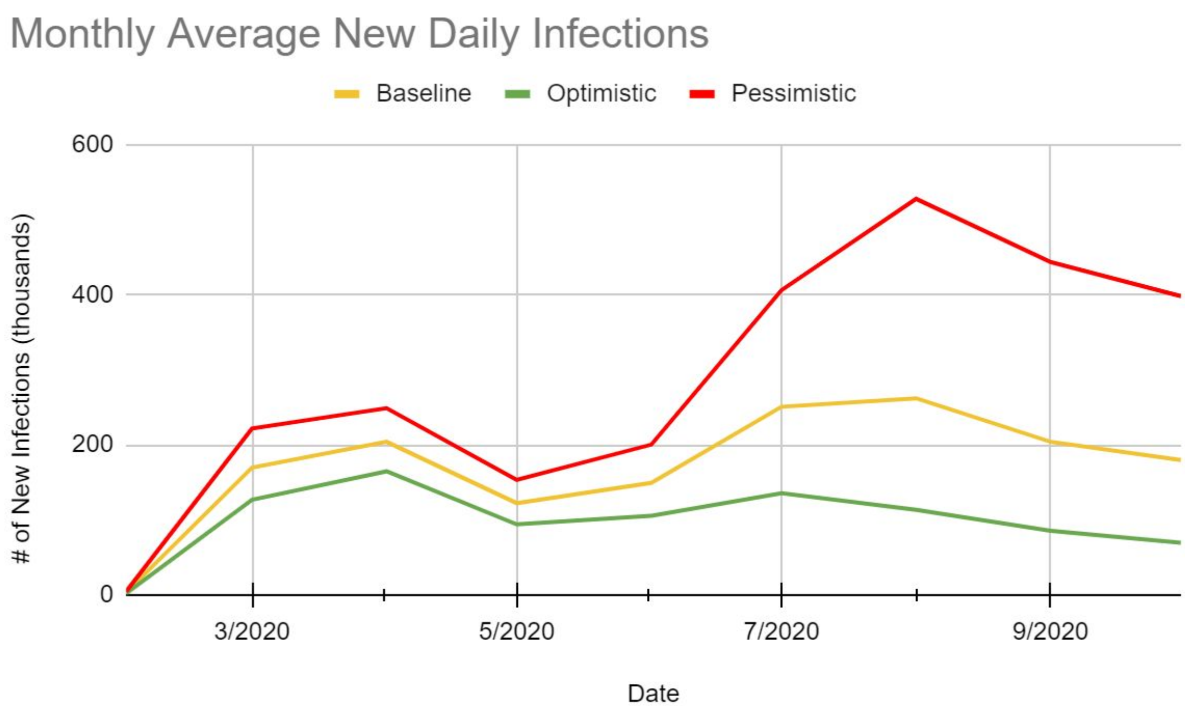

Figure 8.

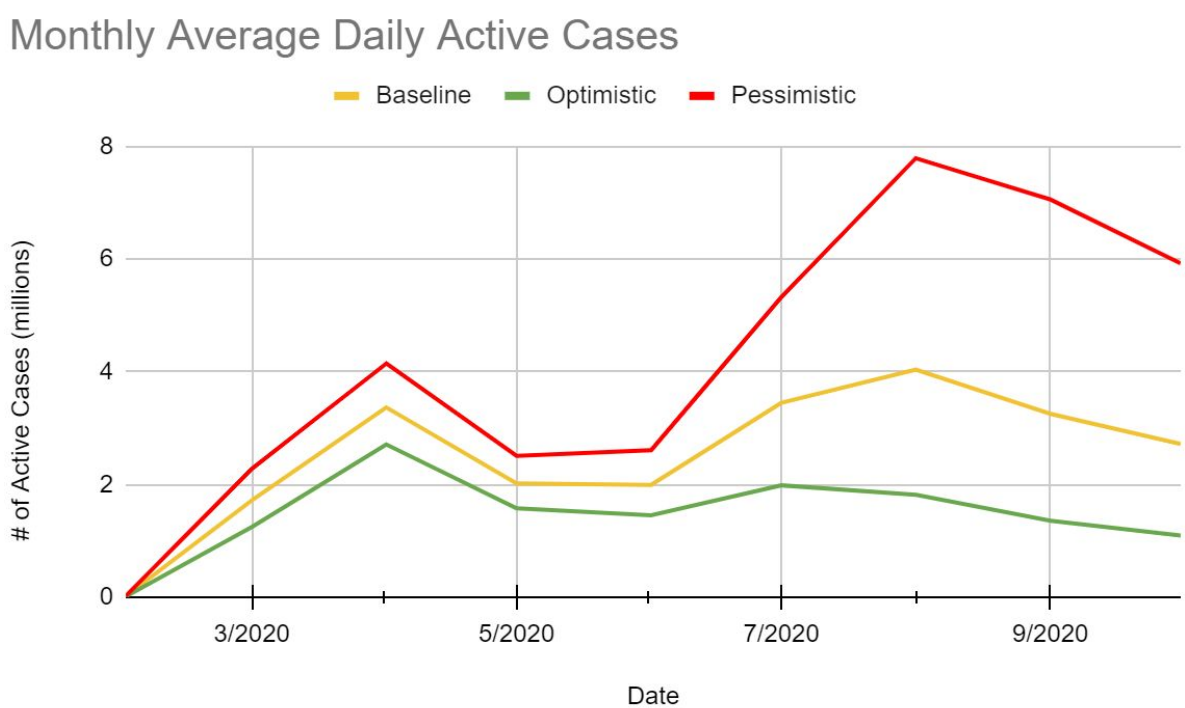

Figure 9.

The second pattern that has been observed is that as the pandemic drags on, people are becoming more willing to fly again (Destination Analysis, Longwoods International)[10]. To capture the duration of the pandemic factor for the model, we are using a variable that represents the inverse[11] of the number of months since April 2020[12].

Demand Label

The standard measure of passenger air travel is RPMs, which is the variable that the model is trying to predict. The RPMs data the model is trained on is sourced from the BTS T-100 Domestic Market Database. However this database, at the time the model was developed,had only released data up until March. To gather RPMs data for April, May, and June, we took the average year over year change in RPMs for each month from the A4A Covid Updates, and multiplied them by the corresponding month from 2019. As A4A don't publish the raw data, the values we came up with were only estimates. The RPMs data from January 1990 to June 2020 is displayed in Figure 10.

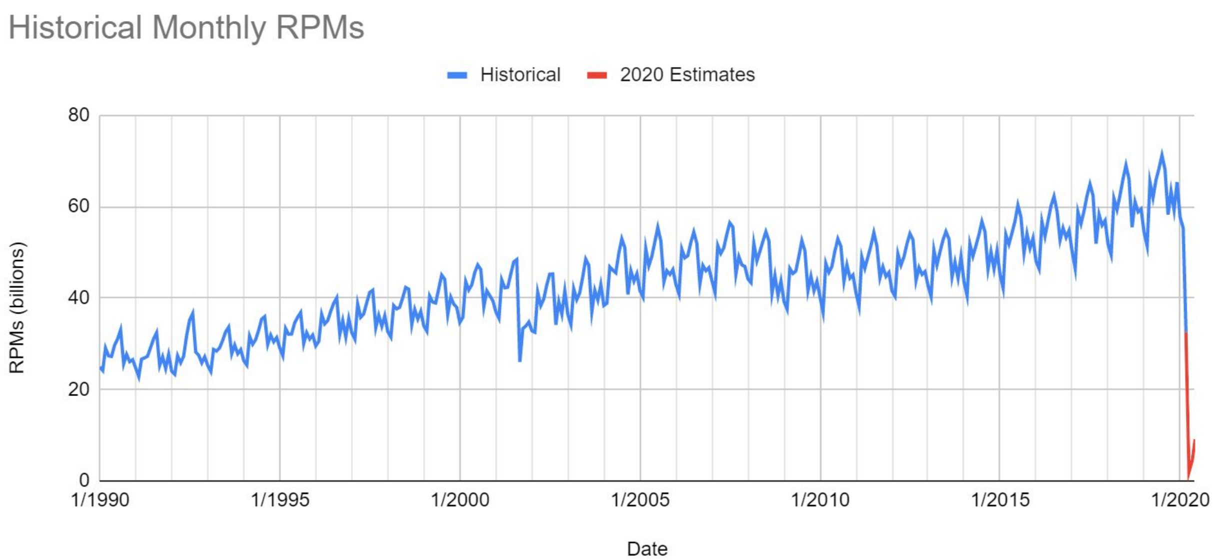

Figure 10.

[10] Although results from both sources show that people are becoming less willing to travel again, it is not as bad as it was in April, even though in July we are experiencing more than 1.5 times the number of cases that were reported in April. The fact that we have more cases now yet more people are willing to travel now than were in April indicates that as the pandemic drags on people do become more willing to travel.

[11] We experimented with different rates of decay and found that modeling the time effect as an inverse relationship resulted in the best accuracy for the model

[12] We start counting from April 2020 because this was the month were people were the least willing to fly

Neural Network

The Artificial Neural Network used by the predictive model consists of 6 layers. In order, the number of nodes on each layer are 512, 512, 256, 128, 128, and 64. The neural network is a regression model, with 27 training features and RPMs as the label. The 27 training features consist of 20 one hot encoded variables and 7 other variables, as shown in Table 3. Like previously stated, the historical data ranges from January 1990 to June 2020, and the prediction data ranges from July 2020 to October 2020. Thus, there are a total of 373 historical and 4 prediction data points for each variable. Similarly, there are a total of 3737 historical data points for RPMs, and the model aims to make projections for the next 4 data points. The model is open source and the source code can be accessed here.

Variable Name	**Description**
Unemployment $Rate_t$	National unemployment rate at month t
Total Nonfarm $Payrolls_t$	Total nonfarm payrolls at month t
Covid-19 $Deaths_t$	Average daily covid-19 deaths at month t
Covid-19 New $Cases_t$	Estimated average new daily cases at month t
Covid-19 Active $Cases_t$	Estimated average active cases at month t
Covid-19 $Elapsed_t$	The inverse of the number of months elapsed since the April 2020 covid-19 peak (Covid-19 $Elapsed_{4/2020}$ = 1)
9/11 $Elapsed_t$	The squared inverse of the number of months elapsed since 9/11 (9/11 $Elapsed_{10/2001}$ = 1)
$9/11_t$	One hot encoded variable that takes a value of 1 if t is September 2001
$Months_t$	Vector of 12 one hot encoded variables that each represent a month and take a value of 1if t is that month and 0 otherwise
Thanksgiving 11_t	One hot encoded variable that takes a value of 1 if t is November and the Sunday after Thanksgiving is in November, and 0 otherwise
Thanksgiving 12_t	One hot encoded variable that takes a value of 1 if t is December and the Sunday after Thanksgiving is in December, and 0 otherwise
Leap $February_t$	One hot encoded variable that takes a value of 1 if t is February during a leap year, and 0 otherwise
Gulf War_t	One hot encoded variable taking a value of 1 from August 1990 to March 1991, and 0 otherwise

Iraq War_t	One hot encoded variable taking a value of 1 from February to April 2003, and 0 otherwise
SARS $Outbreak_t$	One hot encoded variable taking a value of 1 from March to July 2003, and 0 otherwise
Great $Recession_t$	One hot encoded variable taking a value of 1 from December 2007 to June 2009, and 0 otherwise
$RPMs_r$	Domestic RPMs at month t

Table 3.

Validation

Model Performance

Limitations

Appendix B: Counterfactual Reference Model

References