Report Draft

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Title

Table of Contents

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/air freight 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 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

Until covid-19, no event had caused such a resounding impact on the aviation industry as 9/11 did. The hijacking of 4 commercial jetliners during the terrorist attacks of September 11th led to some revolutionary changes that permanently transformed the aviation industry.

Immediately following the attacks there was a transitory shock to the aviation industry, driven by an initial panic and fear of flying. This temporary shock resulted in a 31.3% decrease in air travel demand, however this decrease dissipated 4-5 months after the attack (IATA). However, 9/11 additionally resulted in a permanent decrease in air travel demand of 7.4%(IATA). This permanent impact can be attributed to the increased hassle passengers had to go through because of stricter security measures put in place by the TSA.

The decrease in air travel demand paved the way for 4 major airline bankruptcies and 2 major mergers (Berry and Jia). The airlines that did survive had to shrink their capacity to remain afloat. Almost 48 thousand air travel workers were laid off (BLS). This decrease in capacity resulted in customers having less options when buying tickets. However, this positively impacted airlines because it drove up their load factor (BTS).

In response to the decrease in domestic demand following 9/11, major carriers shifted their capacity to the international market (BTS). LCCs responded to this by aggressively filling in the gaps that were being left by the major carriers, thus increasing LCCs domestic market share (BTS).

Great Recession

The global financial crisis, also known as the Great Recession had economic repercussions that impacted virtually every industry. However, the aviation industry, which is known to be more susceptible to economic conditions than other industries, was especially devastated during this period of economic downturn. With air travel demand plummeting, airlines were forced to completely rethink how they were operating in order to stay afloat.

To survive the recession, airlines modified their business models in various ways. One adjustment was adding auxiliary forms of income by removing services previously included in a standard ticket and charging additional fees for them (DOT). These services include things such as the amount of baggage passengers can take on flights, in-flight meals, in-flight drinks, in-flight entertainment, etc. These additional fees gave airlines a more stable source of income to aid them through unfavorable economic conditions. Another adjustment made by airlines was transitioning from buying aircrafts to leasing them on an as-needed basis (BLS). This allowed airlines to be more nimble in responding to reductions of demand, thus helping them minimize cash burn.

In response to the surplus availability of seats due to the lack of demand, airlines reduced their capacity, with ASMs decreasing an average of 5.1% in 2009 (BLS). Additionally, as demand started picking up at the end of the recession, airlines continued decreasing their ASMs, driving up their load factor and thus increasing profitability (DOT).

The lack of demand during the recession led to three major airline mergers. The mergers meant that airlines could remove redundant and unnecessary flights from the market, further driving up the load factor and giving consumers less options when flying (DOT). Furthermore, major airlines removed small inefficient regional flights, increasing regional carriers' market share (DOT). These changes contributed to flights being longer, larger, and fuller in the years following the great recession.

Passenger Travel

With an increasingly interconnected world, commercial aviation has become a vital mechanism for the global economy and specifically, US airlines, for which passenger travel has been a flourishing source of revenue in the past decade. From 2018 to 2019, revenue passenger miles (RPMs) increased by an impressive 4.3%, escalating to 1.04 trillion (FAA Fact Sheet). Domestic travelers, which encompasses about 89% of US passenger travel, rose to 813.3 million passengers in 2019, a 4.2% increase from the previous year (FAA Fact Sheet). International travelers, making up the remaining 11% of US passenger travel, grew to 103.4 million passengers in 2019, a 3.8% increase from the previous year (FAA Fact Sheet). This growth can be attributed to the rise in both leisure and business travel. The growing necessity for air travel prompted by leisure and business travelers has allowed airlines to expand on profitability through the diversification of in-flight services, capitalizing on business travelers. Leisure travelers spent $762 billion in 2019, 4.1% higher than in 2018 (U.S. Travel Association 2019 Overview). Business travelers spent $334 billion, 2.2% higher than in 2018 (U.S. Travel Association 2019 Overview). Consequently, the aviation industry has been thriving for the past few years, reliant on strong passenger travel demand. But with this growth came repercussions. US airports became more crowded, planes cramped, and flight schedules subject to delays, demonstrating the prioritization of US airlines in favoring profit and functionality over the development of an enjoyable passenger experience for all. Jeffrey Wong, a professor at the University of Nevada, conducted a study comparing consumer satisfaction with airline profits, finding that people will continue to buy tickets regardless of poor service (Airline Profitability and Consumers). Wong noted, “Airlines don’t seem to place a priority on customer service despite the fact that they advertise to the contrary," explaining how airlines have raised profits through cramming more passengers onto planes, helping load factors. In fact, the load factor for US carriers grew almost 12% from 2002 to 2019, showing how airline profitability and flight congestion has increased and in turn caused the passenger experience to continuously decline over the years (BTS Load Factor Stats). However, this flawed prioritization threatens US airlines as it has caused them to sacrifice a fundamental consideration for air travel; passenger welfare, leaving them incapable of ensuring a safe flying experience that can function in a variety of circumstances. Thus once the unprecedented pandemic struck, the crowded nature of air travel transformed from a typical hassle for passengers to a dangerous facilitator for the spread of the coronavirus, condemning air travel as a catastrophic threat to lives across the globe.

Cargo Operations

Urban Air Mobility

The UAM industry was set to take off this year, however many product launches and events have been delayed due to the virus. The virus has not been a complete negative form some companies. “EHang” in particular have blossomed as a UAM company in China due to the pandemic. The company was able to deliver supplies to hospitals without a pilot. Ehang has obtained a permit to operate in Europe in January of 2020. At the same time the FAA invites more members to their drone advisory committee, designed to help create new regulations for autonomous aircraft in the coming years and how to integrate them into the NAS safely. During the pandemic, UAM have become an asset in pandemic due to their ability to deliver packages with no human contact.

Prior to 2020, the Urban Air Mobility(UAM) was a growing industry. In 2017, the industry was expected to grow from $8.2 billion to $11.6 billion in 2017. Growth in the market was driven by "ATM infrastructure capabilities and development, ground infrastructure capabilities, and development, aircraft noise/community noise tolerance, regulatory environment for certification, continued investment, and demand for taxi services." Despite its growth, the rules and regulations needed for UAM to function are still under review. The FAA and state regulation process began in 2017 and is not yet finalized. NASA, the FAA, and other federal agencies have partnered together to establish and explore,

"concepts of operation, data exchange requirements, and a supporting framework to enable multiple beyond visual line-of-sight drone operations at low altitudes (under 400 feet above ground level (AGL)) in airspace where FAA air traffic services are not provided"

NASA and the FAA also developed a 'joint UTM research plant" to research and document the development of UTM.

NASA is working on UAM in an effort to make Advanced Aerial Mobility(AAM) safe, sustainable, accessible, and affordable. NASA's Grand Challenge …

The FAA has had more people join their Drone Advisory Committee as of June 19th. The committee will "aim to improve the efficiency and safety of integrating UAS in the NAS."

Manufacturing

Boeing and Airbus, the world's biggest commercial aircraft manufacturers, dominate 99% of the large jet market. Together, they support airlines, the United States government and allied governments from over 150 countries.

In 2019, Boeing and Airbus had a combined backlog of 13, 450 aircraft, worth seven or more years of production. However, Boeing was suffering financially from the grounding of the 737 MAX Jet, which had previously been involved in two fatal crashes in October of 2018 and March of 2019. Boeing had also slowed the production of the 787 Dreamliner from 14 a month to less than 10 in January 2020. Boeing was looking forward to the return of the 737 MAX in 2020 to restore their customers' trust and bring in revenue. Airbus had similar problems to Boeing. The company announced in February of 2019 that it would cease the production of its wide-body A380 - the manufacturer's largest aircraft, with the capacity to seat more than 850 passengers. Airbus had been struggling to receive orders for the A380, and their situation worsened when Emirates reduced a 53 jet order to fourteen.

Over fifty-percent of Boeing's 787 and Airbus A350 airframes are carbon fiber composite, supplied by the public industrial materials company Hexcel Corp. In 2019, Hexcel saw an 8.6% increase in profits at the end of the year compared to 2018. However, sales were down 1%

during the fourth quarter of 2019, due to the grounding of the 737 MAX and Airbus's decision to cease production of the A380. Hexcel had concerns regarding the return of the 737 MAX and new rates of production, but Hexcel was confident that 2020 would be a good year for the aviation industry. Hexcel also had plans to merge with Woodward Inc. to "drive even stronger investment in innovation and shareholder return in the future". Spirit Aerosystems, another supplier for Boeing, builds several important pieces of Boeing aircraft, including the fuselage and wind components for the 737 MAX, portions of the 787 fuselage, and the cockpit section of the fuselage in nearly all Boeing airliners. That accounts for nearly half of Spirit's yearly revenue, making the company heavily reliant on Boeing's business. GE Aviation's joint venture with Safran SA, CFM, manufactures Leap engines for the 737 MAX jets and the A320 NEO jet from Airbus. In 2019, CFM manufactured 70 Leap-A engines for Airbus. In 2019, Safran delivered and installed 1,736 LEAP engines, six hundred and eighteen more than in 2018. Gael Mehuest, CEO of CFM, acknowledged their sales stating, "2019 was a solid year for CFM. The LEAP family continued to be the engine of choice for new single-aisle aircraft...we surpassed 19,000 total orders." Early this year however, GE announced that it would lay off 70 temporary employees from its Bromont, Canada plant that manufacture the CFM LEAP-1-B engine inside the 737 MAX. This comes as a result from Boeing halting the production of the 737 MAX in 2019.

In terms of innovation, Rolls-Royce and Safran were building fuel-efficient options for aircraft to decrease the carbon footprint left by the aviation industry. They are "developing electric propulsion systems, which would reduce carbon emissions, make flights quieter, and decrease costs." These systems could also benefit the development of UAM. There have also been advances in the development of automated flight decks. The sector was already reliant on automated flight controls and cockpits, and it seems reasonable for the next move to be fully automated flight decks. This transition would most likely reduce the number of crew members in the cockpit, as well as aid the pilot shortage that continues to grow, saving airlines a lot of money.

Deloitte released a 2020 outlook on Global Aerospace and Defense Industry, where they state,

> "After a strong year in 2018, the global aerospace and defense (A&D) industry has experienced a descent in 2019. While the defense sector has continued to soar, growth in the commercial aerospace sector has slowed. In 2020, the A&D industry is expected to get back to its growth trajectory with the commercial aerospace sector recovering from its decline in 2019."- 2020 Global Aerospace and Defense Industry Outlook

Deloitte observes that the commercial aerospace sector made fewer deliveries in 2019 because of production-related issues, such as the grounding of the 737 MAX. 2019 also saw a smaller backlog of orders as a result of order cancellation and a decrease in new orders from customers. Deliveries were expected to bounce back during 2020 in anticipation of the return of the 737 MAX. Aircraft production was also expected to increase during 2020. The sector was expected to grow entering 2020 and onward, citing "a long term demand for commercial aircraft...with nearly 40, 000 units expected to be produced over the next two decades."

The defence sector of aircraft manufacturing was doing well prior to 2020. Lockheed Martin's biggest client is the United States Department of Defense, who is responsible for almost 70% of

the company’s revenue in 2018. A large number of Lockkheed’s international customers are US allies, whom they cannot accept orders from without permission from the US. Lockheed supplies the US government with F-35 Lighting Joint Strike Fighters(JSF) and F-16 Fighting Falcons, which are produced in the US.
In the same 2020 Global Aerospace and Defense Industry Outlook report, Deloitte states that the defense sector maintained its growth during 2019. Bigger security threats have pushed governments from around the world to increase their defense budgets. They expected government defense expenditures to rise between 3-4% in 2020, with the US in the lead. The sector was expected to grow given that global defense spending was also expected to grow by 3% by 2023.

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 semi-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) The US is a global leader in aviation emissions, with about 1/4 of CO2 emissions from global passenger air transport coming 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, a contrast to the 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). Today's aircrafts are more than 70% more fuel 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).

On the other hand, the pandemic has presented an opportunity for the commercial UAM market - commercial drones have been used to deliver essential supplies, accelerating past regulations and restrictions due to the urgency of the pandemic. In addition, while commercial aircraft manufacturers like Boeing and Airbus have experienced an unprecedented decrease in demand, defense aircraft manufacturing has been thriving - Lockheed Martin, the main military aircraft supplier, recorded higher first quarter earnings in 2020 than that of 2019.

Passenger Travel

Passenger travel has metamorphosed as a result of the proliferating spread of COVID-19.Once occurring as a popular leisure pastime and vital business operation, passenger travel is now deemed a menace towards global safety. This has caused passenger numbers to plummet, reaching levels lower than ever before. As of early July 2020, passenger volume levels have dropped 74% from 2019 levels. Domestic travel has decreased by 73% and international travel dropping 93% from 2019, demonstrating that while air travel has plunged from its previous trends of growth, it has also restructured to favor domestic travel as a result of international travel policies. Travel bans restricting travel to and from various countries have been put in place as regions have been forced to disrupt traditional systems and implement lockdowns, in hopes to contain the virus. In the US, travel advisories are being administered at state levels, based on COVID-19 spikes across the region. Overall bookings for US airlines have lowered by 80%, expressing the lasting impact the pandemic has had on air travel. The little demand for US airlines has generated a revenue loss of 91%, causing regional airlines such as Miami Air International to financially collapse, hence, expanding the role of mainline carriers in air transportation. A survey from market research company, Destination Analysts, found that 37.3% of travelers are wary of traveling to places they would under normal circumstances with 47% concerned on the COVID-19 spikes, and 39% concerned on inadequate safety measures being taken. Longwoods International found that 76% of subjects have changed travel plans, with 59% of travelers hesitant to travel outside of their area. With the norm of crowded airports, cramped flights and lack of hygienic services, people no longer envision safety and comfort when traveling through systems of public air transport, losing trust in air travel as a whole. This has had an immense impact as hospitality and public safety are fundamental to generating demand, a core factor that upholds the entire aviation industry. With demand hitting rock bottom, the future survival of aviation as we know it is jeopardized.

Leisure travel

Business travel

Cargo Operations

Urban Air Mobility

Many private delivery-drone companies have seen growth during the pandemic. Wing by Alphabet, a drone delivery service in Christiansburg, Virginia, is the only drone service in the US available to the public. Wing world with FedEx and Walgreens as well as a local bakery and coffee shop in Christiansburg to deliver household essentials during the pandemic. Wing claims that it completed more than 1000 deliveries in two weeks during the pandemic in Christiansburg. Their operation in Australia and Finland have also seen an increase in deliveries during the pandemic. EHang, a Chinese passenger drone company, conducted their first ever flight in South Carolina of a passenger-grade autonomous aerial vehicle(AAV) in January 2020. In February, EHang obtained a permit to operate in Europe for the flight testing of an AAC. During the pandemic, EHang has used passenger and non-passenger AAVs to transport valuable medical supplies and personnel. The AAVs have also served for in-air inspections and to broadcast instructions over populated areas of China. EHang's actions created a market for AAVs in emergency situations, leading the Chinese government to grant EHang permission to carry out commercial pilot operations at the end of May. Additionally, EHang has seen massive financial growth during the pandemic. In the first quarter of 2020 sales of EHang 216 grew 200% compared to the first quarter of 2019. Their revenues also increased by 80.3% this first quarter.

Given the nature of the success of delivery drones during the pandemic, UAM research is absolutely necessary. It is still not clear how long the effects of COVID-19 are expected to last, but we can assume that people will continue to order online. Deliveries will need to become safer, and delivery drones can replace delivery people to make the process as contact-free as possible.

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Manufacturing

Once the effects of COVID-19 began to ripple through the aerospace sector, many manufacturing companies were forced to cease operations temporarily, both as a result of health concerns and a decreased demand in aircraft orders. Commercial aircraft manufacturing companies felt these effects the hardest.

In March, Boeing shut down production in its Seattle facilities in response to the governor's stay-at-home order. In early April, Boeing did the same in South Carolina, putting the production of the 787 Dreamliner on pause. However, in April, Boeing resumed production in Seattle and South Carolina. In total, Boeing's manufacturing came to a halt for a month and a half. Boeing reduced production numbers on the 787 to 10 a month, which suggests that in the month and a half in which production ceased, Boeing lost revenue on approximately thirteen to fifteen 787 Dreamliners.

Many airlines are actively retiring or considering the retirement of many of their Airbus aircraft earlier than predicted to conserve money. Air France announced it would be retiring all nine of its A380s immediately. However, Air France plans on keeping its orders for the next-generation Boeing 787 Dreamliners and A350s to replace the A380s. Lufthansa also announced in April it would retire 6 out of its 14 A380s earlier than expected. Emirates is considering retiring half of its one-hundred A380s early as a direct result of the pressures the aviation industry is facing during the pandemic. The once coveted A380 is nearing its end because airlines struggle to make it profitable due to high operational and maintenance costs. Many more airlines have cancelled aircraft orders in an effort to conserve cash. Air Canada cancelled an order for 11 new aircraft; Gulf Air cancelled four 787 orders; LATAM cancelled one 777 order; Air Lease converted an order for nine 737 MAXs to three 787s. Oman Air converted ten 737 MAX orders to four 787s. In total, there have been 313 order cancellations for the 737 MAX. Airbus has seen 29 cancellation of its A320 family.

As a result, Boeing has had to reduce 787 Dreamliner production. It is estimated that Boeing will need to reduce production from ten to eight 787s per month for the third remaining quarters of 2020 before reducing it again to 6 per month. A first quarter report released by Boeing estimates that production will be reduced to 7 per month by 2022. Boeing's first quarter report for 2020 shows that revenues dropped a total of 26% compared to the first quarter of 2019. Commercial airplane deliveries dropped 66% in 2020, and revenue from that sector dropped 48%. Boeing predicts that during and after the pandemic, 737 MAX production will resume at low rates and then gradually increase, but production levels will continue to be low. In April, Airbus announced that production levels were reduced by a third in response to the crisis caused by COVID-19. Production rates fell from 60 to 40 per month for its A320 aircraft in Alabama. Production was paused in its German sites, as well as in Spain and France, where production lines were paused twice. The activities Airbus can perform during the pandemic are limited to support functions in IT, security, and engineering, as well as essential activities in commercial aircraft, helicopter, and defence and space in Spain.

Parts manufacturers rely heavily on the business Boeing and Airbus give them. In January, prior to the pandemic reaching the US, Spirit Aerosystems announced that it would cut 2,800 jobs due to uncertainties of when 737 MAX production would resume, following its grounding in

March of 2019. Spirit and Boeing negotiated an agreement in which Spirit would slowly build up production to deliver 216 MAX shipsets by the end of 2020 in anticipation of the return of the 737 MAX. This number was later reduced to 125. However, Spirit was directed by Boeing to pause all production of current and future 737 MAX shipsets in June. Spirit decided to place employees working on the 737 MAX on a 21-calendar day unpaid temporary layoff effective June 15 as a result. Spirit also reduced the hourly workforce in its Oklahoma plants. Additionally, Spirit reduced its workforce by more than 4,650 employees in its Kansas and Oklahoma plants combined because of the current health crisis. Spirit saw significant loss in revenue during the first quarter of 2020; earnings were cut nearly in half. Spirit expects to see further losses during the second quarter, losses of approximately $70-90 million from Boeing 737 MAX programs and $15-20 million from Airbus programs. Furthermore, Spirit's fuselage systems saw 48% loss in revenue, as did its wings systems with 29% loss, and propulsion systems with 54% loss.

GE Aviation has also seen significant reduction in its operations. Visits to GE shops from commercial aircraft are down 60%, while the installation of commercial engines is down 45%. Rolls-Royce expects to reduce its global workforce by 9,000 to create and annualized savings of 700 million pounds. In addition, the company plans to cut expenditures in other areas, mainly in their Civil Aerospace business. It will redirect as many resources and employees as it can to their Defence business which has remained robust during the pandemic.

Hexcel Corp, which supplies the material for the 787's carbon fiber frame, said they were aware that once the production of the 787 Dreamliner resumed, the demand from Boeing would be lower. A planned merger between Hexcel Corp and Woodward, worth $6.4 billion, was ended in response to economic uncertainties in the aerospace industry.

In order to adapt to the financial crisis caused by the pandemic, aircraft manufacturers and the supply chain have made major decisions. Spirit Aerosystems announced a temporary production partnership with Vyaire Medical to produce ventilators in response to the ongoing pandemic. Vyaire will benefit from Spirit's high production rates, well-trained workforce, and facilities. Spirit will not only be helping during this crisis, but also be receiving revenue from the ventilators that is much needed.

Hexcel Corp has reduced their workforce significantly to ensure their operations are the right size to meet the new demand levels. In addition, Hexcel has also temporarily reduced salaries, unpaid leave of absences, suspended their 401K match, stopped outside hiring, and restricted capital expenditures as well as discretionary spending. Because Hexcel is also a big source provider for defence and commercial aircraft programs, many of their plants have remained open.

On the other hand, the defense sector of aviation has been doing extremely well during the pandemic. Lockheed Martin has two plants located outside the US that manufacture the F-35 Joint Strike Fighters, both of which were closed for a week or less in March. The plant in Italy closed for two days to clean and sanitize its facilities. The Mitsubishi Heavy Industries F-35 plant in Japan was closed for just one week and reopened the following. LMT's Texas plant, which builds F-35s for the US military and most overseas customers, remained open during March.

LMT reported first quarter net sales of $15.7 billion, compared to $14.3 billion from the first quarter of 2019. Cash operation and net earnings were also higher in the first quarter of 2020 compared to the first quarter earnings in 2019. According to the report, "the outbreak did not have a material impact on the corporation's operation results or business in the first quarter of 2020." Higher net sales are attributed to $695 million in sales of the F-35 aircraft, which saw high production volumes, sustainment and development contracts. LMT has also begun working with the US Department of Defense to provide critical financial aid to vulnerable elements of the US defense industrial base; $600 million in accelerated payments are estimated to flow into LMT's supply chain partners.

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 short term outlooks of domestic air travel demand.* 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 late summer/fall, the baseline model predicts what RPMs may look like in the case of a surge of new coronavirus cases in the late summer/fall that is less severe than 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

[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 B

not occurred[2]. 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. For more information on the performance of the models and some potential limitations, read the Validation section of Appendix B for the predictive models and Appendix C for the counterfactual model. 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[3] 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.

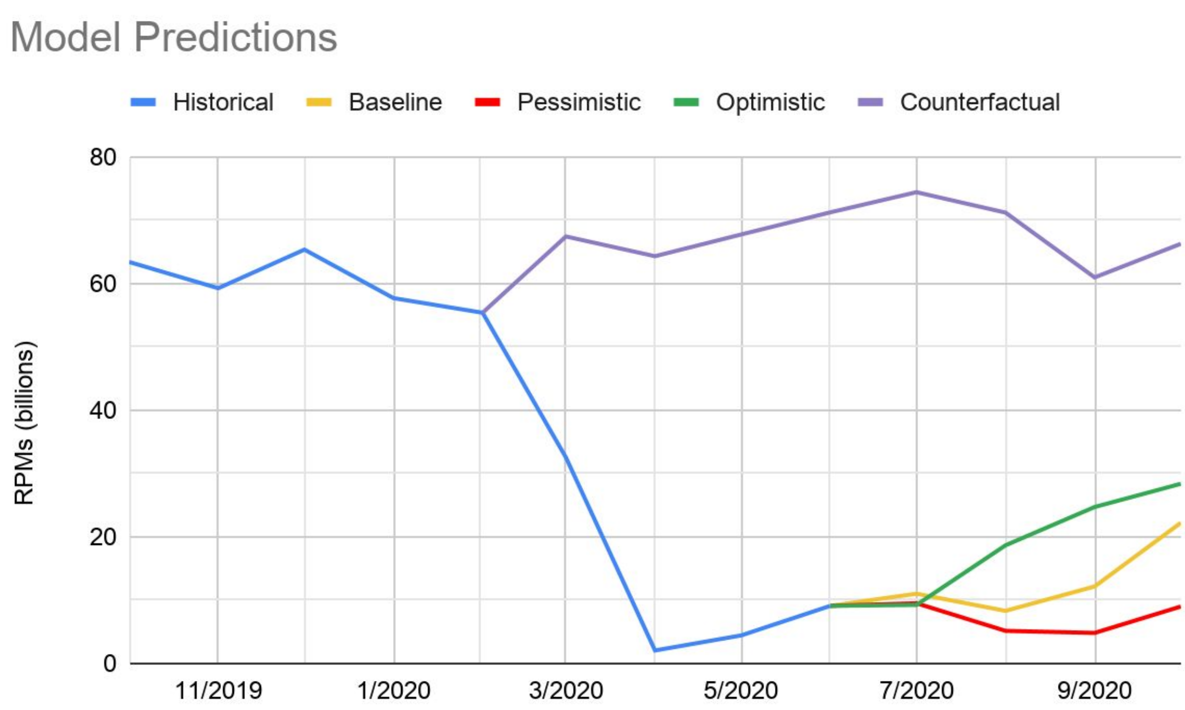

Figure 1.

Model Predictions

Date	Historical	Baseline	Pessimistic	Optimistic	Counterfactual

[2] To view the full methodology of the counterfactual model view the methodology section of Appendix C
[3] Historical RPMs data for April, May, and June estimated from percent decreases given by A4A in their covid-19 updates

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.

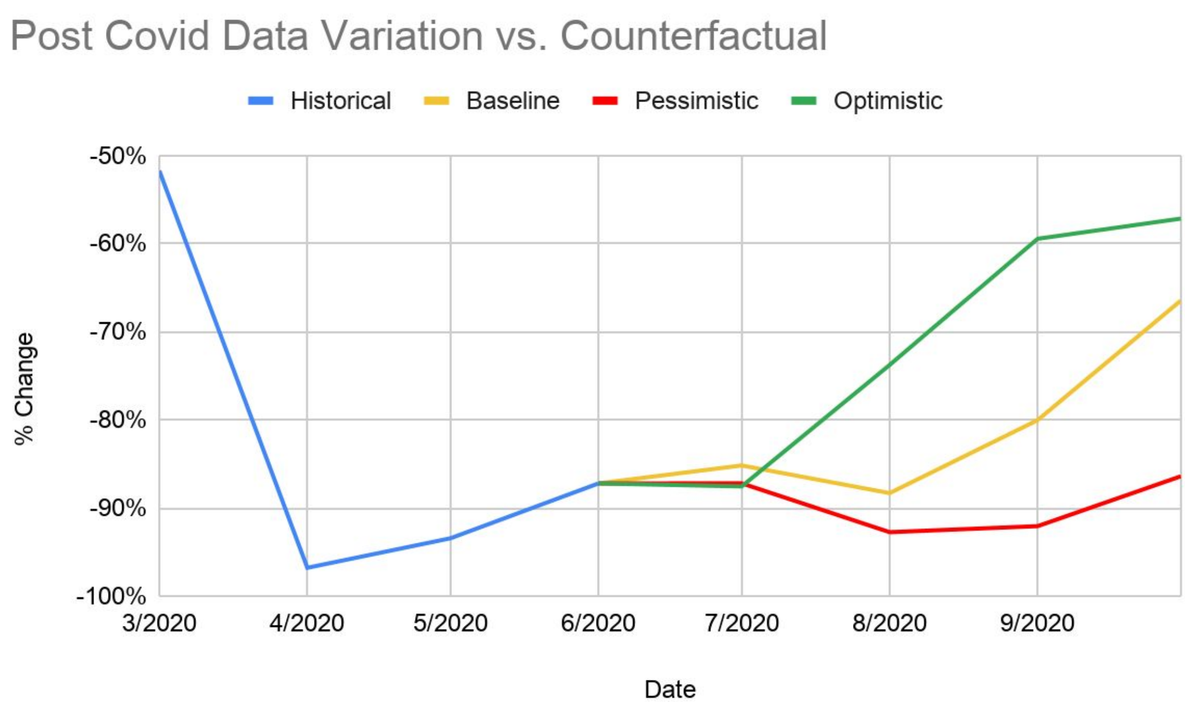

Figure 2.

Post-covid Data Variation vs. Counterfactual

Date	Historical	Baseline	Pessimistic	Optimistic

3/2020	-51.74%			
4/2020	-96.79%			
5/2020	-93.44%			
6/2020	-87.22%			
7/2020		-85.18%	-87.21%	-87.56%
8/2020		-88.32%	-92.75%	-73.78%
9/2020		-80.04%	-92.07%	-59.46%
10/2020		-66.47%	-86.41%	-57.17%

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, the optimistic scenario is predicting that after two months of sustained growth in August and September, growth begins to slow down during October. This can be explained by the fact that although as the covid-19 pandemic is brought under control more people will feel comfortable flying again, there will most likely still be a significant portion of the population that will not be willing to fly as long as covid-19 is 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

With aviation struggling more than ever before, the future of passenger travel remains a crucial question when considering the path to recovery. In order to determine the impact of COVID-19, the National Center for Biotechnology Information interviewed various aviation industry executives about the evolving nature of air travel in these uncertain times. As a result, they concluded that business travel would return to some degree in the short term in order to maintain and strengthen international relationships with clients. However, due to the formation of strict travel bans across the globe, long haul flights are no longer occurring and thus, conferences and exhibitions will take much longer to return. Travel budget cuts and cancelled bookings have also contributed to this lag in recovery, causing businesses to restructure their interactions through regular use of virtual platforms, already having invested for various online workplace mechanisms. As these platforms innovate to better suit business needs, business travel demand will see less demand in the long term therefore threatening airlines as they rely on business travelers for profitability. This will push airlines to emphasize efforts towards leisure travelers, and better the passenger experience in order to generate satisfactory yields. Leisure travel will recover faster than business travel, though will remain low due to a general decline in disposable income of Americans paired with weak traveler sentiment. In order to improve these factors, airlines will have to rely on local authorities for increased tourist marketing and will need to sell tickets to cheaper destinations, completely shifting the marketing focus and traditional vacationing from expensive beach trips to more affordable locations such as in Southern Europe or North Africa. For demand to return, consumers must regain a sense of trust in US airlines through a shift from traditional procedures to new necessary safety precautions. To do this, airlines must sacrifice their traditional priority of profitability and direct their efforts towards the passenger experience through developing extensive safety measures. Recently, the US government devised a new standard, Runway to Recovery, to help airlines adapt to the current circumstances by mitigating health risks and with strict compliance from airlines, recovery will become a clearer path. The IATA predicts that for the rest of 2020, international air travel demand will experience gradual growth while still resulting in a 55% loss in passenger revenues. As it will take a year for a functional vaccine to develop, recovery will continue to lag until passenger health is better assured.

Leisure Travel

Business Travel

Cargo Operations

Urban Air Mobility

NASA's predictions from November 2018 stated that last-mile delivery drones are expected to become profitable by 2030. Air metros are expected to have a viable market by 2028. However, given the success of delivery drones during the pandemic, the market may become profitable and more common before then.
By 2028, air metros will be charging approximately $50 per trip during the first year and later $30 per trip by 2030. A potential market for air taxis is not likely and very limited. NASA expects air taxis to be viable after 2030, and it would be limited to wealthy people who for example work in the city but live in the suburbs and would like to avoid traffic. High investment costs would also hinder success by 2030. However, as we've seen with EHang, they've already made a market for AAvs in China and South Carolina. Their operations have been profitable and are benefiting people during this pandemic. EHang launched its first AAV in Las Vegas in 2016. The EHang 184 had a one-person cabin, 8 propellers on 4 axes, and could carry a passenger with a passenger that weighed up to 200kg for 20 min at a speed of 100km/hour. By 2019, they upgraded their model to a two-seater. The model has gone through 2 000 unmanned and manned flight tests, signalling that it is ready for commercial operation. In order for UAM to become viable, UAM developers will need government support. For example,EHang sees regulations, government approval, and technology as key factors for the viability of UAM. Approval from local governments such as the FAA are needed. The FAA has an Unmanned Traffic System Management in place that will manage multiple drone operations conducted beyond the visual line-of-sight. UAM also requires cutting edge technology from every STEM field, as well as a strong supply chain and a centralized platform for commercial operations.

In a comparison between UAM and existing ridesharing services, EHang points out the many faults in ridesharing. Riding in a car allows for human error, safety concerns, traffic, pollution, and for companies like Uber and Lyft, it has low profit margins. Automated aerial vehicles, however, are fully autonomous, safe, zero emission, have low maintenance costs, and don't have to deal with congestion. EHang recognizes that ridesharing services are successful because they are accessible through mobile apps and offer instant services. They think it is possible to replicate that system, however, they believe it's best to ditch the driver and use autonomous vehicles.

UAM can also solve problems caused by our current transportation systems. UAM can alleviate ground congestion, which means less accidents and less deaths or injuries related to accidents. UAM is also electric,, which can improve the air quality of areas with significant air pollution caused by ground traffic.

Manufacturing

In a shareholder meeting in April, Boeing's CEO Dave Calhoun stated, "It will take two to three years for travel to return to 2019 levels and an additional few years beyond that for the industry's long-term growth trend to return." When the turmoil in the airline industry does stabilize, he says 'the commercial market will be smaller, and our customers' needs will be different.'" When airlines begin to order aircraft again, it is expected that they will turn to narrow-bodied planes which will be used for shorter routes despite the high mileage these aircraft have.

The sudden drop in flight demand during the pandemic resembles the one that followed the 9/11 terror attacks. The drop was caused by fear, rather than economic factors like the Great Recession. After 9/11, air carriers saw 12 straight months of enplanement declines, and it took 22 straight months for the industry to reach pre-9/11 levels. During the recession, air carriers saw traffic declines for 18 months, as well as a two year recovery period. Analysts think a COVID recovery could be quicker, citing the recovery already seen in China air travel. However, airlines who mainly handle international flights and corporate travel (American Airlines, Delta Air Lines, United Airlines) could take longer to recover.

China is a great example of a quick recovery period after the pandemic. By March 2020, Chinese stocks had recovered and their economy is coming back to life. The pandemic has also served to accelerate trends already in the works, such as the shift from brick and mortar to e-commerce. This means that cargo airlines like FedEx Express and Emirates SkyCargo would see massive growth during and after the pandemic. Cargo airlines are seen as an essential business due to the role they play in moving supply chains and delivering critical relief.

China and other virus-stricken countries in Asia were quick to implement monetary, fiscal, and regulatory policies to counter the economic impact. Tax cuts, rebates, interest rate reductions, and requests to banks to be more lenient about loans are all tools that have come into use in China as well as the US.

The funding provided to the US Department of Defense will affect whether they will continue to order aircraft from LMT. The contract LMT has with the US govt could be terminated for convenience and based on negotiable contract terms. Trade policies and sanctions imposed by the US to countries like Turkey and Saudi Arabia will affect LMT's business, as they can only work with countries approved by the US government. Overall, the industry is expected to continue growing as security threats continue to grow .

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 occurring for decades, causing rising sea levels, global temperature increases, dangerous extreme weather patterns, and more. The UN has declared that the globe has 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 (blended wing body, “flying V”, etc), aircraft structure and materials (alloys, morphing wings), and future propulsion technology (open rotors, hybrid electric / full electric aircraft). 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.

Post-covid Industry Outlook Conclusion

From the model and the research analysis of different sectors of aviation, it is clear that COVID-19 has created significant changes across the board that will continue beyond 2020 and will affect the state of the industry after the threat of the virus is eliminated. Passenger travel is slowly increasing but is nowhere close to normal levels- the model explains that even in the most optimistic situation, there will still be more than a 50% reduction in revenue passenger miles than if the pandemic had not occurred. The passenger experience must improve, valuing passenger safety and health, to increase demand. The demand for leisure travel will slowly increase, but business travel has been greatly disrupted by the COVID-19 pandemic, and is unlikely to ever return to 2019 levels. Due to the growing success of e-commerce, on the other hand, there is an expected long-term demand in air freight operations. Shifting to flexible operations and using a variety of more innovative types of aircraft (UAM, passenger planes, etc.) will allow for stable long-term airfreight success. As for urban air mobility, we are on the pinnacle of a UAM breakthrough: the pandemic has shown how quickly drones can be approved and implemented, and in future years, UAM are expected to not just be used for delivery, but also as a means of human transportation, with the development of automated, environmentally friendly aerial vehicles. Manufacturing was one of the sectors of aviation that has been most heavily impacted by the pandemic, closing facilities and noting a huge decrease in orders and demand. As the aviation manufacturing sector looks towards the future, large changes will need to be implemented to ensure the sector's survival. And as the industry focuses its attention on responding to the pandemic, it cannot ignore the significant role the aviation industry plays in CO2 emissions and climate change. Between the various sectors, COVID-19 has produced an unprecedented effect on the aviation industry. Problems that were occurring before the pandemic have been magnified and new concerns have emerged, and the industry must take extreme action to adapt to the changing globe.

It is becoming increasingly evident that the COVID-19 pandemic is an opportunity for the aviation industry to reinvent itself to adapt to the changing industry and globe. Though the industry wants to recover from the pandemic and return to the state of the industry in 2019, this will not happen overnight - our model shows that even in the best case scenario, regular passenger miles will be 50% of what they would have been without the pandemic in the next four months, and external sources state that the industry recovery will take about three years. The industry has been disrupted, and going back to previous operating strategies will lead to failure. Instead, the pandemic presents an opportunity for the industry to focus on reinvention instead of recovery, allowing it to restructure its operations and alter each sector to adapt to the changes in the industry that have emerged due to COVID-19, and prepare for future changes of the industry in the next decade.

Every company and sector within the aviation industry must consider how they will alter their operations to fit the newly disrupted globe. Passenger travel must … Air freight must …

Manufacturers must … UAM must … NAS management must … To ensure the decarbonization of the aviation industry, significant research and development of revolutionary aircraft design and efficient systems is crucial. Widespread changes are needed across the board to ensure a successful revitalization of the industry. We have focused on how NASA should cater its research to the changing climate, and will detail our recommendations below.

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).

Recommendations for NASA's Aviation Research

The COVID-19 pandemic has highlighted many pitfalls of the aviation industry, and provides NASA an opportunity to refocus the industry's direction as it looks to the future. The passenger experience today is widely negative, with cramped aircraft (growing numbers of passengers per aircraft, unable to social distance) with outdated technology (the average aircraft flying for 30 years, with minimal tech entertainment on long flights), and large crowds and tedious security processes at airports. Many Americans have avoided air transport due to fears of contracting COVID-19 in the airport crowds and packed planes with circulating air. There has also been a recent growing awareness of the detrimental effects of aviation on the environment as the globe prepares for the massive effects of climate change.

Short term, NASA must invest in researching the new definition of passenger safety to ensure that air travel is safe and profitable. COVID-19 has created new passenger safety demands, as passengers are concerned with human contact, airflow, and other health demands. COVID-19 is expected to continue for multiple more years (vaccine development is a challenging and slow process), and air travel demand will not increase until the industry proves that traveling by air is not dangerous (in the context of the virus). Similar to the security measures implemented after 9/11, the passenger experience is changing once again, and NASA must research technologies crucial in allowing the aviation industry to regain its credibility as a safe method of transportation. Biological sensors are emerging as a necessity on all aircraft and in all airports, expanding on the health advancements of ecoDemonstrator including their self cleaning aircraft lavatories and use of UV sanitation, and new projects to detect COVID-19 and other biological hazards on aircraft through air monitors. Amidst the COVID-19 pandemic, passengers are hoping to experience an efficient travel journey, from streamlined airport experiences to shorter flights, as passengers want to reduce the amount of time they are potentially exposed to the virus. This notes a potential market for supersonic aircraft in the future, as the powerful supersonic aircraft technology being developed helps greatly reduce flight times.

The next few decades will bring mass innovation across the board as advanced technology emerges. The pandemic has made it clear that unless the industry takes massive strides to adapt to the next generation, air travel will not return to its state of strength in 2019, but will be replaced by other disruptive air travel concepts and emerging innovative transportation sources. We are currently at an inflection point, with an opportunity for the industry to restructure and reinvent itself as it faces the mass disruptions of the industry due to the COVID-19 pandemic.

NASA must strive to support the restructuring and revitalization of the aviation industry, and must develop infrastructure to support the next generation of revolutionary aircraft. NASA must prepare to adapt to the changing state of the national airspace system as supersonic aircraft, UAM, commercial spacecraft, and other non-traditional aviation operations emerge, as advanced air traffic management systems will be needed to safely integrate other revolutionary technologies to the traditional airspace currently in place. The continuation and expansion of current ATM and system management platforms like TestBed will be crucial as the air transportation becomes more complex. In addition, to increase ridership and allow for advanced mobility across different forms of transportation, NASA must ensure that the air transportation is seamlessly connected to other current transportation systems (public transport, cars, ride sharing apps, etc), along with future mobility systems that will emerge in the next few decades (automated vehicles, eVTOL's, and more).

As a national system, NASA must work to adapt to the changing state of air transportation development: expanding beyond the traditional manufacturers like Boeing, Airbus and Lockheed Martin, but also supporting growth of tech companies and startups. Tech companies and startups are innovating on UAM at a fast pace, while traditional manufacturers are struggling from decreased demand and trying to produce innovative aircraft. Airbus is cancelling its electric plane and has finally concluded manufacturing the A380, accepting that wide-body jets are not the future direction of the industry (though they spent decades working towards the goal of larger aircraft). And attempts by Boeing and the traditional aviation manufacturers to innovate quickly has been destructive: the Boeing 737 max crashes emphasized the quality errors associated with attempts to speed up the rate of innovation. NASA must continue to heavily invest in UAM technology, as we can expect an emergence in small and large UAM use in the future, and must provide a platform for nontraditional aerospace groups (startups, tech companies, etc) to support the outside development of UAM. Unlike other sectors of aviation, UAM development was positively impacted by the pandemic, as certain regulations were lifted to allow the delivery of essential goods by UAM. UAM has also emerged as a potentially preferable means of transportation during pandemics due to the reduced human contact it offers. McKinsey analytics explains that the virus causes people to adjust their means of transport to reduce the risk of infection, shifting away from shared forms of transportation and instead increasing personal vehicle use. (McKinsey Covid future mobility) NASA's development of UTM and other technologies will be crucial in implementing UAM, and they must continue to produce revolutionary systems that will aid in UAM's success.

In recent years, aircraft technology and air traffic management systems, along with other aspects of the aviation industry, have become increasingly modernized, with the development and implementation of semi-automated features. Over the next few decades, many aspects of the world as we know it will become automated, including the aviation industry. COVID-19 has propelled the innovation and implementation of automated technologies due to the desire for interactions without any human contact. However, there are few fully automated technologies currently on the market, and demand for modernized aviation systems and autonomous technologies in every sector will greatly increase in coming years. NASA must continue to research automated technologies to help aviation adapt to the changing globe.

As for the environmental concerns of aviation, despite NASA's progress in improving aviation's massive environmental impact, continued research and development is needed in the next few years to ensure that sustainable aircraft are quickly developed as the global climate crisis approaches. Airlines have been able to justify their environmental impact of aviation prior to 2020 as operations grew and revenue increased. However, the industry's stability has already been disrupted by COVID-19, and this is a perfect opportunity for the industry to restructure and refocus on what's important: improving aviation to become more sustainable and help save humanity from the growing threat of climate change. Evolutionary aircraft technologies, including retrofits of current aircrafts, production upgrades, and new aircraft designs, are critical in improving fuel efficiency in the near future. However, there are limitations to the extent of which evolutionary technologies may improve efficiency, and it is estimated that beyond 2030, these improvements will have little impact (Roadmap to 2050). To achieve large scale, long term CO2 emissions, NASA must continue to emphasize the development of revolutionary aircraft technologies. Unlike evolutionary technologies, these nontraditional concepts allow for long term improvement in aviation's environmental impact. Decades of continued research is anticipated, as these revolutionary designs, including nonconventional airframe configurations like strut braced wing, blended wing body, "Flying V", etc, revolutionary structure and materials like shape memory alloy, and various propulsion systems like hybrid electric and full electric, are not currently ready for the market. NASA must continue to invest in both evolutionary and revolutionary technologies, as a combination is needed to reach the industry's environmental goals. The aviation industry is currently on track to triple its emissions by 2050, when it will account for 25% of global carbon emissions (The International Council on Clean Transportation - CO2 Emissions from Commercial Aviation, 2018). In contrast, the industry needs to be zero carbon by 2050 to ensure the safety of the planet, so NASA must take bold steps and invest large resources to redefine the industry's role in emissions and energy use, and make sure decarbonized aviation is a reality.

Conclusion

Appendix AGlossary of Acronyms

Appendix : 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[4], and it also takes into account several major events that have disrupted the air industry. The model then

[4] 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.

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 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[5] and the monthly unemployment rate[6]. 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.

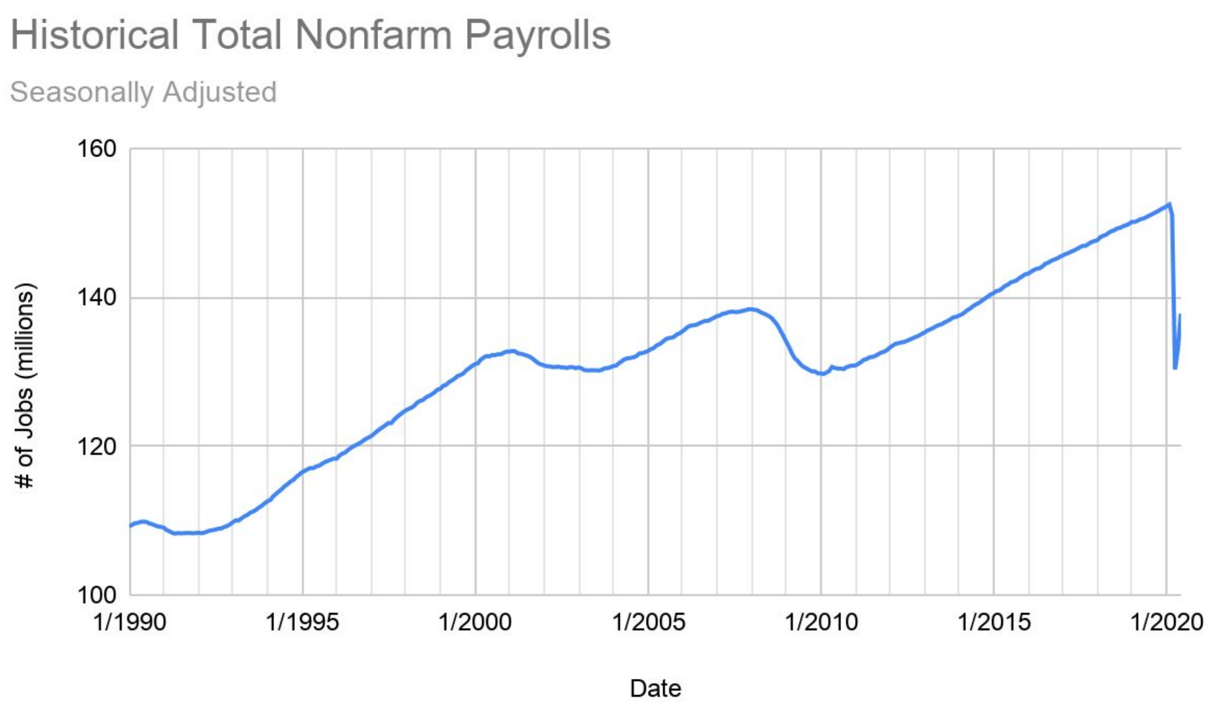

Figure 3.

[5] 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.
[6] 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.

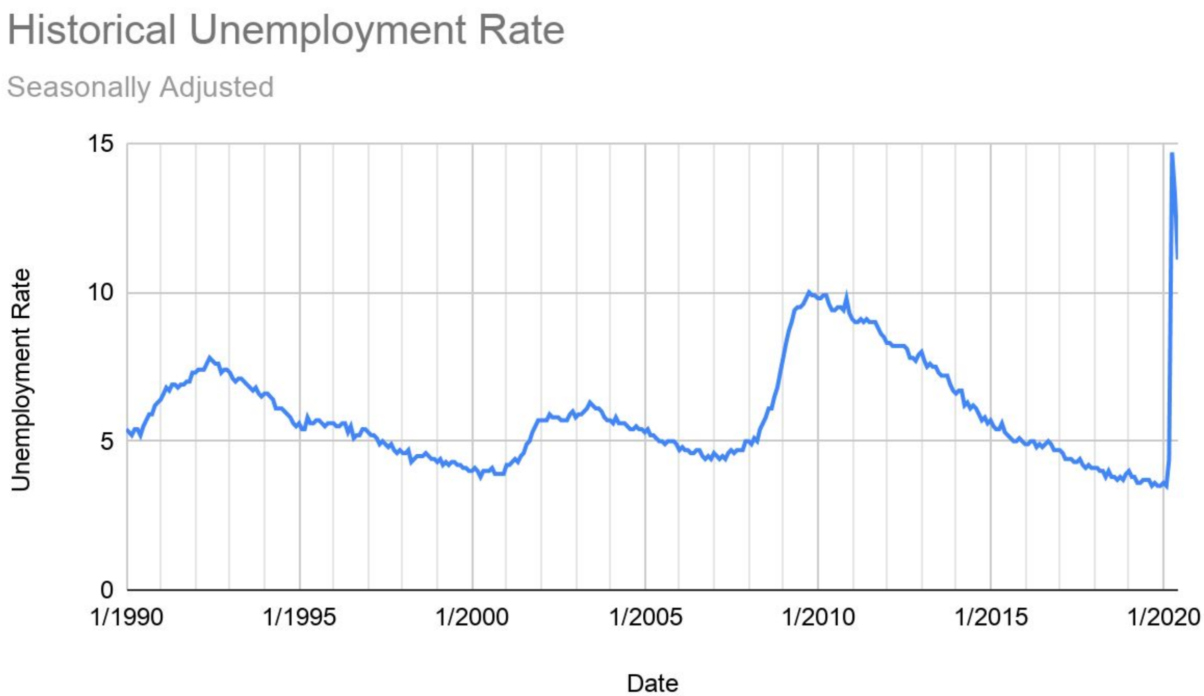

Figure 4.

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.

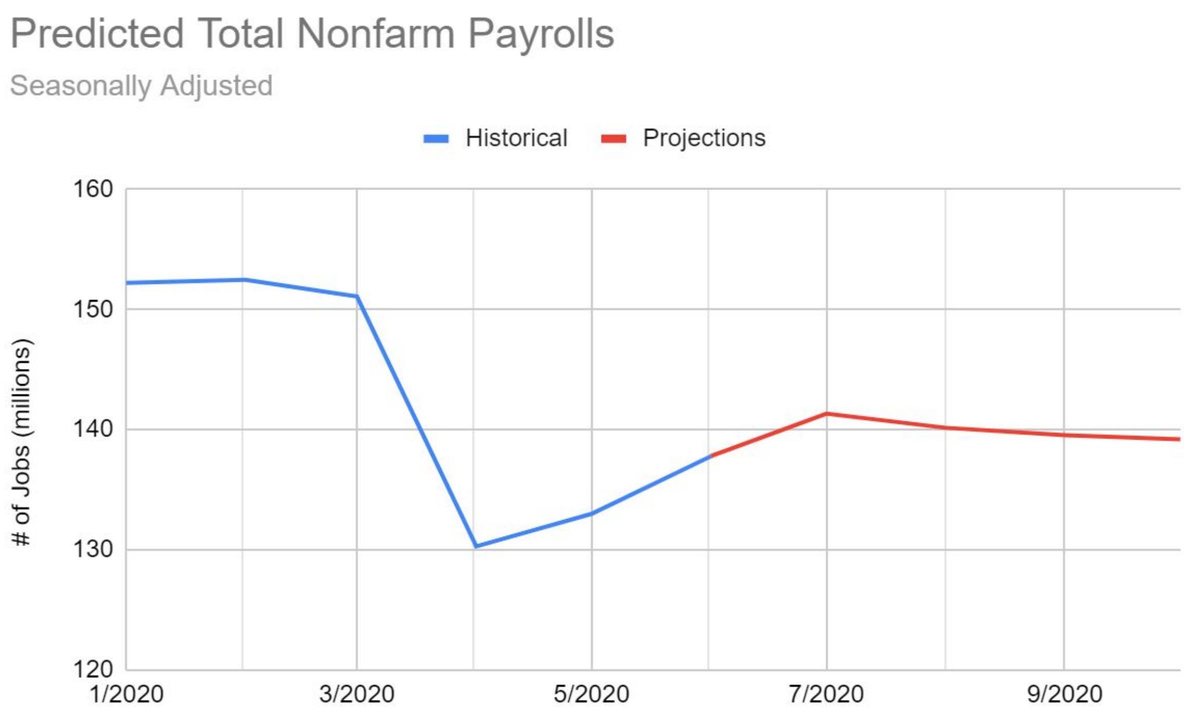

Figure 5.

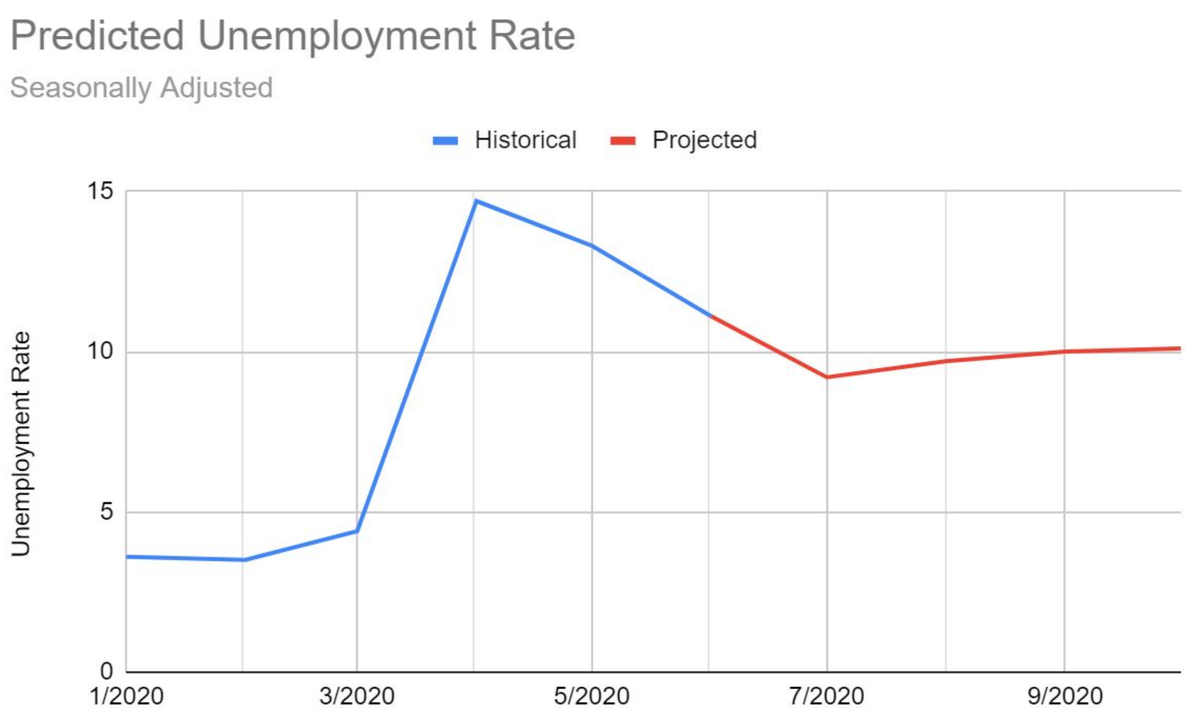

Figure 6.

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[7] of the number of months elapsed since October 2001[8]
- 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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[7] 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

[8] 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[9]. The data for these three variables is sourced[10] 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.

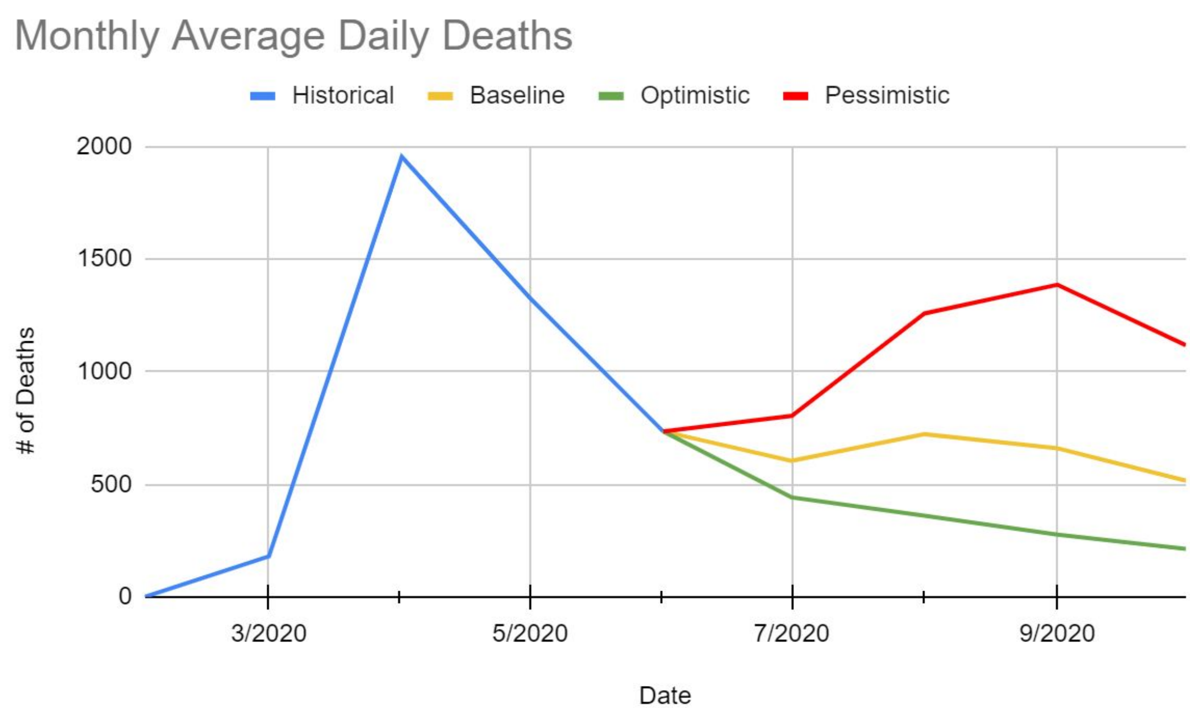

Figure 7.

[9] 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

[10] Data sourced on July 8th 2020

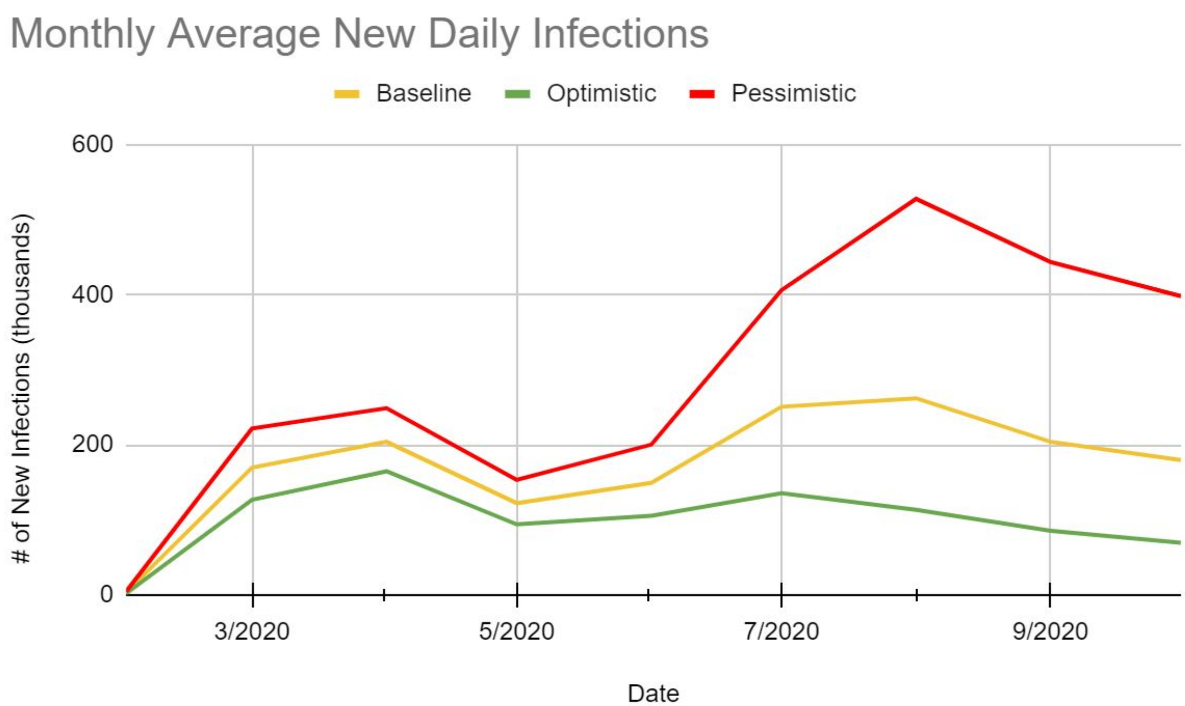

Figure 8.

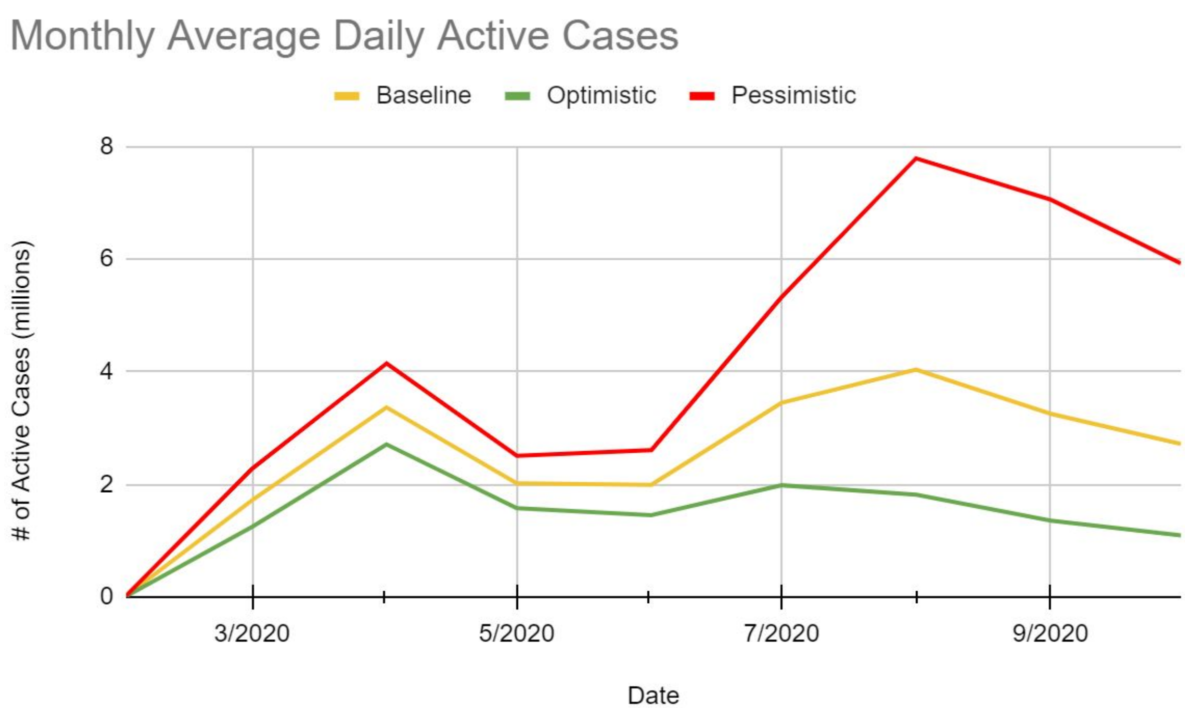

Figure 9.

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)[11]. To capture the duration of the pandemic factor for the model, we are using a variable that represents the inverse[12] of the number of months since April 2020[13].

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.

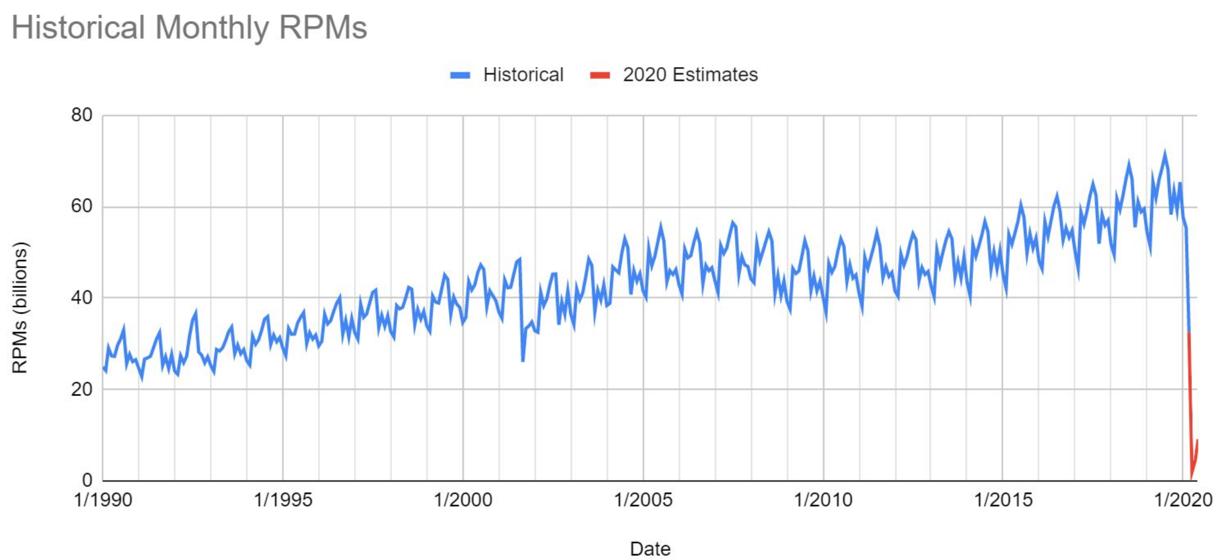

Figure 10.

[11] 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.

[12] 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

[13] 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 $\text{Elapsed}_{4/2020}$ = 1)
9/11 Elapsed_t	The squared inverse of the number of months elapsed since 9/11 (9/11 $\text{Elapsed}_{10/2001}$ = 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

In this section we will discuss the validity of the model and some possible pitfalls that affect the models' accuracy.

Model Performance

To validate the models' predictions, we will look at some metrics that measure how well the models perform when predicting historical data. Figure 11 displays the 3 different models' predictions and how they compare to historical data.

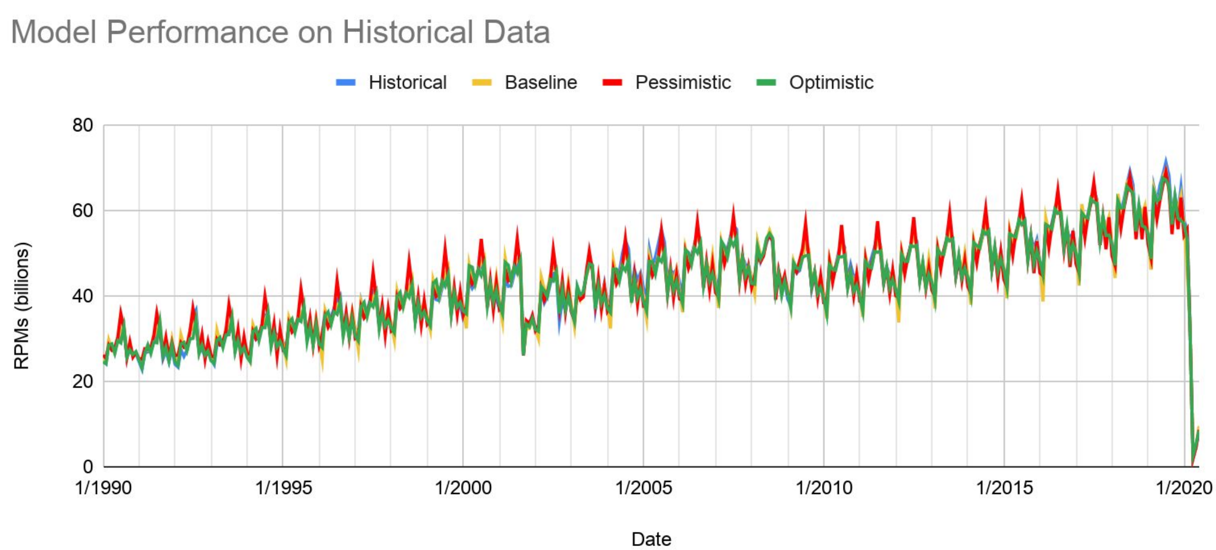

Figure 11.

As you can see, the models serve as pretty good predictors for historical data, including post-covid data. However, it is not enough to just visualize the performance. Table 4 shows different statistical metrics that measure how much the models vary from the historical data.

Model	**MAE (billions)**	**RMSE (billions)**	**MAPE**

Pessimistic	1.59	2.11	3.82%
Baseline	1.20	1.72	2.96%
Optimistic	1.37	1.85	3.31%
Average	1.39	2.89%	3.36%

Table 4.

As shown in table 4, the 3 models have a combined average absolute percentage error of 3.36% when compared to the historical data, which statistically speaking is pretty good. However, in the next section we will discuss some possible limitations of this model.

Limitations

Although the report statistically performs well on historical data, there are some possible limitations that should be taken into consideration when analyzing future projections.

Firstly, to make projections, the model requires predictions for both covid related metrics and economic metrics. Making predictions for those statistics falls out of the scope of this report, thus we rely on outside sources for predictions. Although we tried to choose the most credible predictions available, we can not fully guarantee that these predictions are accurate. Additionally, since we rely on outside sources for covid and economic predictions, we were only able to obtain 3 scenarios for covid data, thus we only use one scenario for economic predictions. This is obviously not the best way to make projections, because if covid cases rise then for example unemployment will drop, and vice versa, which is not taken into account when we are making projections. However, the economic predictions used are still good enough to provide some predictions that can give us an idea of what the few months may look like in terms of demand for air travel.

Additionally, since the covid-19 pandemic has only been around for 7 months at the time of writing this report, and has only really impacted US aviation for 4 months, that gives the model only four data points to train the covid related parameters. Furthermore, the model only takes into consideration 4 covid-related factors, meaning that there may be other underlying factors such as number of hospitalizations, average age of infection, number of states that are in quarantine, etc. that could potentially be affecting air travel demand. This combination of lack of available data and variables that are being used to train the model could mean that the model isn’t able to accurately determine the relationship between the state of the pandemic and an increase or decrease in air travel demand.

The covid-19 pandemic has truly brought unprecedented circumstances to not only aviation but the world in general. These times are very unpredictable and conditions can change very rapidly without much warning. For this reason it is challenging to make predictions on what the future may look like. However, even though there are various limitations, the predictive models outlined in the report offer some valuable insight on what the outlook of air travel demand may look like in the coming months.

Appendix C: Counterfactual Reference Model

This appendix will rigorously discuss how the counterfactual model works, and go over the model's performance and some potential limitations. The purpose of the counterfactual model is to provide a reference for what air travel demand would have most likely looked liked had the covid-19 pandemic not occured

Methodology

The counterfactual model applies multiplicative decomposition to RPMs time series data. The multiplicative model decomposes the time series data into Trend, Seasonal, and Irregular components:

$RPMs_t = Trend_t \times Seasonal_t \times Irregular_t$ where $t = 0$ at 1/2014.

The model uses data from 1/2014 to 2/2020 because during this time period the trend of the data was nearly linear, making it ideal for modeling. The original times series data as well as the Trend, Seasonal, and Irregular components are shown in Figure 5, Figure 6, Figure 7, and Figure 8 respectively.

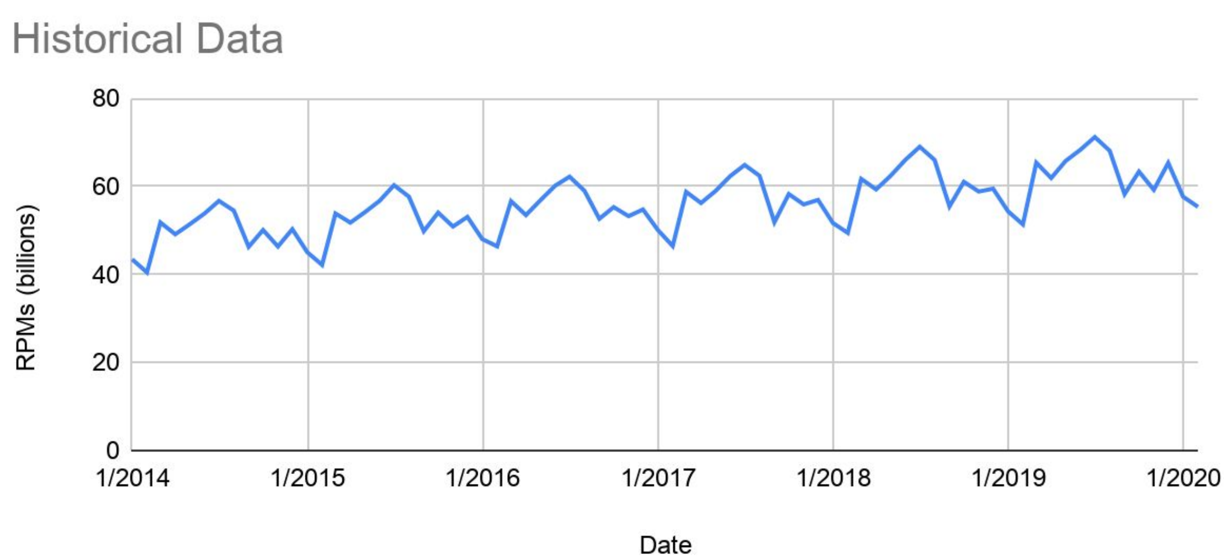

Figure 12.

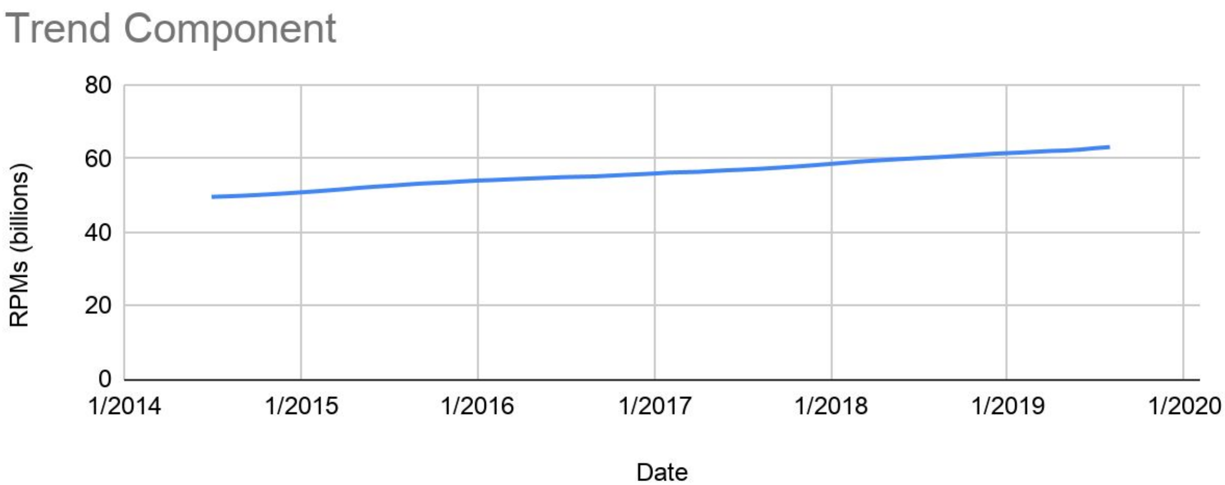

Figure 13.

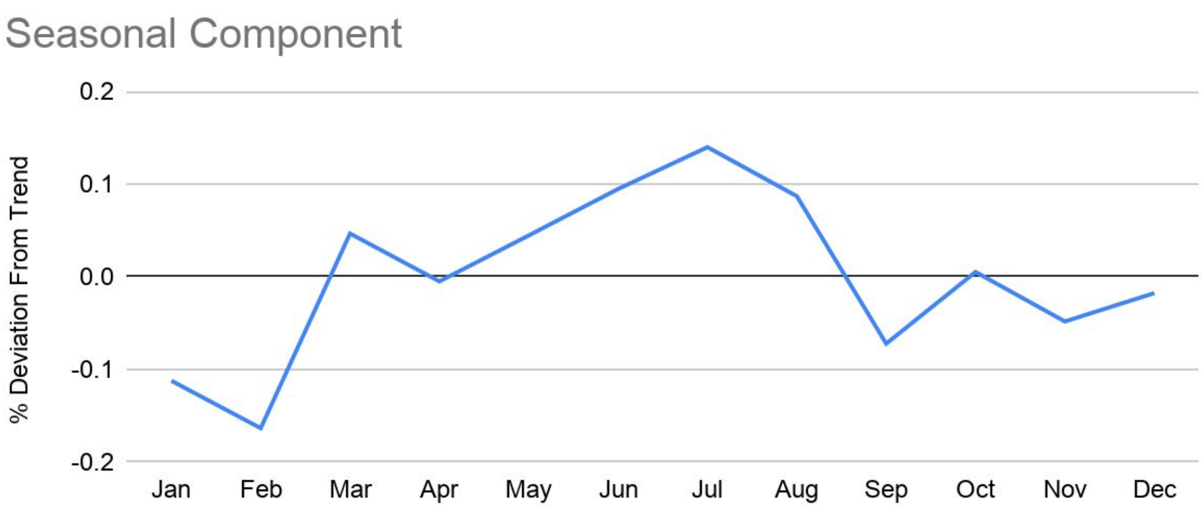

Figure 14.

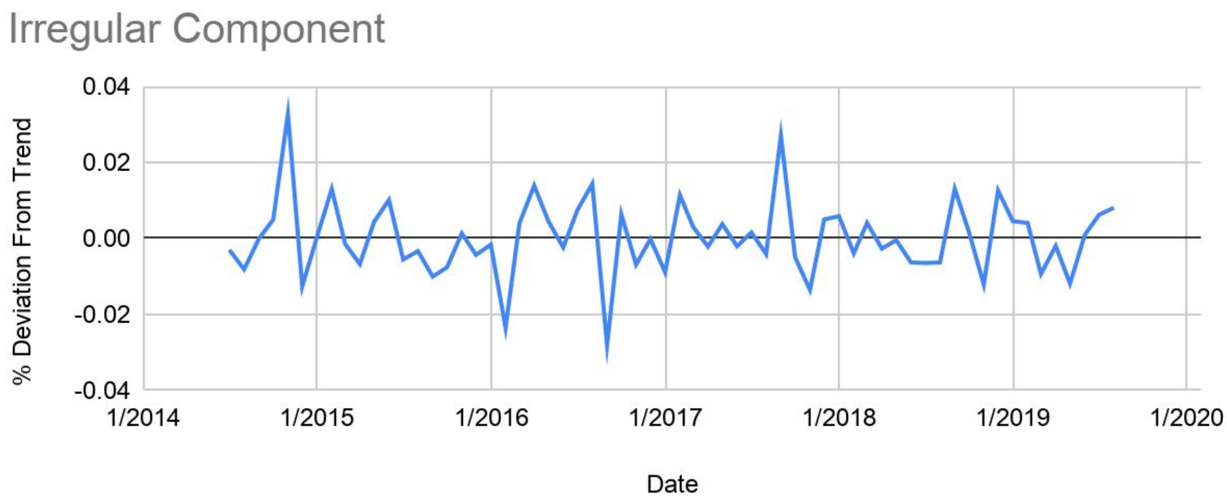

Figure 15.

The seasonal component is estimated by dividing the original time series data by its 12 month moving average, and then normalizing the results by averaging out the irregularities. The estimated times series components are shown in Table 11.

Month	**Seasonal**
January	0.8876499899
February	0.8363806616
March	1.046599498
April	0.9949147069
May	1.044533784
June	1.094736184
July	1.139857178
August	1.086907681
September	0.9276609336
October	1.00506463
November	0.9516411236
December	0.9822295287

Table 5.

Once the seasonal components are estimated, the times series data is deseasonalized by dividing it by the seasonal components. The trend is then estimated by fitting the results with a linear regression model. The resulting estimated trend equation is:

$Trend = 215744169.8t + 48237518346$, where $t = 0$ at 1/2014

Once the Trend and Seasonal components are estimated, the model makes predictions by multiplying the estimated Trend and Seasonal components together.

Validation

In this section we will discuss the validity of the model and some possible pitfalls that affect the models' accuracy.

Model Performance

To validate the models' predictions, we will look at some metrics that measure how well the models perform when predicting historical data. Figure 11 displays counterfactual model's predictions against the actual historical data.

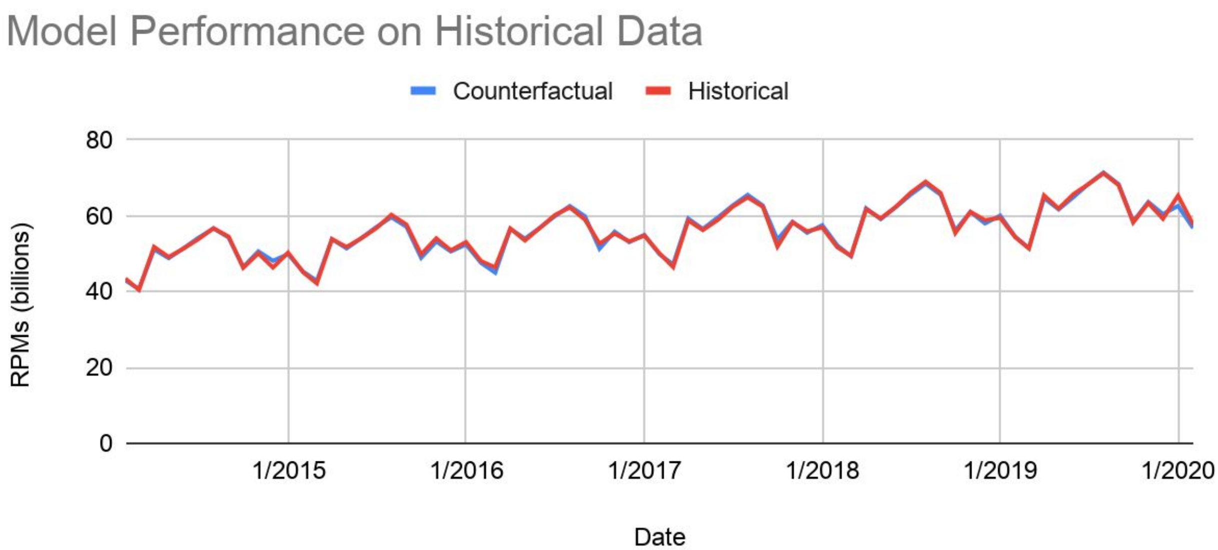

Figure 16.

As you can see, the counterfactual model serves as an excellent predictors for historical data, outperforming the predictive models. However, it is not enough to just visualize the performance. Table 4 shows different statistical metrics that measure how well the counterfactual model performs against historical data.

MAE (billions)	**RMSE (billions)**	**MAPE**
0.51	0.70	0.94%

Table 6.

References