Research Pathways for Sustainable Aviation

Abstract

In order to sustain the increasing rate of aviation/airline demand, there are several solutions that may be implemented. Two main focus points that are being researched and presented with solutions include scheduling and using alternative fuels. Our team centered its attention around these two themes where we researched ground scheduling solutions, such as Integrated Arrival Departure Surface (IADS) which impacts emissions on the ground, as well as alternative fuels which impacts emissions in the air. In our findings we will highlight the multitude of data we collected, identify several strengths and weaknesses of our proposed solutions, and discuss the next steps that can be taken to further improve our findings. Our findings show that softwares like IADS heavily impacts large international airports while biofuels are a key piece to reduce fossil fuel emissions.

Keywords

aviation, sustainability, green energy, renewable fuel, IADS

Authors

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1 Introduction

Carbon emissions in the aviation industry have been rising in recent years and are contributing to climate change. Emissions are being released in all stages of an airline's travel, from the ground to the sky. On the ground, airlines are spending numerous minutes waiting to depart from the gate while exhausting fuel. This fuel is being wasted and could be better used for the flight or not emitted on the ground at all. In the air, flights are emitting emissions at high levels and leaving behind contrails which reflect harmful rays back toward our Earth. When arriving, similar factors arise as when departing. As flights are waiting in lines before passengers can get off the plane they are wasting fuel and polluting the air.

All these issues are currently being examined and potential solutions are being studied to combat these problems. Solutions for flights wasting fuel on the ground involve solutions targeting scheduling and optimizing flight times. One solution that has been implemented to address this problem is a software called Integrated Arrival Departure Surface, or IADS. This program aims to efficiently aid air traffic control and create efficient departure times at terminals so planes are no longer exhausting fuel and wasting time in gateholds. For the issue of fuel releasing harmful emissions, solutions involve investing in alternative fuel production pathways. Fuels created through these alternative methods will reduce the overall emissions of the fuel from its production to its usage.

2 Scheduling

2.1 Schedule-Making Process and Issues

Due to its impact on ticket sales, the most important factor in an airline’s success is travel time. Travel time is a combination of time spent in-flight, connecting at different airports, departure and arrival times, and the available versus desired slots for arrivals and departures [1]. Hence, it is crucial that airlines put an emphasis on scheduling to decrease travel time. The first and most important part of scheduling is the process of creating a schedule. Whether the schedule regards flight scheduling, gate scheduling, or crew scheduling, it plays a large part in ensuring aviation efficiency. Airlines place a heavy emphasis on maintaining and improving the scheduling process. This idea was explored further by Dobson and their team at the University of Rochester [2]:

> The flight schedule fixes a large fraction of an airline’s cost, and also the routes the airline can offer. The schedule determines the quality of the airline’s service in terms of departure times and transit durations of routes. Quality of service and prices affect the airline’s ability to attract travelers. (para. 1)

2.1.1 Process

The flight scheduling process can span anywhere between three to six months. During the schedule generation process, three factors are considered: network design, frequency assignment, and flight schedule.

During network design, the airline identifies “origin-destination city pairs” to create a route network. The two most used route network structures are the hub-and-spoke network and the point-to-point network.

The hub-and-spoke network is made up of an array of “hub airports” throughout the country. The term “hub airport” is a phrase that refers to airports that are connected to the airline’s base. Many routes begin and end at hub airports in an effort to reduce downtime. A notable example is the Los Angeles airport, which is used to connect North American traffic to Asia. Hub airports rely on connecting traffic to fill their flights [3]. Banked hubs, a specific variant of the traditional hub airport, cluster flights around similar times to decrease travel time. As opposed to the hub-and-spoke network, the point-to-point network offers direct flights from the airline to the destination.

A second factor that is considered during the scheduling generation process is frequency assignment. Frequency assignment refers to the quantity of flights scheduled. The amount of flights an airline offers affects ticket sales through increased market saturation. With increased market saturation comes an increase in opportunities for passengers to choose a specific airline. It also affects the total travel time; “With an increasing frequency and, thus, number of departures, the difference between desired and offered departure time decreases, making each flight more attractive to passengers” [4-6].

Finally, flight scheduling is when expected departure times are determined. Arrival times are harder to schedule due to the varying aircraft speeds and uncertainty, so once the aircraft is chosen arrival times are determined.

2.2 Delays

A delay is classified by the Federal Aviation Administration (FAA) as a wait of 15 minutes or more after the scheduled departure time [7]. As inconvenient as delays may be, they are not at the fault of pilots alone. According to the Bureau of Transportation Statistics, 86.05 percent of flights were on time in 2021. Of the delayed flights, 37.13 percent of delays were due to air carrier delays, 27.60 percent of delays were due to late arrivals of aircraft, and 24.73 percent of delays were due to delays of the National Airspace System (NAS) [8]. Carrier delays can result from aircraft cleaning, damages, connecting traffic, baggage, cargo, delays regarding the crew, maintenance/inspections, fueling, and boarding. NAS delays can be attributed to certain conditions, including non-extreme weather conditions, heavy traffic volume, air traffic control, and individual airport operations. Further, crews can suffer from miscommunication, aircraft often fall victim to mechanical issues, and the systems in place are often flawed when it comes to real-life scenarios.

2.2.1 Weather

One of the most prevalent causes of delay is adverse weather conditions. Whether it be rain, snow, sleet, hail, or lightning, the weather is notorious for holding up flights. Weather accounts for 23 percent of all aviation accidents and approximately 70 percent of delays within the NAS

[9]. In 2013, the Federal Aviation Administration documented 6,700 to 7,800+ delays as a result of harsh weather within three airports: Newark, LaGuardia, and Kennedy. The peak of these delays were found in the months May-July. Surface wind, low ceiling and visibility, and convective weather accounted for the majority of these weather-related delays [10].

Convective weather consists of events such as thunderstorms, hail, heavy rain, icing, intense up- and downdrafts, lightning, tornadoes, wind shear, and strong low-level winds. Airports are highly affected by these events due to resulting closures, smaller capacity, lowered departure rates, higher operating costs, and higher maintenance costs. When considering issues with aircraft, icing is an issue that has long plagued operations. According to Wayne Golding of Embry-Riddle, icing is an: "...insidious trap set when stall speed increases from ice buildup on the wing, and then the trap is sprung on a surprised crew. With insufficient available thrust, the crew would be unable to accelerate while remaining in level flight…" [11]. It is crucial that the crew unload the plane through nose down elevation, increase airspeed, and make a safe landing. Not only do these statements stress the importance of weather-based delays, they enforce the importance of the crew behind air operations.

2.2.2 Crew

Due to the vital role that a crew plays in commercial aviation, that is, the plane cannot fly without its crew, it is imperative that crew-scheduling is accurate and robust. When crew-scheduling conflicts occur, delays may follow. After a schedule is designed and a fleet assigned, a crew is scheduled based on size of the aircraft and qualifications. The crew consists of people inside the plane and out, including flight engineers, flight attendants, and pilots [12]. The crew plays an important role in keeping an airline afloat and functioning.

Crew delays can come about when crew members have to move from one aircraft to another in a short period, rest requirements are ignored, and pre-existing plans conflict with flight schedules (e.g., appointments, leave, vacation, or training). While rare, crew delays can result in issues for air carriers [12]. To sum up, crew conflicts can result from human factors and result in what will be covered in section 2.3.

2.2.3 Maintenance

Aircraft maintenance is also a huge reason for delays. Maintenance is an ongoing process, and issues are either identified in previous flights or discovered during night shifts. Once issues have been identified, the airline managers assess how critical the error is and determine the amount of time needed to fix the issue. Airplane maintenance is generally separated into a three step process. First, the problem is identified and reported. Then, the plane is taken to the technicians and they troubleshoot the issue. Finally, any identified errors are fixed. If no issues are reported then the crew performs maintenance checks during the night shift. Any identified problems are classified as either "deferrable" (noncritical) or "not deferrable" (critical) [13].

2.3 Problems from Delays

Delays are detrimental to an airline's success. They can wreak havoc on scheduling, profit, and the environment. "These delays have huge cost implications - for the U.S. economy these costs were estimated at $32.9 billion in 2007" [14]. By sitting on the ground with no purpose, aircraft are burning excess fuel, which in turn, releases carbon emissions into the atmosphere. These emissions contribute to the greenhouse effect, blanketing the planet in its heat and contributing to climate change. Another notable consequence of all of this is aviation noise, which will be covered in section 2.5.1.

2.4 IADS

IADS, or Integrated Arrival, Departure, and Surface Operations, is a software that NASA has been developing over the recent years to better optimize and schedule arrivals and departures. This solution came to fruition when it was noticed that the emissions released while planes were idle on the ground was very alarming. The major causes of delays at airports was the NAS or National Airspace System delay that planes were facing on the ground. According to the FAA, between June 2003 and December 2016 19.41 percent of flights were delayed at Charlotte National Airport. Overall, 7.06 percent of flights were delayed due to the NAS delay. The second leading cause of delay being Aircraft Arriving Late: responsible for 5.33 percent, Air Carrier Delay: 4.83 percent, Cancelled Flights: 1.5 percent, Weather Delay: 0.5 percent, Diverted Flights: 0.15 percent, and Security Delay: 0.04 percent summing up to the 19.41 percent of total flights being delayed [15]. The NAS delay takes the plurality of the causes of delay. Due to the NAS delay being the leading cause of delays, IADS was made to combat it.

Charlotte Douglas International Airport being used as the example for NAS delays, as IADS was implemented into this airport during 2017. The results of implementing IADS were clear. Between June 2003 and December 2016 the NAS delay was 7.06 percent and between January 2017 and May 2021 the NAS delay had dropped to 4.05 percent [15]. Additionally, in the first two phases of ATD-2, IADS was able to save over 1 million gallons of fuel, 21 million lbs of CO_2, and 5,000 hours of engine run time, according to Jeremy Coupe's presentation regarding IADS on June 14th, 2021 [16].

All these benefits were most reasonably tied into the implementation of IADS. Looking at the results of ATD-2, as shown in Figure 1.0, the NAS delay in Charlotte did significantly decrease. Figure 1.0 depicts the graph of the NAS delay of flights in Charlotte Douglas International Airport from 2013 to 2019 from data taken from the FAA [15]. The y-axis represents the delay in minutes due to NAS delay and the x-axis represents the year. One data point represents the sum of delayed minutes from one airline in a given month of that year. So, for example, the year 2017 may have 144 data points as it depicts the delay from 12 airlines over the span of 12 months. The green line between year 2016 and 2017 represents the time when IADS was implemented and is used to show how the data changes over that time. As seen in the graph the data becomes more concreted in the 0 to 10,000 minute delay interval in the years following the implementation of IADS compared to before it was implemented. These data points show how

IADS was working and used to reduce the NAS delay. However, other domestic international airports that did not have AIDS implemented paint a different picture. Several other airports are still struggling with their NAS delay. In Figure 1.1 and 1.2 data is being depicted the same way it was in 1.0, but in these graphs there are significant differences. Figure 1.1 depicts the NAS delays for airlines in LaGuardia International Airport in New York. With the red arrow it can be seen that the NAS delay data points are trending upwards as the years go on. Additionally a similar trend can be seen in Figure 1.2, illustrating the NAS delays in Newark International Airport in New Jersey. Here, an almost opposite trend of Charlotte Douglas International Airport is seen where the data points become more concentrated in the higher delay intervals between 10,000 and 50,000 minutes. This shows how IADS does make a difference at airports and NAS delays do not seem to be going down on their own. IADS does make a difference and it is clear in its implementation in Charlotte. Airports like LaGuardia and Newark could benefit from this software as their data conveys NAS delays headed in the wrong direction.

Departures are where IADS had the greatest impact, as seen in Figure 1.3, which depicts the departure delay of flights in 2018 on Charlotte Douglas International Airport [16]. This graph shows the time difference of a flight on the y-axis where it is calculated by taking the actual time a flight departs and subtracting it from its scheduled departure time. This calculation is found in minutes, and a positive difference would represent a flight leaving "n" minutes after its scheduled time and a negative difference would represent a flight departing "n" minutes before its scheduled time. Ideally, flights would actually depart at their scheduled time causing a difference of 0, but with the data in Figure 1.3 it can be seen that the differences vary. The blue line represents this ideal difference of zero and is plotted to put in perspective how far or close the data is from the ideal difference. The x-axis represents the number of unique flights and is sorted by date with the earliest flight in that year at x=0. All flights were from 2018 and every 4th flight was taken from the data set given from Jeremy Coupe. Meaning ¼ of the flights are shown in the regressions of Figure 1.3 and 1.4. Only ¼ of the data set was taken because the data was too large to compute and plot all of it. The regression was made using a scikit-learn pre-built algorithm called polyfit. Several regressions were run with different degrees of polynomials to find which equation best fit/represented the data. The regressions were evaluated by their r2 score, a statistical term used to find how close data points are to the regression. The regression with the lowest r2 score was used and both Figure 1.3 and 1.4 used a polynomial with a degree of 3 to plot the line of best fit. Since the data is only representative of ¼ of the entire data set, the real regression may have a slight difference in slope, but still the same overall trend without any dramatic discrepancies. The exact details for how all the graphs were made can be found on Github at github.com/FardinHaque60/Team-Falcon-Data-Analysis.git.

As observed in Figure 1.3, the trend of the regression is initially going upward, but then continuing downward for the rest of the plot. This shows a positive impact that AIDS is making as the regression is going downward as the number of flights increases, delays are decreasing as more flights depart. To compare this to Figure 1.4 that follows a similar scale, data source, and regression as Figure 1.3, it can be seen that their regressions are very similar but Figure 1.4 has a less steep downward regression [16]. This may be due to the fact that this Figure is representing the arrival delay at Charlotte Douglas International Airport versus the departure delay in Figure 1.3. IADS is known for optimizing flights leaving the terminals at its host airport, but cannot have as much control over flights coming in from other airports. The software can have some control over the flights when they land, but the majority of arrivals are mostly in the hands of the airports they are departing from. This reveals how IADS has significant control over reducing the departure delay and not as much control over arrivals, but this can be changed if IADS is implemented into more airports where it can be used to communicate information between airports in a network.

Graphs

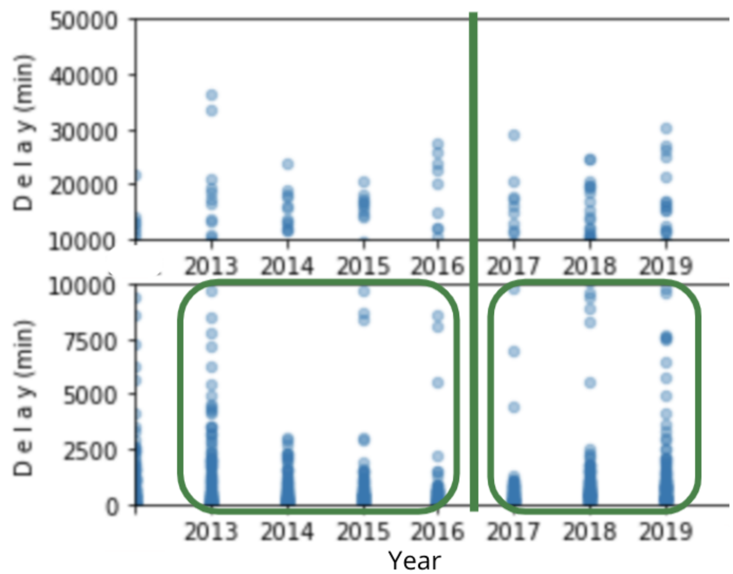

Figure 1.0: NAS Delay of Planes in Charlotte Douglas International Airport between 2013 and 2019

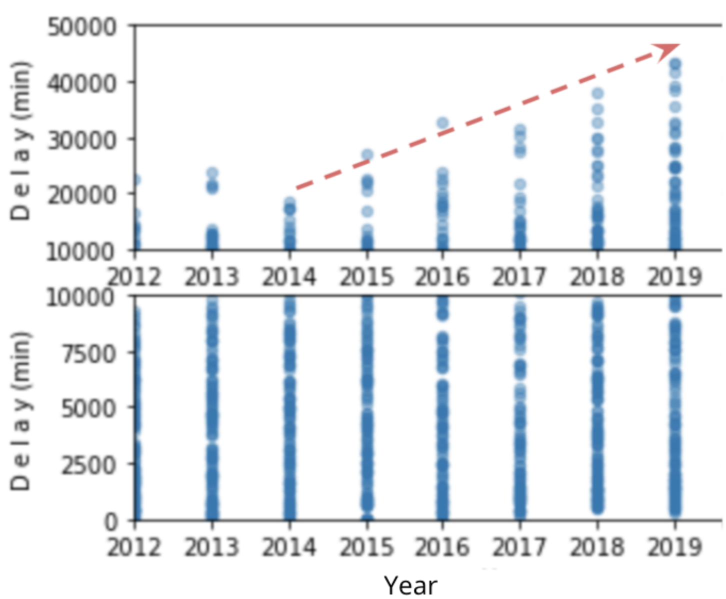

Figure 1.1: NAS Delay of Planes in LaGuardia International Airport between 2013 and 2019

Figure 1.2: NAS Delay of Planes in Newark International Airport between 2013 and 2019

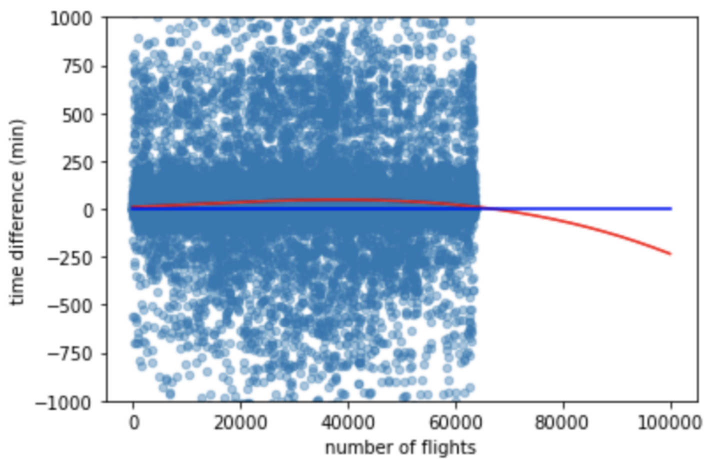

Figure 1.3: Regression of the trend depicting time difference between actual and scheduled departure times.

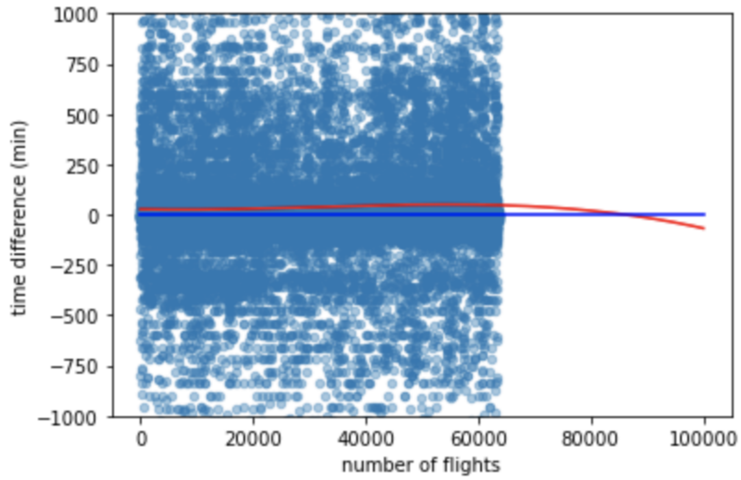

Figure 1.4: Regression of the trend depicting time difference between actual and scheduled arrival times.

Graphs

2.5 Impacts

The impacts of implementing IADS in airports range from conservation of resources to reduction in aviation noise. This research recommends expanding IADS to multiple airports nationwide and implementing trend tracking to best extend this impact.

2.5.1 Conservation of Resources

Implementing IADS in more airports can reduce delays, allowing aircraft to spend less time in flight. Reducing these flight delays and enforcing better scheduling procedures can conserve resources such as fuel, time, and money. The Boston Consulting Group reports that reducing a minute off the time each aircraft remains on the ground can save nearly 5 to 10 million dollars a year in operational costs [17]. Decreasing delays will also benefit the environment: for every kilometer of travel that is reduced, about 254 grams of carbon dioxide is conserved on domestic flights [18].

2.5.2 Aviation Noise

An increase in the number of operations will be accompanied by an increase in aviation noise. The sounds produced by airplanes in flight are associated with a multitude of health effects, impacting the surrounding community and creating ecological consequences. Noises higher than 140 decibels are associated with a myriad of illnesses including sleep disturbance, hypertension, hearing impairment, and heart disease [19]. Furthermore, a study at the Cologne Airport in Germany found that daily exposure to aviation noise increased the risk of heart disease by 61 percent in men and 80 percent in women, with similar findings regarding the risk of heart attacks [19]. Environmentally, consistent exposure of local wildlife to aviation noise can lead to change in foraging patterns, breeding behaviors, and home ranges. Aviation noise also often elicits panicked behavior in wildlife, a similar response to natural predators, leading to more energy expunged. This use of excess energy makes it difficult for larger animals to recuperate, especially during the winter months [20]. Therefore, exposure due to aviation noise can impact the ecological system of an area.

2.5.3 Expansion of IADS

As mentioned in section 2.4, the full benefit of IADS can only be achieved if it is implemented into multiple airports so arrivals and departures can be reduced simultaneously. As seen in Figure 1.2, the slope of the arrivals regression is not as dramatic or steep as the slope of the regression in Figure 1.1. This could be improved if IADS were to be implemented into more airports. The improved scheduling of departing flights would likely result in flights arriving earlier at their destinations. The coexistence of this software being implemented across the NAS, rather than at only one or a few airports, can open up the full impacts of this system. With IADS fully integrated across the NAS, a reduction in overall delay would be expected. This would be very desirable at all airports because it would allow passengers to takeoff and disembark from the plane quicker.

2.5.4 Trend Tracking

Since IADS is a machine learning optimization solution to combat delays at airports, sufficient data analysis would be a key factor to take note of when implementing this into airports. At Charlotte Douglas International Airport IADS took roughly two years to implement and saw stunning results, but there can be several lessons learned from this implementation. The two year implementation period may be reduced for future instances and this may lead to quicker results for busy airports who are short on time. Airports like Newark International and LaGuardia see some of the highest delays in the nation, but at the same time do not have time to implement a software over the span of two years. To solve this, the use of data analysis and machine learning can be used to optimize the implementation of IADS. The basis of IADS is a machine learning algorithm, so teaching it quicker can very easily reduce wait times. Having data analytical teams onboard with daily feedback on IADS reports would be helpful to identify what small changes can be made on the fly in order for implementation times to be cut down to a year, or even to a few months.

3 Fuel

Fuel presents one of the largest problems with sustainable aviation. Conventional jet fuel harms both the environment and economy, with a myriad of adverse health effects. Unlike scheduling, however, the solution cannot simply be optimization, but a complete overhaul of the process. This research proposes three alternative fuel options and a goal programming model to decide which one to pursue.

3.1 Introduction to Environmental Problems with Fuel

Conventional jet fuel (CFJ) currently has environmental and economical problems that make its long-term use in aviation unsustainable. CFJ's main environmental issue is that it releases both carbon and carcinogenic particles. The carbon emissions come from CFJ being sourced from refined crude oil, which also has high aromatics content. The carbon emissions will become trapped in the atmosphere and contribute to climate change. CFJ also has a high aromatics content, which causes problems for the environment and the performance of the aircraft. Firstly, carcinogenic particles are released from aromatics, hydrocarbons in jet fuels, which are necessary in CFJ due to it being high octane and have properties that help jet engines seal properly to prevent leaking. However, because the carcinogenic residue left by aromatics causes adverse health effects to surrounding communities, like increasing cancer vulnerability, they are unsustainable in fuels. As for aircraft performance, when fuels with high amounts of naphthalene, an aromatic hydrocarbon found in CFJ, is burned, carbonaceous particles are formed, which can reduce airflow and cause performance failures if not completely consumed by the flame in the aircraft's engine [21]. The second problem with CFJ is its economic sustainability. Because CFJ is sourced from crude oil, which has a limited supply and high demand, the cost combined with the environmental repercussions of CFJ is not a desired investment. Thus, investing in alternative fuels like bio-aviation fuels (BAF) should be considered; BAF is a biomass-derived synthesized paraffinic kerosene blended with CFJ at usually 50 percent. The three main alternative production pathways for BAF that will be discussed are Hydroprocessed esters and fatty acids (HEFA), Fischer-Tropsch (FT), and Alcohol-to-Jet (ATJ).

3.2 Hydroprocessed esters and fatty acids (HEFA)

HEFA uses mainly first and second generation oil rich feedstocks, such as animal fats and vegetables oils, and its quality is independent of the feedstocks used. HAIFA's ability to access a wide range of oils, in both variety and quality, enables its global production using current-day technology. Another benefit to using HEFA is that its production process is highly efficient. During the early stages of the production process, an exothermic reaction occurs. By reusing the energy generated during this exothermic process the overall energy usage throughout this process can be reduced, ultimately creating positive economic and environmental implications. In addition to higher quality production when compared to Jet A fuel, HEFA boasts superior characteristics such as a "higher heating value (44 MJ/kg) and faster ignition," decreased susceptibility to oxidation, and reduced soot generation with a 35 percent blend of HEFA with Jet A-1 [22].

However, a downside to fuel via HEFA is that while it meets jet fuel standards and can be deployed commercially, its production is heavily limited by resource availability. Currently, the supply of oil HEFA draws from is more naturally suited for diesel fuel rather than jet fuel. Converting the oil supply would require large amounts of hydrogen, which are not available due to high global demand.

3.3 Fischer-Tropsch (FT)

Advantages of fuel via FT is that it uses established resources such as fossil fuel feedstocks like coal and natural gas, and uses established technology in producing liquid transportation fuels. This enables BAF created through FT to be more commercially ready than other BAFs. Another benefit to using FT fuels is they contain aromatics within the standard range. This enables them to be compatible with most commercial airplanes, all while being 100 percent BAF. Fuel via FT also is generally sulfur-free, so when burned it will result in reduced emissions compared to CJF [22]. Additionally, FT technology can produce cheap fuels at prices competitive with crude oil, allowing easier market penetration.

FT, while ready for commercial deployment, will suffer in the long-term as it is sourced from coal and natural gases, a relatively unstable source due to its finite supply and negative environmental impacts. The aromatics found in FT fuels will also contribute to a negative environmental impact. Further, aromatics were found to be unnecessary in more advanced plane technology (currently only used in the military).

3.4 Alcohol-to-Jet (ATJ)

A benefit to fuel via ATJ is that it sources from sugar-rich biomass feedstocks which are converted into ethanol through fermentation, allowing ATJ to access a variety of feedstocks. ATJ is also flexible in that “When ethanol is used as a feedstock, the choice of intermediate defines the reaction pathway taken; examples of the intermediates include ethylene, propylene, higher alcohols, and carbonyl... Brooks et al. (2016) compared these technologies with a variety of parameters including catalyst cost, process efficiency, level of maturity, and process complexity.” Each intermediate produced unique results in regards to those parameters [22]. Additionally, while not as commercially ready as HEFA or FT, ATJ holds equal or greater potential as a green commercial fuel. First, similar to FT fuels, ATJ fuels contain permissible quantities of aromatics and therefore could push for a 100 percent BAD fuel. Second, the production of ATJ by LanzaTech is environmentally friendly as it recycles carbon in waste gas from steel production that otherwise would have been emitted to the atmosphere [23]. Last, Ethanol production is a well-established process, making retrofitting a facility to produce jet fuel a strong method to mass produce ATJ BAF.

The main limitation to ATJ fuel is that it will compete with the petrochemical industry (automobile fuel). That, combined with ATJ’s low yield with bio-alcohol production, will make it difficult to profit from. Lastly, it also contains aromatics which will have negative environmental implications.

3.5 Multi-Objective Goal Programming Model

Goal programming is a branch of multi-objective optimization and decision analysis. The first idea of goal programming arose after the end of WWII. It was mainly used to help solve industrial issues after the war. But, over time it evolved to be able to handle many different goals and objectives and the idea of goal programming as a decision analysis method evolved [24].

The different parts of a goal programming model include decision variables, criterion, an achievement function, goal function, positive & negative deviation, and constraints.

A multi-objective goal programming model was created to analyze each of these promising forms of alternative fuel and help decide which would be the most efficient by optimizing a set of goals while of course also taking into account different constraints and issues. The priorities, which are also known as decision variables, are the main objectives of any goal programming model. Overall, three main objectives were identified: economic sustainability, operational efficiency, and natural resource conservation.

The first objective identified was economic sustainability. Economic sustainability is the progression of economic growth without the compromise or negative impacts on different aspects of our community and environment. The goals used as a part of this objective relate to the betterment of the economic impact and footprint left by aviation. The goals included in this first objective include the maximization of mobility which would involve increasing the number of flights, travels per flight, and increasing the number of seats and cargo per flight. Additional goals that are a part of this first objective would be minimizing the cost of transport and the use of fuel. Fuel usage would be minimized by solving the many scheduling issues mentioned earlier with the further implementation of IADS in airports across the country as well as the improvement of modern technology. For example, current aircraft engines are designed to run on our current form of fuel and making the switch to a more eco-friendly fuel option might result in the complete renovation of aircraft engines.

The next objective was operational efficiency - the measurement of the efficiency of profit earned as a function of the necessary costs. The goals in this objective would include traffic planning and minimizing the turn around of aircrafts. Both of these goals would be greatly beneficial to the overall efficiency of the aviation industry as we would be able to make the maximum amount of profit while taking the required expenditures into account.

The final priority that we searched through was natural resource conservation. Natural resource conservation as a goal focuses on the minimizing of the overall impact on natural resources that come as a result of the improvement of the aviation industry. The goals involved in this objective include minimizing the depletion of natural resources needed to utilize fuels, waste minimization, as well as the minimizing of the total land area [25].

Goal Programming Model Outline

Objective 1: Economic sustainability

- Goal 1: Flight numbers (max)
  - Number of flights
  - Total passengers per flight
  - Increasing # of seats per flight
  - Increasing Cargo per flight
- Goal 2: Cost (min)

- Goal 3: Use of fuel (min)
    - Improving upon current technology
    - Improving scheduling with IADS as mentioned earlier in our presentation

Objective 2: Operational Efficiency
- Goal 4: Air traffic planning (max)
- Goal 5: Turnaround of aircrafts (min)

Objective 3: Natural Resource Conservation
- Goal 6: Depletion of natural resources required to utilize fuels (min)
- Goal 7: Total waste (min)
- Goal 8: Total landing area for aircrafts (min)

The three most prominent types of goal programming models are fuzzy Chebyshev models which essentially create a model for a utility function where the max deviation is minimized, lexicographic models which are used to order the deviations into a number of priority levels, and finally Archimedean models which primarily focus on comparing the goals and priorities themselves.

Chebyshev goal programming was introduced in 1976. Its main purpose is to minimize the total unwanted deviation instead of simply the sum of the deviations. It is also the most common form of modern goal programming. Lexicographic goal programming is used when a clear hierarchy or importance between the main objectives exists. It orders the unwanted deviations into priority levels and tries to minimize the higher ranked deviations first. Archimedean goal programming works to compare and contrast the goals within the objectives and rank them individually [24].

Chebyshev models would be the most applicable for the way the main three objectives were structured for this specific goal programming model.

The Chebyshev model below was created with certain constraints in mind. These constraints would be taken into account along with our priorities in order to ultimately analyze each possible alternative fuel. Financial issues which entails a limitation of funds and costs when it comes to these expensive forms of fuel. Though natural resource conservation is used as one of the three primary objectives of the model, its limitation and non-renewability almost required it to be included in the constraints category as well. This was important because some of these identified alternative fuels, like HEFA, may be problematic as a result of the limited natural resources.

The following model expects to be able to efficiently optimize each priority in our model to come to a fuel source that is essentially “the best of all worlds” and maximize overall sustainability. It is very adaptable to inclusion and revision of new goals and even whole objectives, making it very modular and accessible to be used in the future as well.

Minimize

$$\sum_{i=1}^{m} w_1 [\, d_1^+ + d_2^- + d_3^+ \,] + w_2 [\, d_4^+ + d_5^- \,] + w_3 [\, d_6^- + d_7^- + d_8^- \,]$$

Subject to

Economic Sustainability goals:

$$\sum_{j=1}^{n} A_{fnij\ (flight\text{-}numbers)}\, X_{fnj} = b_1^{ES} - d_1^- + d_1^+$$

$$\sum_{j=1}^{n} A_{cij\ (cost)}\, X_{cj} = b_2^{ES} - d_2^- + d_2^+$$

$$\sum_{j=1}^{n} A_{ufij\ (use\text{-}of\text{-}fuel)}\, X_{ufj} = b_3^{ES} - d_3^- + d_3^+$$

Operational Efficiency Goals:

$$\sum_{j=1}^{n} A_{atij\ (air\text{-}traffic\text{-}planning)}\, Y_{atj} = b_4^{OE} - d_4^- + d_4^+$$

$$\sum_{j=1}^{n} A_{taij\ (turnaround\text{-}of\text{-}aircrafts)}\, Y_{taj} = b_5^{OE} - d_5^- + d_5^+$$

Natural Resource Conservation Goals:

$$\sum_{j=1}^{n} A_{drij\ (depletion\text{-}of\text{-}natural\text{-}resources)}\, Z_{drj} = b_6^{NRC} - d_6^- + d_6^+$$

$$\sum_{j=1}^{n} A_{wij\ (total\text{-}waste)}\, Z_{wj} = b_7^{NRC} - d_7^- + d_7^+$$

$$\sum_{j=1}^{n} A_{laij\ (total\text{-}landing\text{-}area)}\, Z_{laj} = b_8^{NRC} - d_8^- + d_8^+$$

Financial Issues: $\sum_{j=1}^{n} F_j \le T_F$

Limited Resources: $\sum_{j=1}^{n} R_j \le T_R$

and $X_j, Y_j, Z_j, d_i^-, d_i^+ \ge 0$

The following notations are used in this model:

w = goal/objective

d^+ = positive deviation for given goals when they are overachieved

d^- = negative deviation for given goals when they are underachieved

b represents the threshold levels for goal i

X, Y, and Z are the decision variables for achieving each of their respective objectives

Constraints:

F_j is the funds used on any specific goal and T_F represents the total funds

Similarly, R_j is the amount of resources needed for any specific goal with T_R being the total amount of resources allocated to NASA to use for fuel.

Included below is a general goal function that can be applied in accordance with the main achievement function to any goals that may be added in the future for this specific goal programming model:

General Goal Function:

$$\sum_{j=1}^{n} A_{ij} Z_j = b_j - d_j^{\pm} + d_j^{\pm}$$

Unfortunately, due to many of these fuels being relatively new and untested, there is not enough relevant data to utilize this model at this time, but as more data arises, it can be used once more testing has been done and will help decide which alternative fuel of the three that we identified would be the most efficient.

A brief explanation of how exactly this can be utilized is through fuzzy logic and sets. Fuzzy sets are used to handle concepts involving partial truth or in this case, imprecise goals. These imprecise goals would be the same goals and objectives in the model, making goal programming an ideal approach when it comes to the determination of alternative fuels. The fuzzy sets would be used along with big data methods as an input for these mathematical models to help determine which goals are under- or overachieving for which specific fuels, and ultimately help optimize each of these and decide which would be the most efficient.

3.6 Impacts/Conclusion

The two proposed solutions that would create large impacts in sustainable aviation include optimizing scheduling and using biofuels as an alternative fuel source. Both of these solutions present promising means of reducing emissions, as shown by past data.

Scheduling has been a problem that NASA has already targeted and taken into account with its implementation of IADS. As shown in section 2.4, with the implementation of IADS into Charlotte Douglas International Airport improved scheduling can be used to reduce delays for both arrivals and departures, a key takeaway from IADS implementation. IADS primarily improves departure efficiency and should be implemented at more airports to realize its full benefit. The largest benefits would be obtained at larger airports that typically have higher demand and frequency of flights.

The target for biofuel consumption by 2022 is about 36 billion gallons of renewable fuel per year. With the use of biofuels, carbon dioxide emissions will greatly reduce both through direct and indirect manners. While renewable fuel is more expensive compared to conventional jet fuel, this cost increase will indirectly decrease carbon dioxide emissions since airlines would be more efficient and conscious [26]. Additionally, some of this extra cost would be passed down to the consumer, slightling reducing the need for “aviation services.” The environmental advantages of sustainable jet fuel consumption will ensure that conventional fuels will no longer be the norm in the future. Data from the Transportation Research journal further illustrates the benefit of renewable fuel over conventional fuel sources. About 23 pounds of carbon dioxide (CO2) are released per gallon of conventional fuel. On the other hand, renewable fuel releases just 9.6 pounds of CO2 per gallon. For each gallon of conventional fuel that is replaced with biofuel, carbon emissions will be decreased by 13.4 pounds. From this, about 150 gallons of renewable fuel can reduce carbon dioxide overall by one ton, preventing some of the adverse environmental effects resulting from the usage of conventional fuel. Lastly, about 400 dollars are saved per ton of carbon dioxide that is not expunged into the atmosphere [26].

4 Conclusion

Two probable solutions that can be focussed on when approaching sustainable aviation include IADS and the implementation of biofuels. With regards to AIDS, this software is able to optimize flight scheduling, reduce NAS delays, and create an overall more efficient departure for airlines. However, there are two main facets that require further attention when going forward with this software. IADS may be improved to have shorter implementation periods and involve data analysis and trend tracking when being applied into airlines. Shorter implementation times will be key as Charlotte Douglas International Airport took roughly two years to implement IADS and other domestic airports may not have that amount of time to implement a new software.

In order to shorten this implementation period, data analysis may be used to understand where IADS is falling short and target those issues first hand. Additionally, IADS is a machine learning based program and may require changes to be made where appropriate to best suit its host airport. Data from past IADS implementations can be used as supervised learning and extra data to gauge how well IADS is doing in its current airport. This will prompt changes to be made more quickly when a larger sample size is available to analyze the efficiency of the software.

Because there are several biofuel options, each with their own advantages and disadvantages, an extensive amount of data is necessary to conclude which biofuel to focus on. However, biofuels have had relatively little commercial testing, and there is little raw data. Once a larger set of data becomes accessible, the goal programming model can be used to calculate the most cost-efficient and environmentally friendly fuel.

The impacts of implementing IADS and biofuels are vast if explored to their fullest potential. This research recommends expanding IADS to as many domestic airports as possible to not only increase the amount of data available for optimizing software, but also to increase its effect on arrival scheduling. If biofuels are implemented, airports stand to convert to as much as 36 billion gallons of renewable fuels a year. These measures allow for less carbon emissions and less aviation noise, with the potential to mitigate the effects of climate change.

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