CORPORATE RESPONSIBILITY FOR THE U.S. AIR NAVIGATION SERVICE PROVIDER: A DECISION SUPPORT TOOL TO REDUCE CO$_2$ EMISSIONS FROM EN-ROUTE FLIGHTS

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Abstract — **The rise in aviation-related emissions accompanying the increase in demand for air travel is raising concerns about aviation's impact on the climate. There is a growing public interest in climate change issues as a body of activists drives corporations to heed environmental concerns. The Federal Aviation Administration (FAA), the Air Navigation Service Provider (ANSP) for the U.S., controls the transit time for flights in its airspace, which is a major factor that determines the fuel burn and emissions produced. However, the FAA has no current system to estimate emissions from en-route operations, measure performance and set targets for improvement. The purpose of this paper is to provide the U.S. ANSP, the FAA, with a decision support tool to estimate the CO$_2$ emissions produced from en-route flights and analyze alternative routes to increase the ANSP's performance in regard to CO$_2$ taking into consideration the workload of air traffic controllers. The focus of the analysis is to evaluate the impact of using user-preferred routes on the ANSP's performance, which the current U.S. Airspace does not support their use. The alternatives are Near Wind Optimal Routes (NWORs), Great Circle Distance Routes with wind effects, for flights in one or more of the four distance categories of the baseline (Flights flying: less than 500, from 500 to 999, from 1000 to 1500 and greater than 1500 nautical miles). The tool, Aircraft Emissions Decision Support Tool (AEDST), is a deterministic model developed to calculate the fuel burn and emissions for any aircraft given the trajectory data (longitude, latitude, altitude, velocity, and time). The Future Air Traffic Management Concepts Evaluation Tool (FACET) was used to calculate the number of conflicts between flights, which represent the air traffic controllers' workload. The results show the improvement in the ANSP's performance by implementing NWORs for flight distances less than 1500 nautical miles by 19%, which provide the airlines with approximately $16M in fuel savings. Implementing those routes also reduces the workload of air traffic controllers by 2.5%. We recommend making the necessary policy and airspace structure changes to support the use of those routes.**

I. INTRODUCTION

The rapid growth in demand for air travel is increasing the concerns about aviation's impact on climate change. However, because the system is operated by multiple enterprises (i.e. airlines, air navigation service providers, airports, etc.), no single enterprise can be held responsible for emissions. Today, there is a growing public interest in climate change issues and a growing body of activists speaking against corporations that do not heed to environmental concerns. National Air Traffic Services (NATS), the Air Navigation Service Provider (ANSP) for the United Kingdom, designed a corporate responsibility metric called 3Di (3-Dimensional Inefficiency Score). The metric compares the amount of CO$_2$ emission produced from actual routes that aircraft take versus the amount that would be produced from Great Circle Distance (GCD) routes (shortest distance). Through this comparison, NATS established a clear indication of the environmental services it provides, tracked its performance over time, and set targets for improvement [1]. This is an important step to reduce aviation related emissions, in particular CO$_2$, that keep increasing and contribute to the Greenhouse gas effect, which leads to climate change and related consequences, such as floods, storms, and droughts [2].

The Federal Aviation Administration (FAA), ANSP for the U.S., does not utilize such a system because of the absence of incentive to measure their environmental performance. Whereas the U.S. ANSP is a government monopoly and does not have any competition, unlike NATS, which is a privately owned ANSP that has to renew its contract every couple of years, thus it has the motivation to improve. However, the FAA would like to implement a similar system to the 3Di because they will eventually have to take steps to reduce aviation's emissions [3].

One main factor that determines the fuel burn and the emissions produced from a flight is the transit time of the route controlled by the ANSP. For example, the least fuel burn route would be one with the shortest transit time. In a no wind scenario, the shortest transit time route is a GCD route. In the presence of wind (e.g. Jet Stream), the shortest transit time route is the wind-optimum profile. Figure 1 provides a graphical representation of an airway route, a GCD route, and a wind optimal route.
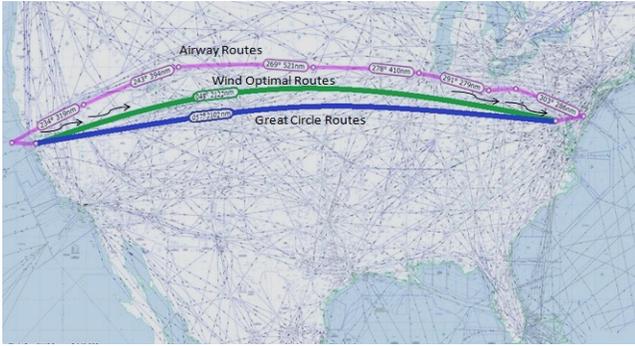
Fig. 1. Airway Route vs. Great Circle Route vs. Wind Optimal Route

Today, most flights must use jet routes, and airways routes, instead of flying user-preferred, wind optimal routes, which are within the airlines' planning capability. This is due to the current structure of the U.S. Airspace that does not support the use of those routes. It is also done for safety to avoid increasing the air traffic control workload, which is resolving conflicts between aircraft that violate vertical and lateral separation, the basis for en-route safety [4]. One flight conflict is the loss of separation between two aircraft. It occurs when aircraft are within five nautical miles laterally and 1000 feet vertically from each other [see FAA Order 7110.65].

This paper explains the design of a *decision support tool* for the U.S. ANSP to estimate the fuel burn and CO_2 emissions produced from en-route flights, making it possible for the FAA to track their performance, and use that information to make changes, which give airlines more options (shorter, more optimal routes) when filing flight plans. The paper analyzes the performance of the ANSP using one day of traffic, measured in terms of transit time, fuel, and, emissions. The paper discusses possible improvements in performance by implementing Near Wind Optimal Routes (NWORs) for flights in one or more of the flight distance categories taking into account the workload of the air traffic controllers.

II. STAKEHOLDER ANALYSIS

There are four major stakeholders with different objectives involved in the project:

A. Air Navigation Service Providers

The ANSP is the primary stakeholder for this project. It is the organization that oversees Air Traffic Control (ATC), which is comprised of Air Traffic Controllers, Air Traffic Control Managers, and Air Traffic Flow Managers. Air Traffic Controllers provide safe separation of traffic in the National Airspace System while Traffic Flow Managers want to ensure the capacity available is used efficiently and approve flight plans filed by the airline dispatchers on that basis.

B. Airlines

Airlines are organizations that provide regular passenger air service. They are broken down into management, pilots,

and dispatchers. The airline management's objective is to reduce cost and maximize profit. One major cost that burdens the airlines is fuel, which accounts for ~ 35% of the operational cost [5]. The airline dispatchers are the ones responsible for filing the flight plans with the ANSP based on the weather and the wind, which provides the best fuel savings for the airlines. The flight plan is then approved in the collaborative decision-making between the dispatcher and the ANSP, more specifically the flow managers.

C. Citizens/ Climate Change Advocates

Citizens are recognized subjects of a country and have different opinions and objectives. The climate change advocates set the environmental goals that are pursued by the citizens, such as reducing the amount of CO_2 emissions in the air that cause climate change and global warming.

D. Government Regulators

Government regulators are broken up into legislative and executive branches; Congress is within the legislative branch and the federal government is considered the executive branch. The federal government is comprised of many departments that include the Environmental Protection Agency (EPA), the Department of Energy (DOE), and the Department of Transportation (DOT). The FAA falls under the DOT in this hierarchy. The objectives of the different government regulators vary from safety, to performance, to protection of human health and the environment.

E. Stakeholder Interactions and Tensions

Earth produces environmental effects causing citizens and climate change advocates to report emissions issues to Congress, who represent the citizens in the government. Subsequently, the executive branch is pressured to solve these problems. The Executive Government Regulators enforce guidelines that are set by EPA, DOE, and DOT, who provide the FAA with the standards regulated to the ANSP and the airlines. The airlines' flight routes, filed by the dispatchers, are approved by the ANSP in the collaborative decision-making.

Tensions, such as changes in the agreed upon flight plans due to weather and airspace congestion, occur between the ANSP and the airlines, which are the two major stakeholders. Those changes lead to deviation from the flight route causing an extensive use of fuel, and thus an increase in emissions. This leads to a conflict of interest, as the airlines want to save fuel while, the ANSP wants to maintain safe separation of aircraft without exhibiting special preference in flight routes to one airline over another. This further causes tension between government regulators, and citizens and climate change advocates, who demand climate change issues to be addressed. Consequently, this leads to tensions between government regulators and the ANSP because regulators want the ANSP to maintain safety and increase performance, while the ANSP has no incentive to do so.

III. PROBLEM, NEED STATEMENT & SYSTEM SCOPE

A. Problem Statement

The FAA, ANSP for the U.S., has the opportunity to improve its en-route operations with regard to environmental decisions by exercising corporate responsibility. The FAA currently has no system to estimate emissions, measure performance of en-route flights, and make changes that give airlines more options while filing flight plans.

B. Need Statement

There is a need to provide the FAA with a *decision support tool*, **Aircraft Emissions Decision Support Tool (AEDST),** to calculate emissions, measure performance, and evaluate alternatives for goals in emissions reduction.

C. System Scope

The scope of the project is limited to the ANSP's operations within the climb, cruise, and descent cycle (CCD). It includes the evaluation of the ANSP's performance for domestic commercial, air taxi, and business flights with a cruising altitude of 18,000 ft. and above in the NAS using a single day of traffic (January 17th, 2011).

The CCD cycle includes all activities that occur at altitudes above 3000 ft., which comprises the phases of flight:

- Climb: actual operations of increasing the altitude of the aircraft and the one where the most fuel burn occurs
- Cruise: level portion of aircraft travel and occurs between climb and descent and the most fuel efficient phase of flight
- Descent: aircraft decreases altitude before landing on the ground

IV. DESIGN ALTERNATIVES

A. Baseline Routes Analysis

Before proposing alternative routes, the analysis of the current status (Airway routes) was required to categorize the flights in regards to the distance flown and emissions produced. Figure 2 shows the average emissions produced from each flight and from each nautical mile flown by stage lengths of 100 nautical miles.
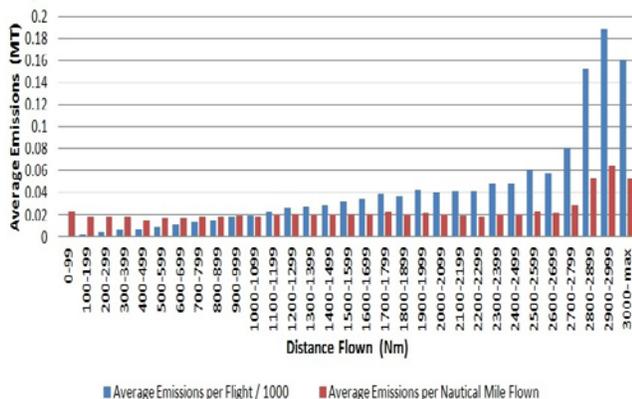

Fig. 2. Average emissions produced from each flight in 100 nautical mile stage lengths (blue) and average emissions produced per nautical mile flown (red)

The flights of the baseline were divided into four categories based on the distance flown. Figure 3 shows the total transit time, fuel burn, and CO_2 emissions produced from flights in each distance category. The categories are:

1) Flights flying more than 1500 nautical miles (A1)
2) Flights flying 1000 to 1499 nautical miles   (A2)
3) Flights flying 500 to 999 nautical miles   (A3)
4) Flights flying less than 500 nautical miles   (A4)

Figure 3 also illustrates that flights in A4 and A3 are more frequent, in comparison to A1 and A2. Flights in A3 produce the most emissions as they fly moderate distances and they are very frequent. On the other hand flights in A4 have the same frequency, but they fly shorter distances and time so they do not produce as much emissions. However, A1 is the least frequent and it produces more emissions than A2.
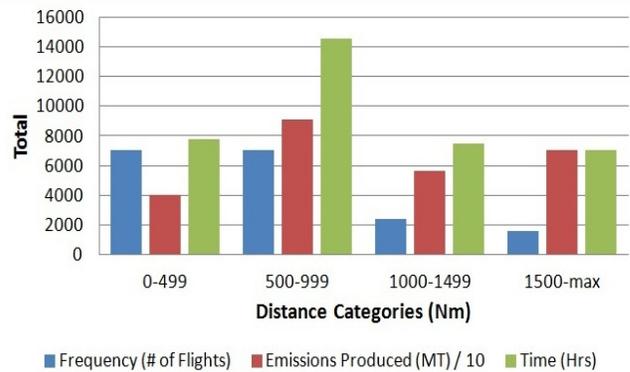

Fig. 3. Total number of flights, total CO_2 emissions and total transit time from the airway routes in each of the distance categories for the sample day.

B. Alternative Routes

The goal of providing alternative routes is to reduce the ANSP's contribution to aviation's emissions and increase performance through reducing transit time for flights in the baseline. The proposed alternatives are Near Wind Optimal Routes (NWORs), which provide the least flight transit time. The alternatives are to implement NWORs for flights in the baseline for one or more of the distance categories (A1, A2, A3, A4), while maintaining the remaining categories to use their same airway routes (baseline).

V. METHOD OF ANALYSIS

Two major tools were used for this project; Aircraft Emissions Decision Support Tool (AEDST), which was designed as a deterministic model using C++, to calculate the total transit time, fuel burn and CO_2 emissions from en-route flights. Another tool, Future Air Traffic Management (ATM) Concepts Evaluation Tool (FACET) was also used to simulate the GCD routes for flights and identify the number of conflicts between flights representing the workload of the air traffic controllers.

A. Aircraft Emissions Decision Support Tool (AEDST)

1. System Requirements

Based on the problem and need statements, the following system requirements have been derived:

- The system shall account for aviation related emissions within the CCD cycle
- The system shall incorporate the amount of CO_2 emissions from aircraft given the flight trajectory data
- The system shall provide a basis for comparing alternative flight plans with respect to CO_2 emissions in the presence of wind.
- The system shall provide a basis for setting performance targets

2. System Assumptions

The system assumes nominal fuel consumption estimates for different aircraft during all phases of flight due to the dependency on the BADA performance files in acquiring the fuel burn rates.

3. System Description

There are two primary sources of data used as inputs for this tool. First, Base of Aircraft Data (BADA) Performance Files provides the thrust specific fuel consumption of different aircraft types given the phase of the flight, altitude, and velocity. Second, Enhanced Traffic Management System (ETMS) Radar Track Data, which provides the detailed flight information and airway routes (trajectory data) in the airspace. This includes flight ID, Departure & Arrival Airports, and Aircraft Type. It also provides the Longitude, Latitude, Altitude, Time, and Velocity of the flight every one minute.

Another Input that replaces the ETMS Track Data for the GCD Routes and the NWORs, is generated using (FACET), which is a simulation model designed by NASA to model trajectories for the climb, cruise, and descent phases of flight for each type of aircraft [6].

Some information is extracted from the actual airway flight plans in the ETMS to input into FACET. This included information such as Flight ID, aircraft type, departure & arrival airports, initial altitude, longitude, and latitude to simulate the GCD routes. The output from FACET provides a file that resembles the ETMS Track Data file and serves as an input into AEDST.

The output of the system shows the transit time, the fuel burn, and the CO_2 emissions produced per flight. It also provides the total fuel burn and emissions for all flights in the national airspace. Figure 4 shows an input and output diagram of the system.
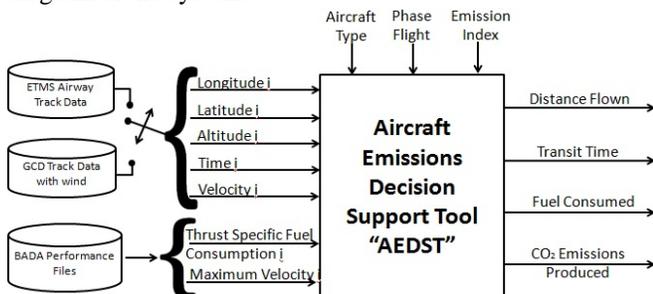

Fig. 4. Input and Output Diagram of the Decision Support Tool

4. System Methodology

AEDST contains various metrics for en-route flights such as transit time, fuel burn, and CO_2 emissions. The system distinguishes the airways and GCD routes from the NWORs in the simulation process.

For the airways and the GCD routes, the ETMS Data and the FACET outputs are given as data records for each flight. There are various calculations that need to be performed for each flight per data record and then summed up for the total distance, transit time, fuel burn, and emissions. The system identifies each flight based on its unique flight ID and marks the aircraft type.

The flight transit time (t) in minutes, as shown in equation (1), is computed through the summation of the time for all data records (t_i) for the unique flight ID, since the aircraft location is given every minute.

$$t = \sum t_i \tag{1}$$

In order to compute the total distance flown for a flight, the distance flown every minute (S) needs to be calculated first, by utilizing equations (2), (3), (4). The latitudes (φ_1, φ_2) and longitudes (λ_1, λ_2) between two records in radians for the unique flight ID and the radius of the earth in nautical miles are used. Then, the total distance (S_T) in nautical miles would be the summation of all calculated distances for a flight ID as shown in equation (5).

$$A = \sin^2\left(\frac{\Delta\varphi}{2}\right) + \cos(\varphi_1).\cos(\varphi_2).\sin^2\left(\frac{\Delta\lambda}{2}\right) \tag{2}$$
$$C = 2\tan^{-1}2\left(\sqrt{A}, \sqrt{A-1}\right) \tag{3}$$
$$S_i = R\sum C \tag{4}$$
$$S_T = \sum S_i \tag{5}$$

The fuel burn calculation involves multiple steps, which start by identifying the phase of the flight whether it is in climb, cruise, or descent. The difference between the altitudes for two records provides the phase of flight. If the altitude difference yields a positive value, the aircraft is climbing. If the difference is zero, the aircraft is cruising, and if negative it is descending. Once the phase of the flight is identified, the first altitude is used to find the fuel burn rate per unit time for the given aircraft type at that point from the BADA Performance Files. Using Equation (6), multiplying the fuel burn rate per unit time (TSFC) in metric tons per unit time by the time of every record (t_i) in minutes provides the fuel burn at that point (f_i). The total fuel burn for the flight (f_T) in metric tons can be acquired by summing up the fuel burn for all the given records for the unique flight ID, as shown in equation (7).

$$f_i = TSFC_i \times t \tag{6}$$
$$f_T = \sum^n f_i \tag{7}$$

Finally, the emissions produced during the flight (E) in metric tons can be calculated by multiplying the total fuel burn during a flight (f_T) by the emissions index ($E.I$), as shown in equation (8). The index is a constant value for all flights, which is 3.16, since all of the specified aircraft are using jet fuel type A [7].

$$E = E.I \times f_T \qquad (8)$$

For the NWORs, the process differs from that for the airways and the GCD routes in regards to the fuel burn and emissions because it requires the implementation of wind for the GCD routes. The wind affects the velocity of the aircraft throughout the flight; therefore, the transit time, fuel burn, and emissions produced will vary. The wind data is extracted from the airway routes to influence the GCD routes assuming that they are impacted by the same wind conditions due to the unavailability of actual wind data. Wind is generated based on the difference between the velocity in ETMS Track data, which is the true airspeed, and the velocity in the BADA Performance files at the same altitude and phase of flight, which is the nominal speed. The wind speed is recorded for every record of each flight to influence the GCD version of the flight to obtain the NWORs.

The distances flown in nautical miles (S) and the initial transit time (t) in hours remain the same as for the GCD Routes of the flight. Now, the true airspeed (V') in Knots for every record can be calculated by adding the wind speed (W) to the groundspeed (V), which is shown in equation (9).

$$V' = V + W \qquad (9)$$

The change in the velocity of the aircraft will impact the transit time, but the distance will not change. Using equation (10), the new transit time per record (t') is computed by dividing the distance traveled (S) by the true airspeed (V').

$$t' = S/V' \qquad (10)$$

After the new transit time is acquired, the same process as the airway and GCD routes is followed for the calculations.

B. Future Air Traffic Management (ATM) Concepts Evaluation Tool (FACET)

A simulation tool designed by NASA initially used to simulate the GCD Routes from all flights [6]. It was also utilized to obtain the number of conflicts that occur between flights. This way the workload of the air traffic controllers from using specific routes can be identified.

1. Baseline Conflicts

The ETMS Track Data provides the actual 4-D trajectory data for the flights using airway routes every one-minute, which means that all provided flights departed and landed safely. Therefore, the conflicts between those flights have been resolved. In order to identify the number of conflicts that occurred from the baseline, the latest filed flight plans before departure for those flights need to be simulated using FACET to acquire the baseline conflicts.

2. Conflicts from Implementing Alternatives

When implementing the NWORs for flights in a certain distance category of the baseline, the flights in the remaining distance categories will remain the same. To detect the conflicts in this case, the track data for the NWORs of the distance category are used in addition to the last filed flight

plans before departure for the other categories to simulate the flights and identify the workload of the controllers in that case. The same process is followed when implementing NWORs for two or three distance categories. However, if the NWORs are implemented for all flight categories in the baseline, then the track data for all the NWORs are used to acquire the conflicts.

VI. RESULTS AND ANALYSIS

A. Simulation Results

Figure 5 provides the percentage of reduction in transit time, fuel burn, and CO_2 emissions from en-route flights within the U.S., when implementing NWORs for each distance category or a combination of categories. This is a method of identifying possible improvements in the ANSPs performance. The figure shows that implementing the NWORs for all flights delivers the maximum improvement in the ANSP's performance by 20% in regard to CO_2 emissions, while implementing the NWORs for flights flying a distance 1500 nautical miles or more (alternative 1) provides the minimum improvement of 1%.
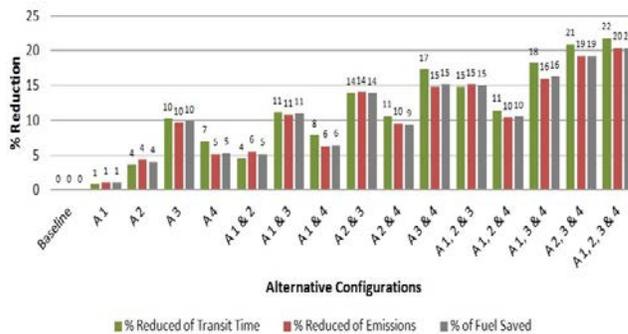

Fig. 5. Percentage of Reduction in Transit Time, Fuel and Emissions for Alternative Configurations

B. Benefit Analysis

Figure 6 shows the airlines' fuel savings from implementing the NWORs for flights within each distance category or a combination of categories translated into cost. These savings are calculated based on the current cost of Jet Fuel Type A per metric ton in North America [8]. The maximum savings are $16.7M provided by applying NWORs to all flight distances, while the least savings are $0.93M delivered by implementing NWORs for flights flying a distance more than 1500 nautical miles.
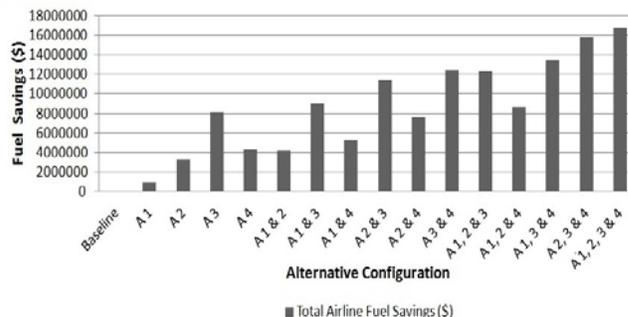

Fig. 6. Fuel Cost Savings for Alternative Configurations

C. Stakeholders' Utility Function

The value hierarchy was defined by two constraints. These were used to rank and select the NWORs for distance categories that increase the ANSP's performance in regards to emissions without increasing the workload of the air traffic controllers. To elicit the weights for the constraints, a survey was given to experts on the subject matter that represent the stakeholders and the swing weights method was used. The following shows each constraint:

1. Emissions Produced (Lower => better)
2. Air Traffic Control Workload (Lower => better)

The utility function is derived from the value hierarchy as shown in equation (11):

$$Utility = 0.55 \times U_{Emissions} + 0.45 \times U_{Workload} \quad (11)$$

D. Analysis based on Utility

Table I below provides the ranked utility of the configurations for the NWORs. The table shows that implementing NWORs for the flight distances less than 1500 nautical miles yields the highest utility score followed by NWORs for all flight distances. Even though implementing NWORs for all flight distances provides the least emissions in the airspace, it increases the ATC workload compared to the NWORs for flight distances less than 1500. On the other hand, implementing NWORs for flight distances more than 1500 nautical miles yields the lowest utility. Although it reduces emissions by 1%, it increases the ATC workload.

Table I:
Utility Analysis Results

Alternative Configuration	Emissions Produced in NAS (0.55)	Impact on ATC Workload in NAS (0.45)	Utility	Rank
A2, 3 & 4	207645	31626	0.83	1
A1, 2, 3 & 4	204709	32052	0.82	2
A1, 2 & 3	218023	30687	0.80	3
A2 & 3	220959	30469	0.79	4
A1, 3 & 4	216050	31212	0.78	5
A1 & 3	229364	29998	0.74	6
A3 & 4	218986	31607	0.71	7
A3	232300	30751	0.65	8
A1, 2 & 4	230430	31271	0.62	9
A2 & 4	232518	31892	0.55	10
A1 & 2	242895	31455	0.48	11
A2	245831	32293	0.37	12
A1 & 4	240922	33637	0.31	13
Baseline	257172	32432	0.24	14
A4	243859	35271	0.14	15
A1	254236	34139	0.13	16

VII. Recommendations and Conclusion

We recommend the designed AEDST to be implemented by the FAA to estimate the flight transit time, fuel burn, and CO_2 emissions. Through the tool, the FAA can track its environmental performance and use that information to make changes that will give airlines more options (shorter, more optimal routes), while filing flight plans. Implementing the tool shows the willingness of the FAA to act responsibly in a world becoming more aware of aviation's contribution to climate change. We also recommend making the necessary changes to policy and the U.S. Airspace structure to support the use of user-preferred/wind optimal routes.

Our analysis provides some benefits to support the use of wind-optimal routes. The time, fuel, and emissions savings by using those routes are significant. Conflicts from using those routes are marginally reduced compared to the airway routes. We recommend the FAA to implement NWORs for flight distances less than 1500 nautical miles, which increase their performance in regard to CO_2 by 19%, provide fuel savings of $16M, and reduce the workload of ATC controllers by 2.5%.

In the future, the authors would like the research to include the evaluation of at least 365 days of en-route flights with proper wind data to get a more detailed picture of the ANSP's performance. Also the authors would like to include analysis on the workload of the air traffic controllers in regard to sector loading as it affects the manageability of the airspace.

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