

# ESTIMATING THE EN ROUTE EFFICIENCY BENEFITS POOL

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## Abstract

The Free Flight program has several tools and initiatives meant to affect the efficiency of flights in en route airspace. A first step in estimating the effectiveness of en route programs is to determine the maximum possible benefit if all flights were optimized. Analyses of individual programs can then determine the fraction of this “benefits pool” that a tool or initiative addresses. In the first part of this paper, we examine the causes of en route inefficiency, and investigate how these causes contribute to the route inefficiency experiences by flights in the NAS today. This study includes an analysis of how route inefficiency changes for different traffic levels. In the second part of the paper, we calculate a potential benefits pool due to flight inefficiencies in the current route structure that accounts for necessary conflict avoidance, and discuss how this calculation might fit into a general benefits approach.

## Introduction

With the establishment of the Terminal Business Unit, the FAA began to segregate investment decisions between en route and terminal automation tools. Because terminal capacity and efficiency problems can be analyzed locally, it is easier to measure the potential value of terminal improvements than it is to measure en route improvements. For example, numerous queuing-based models support the estimation of reductions in delay associated with terminal capacity increases<sup>1</sup>. Using these models, the value of increased terminal capacity can be projected at both current and future demand levels.

In the en route environment, the potential value of new technologies and procedures is not as clear. While it is assumed that the overriding factor

constraining the NAS is terminal capacity, the relative value of en route versus terminal area investments has not been fully explored.

The Free Flight program has several tools and initiatives meant to affect the en route phase of flight. Other FAA initiatives are also aimed at improving en route efficiency and capacity. Critics of the FAA’s investment decision-making process have expressed concerns over the duplication of claimed benefits.<sup>2</sup> The Free Flight Office is beginning to incorporate a unified approach for analyzing benefits among all of its programs. We would advocate that this approach be used for all FAA programs claiming en route user benefits. By using a unified approach to valuing all the en route investments, we would be more assured as to the reasonableness of investment analyses results, and this would ultimately lead to better investment decisions.

A first step in this unified benefits process is to understand the amount and root causes of en route inefficiency today. This paper focuses on estimating a benefits pool due to flight inefficiencies in the current route structure that accounts for necessary conflict avoidance. We begin by explaining the different sources of en route inefficiencies, and how each contributes to actual inefficiency as experienced by flights in the NAS today. We next present a current Free Flight study that calculates the pool mentioned above. Finally, we mention how that study might fit into a benefits framework that would not only use this pool, but would also include sector capacity and severe weather issues not captured in the current estimate.

## En route inefficiency

Before we address the potential pool of benefits available from reduction in inefficiency, it is useful to consider what we mean by inefficiency and to identify the sources of inefficiency in the current NAS. For this discussion, we broadly define en route

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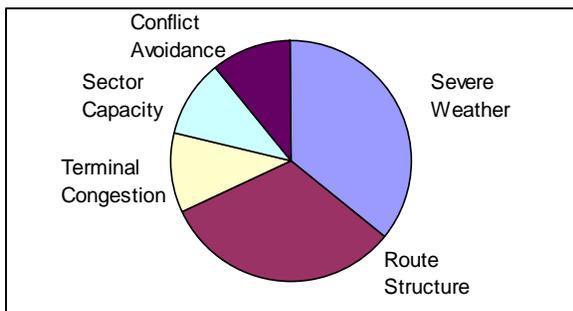
<sup>1</sup> Models include: Total Airspace Airport Modeler (TAAM), NASPAC, DPAT, and standard queuing based modeling used by the FAA’s Free Flight Office.

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<sup>2</sup> Concern expressed through meetings between the Free Flight Office and both the IG and GAO.

inefficiency as distance, flight time or fuel burn in en route airspace in excess of that which would occur if each sampled flight were the only aircraft in the system.

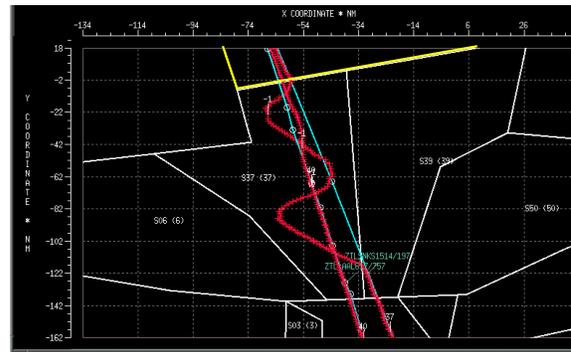
Sources of inefficiency in en route airspace can be separated into five categories: metering due to terminal congestion; delays related to en route sector capacity limitations; conflict avoidance; routing around severe weather; and static inefficiencies in the current airspace route structure. Figure 1 displays these sources in a pie chart. (The relative percentage of each source to the total en route inefficiency is notional.) In the following, we discuss each of these sources individually.



**Figure 1. Notional en route inefficiency sources**

*Terminal Congestion* - At first, it might seem odd that *terminal* congestion is included as one of the sources of *en route* inefficiency. The reason for this apparent inconsistency is that any choice of a boundary between terminal and en route airspace is somewhat arbitrary. For our analysis, we can remove much of the terminal inefficiency by analyzing only flight tracks outside the immediate terminal area. However, some terminal-related inefficiency will still exist in en route airspace; this inefficiency is impossible to completely remove since it may occur hundreds of miles before the terminal area.

For example, many Miles-In-Trail (MIT) restrictions in the en route environment are a pass back from a terminal. Figure 2 shows the actual flight path of an aircraft being metered due to a MIT restriction imposed by Indianapolis Center for flights coming from Atlanta Center. In this case, we believe the actual MIT restriction was a “pass back” from Chicago Center as part of a metering strategy for flights into ORD airport.



**Figure 2. Example of en route vectoring due to terminal congestion.**

*Sector Capacity* – This source refers to en route inefficiencies due to overcrowding of en route sectors. The number of aircraft that can be handled in an en route sector is limited. The Monitor Alert Parameter (MAP) represents a nominal limit. Conditions may allow traffic to exceed the MAP value, but the MAP is used as a guide for en route strategic planning. When the capacity of a sector is going to be exceeded, flights may be rerouted or delayed at their origin, causing inefficiency. Tools or initiatives that can either increase the MAP value by increasing controller efficiency (CPDLC, ERAM, etc.), or decrease the space necessary between en route planes (e.g. RVSM) should be able to decrease flight inefficiency due to sector capacity.

Detailed studies of en route delay at the FAA Command Center suggest that most sector capacity problems are currently addressed by holding departing aircraft on the ground until there is an opening in the overhead stream. This technique does not affect the efficiency of flights already in the en route airspace, and is comparable to metering cars onto an interstate. MIT restrictions are often used for flights coming out of a major airport heading onto a major jet route. For example, even in good weather, there are instances where flights departing Chicago, Cincinnati, and Detroit are held on the ground because of en route congestion.

*Conflict Avoidance* – This refers to the time or distance exceeding the minimum necessary to avoid conflicts in a safe manner. While there will always be some course, altitude or speed changes needed to avoid collisions, the magnitude of these changes depends on the type of correction necessary and the time when the avoidance correction is initiated. It is hoped that tools such as URET, PARR, Direct-to, etc. will help to choose the optimum correction at times far in the future compared to current conflict avoidance procedures [1, 2, 3].

*Severe Weather* – The need to avoid storm cells adds delay and inefficiency on top of more routine inefficiency in the NAS. There are currently a large variety of initiatives that provide both tactical (more weather information in cockpit, more efficient routes in adverse weather) and strategic (adverse weather playbooks, ground stops) solutions. Severe weather in the form of convective activity magnifies the terminal congestion and en route sector capacity inefficiencies mentioned earlier. As a first case, we believe that benefits should be calculated for good weather scenarios and subsequent analyses should tackle the weather issues.

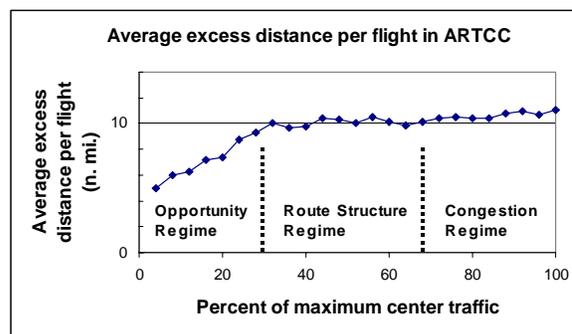
*Route Structure* – As we will discuss below, in good weather, the largest source of inefficiency in the NAS is the current route structure. A major goal of the Free Flight program is to allow more user defined routes. Tools like URET, PARR and Direct-To should allow aircraft to fly more direct routes and avoid the route inefficiencies that are currently built into many flight plans.

## En Route Inefficiency and Traffic Load

In this section, we consider how the different sources of inefficiency, introduced in the last section, contribute to the inefficiency experienced by flights in the NAS today. To this end, we have analyzed ETMS data from the eight Wednesdays and Thursdays in March 2002. (See the next section for details on this data source.) For each of the twenty en route centers, we have calculated the excess distance for each flight traversing the center airspace, where excess distance is defined as the difference between the actual flight path length and a great circle path connecting the entry and exit points of the flight for that center. Additionally, we have counted the total number of flights handled by the center, summed over a 15-minute bin. To normalize the traffic loads, we have determined the maximum 15-minute load in our data set for each center; the traffic load for each individual 15-minute bin is then expressed as a percentage of this maximum center load. To investigate how en route inefficiency relates to traffic level, we have calculated the average excess distance for flights in each center during each 15-minute time bin.

Shown in Figure 3 is the average excess distance per flight in an en route center, plotted as a function of the traffic load in that center. The curve represents an average over all twenty en route centers. The shape of the distribution is quite

interesting—at low traffic values, the excess distance is low, increasing slowly until reaching a plateau at around 30% maximum traffic level. The distribution remains around this plateau value until around 70% of maximum traffic level, where it begins to slowly increase. For discussion purposes, we have separated this distribution into three sections: Opportunity Regime, Route Structure Regime, and Congestion Regime.



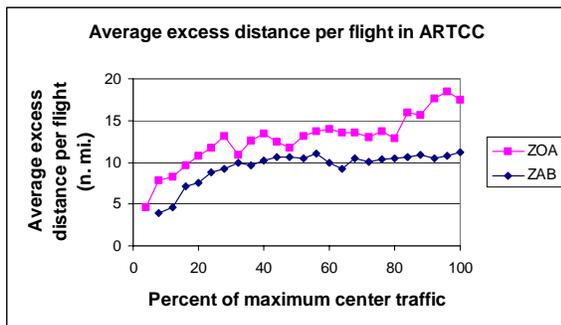
**Figure 3. Average excess distance per flight in en route centers versus center traffic load**

For moderate traffic levels, between roughly 30% and 70% of maximum, the excess distance experienced by flights is fairly constant. We have labeled this the “Route Structure Regime”, on the assertion that in this operating environment, the dominant contributor to excess distance is the inherent inefficiency in the airspace route structure. Traffic levels are sufficiently high that flights are generally constrained to stay on the route structure, but not so high that extensive maneuvering is required to control traffic flow. Tools or initiatives (e.g. RVSM, RNP, choke point initiatives, airspace redesign, dynamic resectorization, etc.) that reduce the inefficiency in the airspace structure would be expected to reduce the “plateau value” of excess distance in the Route Structure Regime.

In the “Opportunity Regime”, below around 30% of maximum traffic load, some flights are able to leave the airspace structure and fly more direct, reducing the excess distance. Tools that enable more direct flights, e.g. URET, could affect this region in two ways—by pushing down the overall excess distance in this regime, and by increasing the traffic level at which flights are constrained to the route structure (the boundary between the opportunity and route structure regimes).

In the “Congestion Regime”, traffic levels are high, creating new sources of inefficiency beyond the base level associated with route structure. In this regime, terminal capacity constraints, sector capacity constraints and conflict avoidance become more important, forcing up the average excess distance. Tools that increase sector or terminal capacity (e.g. CPDLC, TMA, etc.) should reduce the excess distance in this regime. Also, tools that improve the efficiency of conflict resolution (e.g. URET, and CPDLC via reduced controller workload) can also reduce inefficiency in this regime.

In the average over all centers as shown in Figure 3, the increase in excess distance in the congestion regime is not as pronounced as it is in some individual centers. As an example, excess distance distributions for ZAB (Albuquerque center) and ZOA (Oakland center) are shown in Figure 4. As can be seen, the overall level of excess distance in the route structure and opportunity regimes is higher in ZOA than ZAB, and there is a significant upturn in excess distance in the congestion regime for ZOA. Both of these phenomena are consistent with our interpretation of the sources of inefficiency. Overall, traffic levels are higher in ZOA than in ZAB, and ZOA handles a larger proportion of arrivals/departures than ZAB, both of which require a more complex airspace and incur a greater susceptibility to capacity-related effects in the congestion regime.



**Figure 4. Average excess distance in Albuquerque (ZAB) and Oakland (ZOA) Centers**

One source of inefficiency that we have not mentioned is severe weather. Since Figure 3 is an average over the full NAS, some of the inefficiency is probably due to severe weather effects. We have generated distributions like Figure 3 for summer months (when convective weather is most prevalent)

as compared to winter months. We have found that for summer months, the overall excess distance distribution is somewhat higher than for winter, but the shape of the distribution is very similar. Thus, tools that address inefficiency in dealing with severe weather could be expected to reduce the excess distance over the full traffic spectrum.

We have discussed how various tools might affect the en route inefficiency in different traffic level regimes. However, even the most ideal tools and procedures cannot reduce the excess distance to zero. Some conflicts are inevitable even in an ideal airspace, and resolution of these conflicts incurs some unavoidable inefficiency. Thus, a reasonable estimate of the potentially achievable efficiency benefits must take conflict resolution into account. In the next section, we describe our calculation of the magnitude of the achievable efficiency benefits pool.

### Calculating a Benefits Pool

In order to measure a benefits pool, we must refine the definition of inefficiency. Possible choices for measures include delay, flight times, flight distances, and fuel burn. A choice of one of these options necessarily changes the interpretation of what we measure.

In a recent study performed for the Free Flight Office, we chose to examine flight distances. The en route inefficiency was defined by the amount of additional distance an aircraft flies in comparison to the shortest possible great circle route of flight. We chose distance to avoid accounting for winds, which highly affect estimates based on flight time. The choice of distance limits our ability to examine speed control and ignores delays taken on the ground due to ground stops, etc

In the study, we first examined Enhanced Traffic Management System (ETMS) data for a single day, comparing actual tracks, current structured flight plan routes, and great circle routes. This analysis provided an initial indication of the flight distance savings possible from NAS-wide Free Flight. In order to refine this estimate, we then considered the effects of aircraft-to-aircraft conflicts (and the necessary maneuvering to maintain required separation) on the potential direct routing benefits pool. We used NASA’s Future ATM Concepts Evaluation Tool (FACET) to simulate flights on both structured routes and direct routes. This model considers aircraft climb and descent profiles, counts potential conflicts, and has the ability to perform some conflict resolution. In order to account for conflicts in our benefits pool estimation, we devised a

method to calculate typical distance penalties for different types of conflicts. We then used information from both the model and the actual data to refine the benefits pool estimate. Finally, we compared this estimate with results from past similar studies

The data source was ETMS track data from the FAA Air Traffic Airspace Laboratory (ATALAB)[4]. The ETMS archives contain flight track data (sampled approximately once per minute) for IFR traffic, as well as structured waypoint information for filed flight plans. For both the actual tracks and filed flight plans, we included only flights that had non-null departure and arrival. Since our focus is on the contiguous U.S., we also removed international flights and those departing from or arriving to Alaska, Hawaii, or Puerto Rico. We further filtered the data by excluding flights that arrive and depart from the same airport (so-called “round robin” flights). This removed many military training flights and general aviation flights for which shortening distance or time en route is not a desired outcome. We considered removing all other military and general aviation traffic from the set as has been done in other studies, but since there is little justification for this, and the results did not change appreciably, we elected to retain these flights.

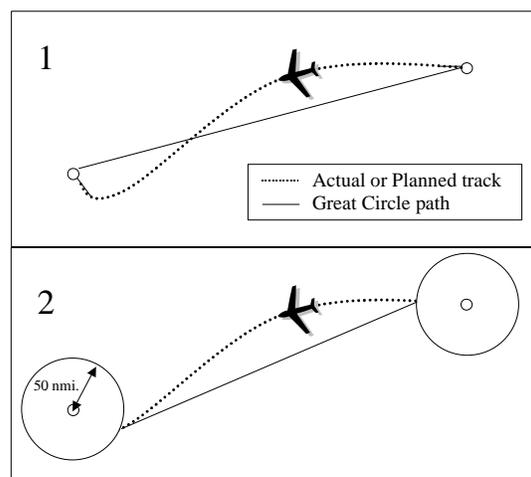
To isolate en route and terminal airspaces, we considered the terminal area to exist within a 50 nmi. radius around both the departure and arrival airports. We then defined the en route portion to exist only between these 50 nmi. radius rings. Using this definition, flights under 100 nmi. are excluded from the analysis set.

In order to examine the en route inefficiency due to excess distance in different portions of the flight, we measured it using two distinct algorithms:

**Method 1: Airport-to-Airport.** Connect all position reports in actual track data or waypoints in plan data. Add the distance from the departure airport to the first recorded point and add the distance from the arrival airport to the last data point. Compare this data to great circle path between departure and arrival airports. See top portion of Figure 3.

**Method 2: Circle-to-Circle.** Connect all position reports in actual track data or waypoints in plan data. Find flight distance between circles of radius 50 nmi. around both departure and arrival airports. Interpolate between points outside and inside terminal circles to find start and end points on 50 nmi boundary. Compare to great circle path between exit of departure terminal circle and entrance of arrival

terminal circle. Only valid for flights longer than 100 nmi. See bottom portion of Figure 5.



**Figure 5. Excess distance methods**

Method 1 should give us the best estimate of the total excess distance per flight. However, using this value for measuring the en route benefits pool is unrealistic since restrictions at the airport should dominate this number. Nevertheless, it is interesting to measure it in order to compare the amount of excess distance in the terminal to excess distance en route. In most cases 50 nmi. is far enough to assume limited terminal effects, so Method 2 should isolate much of the en route excess distance.

**Table 1. ETMS excess distance results**

Metric	Method 1		Method 2	
	Actual	Plan	Actual	Plan
Mean (nmi)	28.5	22.0	9.3	10.0
Sum (nmi)	1,296,556	1,141,967	369,968	427,803
% flight	7.7	6.9	2.4	3.1

Table 1 presents the results of the excess distance calculations. As expected, the excess distance using the airport-to-airport method (Method 1) is much higher than that from the circle-to-circle method (Method 2), signifying that restrictions in the terminal area cause much of the excess distance. In fact, focusing on the sum of the actual track data, we find that 71 percent of the total excess distance takes place within terminal airspace and the remaining 29 percent occurs in en route airspace.

Excess distances for actual flight tracks using Method 1 tend to be larger than the flight plan excess distances, no doubt due to the fact that the flight plans do not include all terminal area details and restrictions. This trend reverses in the en route portion of the flight, where excess distance for actual flight plans using Method 2 is slightly less than for flight plans.

The preceding calculation of excess distance treated each plane separately, ignoring all interactions with other aircraft. In order to realistically estimate the benefits pool for direct routings, we need to account for aircraft-to-aircraft conflicts. To do this, we simulated the NAS using the Future ATM Concepts Evaluation Tool (FACET) developed by NASA [5]. This simulation tool uses flight plan information to construct trajectories, including ascent and descent profiles for specific types of aircraft. FACET can also simulate direct routings between airports, and it will tally conflicts when aircraft have less than five nmi. of horizontal separation. In order to isolate conflicts in en route airspace, we used the circle-to-circle flight plan data and ignored conflicts at flight levels below FL180. The flight plan data was used instead of the actual track data because the actual tracks already have conflicts resolved. We set the departure time for each flight to be its actual departure time, as opposed to its scheduled departure time, so as to avoid conflicts for flights scheduled to leave at the same time.

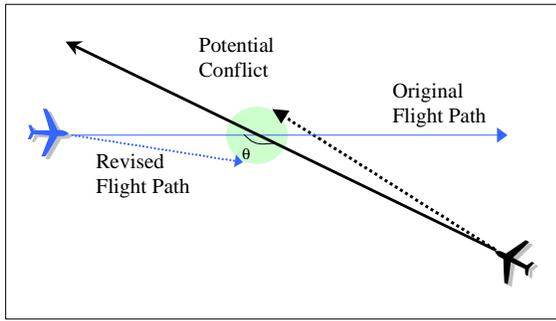
The result of this modeling showed that on the flight plan routes 10,157 potential conflicts occurred, while 8,008 potential conflicts occurred for that same set of aircraft on direct flights. The direct routes suffered over 2,000 less conflicts than the planned routes. This translates into 28 percent of the planes having at least one conflict in the flight plan case and 24.3 percent in the direct case. This is to be expected, since aircraft on structured flight plan routes have a limited number of pathways. These results generally agree with a similar study performed by NASA that also used FACET to count NAS-wide conflicts for structured and direct routings [6].

We are interested in accounting for the cost of conflicts during direct flights to better estimate the en route benefits pool. FACET includes some conflict resolution capability, so the most obvious way to accomplish this would be to use FACET to simulate the flights both with and without conflict resolution, and then simply take the difference in total distance flown between the two cases. While we believe that the conflict detection algorithm in FACET is

reasonable, we think the current conflict resolution algorithms included underestimate the cost of avoiding a conflict because they rely on speed control and altitude changes for resolution. We therefore decided to develop a separate calculation to estimate the cost of en route conflict resolution.

From discussions with controllers, we learned that the most common method for conflict resolution in the en route environment is vectoring. While speed control and vertical maneuvering are also used to resolve conflicts, these tactics are much more common in the terminal area where planes are already undergoing changes in altitude and speed. Therefore, we limited our focus to the horizontal plane (see Figure 4). We set out to calculate analytically the minimum excess distance needed to avoid a loss of separation. This minimum distance depends on four parameters: the speeds of the conflicting aircraft, the conflict angle ( $\theta$ ) between the flight paths of the two aircraft, the minimum distance allowed between the planes, and the amount of time before the actual loss of separation that the maneuvering begins.

For each potential conflict detected in the FACET model we recorded the speeds and the conflict angle. For minimum distance, we examined two possible conflict penalties. In the first, the minimum separation was 5 nmi., the absolute minimum horizontal separation currently allowed by the regulations in en route airspace. In the second case, a 5 nmi. buffer was added, increasing the desired minimum separation to 10 nmi. between conflicting planes to account for uncertainties in the system and comfort factor for controllers. Finally, for the conflict avoidance initiation time we assumed a conservative value of 4 minutes before loss of separation. We based this value on discussion with controllers, and an analysis of the PARR add-on to URET [2] where the researchers found that 66 percent of controller actions occurred less than 3 minutes before the start of a conflict.



**Figure 6. Finding the minimum conflict penalty**

Using a numerical solution for the minimum horizontal distance necessary to avoid conflicts that used the parameters mentioned above, we estimated the excess distance needed to avoid conflicts for the direct routing scenarios. Table 2 lists the mean conflict avoidance cost per aircraft, the sum of the costs for all the flights, and the percentage that this conflict cost decreases the previously calculated excess distance benefit pool.

**Table 2. Conflict avoidance distance costs**

Metric	Minimum	Buffered
Mean	1.4 nmi	3.63 nmi
Sum	22,407 nmi	58,149 nmi
% excess distance benefit	6.0	16.0

Combining the data from Table 1 with that of Table 2 allows us to estimate the potential en route benefits in terms of excess distance. The most reasonable estimate in Table 1 is the one where we examine the excess distance between 50 nmi. rings surrounding airports (Method 2) for aircraft with actual track data. We believe this is the most accurate measure of the current en route excess distance. From this value, we subtract the distance necessary to resolve conflicts when flying direct routes in order to calculate a benefits pool. Using the minimum conflict cost the final excess distance estimate is about 348,000 nmi., while the buffered case gives an estimate of approximately 312,000 nmi. As presented in Table 2, the buffered case decreases the original benefits pool by approximately 16

percent. The minimum conflict penalty case this fraction drops to 6 percent.

There have been several estimates made of an en route benefits pool in previous papers [3,8,9,10,11]. Many of these estimates use quite different methods and do not use excess distance to quantify potential benefits. In order to better compare with these other estimates it is necessary to translate our daily excess distance benefit into a yearly economic benefit. A simple method to do this entails dividing the excess distance by the mean cruising speed to get an excess time, and then multiplying by the mean direct operating cost. We derived these values from the information found in [12], accounting for the mix of air carrier, freight, air taxi, and general aviation aircraft in our estimate.

In order to translate the daily values into a yearly benefit, we multiply the result by 343 effective days. We use 343 instead of 365 days in order to account for lower weekend traffic and some holidays[9]. Table 3 lists the annual economic value thus derived, as well as annual benefits values from other related studies. The table also lists the number of flights considered eligible for direct routings in each study, and the daily benefit per eligible flight.

The variation in results mirrors the variation in criteria and methods used in the different analyses. In the paragraphs below, we include a brief summary of the comparison studies shown in Table 3. These descriptions focus on the differences with the current study. For more details see the various references. Note that that while the annual benefit variation is large, the daily benefit per eligible aircraft is strikingly similar. This shows that most of the methods give similar results per flight, but it is the method for choosing eligible flights that drives the large differences in annual benefit.

The NASA Ames study[3] used a modification of FACET to determine the annual benefits of the Direct-To tool on a Center-by-Center basis. The model produced time savings ranging from 169 to 439 hours/day, which the researchers translated into economic terms. The researchers used FACET conflict detection to determine that the difference in the number of conflicts should not affect controller

**Table 3. Comparison of potential cost savings for direct flights**

Study	Annual Benefit (dollars)*	Number of Eligible Flights per day	Daily Benefit per Eligible Flight (dollars)
Current Study	699M-786M	39,753	51.3 – 57.6
Delta Airlines[11]	42M – 92M	2,000	61.2 – 134.1
MITRE ETMS[8]	~700M	29,045	70.3
MITRE TMAC[9]	620M	31,000	58.3
NASA Ames[3]	107M – 279M	5399 - 9488	57.8 – 85.7
Seagull Technology[10]	557M – 652M	40,437 – 50,157	37.9 – 40.1

\* The Current study and the Seagull Technology study are presented in 1998 dollars. Both MITRE studies were published in January 2000 and use Air Transport Association cost values but do not specifically document a year. The NASA Ames study uses a value of \$29/minute without reference. The Delta Airlines analysis was published in 1996, but the reference to this study in the NASA Ames document does not detail the reference year.

workload, but did not examine penalties caused by these conflicts. The paper describing the NASA Ames study also outlines an analysis performed by Delta Airlines[11] The Delta study focused on time savings for 2,000 aircraft flying direct routes using the Direct-To tool.

A simulation called the Traffic Management Analysis Capability (TMAC) was used to model direct benefits in the NAS in the MITRE TMAC study[9]. The model used actual track data from 3 May 1995 as a baseline and excluded military and general aviation traffic. TMAC computed time savings for wind-optimal flights, excluding any savings within a 20 nmi. ring around each airport. The final result includes a benefit for unrestricted descent fuel savings in addition to that from direct flight time savings.

A Seagull Technology study[10] of various advanced air traffic technologies addresses many of the same issues as the current analysis. The Seagull study considered extending the use of User Preferred Routes (UPR) to all flights, and estimated the resulting fuel and time savings. The analysis considers traffic levels in 1995 and 2005 and the results are of the study are presented in 1995 dollars. The first value in Table 9 represents the estimated 1995 benefit, while the higher value denotes the projected 2005 benefit. The results were inflated to 1998 dollars using the GDP chain type price index.

The MITRE ETMS study[8] considered excess distance in a very similar manner to the current study, examining the excess distance of actual tracks on the sample day of 23 October 1998. However, the

MITRE ETMS analysis excluded all military and general aviation traffic, and captured all the excess distance between the first and last positions recorded in the ETMS database. The result was 559,119 nmi. of total excess distance. In the paper describing the MITRE TMAC analysis [9] the researchers used the same method we used to estimate the cost of excess distance, but included only 95 percent of the value to account for unavoidable terminal area excess.

As a final note, we note that our current approach estimates inefficiency in actual routes flown under current NAS operating procedures, and in particular current separation standards. Programs that change these standards, e.g. RVSM, would change what we have referred to as a conflict, and thus would change our benefits pool.

## Future benefits framework

The purpose of the preceding study was to provide an overall context in which to consider benefits estimates for individual programs. While the current study has some limitations, we can use it to check the reasonableness of past Free Flight benefits estimates for different tools. For example, a recent study of URET benefits [13] found a resulting future benefit that corresponds to approximately seven percent of the current en route benefits pool calculated above. This proportion seems consistent with expectations, and gives us some confidence that our benefits estimate is reasonable.

By providing an overall context, the preceding study could constitute a first step toward a general framework for performing en route benefits

estimates. The purpose of estimating an overall pool is to protect against double counting of benefits by assuring that the sum of the parts does not exceed the whole. The logical next step in improving the cross-comparability of benefits estimates would be to establish a single set of tools to be used for performing estimates.

We have discussed inefficiency estimates in this paper, but a universal model would need to include other factors as well. Such a model would need to account for sector capacity limitations. While today's system produces minimal en route sector capacity delay, recent NASPAC modeling by the FAA's Technical Center indicates the inefficiency driven by en route sector capacity shortfalls will be comparable to route structure inefficiency by 2010. In 2020, sector capacity limitations become the largest source of inefficiency.

A second addition is the inclusion of severe weather. Analyzing the impact of severe weather on efficiency has been attempted; however, calculating how much of the inefficiency was avoidable for a convective weather event has not been achieved [14]. Another recent study [15] has proposed a way to weight severe weather on a NAS-wide basis in order to better compare days that have similar weather effects. These studies could be used to attain a better understanding of how severe weather limits the available benefits pool.

An important consideration in developing a framework is the ability to validate the model by comparing calculated values with actual data under current conditions. This would necessarily include the ability to model observed data for different traffic levels (i.e. busy days vs. non-busy days), since the ability to extrapolate to higher future demand is key to predicting future benefits. The combination of actual data analysis and modeling would provide a way to probe en route inefficiency both today and in the future. If all FAA programs that hope to increase efficiency in en route airspace were to agree on a single framework for analysis, including an agreed upon set of initial assumptions and a common modeling methodology, it would provide each program with a better understanding of their relative contribution to the overall improvement of NAS operations.

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