# Benefits Analysis of NASA Terminal Arrival Spacing and Scheduling Tools

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**An ongoing challenge for government agencies involved in the Federal Government's NextGen initiative is the need to estimate the potential costs and benefits of future Air Traffic Management (ATM) Concepts and Technologies (C&Ts). The Federal Aviation Administration (FAA), the National Aeronautics and Space Administration (NASA), and the Joint Planning and Development Office (JPDO) have been involved in collaborative efforts over the past decade to define, develop, evaluate and deploy NextGen concepts, capabilities and technologies. NASA has a long history of research and development in aviation and Air Traffic Management. In particular, NASA has developed a number of ground-based and airborne decision support tools (DSTs) that support concepts and technologies such as time-based-arrival-metering and flight-deck-interval-management. In order to evaluate the potential costs/benefits of these decision support tools, modeling, simulation, and analysis techniques must be applied to represent the operational impacts of these tools. In this paper, we describe the development and application of an approach to assess the potential benefits of several NASA DSTs in terms of time and fuel savings at a number of key airports in the National Airspace System (NAS). The benefits are assessed for individual DSTs as well as for various combinations of DSTs that represent distinct applications of concepts and technologies. Results show that the potential benefits of the individual and combined DSTs are highly-dependent on the assumed implementation and deployment timeline.**

## I. Introduction

NASA's Aeronautics Research Mission Directorate (ARMD) Airspace Systems Program (ASP) has been sponsoring and conducting Concept & Technology (C&T) research to enable capacity, efficiency, and safety improvements in the NAS. These C&Ts provide various operational benefits, such as improved airport departure/arrival throughput and fuel saving for specific costs for implementation and support. Costs and benefits are shared among various Air Traffic Management (ATM) system stakeholders including the FAA, airports, aircraft operators, and the public. This paper focuses on evaluating the time-saving benefit and fuel-saving benefit for four terminal-arrival related Decision Support Tools (DSTs): Traffic Management Advisor – Terminal Metering (TMA-

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TM), Efficient Descent Advisor (EDA), Controller Managed Spacing (CMS), and Flight Deck-based Interval Management (FIM). These DSTs are tools required to realize C&Ts. EDA, CMS and FIM are ground- and airborne-based trajectory management technologies providing improved conformance at meter fixes, merge points, and runways, whereas TMA-TM is a TRACON traffic-scheduling technology providing schedules at terminal merge points and runways. [1]

TMA is the baseline tool currently used in the NAS to manage demand/capacity imbalances in an arrival environment. It creates a schedule for all arrivals at the meter fix and the runway. TMA-TM adds TRACON merge point scheduling as well as better runway time prediction to the existing TMA algorithm. The TMA and TMA-TM scheduling will be used in conjunction with some of the C&Ts (EDA, CMS, and FIM) that can improve meet-time performance. Each C&T provides functions to enhance operational efficiency and accuracy for terminal arrival operations. EDA, CMS, and FIM provide real-time speed advisories to control individual arrival flight trajectories in or near the terminal airspace domain to meet specified times of arrival to the meter fix, merge points, and/or runway threshold. Specifically, EDA is intended to improve arrival conformance at the meter fix and subsequently at the runway.[2] CMS is intended to improve arrival conformance at merge points within the TRACON airspace and at the runway in conjunction with TMA-TM.[3] FIM and flight deck automation are intended to improve both meter fix and runway conformance using Automatic Dependent Surveillance – Broadcast (ADS-B) technology.[4]

A previous paper[5] discussed the assumptions and modeling approach used to assess the arrival throughput improvements for different C&T combinations at New York John F. Kennedy International Airport (JFK). Table 1 shows the arrival throughput capacity, the C&T combination throughput to the theoretical maximum throughput ratio for each C&T combination for JFK's 31L/31R arrival configuration, and the runway buffer size:

| C&T Combination | Throughput Capacity (aircraft per hour) | The C&T Combination Throughput to the Theoretical Max Ratio | Runway Buffer |
|---|---|---|---|
| TMA only | 58 ac/hr | 73% | 1.2 nmi |
| TMA + EDA | 65 ac/hr | 83% | 0.7 nmi |
| TMA-TM + CMS | 72 ac/hr | 91% | 0.3 nmi |
| TMA-TM + CMS + EDA | 72 ac/hr | 91% | 0.3 nmi |
| TMA-TM + FIM | 74 ac/hr | 97% | 0.2 nmi |
| Theoretical max | 79 ac/hr | 100% | 0.0 nmi |

**Table 1. C&T combinations, Runway Buffers, and Throughput Comparison at JFK 31L/31R Arrival Configuration.**

EDA, CMS and FIM all intend to reduce the spacing requirements between aircraft by improving arrival scheduling conformance at all metering points while TMA and TMA-TM provide the scheduling function to each flight in the terminal airspace.

If a C&T improves arrival conformance, the work in the previous paper estimated how close in distance two consecutive arrival aircraft could be, which is supplied as the additional runway buffer above the minimum wake vortex. Reducing the runway buffer between two consecutive arrival aircraft is equivalent to increasing the potential maximum arrival throughput. The theoretical maximum throughput represents the maximum number of arrival flight per hour for a measured fleet mix and a JFK arrival configuration. This throughput number is derived assuming minimum wake vortex is used to separate any two consecutive flights. The throughput efficiency of each C&T can be shown as a percentage of the theoretical maximum arrival throughput. Using the same methodology and assumptions, we modeled the most frequently used arrival configuration at fourteen additional Continental United States (CONUS) airports and estimated the throughput improvements for each C&T combination against the theoretical maximum throughput, as shown in Figure 1.

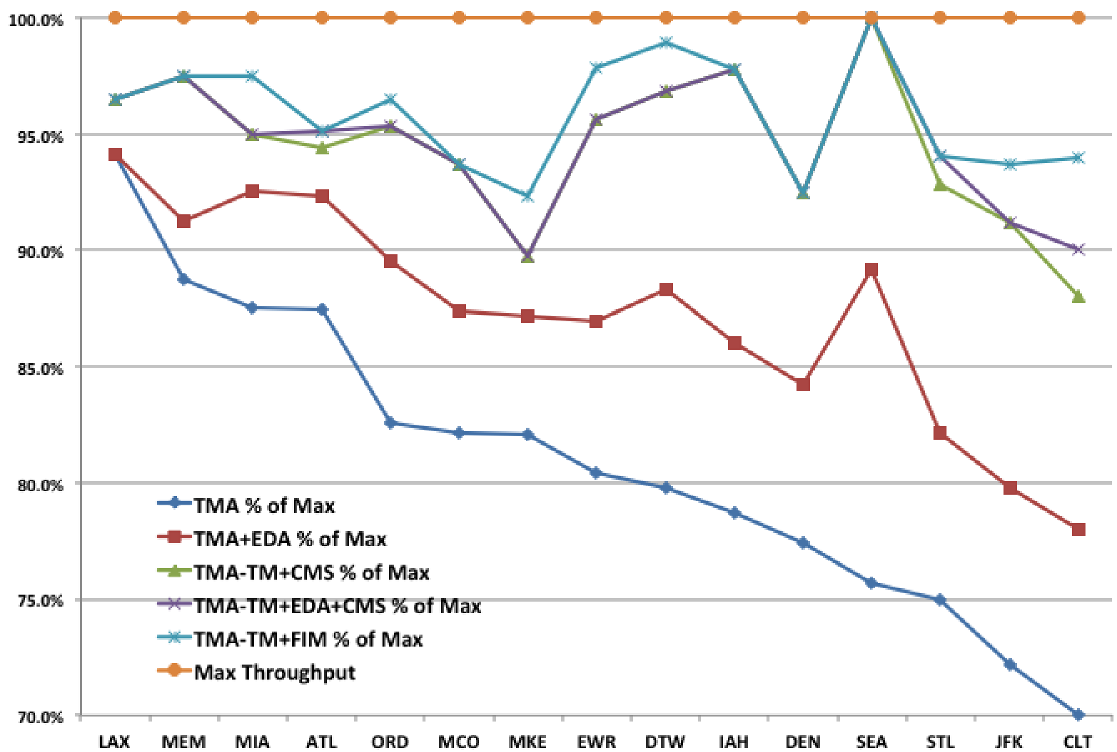


**Figure 1. C&T Combination to Theoretical Max Throughput Ratio for 15 CONUS Airports**

The throughput improvement percentage compared to the baseline TMA technology can be used to calculate the arrival capacity improvement at each airport when a C&T combination is implemented. The improved arrival capacity values are used as the basis for estimating both time-saving benefit and fuel-saving benefit, which are discussed in the next two sections.

## II. Time-Saving Benefit Evaluation through Simulation of Delay Reduction at Each Airport

The arrival capacity improvement from the baseline TMA technology (58 flight arrivals/hour) to the TMA-TM+FIM technology (74 flight arrivals/hour) is significant at JFK. However, this improvement can be realized only when the arrival demand exceeds the capacity at the airport; and airports generally don't operate under such conditions except during peak hours. To properly assess the actual time-saving benefit these technologies have at each airport, we use a queuing model to examine demand and capacity imbalances based on realistic demand scenarios for both current and future traffic.

We use a Pareto Frontier[6] to estimate actual time-saving benefit against a realistic demand scenario for each C&T combination. The capacity at an airport is defined by three capacity values, the maximum arrival capacity, the maximum departure capacity, and the maximum total capacity. In this analysis, we use capacity values developed by the Joint Planning and Development Office (JPDO)[7] to represent baseline airport capacities in the year 2009. The Pareto Frontier is used to describe the relationship for the three capacity values at an airport. On a Pareto Frontier chart, one axis represents the value of arrival capacity, and the other axis represents the value of departure capacity. The Pareto Frontier line usually starts from a point on the x-axis, which represents the maximum departure capacity, extends upward vertically, slides inward and forms a slope representing the isoline of the maximum total capacity value, and finally bends horizontally and connects to the left to the y-axis, which represents the maximum arrival capacity. Example Pareto Frontiers are shown in Figure 2. The slope shows the maximum total capacity at an airport when operating with mixed arrival and departure traffic, which is generally smaller than the maximum departure capacity plus the maximum arrival capacity[8].

Figure 2 below shows two Pareto Frontiers for JFK. For the baseline case, JFK has a maximum arrival capacity of 20 aircraft, a maximum departure capacity of 22 aircraft, and a maximum total airport capacity of 27 aircraft. Each green dot in Figure 2 represents a 15-min departure and arrival demand combination at JFK in a year 2020 demand scenario (supplied by the JPDO[7]). The sloped line, representing the maximum total airport capacity of 27 aircraft, shows the trade-off that occurs whenever the airport is operating in a region with both arrivals and departures (mixed operations).

In this study, two approaches, depending on the airport configuration types, are used to estimate the increased arrival throughput Pareto Frontiers: 1) a single runway configuration approach and 2) a multiple runway configuration approach. For the left Pareto Frontier in Figure 2, the airport configuration is assumed to be either a single runway or highly-dependent runways. The increased arrival capacity is traded off with the departure capacity. As a result, the maximum airport capacity does not increase, but only the arrival rate improves due to the impact of C&Ts. This is the single runway configuration approach. The right Pareto Frontier in Figure 2 assumes that the airport has independent arrival and departure runways. So, even though the arrival capacity is increased, it does not adversely affect the departure capacity. In fact, the departure capacity and total capacity are also increased due to the arrival capacity improvement. This is the multiple runway configuration approach. Each airport, depending on the arrival runway configurations, is assigned specific approach category for this analysis.

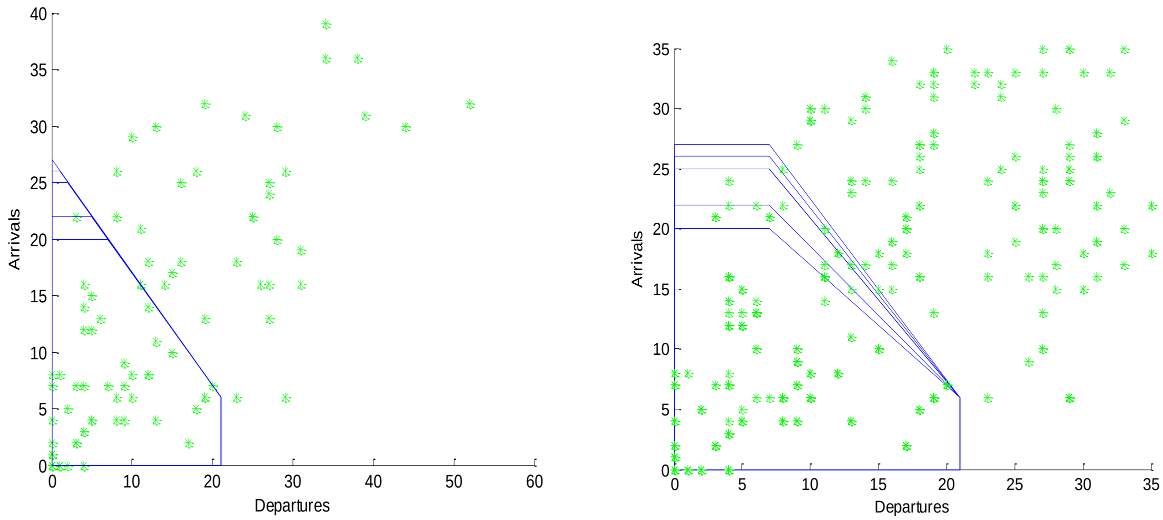


**Figure 2. Two Approaches Determining Capacity Improvements Impact Using 15-min Pareto Frontiers at JFK**

We analyzed all 15 airports' most commonly used runway configurations from the ASPM data and examined the interaction between the arrivals and departures operations. If strong interactions between departure and arrival runways were observed, the single runway configuration Pareto Frontier approach is used to model the arrival and departure capacity at this airport. Conversely, if the interactions between departures and arrivals were not significant, the multiple runway configuration approach was used. The approach used for each of the 15 CONUS airports is listed in Table 2 below.

**Table 2. Pareto Methodology Selection**

| Airport | Arrival \|Departure Runway Configuration | Pareto Frontier Methodology |
|---|---|---|
| **ATL** | 26R,27L,28 \| 26L, 27R | Multiple Runway Configuration |
| **CLT** | 23 \| 18C | Single Runway Configuration |
| **DTW** | 21L,22R \| 21R, 22L | Multiple Runway Configuration |
| **EWR** | 22L \| 22R | Multiple Runway Configuration |
| **IAH** | 26L,26R,27 \| 15L, 15R | Multiple Runway Configuration |
| **JFK** | 31L,31R \| 31L | Single Runway Configuration |
| **LAX** | 24R,25L \| 24L, 25R | Multiple Runway Configuration |
| **MCO** | 17L,18R \| 17R, 18L | Multiple Runway Configuration |
| **MEM** | 18L,18R \| 18C, 18L, 18R | Single Runway Configuration |
| **MIA** | 8L,9 \| 8R, 12 | Single Runway Configuration |

| | | |
|---|---|---|
| **MKE** | 25L \| 19R | Multiple Runway Configuration |
| **ORD** | 27L, 27R \| 22L, 28 | Multiple Runway Configuration |
| **SDF** | 35L,35R \|35L, 35R | Single Runway Configuration |
| **SEA** | 16C, 16R \| 16C | Single Runway Configuration |
| **STL** | 12L, 12R \| 12L, 12R | Single Runway Configuration |

Even though an airport may have a large increase in arrival throughput due to C&T improvement, if the arrival demand does not exceed the baseline capacity, not much delay reduction is then observed. Thus, we use JPDO demand scenarios[Error! Bookmark not defined.] as realistic future traffic representations for assessing the time-saving benefit each airport experiences with the improvements provided by the C&T combinations. There are total eight JPDO days representing typical air traffic across the NAS. Each day contains both current demand as well as future traffic in yearly increments from 2009 – 2030 and in five-year increments from 2035 – 2060. The traffic count for the baseline year (2009) for each of these days is shown in Table 3.

**Table 3. Traffic Count for Different JPDO Scenario Days for Fiscal Year 2009**

| Day | Total flights |
|---|---|
| **11-08-2008** | 33,576 |
| **11-20-2008** | 49,295 |
| **01-18-2009** | 33,390 |
| **03-19-2009** | 48,134 |
| **04-12-2009** | 36,507 |
| **06-18-2009** | 49,359 |
| **08-13-2009** | 51,082 |
| **09-28-2009** | 38,381 |

A simple queuing model is used to calculate the delay at each airport for a specific demand and capacity combination. In the time-saving benefit analysis, we assume the capacity at an airport remains the same throughout the analysis. The arrival and departure demand at an airport is sequenced and divided into 15-min time interval bins. For each 15-min time interval, the departure and arrival demand at an airport is calculated. The departure and arrival demand combination is then projected on to the Pareto Frontier of the airport, as shown as the light blue dot in Figure 3. A line is drawn from the blue dot to the origin, and the intersection between the line and the Pareto Frontier is the actual arrival and departure capacity operated during that 15-minute interval. The flight demand that cannot be realized during that 15-min interval will be pushed to the next time interval until the demand is realized. The difference between the scheduled arrival time in the demand scenario versus the actual arrival time generated using the queuing model is the delay. The total arrival delay is then calculated by summing up all arrival delay at the airport. By comparing the total delay using the Pareto Frontier from the baseline and the one of the C&T combinations with the same demand scenario, we can then obtain the time-saving benefit for a specific C&T combination for a specific demand scenario.

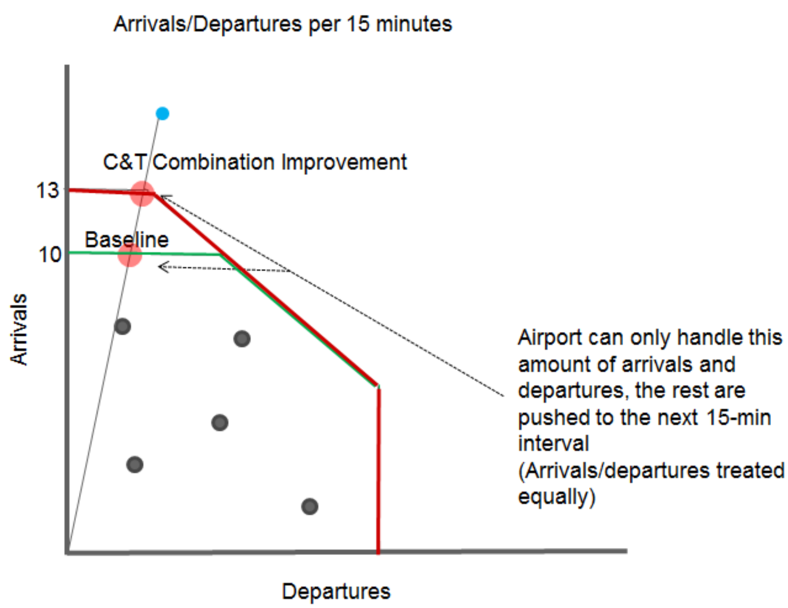


**Figure 3. Pareto Frontier Demand to Capacity Analysis**

The C&Ts are designed to be implemented in facilities that are currently operating with TMA. In addition to the 15 airports that are modeled explicitly, the following airports, as shown in Table 4, also have TMA implemented.

**Table 4. TMA Airports to Analyze**

| TMA Airport | Airport Mapped To | Pareto Frontier Methodology |
|---|---|---|
| **BOS** | EWR | Multiple Runway Configuration |
| **BWI** | EWR | Single Runway Configuration |
| **CLE** | EWR | Multiple Runway Configuration |
| **CVG** | ATL | Single Runway Configuration |
| **DCA** | EWR | Single Runway Configuration |
| **DFW** | ATL | Single Runway Configuration |
| **FLL** | EWR | Single Runway Configuration |
| **IAD** | ATL | Multiple Runway Configuration |
| **LAS** | EWR | Multiple Runway Configuration |
| **LGA** | EWR | Single Runway Configuration |
| **MDW** | EWR | Single Runway Configuration |
| **MSP** | EWR | Single Runway Configuration |
| **PDX** | EWR | Single Runway Configuration |
| **PHL** | EWR | Single Runway Configuration |
| **PHX** | EWR | Multiple Runway Configuration |
| **PIT** | EWR | Single Runway Configuration |
| **SAN** | EWR | Single Runway Configuration |
| **SFO** | EWR | Single Runway Configuration |
| **SLC** | ATL | Single Runway Configuration |
| **STL** | EWR | Single Runway Configuration |
| **TPA** | EWR | Single Runway Configuration |

Without necessary track data for airport specific throughput improvement percentage calculation, each TMA airport listed above is assumed to have the same arrival throughput improvement percentage as one of the airports that is modeled. Each of these airports is first analyzed to look for their most common runway configuration based on 2011 Aviation System Performance Metrics (ASPM) data. The arrival runway configuration at each airport is compared to the modeled TMA airports to find similarities. Depending on the arrival configuration, they may look like one of the airports that were already analyzed. Each of the airports is then mapped to a modeled TMA airport, as shown in Table 4. For the Pareto Frontier delay analysis, each airport's Pareto Frontier approach is also specified in Table 4 too.

## III. Fuel-Saving Benefit Evaluation through Simulation of Delay Reduction at Each Airport

The benefits from time savings and from flying Optimal Profile Descents (OPDs) are estimated separately, since there are differences in the estimation approaches. Several studies have estimated benefits from flying OPDs, but these studies estimated the maximum potential fuel-saving benefits possible from OPDs and not benefits related to different concepts or decision support tools that will enable flying OPDs. The C&Ts examined in this paper will enable OPD trajectories but not enable all arrivals to fly OPDs. Thus, we needed to find an approach to estimate the extent to which the different C&T combinations will enable OPDs.

A paper by Robinson and Kamgarpour[9], estimated the average potential fuel savings per flight flying an OPD. This estimate represents the maximum potential fuel savings per average flight. The results of the Robinson and

Kamgarpour study were adapted to help estimate the fuel saving from OPDs as enabled by the concept sets examined in our study. Our approach used the maximum potential fuel savings per flight estimated by this study for the 14 TMA airports that were examined by the study. A method was designed to extend the results of the Robinson and Kamgarpour study to the remainder of the TMA airports. Then a method was developed to make downward adjustments to the maximum potential per-flight fuel savings to account for the extent to which each concept set will enable OPDs.

***Calculating Maximum Potential OPD Fuel Savings at TMA Airports***

The study from Robinson and Kamgarpour used historical data on descent trajectories at a number of airports, including 14 of the TMA airports we examined. The level portions of these descent trajectories were identified using a software program. To represent the trajectories flown under OPDs, the level portions of the descent trajectory were moved to the top of descent. There is less fuel usage if the level portions are flown at a higher altitude. BADA (Base of Aircraft Data), which is a model that determines fuel burn for aircraft flying at various altitudes, was used to calculate fuel use in flying the level portions at the higher altitude (i.e., OPD trajectories) and at the different lower altitudes of the historical trajectories when not flying OPDs. The differences in these fuel burns are the fuel savings from flying OPDs. Thus, the study provides estimates of the maximum per flight fuel savings for flying OPDs at 14 TMA airports. In moving the horizontal segments of arrival trajectories to the top of descent, this study considers only a change in the vertical component of the trajectory and not the lateral component, and thus the OPD is defined within the vertical dimension. Since we use this study as a basis, this definition applies to our study also.

Results for the 14 TMA airports analyzed were used directly as estimates of the maximum potential OPD fuel savings for these airports. However, we also need estimates of the maximum potential per flight OPD fuel savings for the remaining TMA airports. Three other studies, Melby and Mayer[10], FAA Performance Analysis and Strategy Office[11], and FAA Research and Technology Office[12], were identified that estimated OPD fuel savings at these other TMA airports.

A method is used to create fuel savings for additional airports:

For each of the three studies, we found ratio of fuel savings at each airport other than the 14 to fuel savings of each of the 14 airports from Robinson and Kamgarpour study (produces 14 ratios per airport for each study); (2) averaged the 14 ratios across the 3 studies; (3) multiplied the averaged ratios for each additional airport by the Robinson and Kamgarpour values for the 14 airports (produces 14 estimates of savings per airport); (4) took the average of the savings estimates. The results of these calculations yields an estimate of the maximum potential per flight OPD fuel savings for each of the other TMA airports based on the fuel savings estimated for the 14 airports in the Robinson and Kamgarpour study.

From the Robinson and Kamgarpour study, we directly have the maximum potential per flight OPD fuel savings at the 14 TMA airports covered in the Robinson study. For the remaining TMA airports, the above calculation yields the maximum potential per flight OPD fuel savings at the TMA airports not addressed in the Robinson and Kamgarpour study.

***Calculating the Percentage of the Maximum Potential OPD Fuel Savings Enabled by each Set of Concepts***

As previously discussed, the Robinson and Kamgarpour study, as well as the other three studies mentioned above, estimated the maximum potential average flight OPD fuel savings rather than evaluating the fuel saving enabled by any particular concept, which would likely be less than this maximum potential fuel savings. We designed an approach to estimate the percent of this maximum potential per flight fuel savings that would be enabled by each set of concepts we are examining.

In our simulations of the time savings benefits addressed in the previous paper, curves were generated that show controller intervention rate over all pairs of arriving aircraft versus the size of the runway buffer, as shown in Figure 4. The controller intervention rate in these curves refers to the percent of arrivals for which there will be a potential loss of separation at a metering point, and the controller needs to intervene to provide a conflict resolution to change the trajectory of an arriving aircraft. As the inter-arrival spacing is reduced, the chances of a conflict are increased; but each C&T combination improves arrival conformance to the schedule compared with TMA, and thus requires less inter-arrival spacing at the scheduling points. A sample of these curves for Denver Airport is shown in Figure 4, and each curve in the set represents a particular C&T combination. The curves are created based on saturated demand. This is suitable for our analysis, since the C&T will provide a benefit at high demand levels. At low demand levels, the concepts may not be necessary to allow aircraft to fly OPDs.

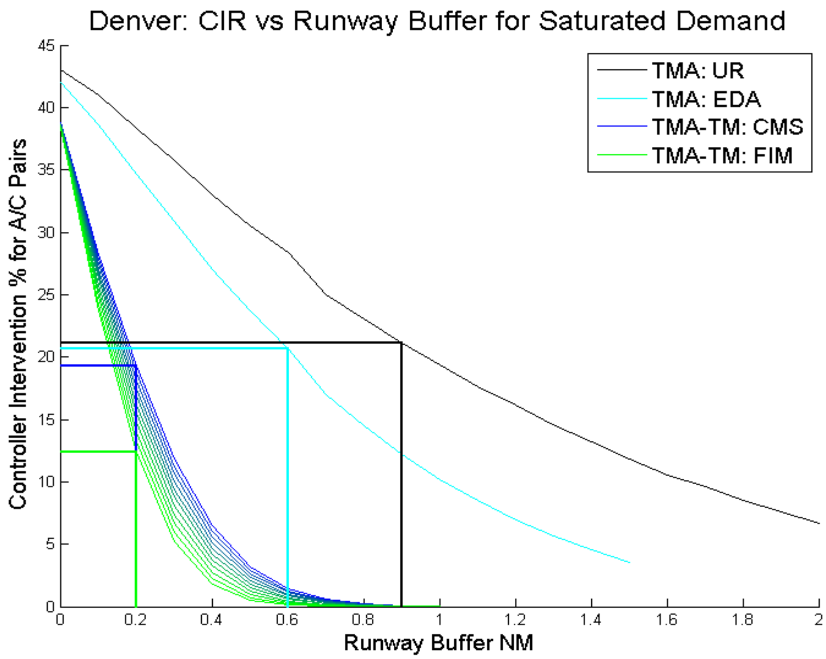


**Figure 4. Controller Intervention Rate vs. Runway Buffer at Denver Airport**

In our approach, we assume if the controller intervenes with a conflict resolution advisory, then the OPD is not flown by that aircraft, and there is no fuel savings benefit for that arrival. This is a worst case assumption in the sense that part of an OPD may have been flown before the controller intervention. However, the fidelity of the model does not allow us to estimate where during an arrival trajectory a controller intervention would take place, so we have assumed that the location of the controller intervention would not differ dramatically between the scenarios.

The runway buffer correlates to the airport throughput rate, since a smaller runway buffer allows for an increase in airport throughput and vice versa. Thus, the curves can be viewed as controller intervention rate vs. throughput for each C&T combination. From these curves, the percent of arrivals with controller intervention for a particular throughput indicates the percent of arrivals with controller intervention which, based on our assumption, is the percent of arrivals where an OPD is not flown. We then calculate [1- controller intervention percentage] as the percent of arrivals that would be flown as OPDs (i.e., no controller intervention and hence the OPD success rate). Figure 5 shows an example of Figure 4 showing controller intervention rate versus runway buffer converted to showing hourly arrival capacity.

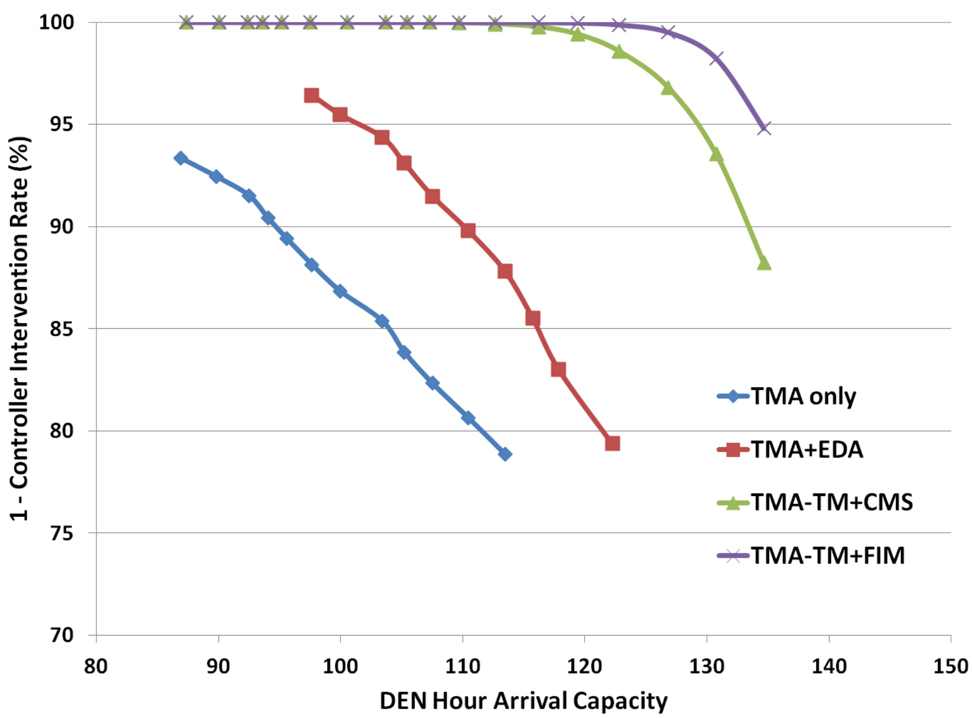


**Figure 5. Arrival Capacity vs. 1- Controller Intervention Rate at Denver Airport**

The first approach in this section gives the maximum potential average per flight OPD fuel savings at each TMA airport; the second approach in this shows how we determine the percent of this potential that will be obtained for each set of concepts studied. Multiplying these two values together provides the per flight OPD fuel savings for each concept set at each TMA airport.

The flight count for OPD arrivals for each TMA airport by demand scenarios for each C&T combination was obtained from the future JPDO demand flight arrival counts for estimating the time-saving benefits. Multiplying this number of arrivals by the per flight OPD fuel savings and totaling fuel savings across all TMA airports gives the total annual OPD fuel savings for each concept set for each future year in the demand scenario.

## IV. Time-Saving and Fuel Saving Benefit Results

Each of the modeled scenarios depends on one or more C&Ts (EDA, TMA-TM, CMS, and FIM). The benefits depend on the NAS-wide rollout of these technologies to the selected airports. Reasonable implementation schedules for EDA, TM and CMS were obtained from subject matter experts via interview and documents. The FIM implementation schedule is based on recent assumptions used in the May, 2012 FAA Surveillance and Broadcast Services (SBS) investment decision[13].

We first present the benefits without considering implementation schedules, and then apply the assumed implementation schedules. Showing both these estimates should allow the reader to observe the change of benefits with the implementation schedule of each C&T combination.

When applying the implementation schedule, as shown in Figure 6, the benefits were assumed to start in the year after implementation, because of uncertainty in the application start date and to allow time for a learning curve. None of the implementation assumptions are airport-specific, so benefits accrue at each airport using the percentage rollout across the NAS. This is a conservative assumption, because an operational program would most likely implement at the higher benefit airport sites first.

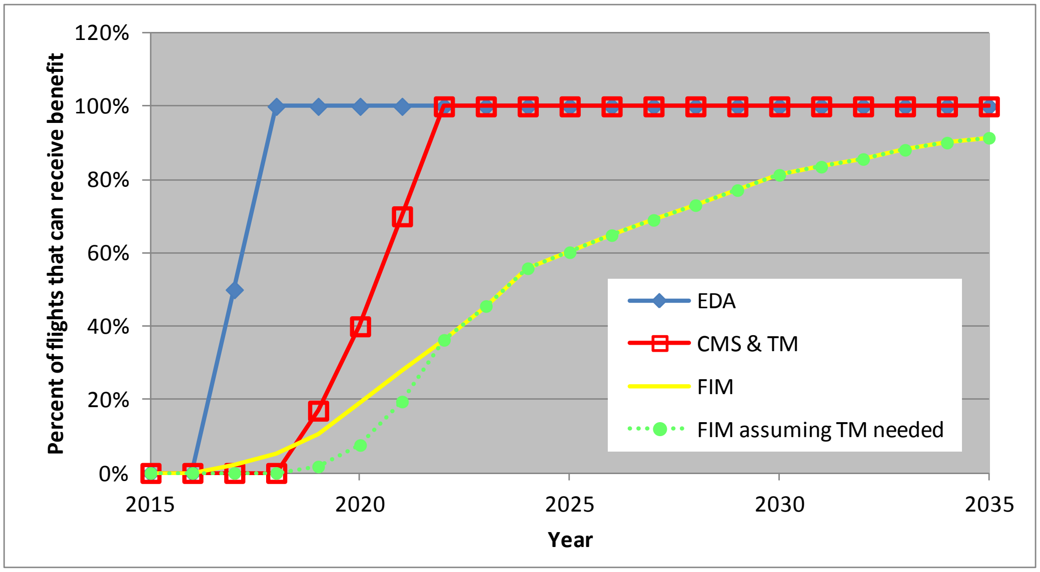


**Figure 6. Percent of Flights that Receive Benefit per Year from Supporting Technologies**

The time-saving benefits are derived in hours and monetized in terms of variable Aircraft Direct Operating Costs (ADOC) and Passenger Value of Time (PVT). The fuel-saving benefits are derived in gallons of fuel saved and monetized directly using an assumed fuel cost.

Each year, the FAA Investment Planning and Analysis Office produces guidance on values to use for economic analysis. This analysis uses the April, 2012 version of that guidance that lists values in Fiscal Year (FY) 2012 units. For ease of use, average the FAA presents ADOC and PVT for 4 major aircraft categories (Air Carrier, Commuter & Air Taxi, General Aviation, and Military). The categories conform to the categories used for airport operations forecasts produced by the FAA Policy and Plans Office Terminal Area Forecast (TAF).

Table 5 presents the variable ADOC per phase of flight and TAF aircraft category. Variable ADOC includes costs associated with fuel, oil, crew and maintenance. The average fuel price from 2012 to 2032 is $3.00 per gallon in FY12$ and was used to monetize the fuel-saving benefits directly.

**Table 5. Variable Aircraft Direct Operating Costs per phase of flight and TAF Aircraft Category**

| | Variable Aircraft Direct Operating Costs (ADOC) FY12 $ | | |
|---|---|---|---|
| **TAF Aircraft Category** | **Per Airborne Hour** | **Per Ground Hour** | **Per Gate Hour** |
| **Air Carrier** | $5,064 | $2,358 | $1,507 |
| **Commuter & Air Taxi** | $1,363 | $633 | $403 |
| **General Aviation** | $780 | $362 | $230 |
| **Military** | $8,528 | $3,976 | $2,550 |

As seen in Table 5, ADOC varies by phases of flight. The FAA guidance on applying ADOC for generic time savings is to default to 18 percent Airborne, 41 percent Ground and 41 percent Gate. While the time savings in this study is most likely related to airborne delay, we decided to apply the generic delay savings to be conservative. The C&Ts involved in this study are terminal arrival related C&Ts. These C&Ts are meant to create better arrival compliance and thus reduce unnecessary vectoring and level-off on the arrival flights. Therefore, the time savings in this study is mainly related to airborne delay. Table 6 presents the weighted ADOC used to monetize the delay savings.

**Table 6. Weighted Variable Aircraft Direct Operating Costs per TAF Aircraft Category**

| Weighted Average ADOC per hour (weighted by phase of flight) | | | |
|---|---|---|---|
| **Air Carrier** | **Commuter & Air Taxi** | **General Aviation** | **Military** |
| $2,496 | $670 | $383 | $4,211 |

PVT is calculated per passenger per hour and is based on Office of Management and Budget guidance. To calculate PVT per aircraft category the number of passenger seats (capacity) and load factor are needed. In December, 2011, the OMB released a memo that stated that PVT per passenger would increase by 1.6 percent per year over and beyond inflation; this means the value of PVT increases each year even when calculating benefits in base year (e.g. FY12) dollars. Table 7 presents the passenger capacity and load factor.

**Table 7. Passenger Capacity and Load Factor per TAF Aircraft Category**

| TAF Aircraft Category | Passenger Capacity | Passenger Load Factor |
|---|---|---|
| **Air Carrier** | 102.2 | 83% |
| **Commuter & Air Taxi** | 35.0 | 77% |
| **General Aviation** | 4.0 | 53% |

Figure 7 and Figure 8 display the yearly combined throughput and OPD savings in FY12 $M for the test scenarios before and after applying the implementation schedule. The final NAS-wide results are driven by the throughput-related time savings. A primary finding of this assessment is that the savings (without considering implementation timelines) is virtually identical for 3 of the test scenarios in the later years: TMA-TM+CMS, TMA-TM+CMS+EDA, TMA-TM+FIM. This implies that there is overlap on the benefit results between the three C&T combinations when examining throughput. When the implementation schedule is applied, the TMA-TM+FIM result is lowered because 100 percent FIM equipage was never assumed.

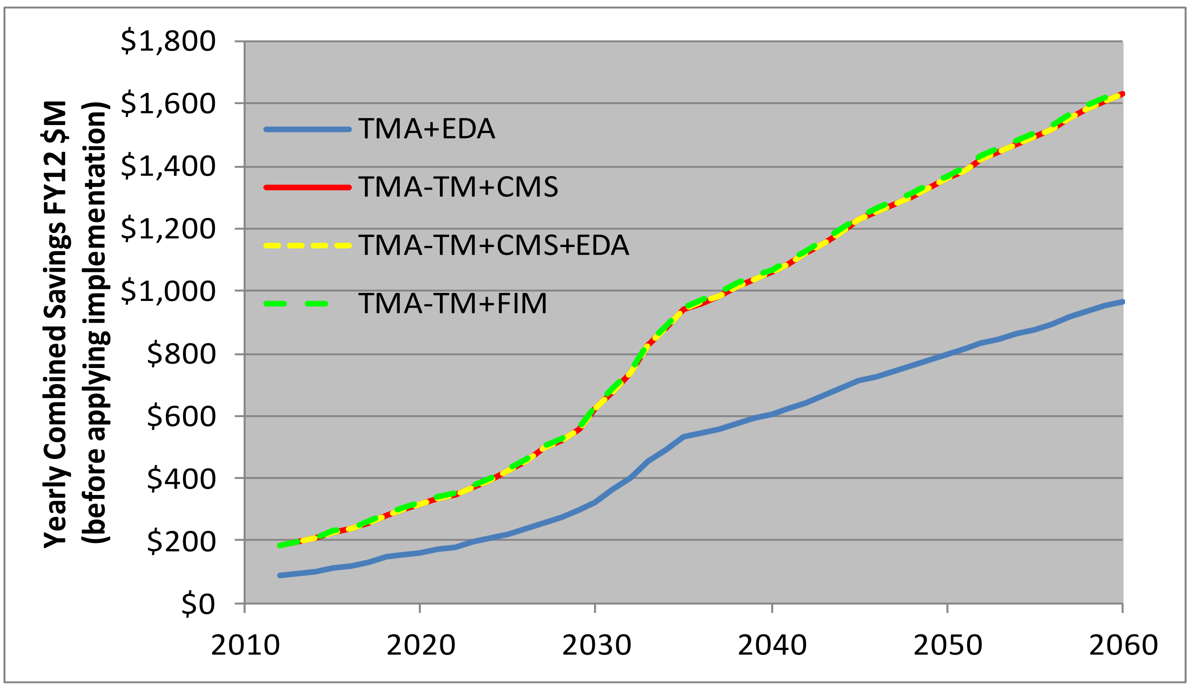


**Figure 7. Yearly Combined Savings in FY12 $M before Applying Implementation**

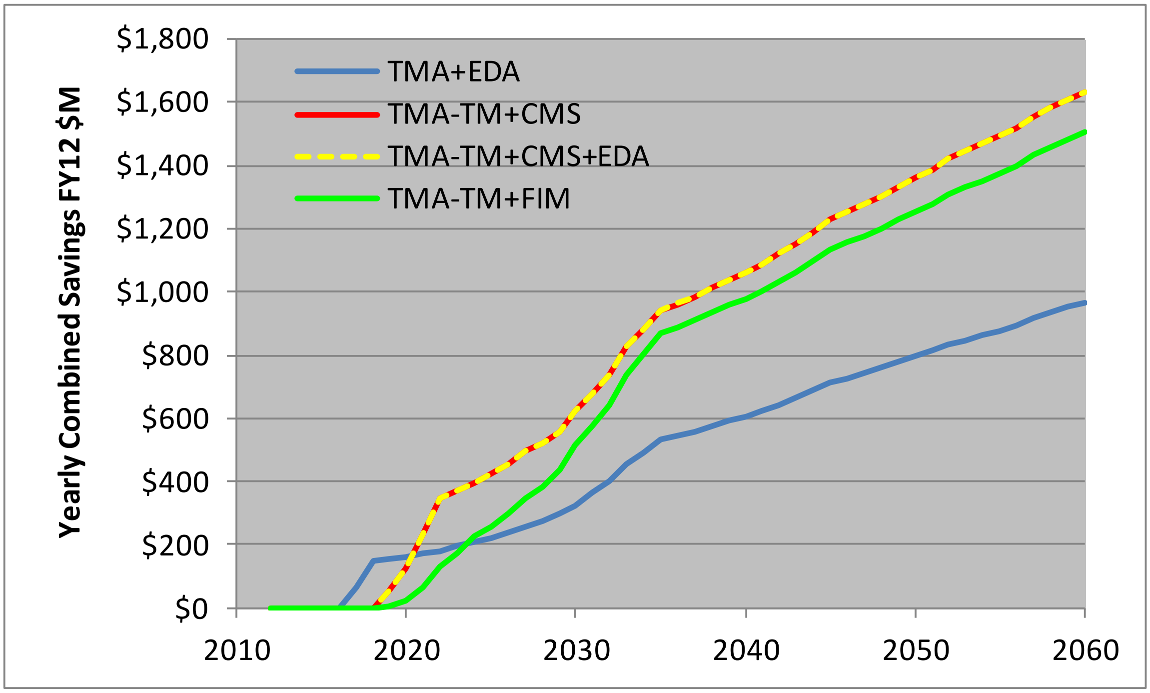


**Figure 8. Yearly Combined Savings in FY12 $M Considering Implementation Schedule**

Figure 9 displays the total benefit (after applying implementation schedule) between 2012 and 2060 at each airport divided into categories of valuation (ADOC, PVT, and OPD). This was done to acknowledge that different stakeholders may consider part of the benefit more applicable to them than the others. Figure 10 displays the percentage of the total benefit at each airport related to each of the categories of valuation (ADOC, PVT, and OPD). This was done to show the relative importance of each benefit at each site.

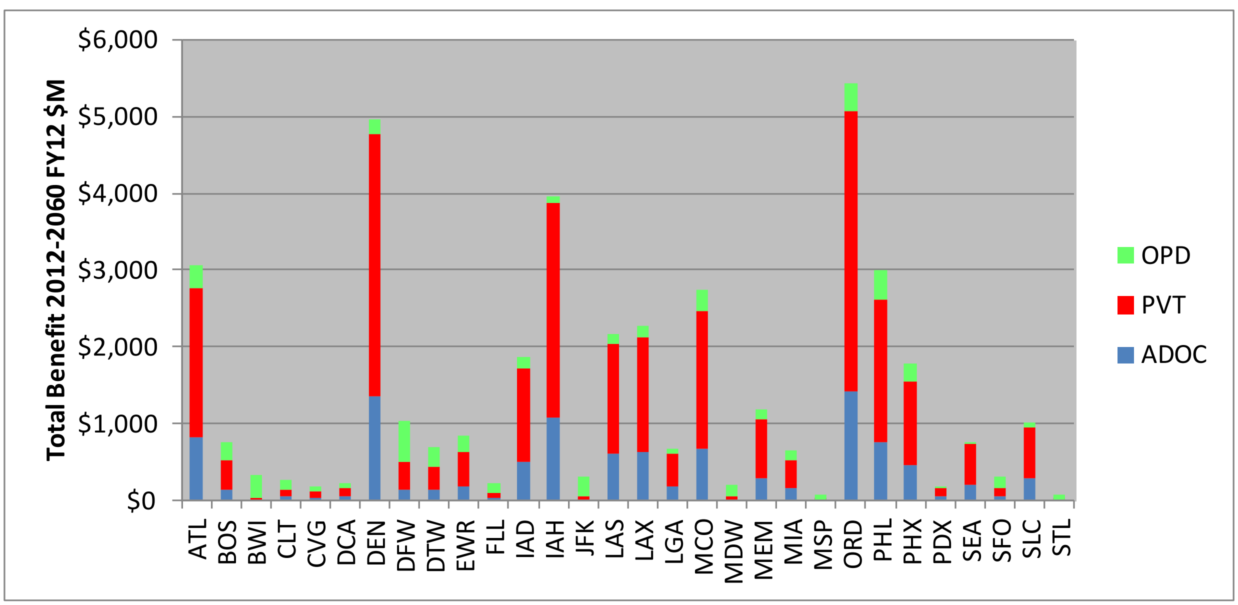


**Figure 9. Total Benefit 2012-2060 in Each Category (ADOC, PVT, and OPD) per Airport**

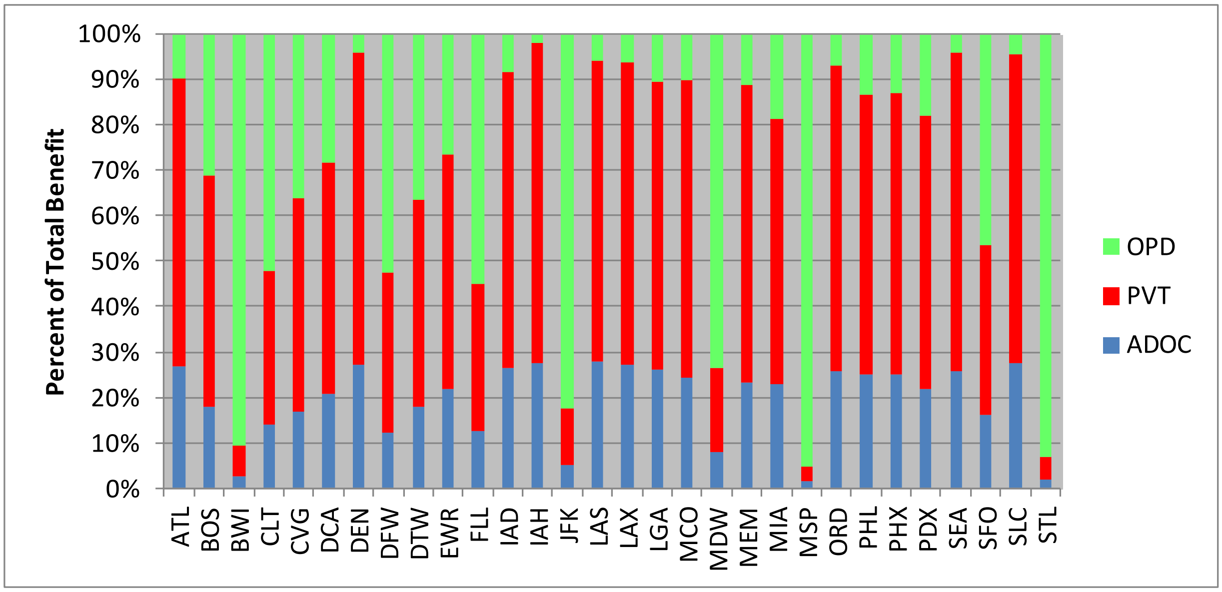


**Figure 10. Percentage of Total Benefit 2012-2060 in Each Category (ADOC, PVT, and OPD) per Airport**

The benefits presented above can be considered point estimates, because no attempt was made to risk-adjust the results. There are several possible variables that could be used to risk-adjust the model including projected demand, implementation schedule, and system effectiveness. Changes in many of these variables would impact each scenario similarly.

## V. Conclusion

This paper applies a unified methodology for estimating arrival throughput improvements for various combinations of NASA-developed C&Ts to all TMA airports. In addition, a queuing model is developed and applied to each individual TMA airport to estimate the NAS-wide time saving benefit. The model uses Pareto Frontier and future demand scenarios developed by the JPDO to examine the demand and capacity imbalance when different C&T combinations are applied. The fuel-saving benefit uses an approach based on the controller intervention rate and runway buffer chart developed to model the C&T time-saving benefits. By converting the controller intervention rate to OPD success rate and runway buffer to arrival throughput, we can then derive the fuel-saving benefit for all TMA airports, for both current and future traffic levels. The time-saving and fuel-saving benefit results show that there is overlap between several C&T combinations when examining their operational impact and effect on throughput. TMA+EDA provides incremental benefits compared with the baseline TMA system. The three C&T combinations using an improved version of TMA (TMA-TM+CMS, TMA-TM+CMS+EDA, and TMA-TM+FIM) all provide substantially higher benefits compared with the TMA baseline and the TMA+EDA combination if implementation schedule is not considered. However, when an implementation schedule is applied, TMA-TM+FIM is the most-negatively impacted combination because it is dependent on aircraft equipage to enable FIM operations.

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## References


[1] Swenson, H., Thipphavong, J., Sadovsky, A., Chen, L., Sullivan, C., Martin, L., "Design and Evaluation of the Terminal Area Precision Scheduling and Spacing System," Ninth USA/Europe Air Traffic Management Research and Development Seminar (ATM2011).

[2] Sweet, D., Dorsky, S., Mueller, T., "Data Analysis Report for the July, 2004 En Route Descent Advisor Simulation," Contract report prepared by Seagull Technology, Inc., Advanced Air Transportation Technologies Project, NASA Ames Research Center, Moffett Field, CA, Oct. 2004.

[3] Isaacson, D., Robinson, J., Swenson, H., "A Concept for Robust, High Density Terminal Air Traffic Operations," 10th AIAA Aviation Technology, Integration, and Operations (ATIO) Conference, Fort Worth, TX, Sept 2010.

[4] Barmore, B., "Airborne Precision Spacing: A Trajectory-Based Approach to Improve Terminal Area Operations," Proceedings of the 25th Digital Avionics Systems Conference, Portland, Oregon, Oct. 2006.

[5] Trapani, A., Yu, P., Huang, A., Timar, S., An Airport Adaptation Methodology and Arrival Throughput Analysis of Terminal Metering Concepts, AIAA 2012-5639, 12th AIAA Aviation Technology, Integration, and Operations (ATIO) Conference Indianapolis, Indiana, September 17-19, 2012.

[6] Transportation Research Board, Airport Cooperative Research Program (ACRP) Project 03-17 Evaluating Airfried Capacity, ACRP Report 79, ACRP Project 03-17, ISBN 978-0-309-25873-9, Washington DC, 2012, Page 57

[7] Gawdiak, Y., Carr, G., Hasan, S., JPDO Case Study of NextGen High Density Operations, AIAA 2009-6918, 9th AIAA Aviation Technology, Integration, and Operations Conference (ATIO), Hilton Head, South Carolina, 21 - 23 September 2009

[8] Kostiuk, P., Lee, D., and Long, D., Closed Loop Forecasting of Air Traffic Demand and Delay, 3rd USA/Europe Air Traffic Management R&D Seminar, Napoli, 13-16 June 2000

[9] Robinson, J., Kamgarpour, M., "Benefits of Continuous Descent Operations in High-Density Terminal Airspace Under Scheduling Constraints," NASA Ames Research Center, Moffett Field, California, 94035

[10] Melby, P., Mayer, R., "Benefit Potential of Continuous Climb and Descent Operations," AIAA 2008-8920, ICAS 2008 Congress including the 8th AIAA 2008 ATIO Conference, September 2008.

[11] FAA Performance Analysis and Strategy Office, "Projected Benefits of CDAs," July 31, 2008.

[12] FAA Research and Technology Development Office, Air Traffic System Concept Development Group, "4D Advanced Arrivals Metrics/Benefits Analysis Report," December 2009.

[13] FAA, FAA Study of ADS-B In adoption rates and metrics used in the Surveillance and Broadcast Services (SBS) Joint Resources Council decision, May, 2012.