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Have Descents really become more Efficient?

Trends in Potential Time and Fuel Savings in the Descent Phase of Flight after implementation of multiple procedures and ATC tools

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***Abstract*— Several ANSPs have implemented procedures to permit fuel-optimal descents and additional ATM tools to enable these descents during times of congestion. Many studies have proposed metrics to estimate the potential benefits of optimizing the descent phase of flight. This study uses versions of the proposed metrics to examine if there have been significant changes in the vertical efficiency pools after implementation of multiple efforts at the FAA Core 30 airports. The trends in the vertical efficiency pools are examined both over time and for differing levels of congestion. The results are compared to more general metrics produced in a related NextGen scorecard and consider the impact of the initiatives that have been deployed at each site. If an initiative had the desired impact on descent efficiency, and appropriate normalization factors are chosen, then the trend in the benefits pool should decrease after implementation. The results indicate that the vertical efficiency pool has decreased significantly for airports with both OPDs and time-based metering to the TRACON as compared to airports with OPDs only or those without OPDs.**

Keywords-component; ATM Benefit Pools, fuel savings, OPDs, Time-based metering

I. INTRODUCTION *(HEADING 1)*

The primary purpose of the Air Traffic Control (ATC) system is to prevent a collision between aircraft operating in the system, to provide a safe, orderly and expeditious flow of traffic, and to provide support for National Security and Homeland Defense. [1]. Most organizations that provide ATC services are continually upgrading procedures and automation to improve service to their customers (the airlines and the flying public). The first step in improving service is to determine where there is an opportunity to improve. A common method for determining the magnitude of the opportunity is to estimate a benefits pool. Most studies then use the identified pools to examine the potential for future initiatives.

The purpose of this study is to use the proposed metrics from past benefits pool studies to examine whether historical initiatives have had an impact. If an initiative had the desired impact, and appropriate normalization factors are chosen, then the trend in the benefits pool should decrease after implementation.

More specifically, this study gauges the impact of FAA initiatives on the efficiency of aircraft in the descent phase of flight. Many past studies focus on estimating the opportunity for fuel-efficient descent procedures, such as Continuous Descent Operations or Optimized Profile Descents (OPDs) [2, 3, 4, 5]. Each of these studies develops a benefits pool related to descents. Robinson and Kamgarpour [4] further examine the impact of airport congestion on the benefits pool, while Knorr et al. [5] examines the potential impacts of en route speed control on the pool. In this study, the vertical part of the descent efficiency benefits pool is examined over time and compared with FAA initiatives implemented over the same period at the Core 30 airports. The pool is also separated into levels of congestion to test the impact.

II. INITIATIVES TO IMPROVE EFFICIENCY IN THE DESCENT PHASE OF FLIGHT

The FAA has made many investments in both procedure design and automation to increase and enable aircraft efficiency in the descent phase of flight. The backbone of these initiatives is the concept of Performance Based Navigation (PBN) currently being implemented in terms of Area Navigation (RNAV) and Required Navigation Performance (RNP) procedures. These procedures allow for more predictable and fuel-efficient trajectories including OPDs. PBN procedures have been implemented widely across the NAS and are also included in large-scale airspace redesign efforts such as the Metroplex project.

In the current environment there are constraints that limit the full potential of PBN. The primary constraint is congestion caused by a daily NAS demand of approximately 60,000 flights that are competing for the same resources (airspace and airports). These resources have a finite capacity that changes dynamically based on weather and workload. One strategy to address this constraint is to create a common schedule for all aircraft to avoid unnecessary delay and inefficiency that results from tactical conflict management. The FAA is developing the common schedule using Time Based Flow Management (TBFM). TBFM is a portfolio of capabilities that provide a time-based metering schedule and tools to assist controllers in meeting that schedule in all phases of flight. The challenge for TBFM is to develop a system that enables PBN by providing a common schedule but is flexible enough to deal with changes dynamically.

While TBFM has been deployed across the NAS (to all 20 FAA en route Centers), it has not been used consistently for a few reasons:

1. The system is evolving at the same time as PBN, enhanced surveillance (Automatic Dependent Surveillance-Broadcast), and data sharing capabilities (Datalink Communications, System Wide Information Management).
2. One goal of TBFM is to apply spacing only when needed. Some airports do not have the demand to need it, and other airports are not ready for it.
3. The current tools may not be flexible enough to meet the goal in all situations (weather, etc.). Ensuring flexibility so that the tools do not make things worse through an overly rigid schedule is a concern.
4. The TBFM portfolio consists of an evolving set of capabilities that are still being implemented (Terminal Sequencing and Spacing-TSAS, Path Stretch, Interval Management, etc.)

In the end, PBN and TBFM should work together to increase efficiency in many areas across the NAS. All FAA Core 30 airports (except HNL) have been impacted in some way by both PBN procedures and TBFM. This study is interested in the descent phase of flight so the focus is placed on two initiatives that have been implemented at multiple facilities: OPD procedures and time-based metering of arrivals to the TRACON using TBFM.

Table I displays where OPDs, metering arrivals to the TRACON using TBFM, or both are used at 29 of the FAA Core 30 airports (did not examine HNL). The NextGen Performance Snapshots website [6] contained data on whether OPDs were available at each of the airports. The list of airports that applied significant metering to the TRACON in at least half of 2015 was obtained from the TBFM Performance Summary Dashboard maintained by MITRE [7]. In later sections, the correlation between the descent efficiency pools and these initiatives is explored.

TABLE I. DESCENT EFFICIENCY INITITIVES AT CORE 30 AIRPORTS IN FY2015

Airport	*OPDs*	*Metering to TRACON*	*Airport*	*OPDs*	*Metering to TRACON*
ATL	✓		LGA		
BOS	✓	✓	MCO		
BWI	✓		MDW	✓	
CLT	✓	✓	MEM	✓	
DCA	✓		MIA		
DEN	✓	✓	MSP	✓	✓
DFW	✓	✓	ORD	✓	
DTW			PHL		✓
EWR		✓	PHX	✓	✓
FLL			SAN	✓	✓
IAD	✓		SEA	✓	✓
IAH	✓	✓	SFO	✓	✓
JFK			SLC	✓	✓
LAS	✓	✓	TPA		
LAX		✓			

III. METHODOLOGY

The potential vertical fuel and time savings methodology relies on track data recorded in the Traffic Flow Management System (TFMS) archives. The track data consists of 1-minute position points including latitude, longitude, altitude, and time for each flight and flight information including aircraft type, call sign, origin, and destination.

Performing the analysis on all days in a year was time prohibitive, so a set of representative days for each year was selected. The representative days are the same ones chosen by the FAA NextGen organization each year and are used in many analyses and simulations to support FAA programs. The days are chosen so that they represent a wide variety of demand and weather conditions and when extrapolated to a year most closely match many yearly metrics. Table II presents the NextGen days used for 2010 and 2015.

TABLE II. NEXTGEN REPRESENTATIVE DAYS

FY2010	**FY2015**
10/6/2009	11/18/2014
10/17/2009	12/13/2014
11/20/2009	12/16/2014
1/10/2010	12/26/2014
3/9/2010	1/11/2015
3/25/2010	1/24/2015
5/6/2010	3/6/2015
5/18/2010	3/19/2015
6/5/2010	4/25/2015
7/3/2010	5/12/2015
7/13/2010	6/2/2015
7/22/2010	6/14/2015
	7/7/2015
	7/16/2015
	7/19/2015
	8/31/2015

A. *Potential Vertical Fuel and Time Savings*

Potential fuel savings were calculated on a per-flight basis by identifying level segments in the descent phase of flight and comparing the total fuel burned across each level segment to the total fuel that would have been burned if all level segments were moved to the aircraft's cruise altitude. Likewise, potential time savings were calculated by comparing the time flown across all level segments to the time flown that would have occurred if all level segments were moved to the aircraft's cruise altitude. Level segments were defined as consecutive altitude reports that differed by 300 feet or less. BADA 3.13 performance tables were used to estimate fuel and speed parameters for individual aircraft types at every altitude level.

Due to a variety of data quality issues, many flights in the TFMS archives were unusable for the analysis and were removed from consideration. While both 2010 and 2015 contained flights with these issues, the issues were more prevalent with the 2010 data set as the data quality has continued to improve over time. Flights were filtered from the analysis for any of the following reasons:

- Flight's arrival time was not available.
- Flight's arrival time and last trajectory time stamp differed by more than 5 minutes.
- Flight's aircraft type was not included in BADA.
- Flight cruised at an altitude higher than BADA's highest modeled altitude for the particular aircraft type.
- Flight's cruise altitude was lower than Flight Level (FL) 250.
- Flight's altitude profile included "spikes", suggesting faulty altitude reports.

After filtering flights with data quality issues, thousands of flights were considered for each year and at each airport. The following algorithm was applied to calculate a potential fuel and time savings for each remaining flight:

1. Identify the cruise altitude as the maximum altitude in the flight's altitude profile.
2. Identify the descent profile starting point as the first data point located within a 100 nautical mile (NM) radius of the arrival airport.
3. For each point in the flight's descent profile, identify a level segment as two or more consecutive altitude reports that vary by 300 feet or less.
4. For each level segment, calculate the level segment distance flown as the sum of the distance between each latitude/longitude included in the identified level segment.
5. For each level segment, calculate the level segment time flown as the level segment distance flown divided by the BADA reported speed at the altitude for which the level segment occurs.

   $$LevelSegmentTime = LevelSegmentDistance / BADAspeedAtLevelSegmentAltitude$$

6. For each level segment, calculate the level segment fuel burned as the level segment time (in minutes) multiplied by the BADA specified fuel flow rate for the level segment altitude.

   $$LevelSegmentFuelBurn = LevelSegmentTime * BADAfuelflowrateAtLevelSegmentAltitude$$

7. For each level segment, calculate the cruise segment time flown as the level segment distance divided by the BADA reported speed at the flight's cruise altitude.

   $$CruiseSegmentTime = LevelSegmentDistance / BADAspeedAtCruiseAltitude$$

8. For each level segment, calculate the cruise segment fuel burned as the cruise segment time (in minutes) multiplied by the BADA specified fuel flow rate for the flight's cruise altitude.

   $$CruiseSegmentFuelBurn = CruiseSegmentTime * BADAfuelflowrateAtCruiseAltitude$$

9. For each level segment, calculate the level segment fuel savings as the level segment fuel burned minus the cruise segment fuel burned.

   $$LevelSegmentFuelSavings = LevelSegmentFuelBurn - CruiseSegmentFuelBurn$$

10. Calculate the flight's potential fuel savings as the sum of all level segment fuel savings.

    $$FlightPotentialFuelSavings = \sum LevelSegmentFuelSavings$$

11. For each level segment, calculate the level segment time savings as the level segment time minus the cruise segment time.

    $$LevelSegmenTimeSavings = LevelSegmentTime - CruiseSegmentTime$$

12. Calculate the flight's potential time savings as the sum of all level segment time savings.

    $$FlightPotentialTimeSavings = \sum LevelSegmentTimeSavings$$

Once the level segment potential fuel and time savings were calculated for each flight, the results were aggregated at each airport and in each year, and the median was used as the reporting metric. In order to account for different levels of congestion that might impact the potential fuel and time savings for an individual flight, a congestion metric was developed and is described in the following section.

B. Congestion

Likely the most important constraint to enabling the use of OPDs beyond design of the procedure itself is demand congestion. Congestion not only depends on the demand at the airport but also the capacity. The ratio of arrival demand to arrival capacity is the congestion metric used in the remainder of this study.

The arrival demand can be calculated in multiple ways. For this study the demand was calculated per aircraft by defining the arrival queue ($Arrivals_Q$) as the number of aircraft that land between the time when an aircraft enters the study (in our case a 100 NM ring around the airport) and when it lands. In essence, this assumption treats the airport as a single server queue which is likely false; however, a similar assumption is made in many studies that examine a single arrival departure capacity curve for an airport.

Reference [5] presents a figure where $Arrivals_Q$ is used as the independent variable when examining transit time at LHR airport. Similar queue metric techniques to normalize for demand during post-implementation analysis have been used in multiple surface traffic studies [8, 9, 10, 11]. Fig. 1 displays the potential fuel savings (gallons) vs. $Arrivals_Q$ for Midway and Memphis International Airports using data from the 2015 NextGen days.

To compare arrival queue results between airports, the analysis needed a method to normalize for both demand and capacity. Some airports have high congestion much of the day, whereas other airports rarely approach capacity even on relatively high demand days.

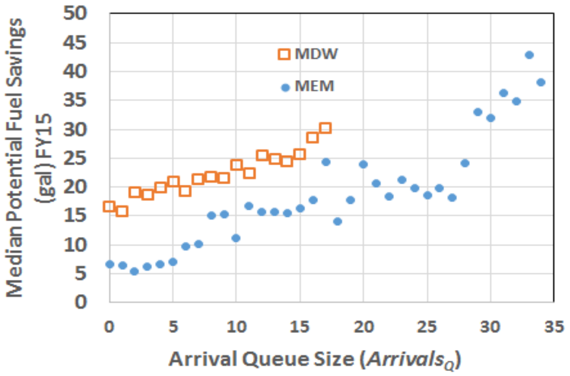

FIGURE 1. POTENTIAL FUEL SAVINGS VS. ARRIVALS$_Q$ AT MIDWAY AND MEMPHIS AIRPORTS IN FY2015

The FAA Aviation System Performance Metrics (ASPM) database [12] contains many useful metrics for major FAA airports that can be aggregated over long periods. For each airport, we found the maximum Airport Acceptance Rate(AAR) over the 16 NextGen days for FY2015. The AAR is the maximum arrival throughput per hour recorded for airports in controller logs. The second piece of information gathered from ASPM was the average flight time in minutes from a 100 NM ring around the airport to the runway ($Time_Q$). To find the average arrival queue for some specific level of congestion demand/capacity, we treat the airport as a single server queue and calculate the following:

$$Arrivals_{HOUR} = 60*Arrivals_Q / Time_Q \tag{1}$$

$$Congestion = Arrivals_{HOUR} / AAR = x\% \tag{2}$$

$$Arrivals_Q = x\%*Time_Q*AAR/60 \tag{3}$$

To estimate aggregated levels for low, medium, and high congestion we rely on a simple estimation used in the FAA 2007 Surveillance and Broadcast Services Benefits Basis of Estimate [13] that claimed for congestion lower than 40% OPDs could proceed without automation, for congestion >40% and <70% some automation might be required to allow OPDs, and for congestion >70% OPDs would require advanced automation and aircraft tools. Table III presents the maximum AAR, Time$_Q$ and Arrivals$_Q$ values related to 40% and 70% of the maximum AAR.

Table IV shows the percent of flights in each congestion level by airport for 2015. While the chosen metric does not take into consideration many of the factors that likely affect airport congestion, the resulting percentage of flights in each level does show some logical trends.

The three airports (LGA, DCA, and EWR) with the largest percentage of flights in the High congestion level are the same ones that were slot-controlled by the FAA in 2015 (In 2016, EWR was removed from the slot-controlled list). Slot control generally tries to limit congestion by designating capacity and requiring reservations for arrival slots.

Airports with a prevalence of flights during Low congestion periods, include both those airports with somewhat smaller demand overall (e.g. MEM, SLC, TPA) and those with larger demand but a large number of arrival runway choices (e.g. DFW, DTW, DEN).

TABLE III. ARRIVAL QUEUE SIZE RELATED TO AIRPORT ACCEPTANCE RATE

Airport	**Max AAR**	**Average minutes 100 to 0 (*Time$_Q$*)**	**Arrival Queue size (*Arrivals$_Q$* related to x% of AAR**	
			40%	**70%**
ATL	132	23.3	21	36
BOS	61	25.9	11	18
BWI	40	24.8	7	12
CLT	92	25.5	16	27
DCA	36	24.4	6	10
DEN	152	22.9	23	41
DFW	120	23.5	19	33
DTW	104	24.9	17	30
EWR	48	27.2	9	15
FLL	52	24.5	8	15
IAD	55	24.6	9	15
IAH	100	23.8	16	29
JFK	96	27.1	15	27
LAS	64	22.3	12	20
LAX	68	22.5	10	18
LGA	74	25.6	11	19
MCO	40	23.1	7	12
MDW	86	25.1	13	23
MEM	32	25.0	5	9
MIA	100	23.3	17	29
MSP	72	23.7	11	20
ORD	90	25.1	14	25
PHL	115	27.6	19	34
PHX	60	22.8	11	19
SAN	78	22.2	12	21
SEA	24	24.7	4	6
SFO	48	23.3	8	14
SLC	54	22.9	8	15
TPA	82	23.0	13	22

TABLE IV. PERCENT OF FLIGHTS BY CONGESTION LEVEL

Airport	**Percent of flights in each Congestion Level**		
	Low	**Medium**	**High**
ATL	20%	47%	33%
BOS	46%	42%	13%
BWI	43%	41%	16%
CLT	30%	30%	40%
DCA	18%	33%	49%
DEN	67%	30%	2%
DFW	31%	52%	17%
DTW	53%	32%	15%
EWR	24%	29%	47%
FLL	42%	47%	10%
IAD	70%	24%	6%
IAH	39%	45%	15%
JFK	35%	42%	23%
LAS	37%	53%	10%
LAX	22%	41%	38%
LGA	14%	22%	64%
MCO	71%	28%	0%
MDW	21%	33%	45%
MEM	75%	19%	7%
MIA	36%	48%	16%
MSP	48%	35%	17%
ORD	17%	42%	41%
PHL	27%	29%	44%
PHX	45%	42%	13%
SAN	30%	27%	43%
SEA	30%	41%	28%
SFO	27%	47%	26%
SLC	68%	25%	7%
TPA	85%	14%	1%

IV. RESULTS

The majority of results in this section are presented as a percent reduction in either the median vertical potential fuel savings or the median vertical potential time savings between 2010 and 2015 at each of the selected airports. A positive reduction indicates that the pool for benefit has decreased, and consequently, vertical efficiency has increased. Conversely, a negative reduction indicates that vertical efficiency has decreased between the two years.

The results are presented by airport and then grouped by initiative using the mean and the median of the individual airport results. In the aggregate results, the airports are treated equally and no weighting between airports is applied.

It is recognized that many other factors (for example changes in fleet mix and runway configuration) likely impact the measurements. Also, as noted in [5] it is also important to consider the lateral impact when considering overall descent efficiency. While no effort has been made in the current study to normalize for other factors or measure lateral efficiency, the last section recommends these as further steps in the analysis.

A. *Vertical Efficiency Pool*

Table V presents the median potential fuel savings (in gallons) and the median potential time savings (in minutes) at 29 of the Core 30 airports. The table includes results for the 2010 and 2015 representative days, as well as the percent reduction in each pool between the years. The table also indicates the initiatives available at each airport (in FY2015), effectively segregating the airports into 3 groups: airports with no OPD procedures, airports with OPD procedures but no time-based metering of arrivals, and airports with both OPDs and time-based metering of arrivals to the TRACON.

Table VI presents a summary of the results aggregated by initiative grouping. Both the median and the mean are shown in the table. The *OPD + metering to TRACON* grouping shows a much higher mean and median reduction in both potential fuel savings and potential time savings as compared to the other two groupings, implying an increase in vertical efficiency. For three out of the four metrics, the *OPD-only* grouping has a higher reduction than the *No OPD* grouping.

The results suggest that the application of OPD procedures alone do increase vertical efficiency at an airport but time-based metering to the TRACON allows use of those procedures more consistently.

TABLE VI. Percent Reduction by Initiative Grouping from TFMS Analysis

Initiative grouping	**Potential fuel savings**		**Potential Time savings**	
	Mean % reduction	***Median % reduction***	***Mean % reduction***	***Median % reduction***
No OPD	4.2%	7.6%	3.0%	4.9%
OPD-only	7.5%	6.0%	15.8%	9.7%
OPD+metering to TRACON	42.6%	43.8%	39.1%	38.9%

TABLE V. Potential Fuel and Time Savings during descent

Airport	**Potential Fuel Savings (gallons)**			**Potential Time Savings (minutes)**			**Initiatives (FY2015)**		
	2010	***2015***	***Percent Reduction***	***2010***	***2015***	***Percent Reduction***	***No OPDs***	***OPD-only***	***OPD + metering to TRACON***
ATL	9.1	10.1	-10.7%	1.3	1.2	4.0%		✓	
BOS	17.2	9.1	47.0%	2.0	1.0	52.1%			✓
BWI	13.2	12.2	8.0%	1.4	1.3	12.6%		✓	
CLT	10.1	8.2	19.4%	1.8	1.5	17.7%			✓
DCA	9.7	6.8	29.8%	1.3	1.0	27.1%		✓	
DEN	5.6	3.3	41.8%	0.4	0.3	23.2%			✓
DFW	14.5	5.2	64.2%	1.8	0.8	57.3%			✓
DTW	13.0	11.0	15.0%	2.2	1.8	17.2%	✓		
EWR	26.2	24.3	7.2%	3.3	3.1	7.7%	✓		
FLL	14.8	15.3	-3.4%	1.5	1.6	-2.4%	✓		
IAD	11.8	11.1	6.0%	2.0	1.8	9.7%		✓	
IAH	9.6	6.4	33.6%	1.6	1.1	30.4%			✓
JFK	26.9	24.8	8.0%	2.2	1.9	11.8%	✓		
LAS	9.1	6.1	33.4%	1.1	0.6	40.9%			✓
LAX	3.9	2.4	40.5%	0.4	0.2	43.3%	✓		
LGA	18.9	19.6	-3.3%	3.0	3.3	-11.9%	✓		
MCO	8.9	10.8	-21.7%	0.8	1.0	-20.2%	✓		
MDW	21.9	21.5	1.5%	3.0	2.9	3.2%		✓	
MEM	16.5	13.5	18.1%	2.1	1.0	52.3%		✓	
MIA	11.2	10.2	9.0%	1.0	0.9	2.1%	✓		
MSP	13.4	4.3	67.8%	2.0	0.8	58.1%			✓
ORD	14.2	14.3	-0.4%	2.1	2.0	1.8%		✓	
PHL	21.9	19.6	10.6%	2.8	2.5	11.7%	✓		
PHX	7.8	2.3	70.5%	0.9	0.2	77.1%			✓
SAN	4.5	2.5	45.9%	0.4	0.3	23.7%			✓
SEA	9.0	4.1	54.3%	1.0	0.5	52.3%			✓
SFO	4.4	3.1	29.9%	0.5	0.4	24.9%			✓
SLC	4.8	4.6	3.5%	0.6	0.6	-1.6%			✓
TPA	6.9	8.3	-20.0%	0.7	0.9	-29.9%	✓		

TABLE VII. PERCENT REDUCTION POTENTIAL FUEL AND TIME SAVINGS DURING DESCENT BY CONGESTION LEVELS

Airport	**Percent Reduction Potential Fuel Savings**			**Percent Reduction in Potential Time Savings (minutes)**		
	Low	***Medium***	***High***	***Low***	***Medium***	***High***
ATL	-30.2%	-20.0%	-8.5%	-22.8%	-8.7%	8.1%
BOS	57.1%	36.1%	24.8%	57.9%	47.4%	42.2%
BWI	4.4%	0.5%	-5.3%	-2.2%	3.5%	1.6%
CLT	24.2%	19.2%	18.4%	19.8%	20.8%	11.2%
DCA	48.3%	40.1%	22.2%	40.7%	38.6%	18.3%
DEN	40.3%	28.2%	35.1%	25.7%	-10.9%	-1.6%
DFW	70.6%	60.4%	74.2%	62.5%	55.4%	65.5%
DTW	16.2%	8.7%	8.4%	21.4%	11.1%	-1.5%
EWR	17.7%	-5.6%	4.7%	10.3%	4.6%	6.8%
FLL	-6.2%	-1.9%	20.9%	-8.2%	-0.8%	15.2%
IAD	5.5%	-1.2%	6.0%	4.3%	3.9%	-5.8%
IAH	31.3%	24.8%	40.2%	26.7%	21.3%	32.3%
JFK	7.5%	12.4%	-1.1%	12.0%	15.6%	-2.1%
LAS	41.3%	26.6%	2.2%	49.7%	35.6%	9.1%
LAX	53.9%	65.2%	18.4%	52.7%	70.7%	-0.8%
LGA	-0.3%	-0.7%	-2.9%	-5.9%	-15.1%	-9.1%
MCO	-21.1%	-24.5%	-84.9%	-15.9%	-23.2%	-80.9%
MDW	-8.8%	4.3%	2.2%	-5.8%	2.7%	5.3%
MEM	41.2%	-12.8%	-311.4%	52.7%	45.8%	16.0%
MIA	7.3%	22.4%	26.5%	4.9%	15.5%	14.2%
MSP	70.1%	67.5%	58.0%	60.0%	56.2%	44.4%
ORD	-6.3%	-9.2%	10.9%	-5.6%	-8.4%	8.9%
PHL	5.0%	8.5%	14.3%	-0.6%	4.5%	13.3%
PHX	72.5%	68.6%	71.9%	80.5%	76.0%	75.2%
SAN	63.9%	36.1%	39.7%	57.1%	34.1%	27.3%
SEA	59.4%	59.3%	37.4%	58.4%	58.1%	33.5%
SFO	53.0%	30.3%	47.5%	9.3%	32.8%	48.7%
SLC	1.5%	2.7%	11.7%	-1.5%	-4.9%	1.4%
TPA	-19.5%	-10.4%		-30.3%	-23.1%	

B. Congestion

The results in the previous section were segregated into the congestion levels presented in Tables III and IV to better examine the impact of congestion on vertical efficiency. The authors expected to see the following trends:

- At the low congestion level, the vertical efficiency (reduction in potential fuel and time savings) would increase the most at airports with OPDs as opposed those without.
- At medium and high congestion levels, increases in the vertical efficiency would depend on having both OPDs and metering of arrivals to the TRACON, so we might expect to see a drop off in vertical efficiency in airports without metering of arrival to the TRACON.

Table VII presents the percent reduction in median potential fuel savings and the median potential time savings by congestion level between 2010 and 2015 at 29 of the Core 30 airports. Table VIII presents a summary of the results by congestion level aggregated by initiative grouping. Figure 2 graphs the values in Table VIII for visual inspection of the trends.

The results in each cell in Table VII represent medians over widely varying sets of flights, as implied by the percent of flights by congestion level seen in Table IV. There is no value for the high congestion level for TPA because there were no valid flights at this congestion level after the filtering described in Section III.

While some of the trends expected by the authors are generally upheld across the airports, there are definitely some trends not explained by the reasoning.

TABLE VIII. PERCENT REDUCTION BY INITIATIVE GROUPING FROM TFMS ANALYSIS BY CONGESTION LEVEL

Initiative grouping	**Mean % Reduction Potential fuel savings**		
	Low	***Medium***	***High***
No OPD	6.0%	7.4%	0.5%
OPD-only	7.7%	0.2%	-42.2% (2.7%)
OPD+metering to TRACON	48.8%	38.3%	38.4%
Initiative grouping	**Mean % Reduction Potential time savings**		
	Low	***Medium***	***High***
No OPD	4.1%	6.0%	-5.0%
OPD-only	8.7%	11.1%	5.1%
OPD+metering to TRACON	42.2%	35.2%	32.4%

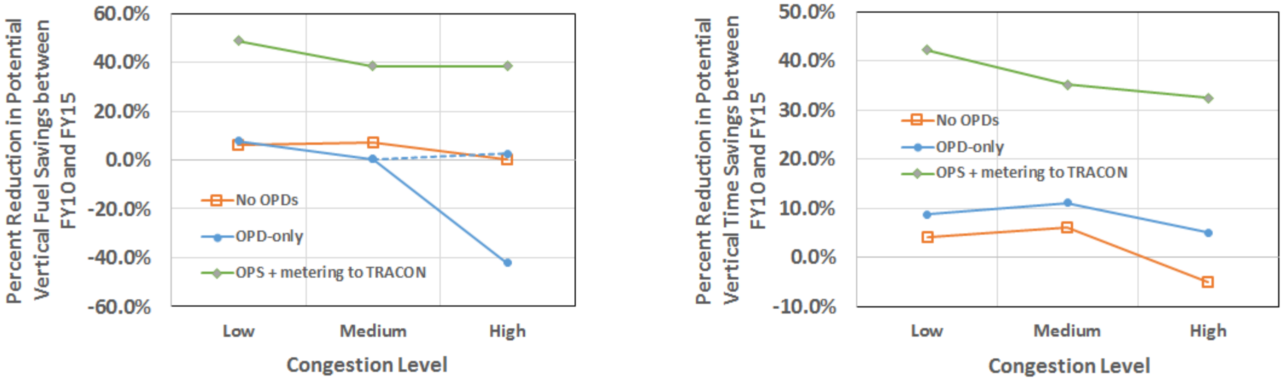

Figure 2. Trends in the Percent Reduction of potetial fuel and time savings by levels of Congestion and Initiative Grouping

The airports with both OPDs and metering to the TRACON show a significant increase in vertical efficiency across all congestion levels. The difference between airports with OPDs-only and those without OPDs is somewhat less clear, especially in the potential vertical fuel savings metric where the *No OPD* grouping displays higher values than the *OPD-only* grouping for the medium and high congestion levels.

The *OPD-only* grouping included a potential outlier in MEM at high congestion that shifts the value negative by a significant amount. The results for the *OPD-only* case without the outlier are indicated in the Table VIII using parentheses and in Figure 2 by a dotted line.

V. Comparison with NextGen Performance Scorecard

As a separate check, the results were compared to those found in the NextGen Performance Scorecard [6]. The scorecard for each airport contains two metrics related to descent efficiency: Distance in level flight from top of descent to runway (NM) and Number of level offs per flight. The data is recorded yearly and the first year for both metrics is 2011 while the last year is 2015.

Table IX presents the average distance in level flight from top of descent to the runway (in NM) and the average number

Table IX. NextGen Performance Scorecard Data from [FAA 2016]

Airport	**Distance in level flight from top of descent to runway (NM)**			**Number of level offs per flight**		
	2011	***2015***	***Percent Reduction***	***2011***	***2015***	***Percent Reduction***
ATL	38.7	37.3	3.6%	2.6	2.4	7.7%
BOS	49.3	34	31.0%	3	2.2	26.7%
BWI	51.4	50.4	1.9%	3.5	3.5	0.0%
CLT	44.6	41.7	6.5%	3.1	3	3.2%
DCA	53.9	47.6	11.7%	3.5	3	14.3%
DEN	26.6	22.3	16.2%	2	1.6	20.0%
DFW	27.9	20.1	28.0%	1.8	1.7	5.6%
DTW	49.8	50.2	-0.8%	2.8	2.8	0.0%
EWR	62.1	62	0.2%	4.2	4.1	2.4%
FLL	32	32.3	-0.9%	2.5	2.4	4.0%
IAD	53.8	48.5	9.9%	3.6	3.3	8.3%
IAH	31.6	21.7	31.3%	2.4	1.7	29.2%
JFK	41.2	44.1	-7.0%	3.2	2.9	9.4%
LAS	43.7	43.2	1.1%	2.2	2.1	4.5%
LAX	17.1	17	0.6%	1.3	1.3	0.0%
LGA	57.9	62.4	-7.8%	3.9	4	-2.6%
MCO	42	44.7	-6.4%	2.6	2.7	-3.8%
MDW	59.3	60.5	-2.0%	4.1	4.2	-2.4%
MEM	30.7	23.3	24.1%	2.5	1.8	28.0%
MIA	24.9	24.6	1.2%	2.1	2	4.8%
MSP	34.9	27.5	21.2%	2.3	1.9	17.4%
ORD	60.4	55.9	7.5%	3.4	3.3	2.9%
PHL	65.5	61.9	5.5%	3.9	4.1	-5.1%
PHX	33.1	26.3	20.5%	2.2	1.4	36.4%
SAN	25.8	24	7.0%	1.5	1.3	13.3%
SEA	13.9	12.4	10.8%	1.1	1.1	0.0%
SFO	21.4	15.3	28.5%	1.5	1.2	20.0%
SLC	36.1	31.7	12.2%	2.5	2.2	12.0%
TPA	25.2	28.6	-13.5%	2	2.2	-10.0%

of level offs per flight at 29 of the Core 30 airports. The table includes results for the 2011 and 2015, as well as the percent reduction in each metric between the years.

Table X presents a summary of the results aggregated by initiative grouping. The results in Table X show very similar trends to the reduction in the benefits pools from Table VI. The Scorecard results show a somewhat more noticeable difference between the *OPD-only* and the *No OPD* groupings than the benefit pool results.

TABLE X. PERCENT REDUCTION BY INITIATIVE GROUPING FROM NEXTGEN SCORECARD DATA

Initiative grouping	**Distance in level flight from top of descent to runway**		**Number of level offs per flight**	
	Mean % change	***Median % change***	***Mean % change***	***Median % change***
No OPD	-2.9%	-0.9%	-0.1%	0.0%
OPD-only	8.1%	7.5%	8.4%	7.7%
OPD+Metering to TRACON	17.9%	18.4%	15.7%	15.4%

VI. CONCLUSIONS AND NEXT STEPS

In answer to the question in the title, yes, descents at FAA airports with procedures and automation to enable them have become more vertically efficient. Furthermore, this analysis implies that the FAA can claim that procedures plus time-based metering of arrivals to the TRACON enables more vertically efficient descents than procedures alone.

One obvious next step for this analysis is to examine the impact on the lateral as well as the vertical efficiency. This type of examination was suggested in [5] and should provide a better understanding of the entire descent efficiency. Data to account for arrival fix, runway use, and possibly wind will need to be correlated to the current data to properly take lateral efficiency into account. Examining the entire descent efficiency will likely improve the congestion level results. The data necessary to examine lateral efficiency could also be used to better define arrival queues and congestion levels by runway or arrival fix, as opposed to over the entire airport.

There are, of course, other factors not examined in this study that influence the overall results. Such other factors that differ by airport and at each airport over time include the geometry of the airspace, the mix of arrival gates used, the aircraft mix, the aircraft equipage, the weather, and the procedure design effectiveness. A major assumption of the current work is that the impacts of some or most of these factors are lessened by the amount of data used and the distribution of days. Further analysis could examine the impact of each of these factors to determine if they differ significantly between the baseline year and the test case year. If significant differences are found, then the analysis should be repeated to account for those results.

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REFERENCES

[1] FAA Order JO 7110.65W, December 2015. Available from FAA web page: https://www.faa.gov/documentlibrary/media/order/atc.pdf

[2] Melby, Paul C., Ralf H. Mayer, Benefit Potential of Continuous Descent and Climb Operations, MP070200, The MITRE Corporation, September 2007.

[3] Alcabin, M., Schwab, R. W., Soncrant, C., Tong, K.-O., and Cheng, S. S., “Measuring Vertical Flight Path Efficiency in the National Airspace System,” 9th AIAA Aviation Technology, Integration, and Operations Conference (ATIO), Hilton Head, SC, Sep. 21-23, 2009, AIAA-2009-6959.

[4] Robinson, John E, III and Kamgarpour, Maryam, “Benefits of Continous Descent Operations in High-Density Terminal Airspace Under Scheduling Constraints”, American Institute of Aeronautics and Astronautics, Anaheim, CA, 2010.

[5] Knorr, D., Chen, X., Rose, M., Gulding, J., Enaud, P., Hegendoerfer, H., “Estimating ATM Efficiency Pools in the Descent Phase of Flight”, 9th USA/Europe ATM R&D Seminar, Berlin, Germany, 2011.

[6] FAA, NextGen Performance Snapshots-Airports web page, data collected form Scorecard section from each of the Core 30 airports in January 2017, https://www.faa.gov/nextgen/snapshots/airport/.

[7] MITRE CAASD, TBFM Performance Summary Dashboard, data collected January 2017.

[8] Shumsky, R., (1997), “Real-Time Forecasts of Aircraft Departure Queues,” Air Traffic Control Quarterly, 5 (4).

[9] Idris, H., Clarke, J-P., Bhuva, R., and King, L. (2002), “Queuing Model for Taxi-Out Time Estimation,” Air Traffic Control Quarterly, 10 (1).

[10] Howell, D., “Effect of Surface Surveillance Data Sharing on FedEx Operations at Memphis International Airport,” Air Traffic Control Quarterly, Vol. 13, 4, 2005.

[11] Howell, D., Flanders, I. and Shema, S.,"Using Surface Demand Trends to Evaluate Multiple Airport Surface Initiatives," presented at AIAA 7th Aviation Technology, Integration, and Operations Conference, Belfast, Northern Ireland September 2007, AIAA-2007-7765.

[12] FAA, Aviation System Perfromance Metrics (ASPM) Web Data System, data collected for each of the Core 30 airports in January 2017, https://aspm.faa.gov/apm/sys/main.asp.

[13] FAA, “Benefits Basis of Estimate for Surveillance and Broadcast Services Program,” 2007.

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