AN APPROACH TO INCORPORATING DEMAND UNCERTAINTY IN NAS-WIDE MODELING

William Baden, Glenn Foster, David Millner, George Solomos
Center for Advanced Aviation System Development (CAASD)
The MITRE Corporation
McLean, VA 22102

Background

The Federal Aviation Administration's (FAA's) Operational Evolution Plan (OEP) was initiated in 2000 as a 10-year plan to improve the capacity of the National Airspace System (NAS). MITRE/CAASD has supported the FAA in its assessment of the OEP by using a discrete event simulation of the NAS. Regular performance assessments have provided point estimates of both NAS-wide delays and airport delays. However, the use of point estimates has limited the insight decision-makers have about the amount of uncertainty in the performance estimates of the future NAS.

Some level of uncertainty in future performance is driven by uncertainty in future demand levels. Performance assessments have used the FAA's official forecast, the Terminal Area Forecast (TAF), as the basis for determining how much growth to include in future demand. The TAF is an annual publication that forecasts the annual level of operations to be expected at over 3000 NAS airports. The most recent TAF, the 2005 TAF, forecasts yearly operation levels through 2025. TAF traffic level forecasts are based on long-term forecasts of economic and demographic data and are adjusted at the largest airports based on factors particular to the airport.

From publication to publication of the TAF, changes occur at each airport that impact the forecast. Demand may have grown more quickly than was previously forecast. A major airline may have announced plans to reduce operations at an airport. An airline may have newly established an airport as a hub in their network. These are some simple examples of situations that occur every year, each with implications on the level of operations forecast by the TAF. The forecasted level of operations in a future year can change dramatically from one year to the next. Table 1 shows the change in the forecasted level of 2015 operations at the 35 OEP airports between the 2004 TAF and the 2005 TAF. The forecast at seven airports (in green) was revised downward by more than 10%, with the forecast at Washington Dulles International Airport (IAD) dropping by 30%. On the other hand, just one airport (in red) increased by more than 10%, with Las Vegas McCarran International Airport's (LAS) forecast up 20%. Past analyses have shown that changes of this magnitude are not uncommon from one TAF to the next, and can have an impact in both short-term and long-term forecasts and performance estimates. The uncertainty resulting from these changes in the forecast level of demand not only have significant ramifications on the modeled future performance of the NAS and of individual airports, but they may result in poor acquisition decisions.

Understanding the impact of the uncertainties in the forecast is critical to producing useful estimates of future performance. By developing an approach to produce ranges of possible future demand, performance assessments can demonstrate how significant the impact of uncertainty in forecast demand levels can be on modeled system, and airport, performance. This paper describes an approach that was developed to introduce demand uncertainty into the performance assessments conducted for the OEP in early 2006. Important findings from modeled performance assessments regarding individual airports and the NAS through 2015 are included, detailing the added understanding provided by the use of ranges of future demand.

Modeling Approach Overview

In assessing the performance of the NAS in 2015, both the demand and capacity expected in 2015 must be modeled. Demand is modeled by growing base year demand (in this case, a day representing a typical day in 2006) to 2015 levels according to the growth projected by the TAF. The resulting 2015 demand is named the 2015 good weather demand, and a slightly reduced version of this demand is named the 2015 bad weather demand. Airport capacities expected in 2015 are based on the most recent plans as described in OEP version 8.0 [1], and are modeled using the same methodology used to produce the 2004 Airport Benchmark Report [2]. En route capacities are modeled by manipulating flight times to achieve target on-time performance goals. OEP improvements benefiting the airport increase airport capacity, while those providing additional en route

Airport	TAF 2004	TAF 2005	% Change
ATL	1,279,975	1,140,615	-11%
BOS	517,087	537,940	4%
BWI	448,306	401,127	-11%
CLE	316,749	315,121	-1%
CLT	622,634	599,188	-4%
CVG	699,692	509,511	-27%
DCA	288,477	300,004	4%
DEN	746,662	704,505	-6%
DFW	900,830	889,425	-1%
DTW	754,909	671,847	-11%
EWR	564,969	558,884	-1%
FLL	430,689	459,797	7%
HNL	383,934	393,922	3%
IAD	923,001	647,107	-30%
IAH	786,582	731,275	-7%
JFK	501,479	508,325	1%
LAS	717,257	861,482	20%
LAX	864,500	827,302	-4%
LGA	403,463	416,261	3%
MCO	506,649	459,420	-9%
MDW	351,992	352,508	0%
MEM	528,274	483,934	-8%
MIA	460,307	478,824	4%
MSP	756,200	725,667	-4%
ORD	1,191,376	1,212,581	2%
PDX	342,818	329,903	-4%
PHL	696,909	695,321	0%
PHX	773,334	711,498	-8%
PIT	319,956	284,571	-11%
SAN	269,959	288,251	7%
SEA	464,444	443,068	-5%
SFO	465,481	448,318	-4%
SLC	600,703	513,754	-14%
STL	350,006	344,679	-2%
TPA	330,348	332,015	1%

Table 1. Comparison of 2015 Airport Operation Levels (TAF 2004 vs. TAF 2005)

capacity are modeled as reducing flying time. Likewise, bad weather can reduce airport capacity and increase flying time.

Demand and capacity inputs are provided to MITRE's Mid-Level Model (MLM)[1], a NAS-wide discrete event simulation, to assess the performance of the NAS. Since there are many aspects of the NAS that are not being modeled, the performance assessment focuses on how performance changes between model runs. Both good and bad weather scenarios are run through the MLM for both the base year (2006) and the future year (2015). The difference between the output of those scenarios is indicative of how performance could change from 2006 to 2015. NAS-wide average delay per flight is a traffic-weighted average of the average delay per flight at each of the 35 OEP airports. NAS-wide average delay per flight is calculated for both good and bad weather, and on an annual basis.

Demand Modeling Approach Using a Point Forecast

Modeled demand in scenarios used to simulate the NAS is drawn from several sources. A base schedule is generated from the Official Airline Guide (OAG), producing an actual schedule planned for a day in the NAS. Non-scheduled traffic at 56 airports of interest (including the 35 OEP airports) is added to the scheduled traffic to form the base year demand. The amount of non-scheduled traffic per airport is derived from the Air Traffic Activity System (ATADS) during known good weather days.

This base year demand is supplemented for future demand scenarios. Demand is added at each airport based on the TAF forecast for the future year. While the TAF is a forecast of airport operations, flights travel between airports, requiring a methodology for growing demand that satisfies the TAF forecast for each airport at the same time. This is achieved using an implementation of Fratar's Algorithm [3] to determine the level of future traffic between airports. The algorithm requires *growth factors* for each airport in the system. Growth factors used in the algorithm are determined by dividing the future year (in this case, 2015) operations by the base year operations (in this case, 2006), based on the total airport operations identified in the TAF. Ranges of future demand, that will dictate the modeled uncertainty in system and airport performance can be produced by modeling various levels of growth factors. One method for determining the different growth factors to use is based upon historical data analysis. It is this analysis that provides the ranges of demand used to produce ranges of performance.

Because growth factors are based on the total airport operations in the TAF, the base year demand provided as input to Fratar's algorithm consists of both scheduled and non-scheduled demand. The scheduled flights added in the future year demand are assumed to have the same daily departure and arrival profiles at each airport as in the base demand. The non-scheduled flights added in the future year demand are distributed uniformly throughout the operating day.

[1] MITRE has since produced a new simulation model, systemwideModeler, that improves upon the functionality offered by MLM.

In some model scenarios, future demand may be substantially larger than the available capacity expected at the airports. When this occurs, delays can become very large. The large delay produced by this small number of airports can introduce a bias into NAS-wide delays that would not be observed in reality. An algorithm has been developed to reduce the demand in the most congested times of day in an effort to limit unreasonable delays that would not occur in reality[2].

Non-scheduled traffic is added to the scheduled traffic and is different for good and bad weather days. To generate the bad weather demand, a derived percentage[3] (varies by airport) of non-scheduled flights in the good weather demand are removed at each of the 56 airports. The good and bad weather scenarios, using the appropriate demand and capacities, are then run through the MLM for 2006 and 2015.

Modeling Ranges of Future Demand

The methodology used to generate ranges of future demand relies on producing a range of growth factors for each airport to use as input to Fratar's algorithm. This range of growth factors can be built by using what is known about historically observed total airport operations. For each airport, counts of observed total airport operations are available in the TAF for each year from 1976 to 2005. Figure 1 plots the annual total operation counts over that time for Denver International Airport (DEN). As Figure 1 shows, annual total airport operation counts have risen from around 400,000 operations in 1976 to nearly 600,000 operations in 2005. While the long-term trend was for total airport operation counts to rise over that time, year by year growth was by no means steady. Some years experienced rapid growth, while other years saw reduced operations.

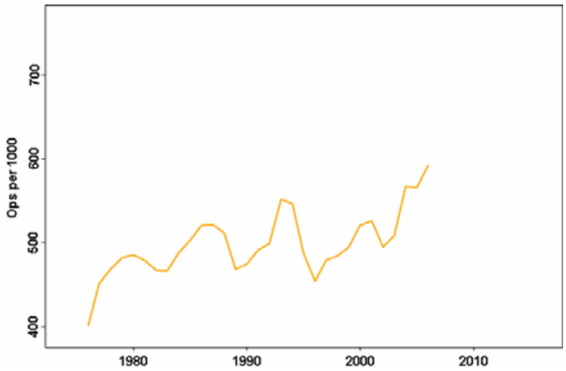

Figure 1. Actual Total Annual Operations at DEN (1976-2005)

To understand how this data is incorporated into the methodology for developing ranges of growth factors, some terms must be defined. The "long-term trend" of growth in total airport operations is the annual change in total airport operations over some number of years, or period. This long-term trend can be found by fitting a trend line to the data over that period. The period may include all observations from 1976 through 2005, although that is not necessary. Since this performance assessment required growing demand scenarios from 2006 to 2015, long-term trends over 10-year periods were of interest. For example, the dotted green line in Figure 2 illustrates the long-term trend from 1979 to 1988. Notice that the long-term trend in total airport operations at DEN was different for the 10-year period from 1979 to 1988 than in the 10-year period from 1994 to 2003. For each airport, 22 long-term trends with a ten-year period can be derived from the annual total operation counts identified in the TAF from 1976 to 2005.

A second term that must be understood is the "deviation" from the long-term trend. Within a 10-year period, there are ten observed annual total operation counts from the TAF for an airport. The observed annual total operation counts in any 1 year are unlikely to correspond to the annual total operation counts expected from the long-term trend. The difference between the observed annual total operation counts and the annual total operation counts expected from the long-term trend is called the "deviation." The "series" of deviations are the set of all deviations within the period of the long-term trend. The green arrows in Figure 2 illustrate the series of deviations from the long-term trend for the periods from 1979 to 1988 and 1994 to 2003. Note that some periods may have the same long-term trend despite having different series of deviations. The differences in the series of

[2] With this new algorithm, if there is not sufficient capacity at an airport to maintain the demand profile, individual flights may be moved up to two hours from their intended departure or arrival time. If the airport still cannot accommodate the flight after a move of two hours, the flight is removed from the modeled demand. The resulting set of flights is called the good weather demand.

[3] The reduction percentage for non-scheduled demand is based on the difference between the average number of operations in good weather and the average number of operations in bad weather (defined as the 10th percentile or worse days in terms of number of hours of visual approaches according to Aviation System Performance Metrics (ASPM)).

deviations are what drive the methodology used to develop ranges of growth factors.

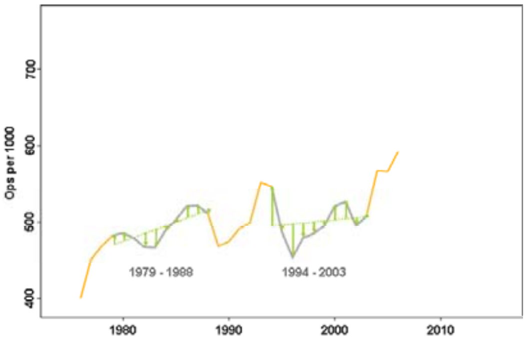

Figure 2. Annual Deviations to Long-Term Trends (DEN)

In addition to observed annual total airport operation counts for 1976 to 2005 for each airport, the TAF also provides a forecast of the count of total airport operations for 2006 to 2025 for each airport. The forecast usually takes into account the most recent information available about the demand at each airport, estimates an expected total airport operation count for the first forecast year (2006), and calculates the expected total airport operation count for each future year. In effect, the TAF can be used to indicate what the long-term trend of growth should be through 2025, without accounting for the deviations that will occur in future years. The red line in Figure 3 shows the TAF forecast for DEN from 2006 through 2015.

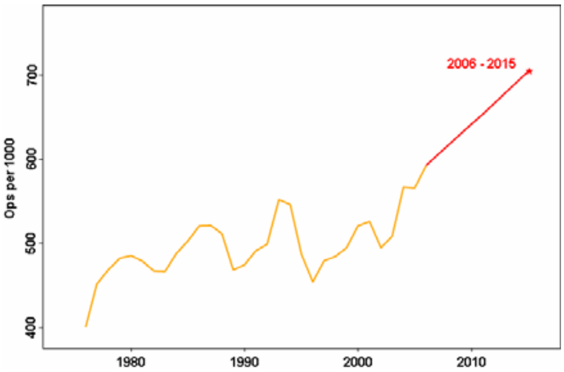

Figure 3. DEN Forecasted Growth 2006-2015

The TAF does not account for the deviations that will occur in future years, but deviations will occur. The approach for producing a range of growth factors assumes the same long-term trend forecast by the TAF from 2006 to 2015, but uses different series of deviations to produce the range of growth factors. More specifically, the series of deviations that will occur from 2006 to 2015 are assumed to repeat the series of deviations that were observed in previous 10-year periods. For example, one possibility is that the series of deviations will mimic the series of deviations that occurred from 1979 to 1988. The green arrows in Figure 4 show the deviations that occurred from 1979 to 1988. If the same year by year changes in total airport operation counts occur from 2006 to 2015 as occurred from 1979 to 1988, the resulting total airport operation counts would be identified by the solid green line in Figure 4.

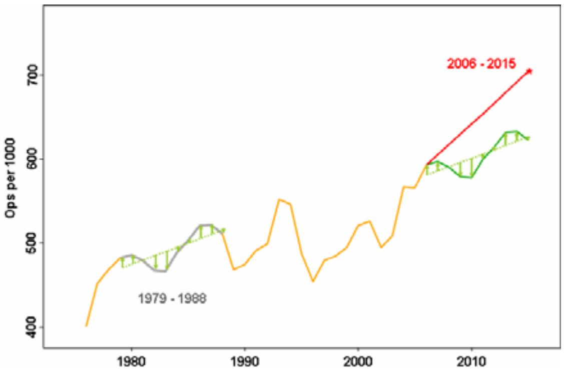

Figure 4. Applying a Historic Long-Term Trend as a Possible Future Trend (DEN)

Notice that the series of deviations from 2006 to 2015 are the same as the series of deviations from 1979 to 1988 because the long-term trend is also the same (although it is now offset relative to 2006 instead of 1979). The long-term trend that occurred from 1979 to 1988 has a flatter slope than the long-term trend that is forecast by the TAF, indicating that the TAF expects demand to grow more quickly from 2006 to 2015 than it did from 1979 to 1988.

The approach used for building ranges of growth factors assumes that the TAF forecast provides the correct long-term trend from 2006 to 2015, but that the deviations that occurred in the past may occur again. By substituting the long-term trend from the TAF for the long-term trend from 1979 to 1988, and using the historic deviations, a new projection of total aircraft operation counts can be made for each year from 2006 to 2015. This new projection is shown in Figure 5. The long-term trend of the new projection is indicated by the dotted red line. This is the same long-term trend as the TAF, but it begins at a different 2006 level of total airport operations because of the deviation applied in 2006. The deviations (indicated by the blue arrows) have now been applied to this new long-term trend line. The resulting dotted blue line indicates the total airport operation counts for each year from 2006 to 2015 when the series of deviations from 1979 to

1988 is applied to the long-term trend from the TAF. The point of interest is the resulting number of total airport operations in 2015. While this 2015 level of total airport operations is smaller than the level of total airport operations forecast by the TAF, it assumes the same long-term trend in demand growth. To derive the growth factor to provide to Fratar's algorithm, simply divide the new projected 2015 total airport operation counts by the 2006 total airport operation counts.

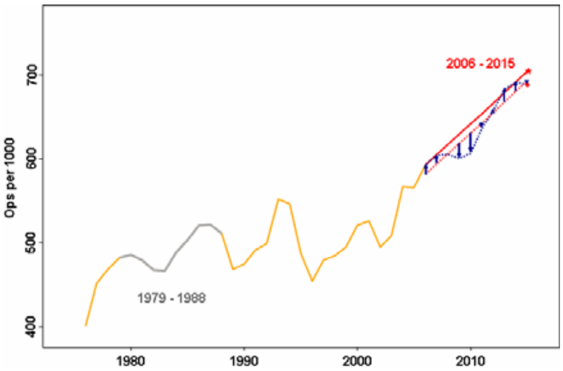

Figure 5. Applying Historic Deviations to Current Forecast (DEN)

To produce a full range of growth factors, repeat for each 10-year period of historical total airport operation counts. Figure 6 shows the annual total airport operation counts that are derived for DEN using each of the series of deviations that were observed over 10-year periods from 1976 to 2005. Each point in the resulting range of total airport operation counts in 2015 is divided by the total airport operation counts in 2006 to produce a range of growth factors.

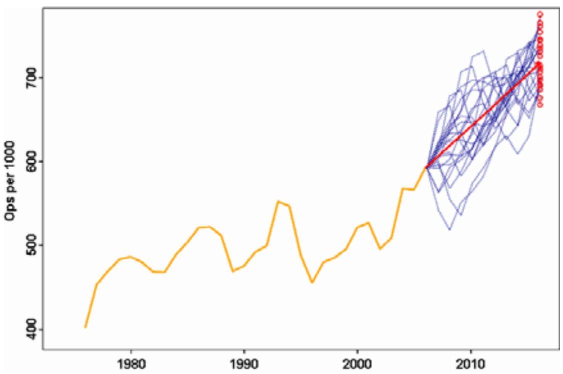

Figure 6. Total Annual Airport Operations Derived from All Time Periods (DEN)

While the 2015 level of demand is the only value used to calculate the growth factor to be used in Fratar's algorithm, using the 10-year series of deviations serve to maintain dependencies over time. Shocks such as September 11, 2001 (9/11) and deregulation will be evident in the data, and other significant events may well impact demand in a dramatic way in the future. While these shocks cause the total airport operation counts to change dramatically from one year to the next, the modeling of the 10-year period as a series also allows the opportunity to recover from that shock and get back to a long-term trend. If demand was modeled to grow each year without regard for how demand had grown in preceding years, shocks such as 9/11 could render the range of possible demand too wide to be useful.

Figure 7 shows how the approach would look for DEN when different look-ahead periods are used (10-year periods to 2015, 15-year periods to 2020 and 20-year periods to 2025).

To maintain empirical correlations in the series of deviations for each airport, this methodology is applied simultaneously to each of the 56 airports of interest for each 10-year period from 1976 to 2006 when constructing demand scenarios. For example, when the growth factor for DEN is based on deviations derived from the 1979 to 1988 historical operations, growth factors at each of the other 55 airports also are derived from their 1979 to 1988 historical operations. In this way, any empirical correlation between airports exceeding (or falling short of) their respective long-term trends will be maintained in the modeled demand. Figure 8 shows the range of growth—that is, the change in total airport operation counts from 2006 to 2015 divided by the total airport operation counts in 2006—modeled at each of the 35 OEP airports.

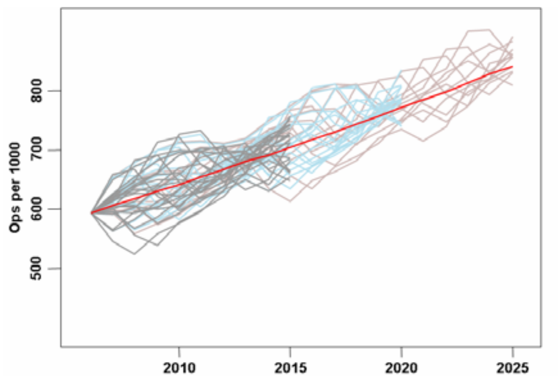

Figure 7. Using Approach with Look-ahead Periods of Different Lengths (DEN)

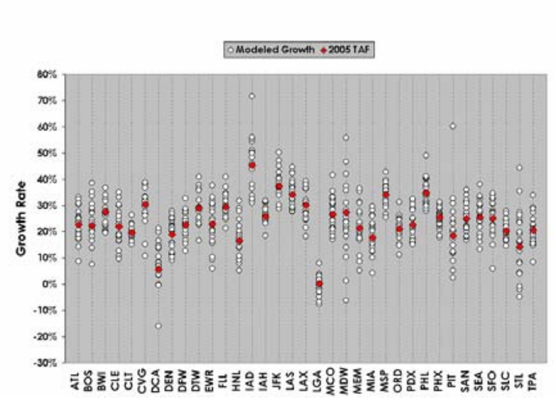

Figure 8. All Modeled Growth Rates at the OEP Airports

Results

Each of the demand scenarios was provided as input to the MLM, to produce an estimate of future performance. Demand scenarios were run through the MLM assuming both 2006 capacity, which represents the future state of the system if no OEP improvements are implemented, as well as the 2015 capacity, which represents the future state of the system with the successful implementation of OEP version 8.0. Good and bad weather scenarios were run with each of the demand scenarios, and the results were aggregated to produce an annual estimate of schedule arrival delay per flight. Figure 9 shows traffic-weighted average schedule arrival delays for the OEP 35 airports. The yellow diamonds indicate the actual level of schedule arrival delay across the 35 OEP airports when the OEP was initiated, Fiscal Year (FY) 2000. The white diamonds indicate modeled delays in 2015 if demand materializes as forecast in the TAF. Using only the demand forecast by the TAF, delays were modeled to be 14.2 minutes on an annual basis in 2015 if the OEP is implemented as planned, nearly the same as was observed in 2000 (13.9 minutes per flight). Likewise, if no improvements would be implemented beyond the capacity available in 2006, using the TAF forecast demand would indicate an average delay per flight of 27.4 minutes. Single point estimates of the future performance of the NAS show that the improvements planned in OEP version 8.0 will provide significant benefit to the NAS.

Single point estimates of the future performance of the NAS, however, fail to provide a thorough understanding of the uncertainty of our results. By modeling a range of demand scenarios—all of which assume the same long-term trend at each airport as was forecast by the TAF—using the approach described in this paper, 22 additional simulated runs can be performed to model the performance of the system in 2015. Using these additional demand scenarios, it is possible to see how varied the future performance of the system may be. In particular, annual average delays in 2015 with the OEP in place (in dark red diamonds in Figure 9) can range from as little as 11 minutes per flight to as much as 18 minutes per flight if the deviations observed in historical total airport operation counts are reflective of the deviations that may occur in the future. While the low side of that range may be acceptable, future performance on the upper end of the range may be enough to warrant considering additional capacity enhancements. The range of delays per flight is far greater without the OEP in place (the red diamonds in Figure 9). As the demand approaches the capacity that can be handled by the system, the performance of the system becomes far less certain because delays do not grow linearly with demand. Notice that while the annual average delay per flight ranges from 11 to 18 minutes with the OEP, the annual average delay per flight ranges from 17 to 36 minutes without the OEP in place, a much wider range. Implementing new improvements not only improves system performance, but also increases the certainty that the system will be able to operate at a satisfactory level.

In addition to NAS-wide delays, this study provides insight into how sensitive performance at individual airports can be to the demand forecast for that airport. The red diamonds in Figure 10 show the level of delay modeled in 2015 at each of the 35 OEP airports if the OEP is implemented as planned and demand grows as forecast in the TAF. The white circles show the range of delays produced by varying the demand in accordance with the methodology described in this paper. The average delay per flight at many airports (such as CVG, DFW, and HNL[4]) showed little sensitivity to the level of demand, but the average delay at five airports (EWR, FLL, LAS, ORD, and PHL) varied dramatically across the model runs. Because delays do not grow linearly with demand, the sensitivity of these airports indicates that the demand modeled for these airports stresses the limits of the capacity expected to be available at the airport.

While delays at those five airports are very sensitive to the demand that is modeled, other airports may also require the attention of those planning for the future capacity needs of the NAS. Figure 11 shows, for each of the OEP airports, the percent of the 23 simulated runs in which the airport exceeds 12 minutes of delay per flight in 2015 once the OEP is implemented. Five airports (EWR, FLL, LAS, PHL, and TPA) are exceeded 12

[4] See list of 35 OEP airport identifier codes at the end of this report.

minutes of delay per flight in each of the simulated runs. These airports will likely need additional capacity enhancements by 2015 if the demand forecast by the TAF materializes, even with the implementation of improvements planned in OEP version 8.0. Decision makers should consider devoting resources toward improving the capacity of these airports now. Figure 11 also shows 12 airports (CLE, CVG, DEN, DFW, DTW, HNL, IAH, MEM, MSP, PDX, SLC, and STL) that do not have delay exceeding 12 minutes in any demand scenario. These 12 airports may not need additional capacity in 2015 beyond what is already planned. The remaining 18 airports may need additional attention by 2015, depending on how demand grows in the future. Decision makers can more closely monitor these airports in the future, recognizing that the demand that ultimately materializes at the airport will determine whether additional improvements will be necessary by 2015. They can also use this information to decide at what level of uncertainty they want to begin taking a closer look. For example, if the chosen level is 75% of the runs exceeded 12 minutes, they would want to begin focusing on ORD, LGA, JFK and MCO as well.

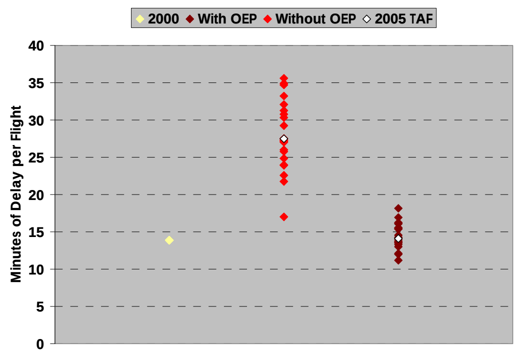

Figure 9. 2015 NAS Performance Assessment Using Demand Ranges

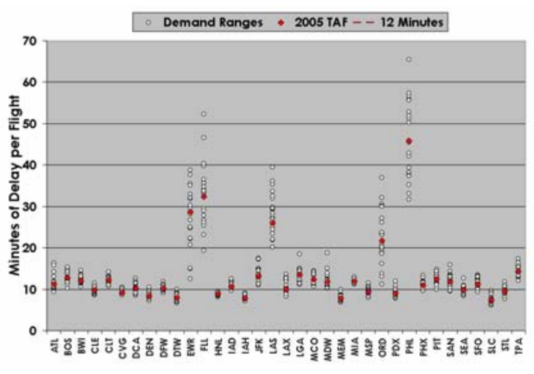

Figure 10. 2015 OEP Airport Performance Assessment Using Demand Ranges

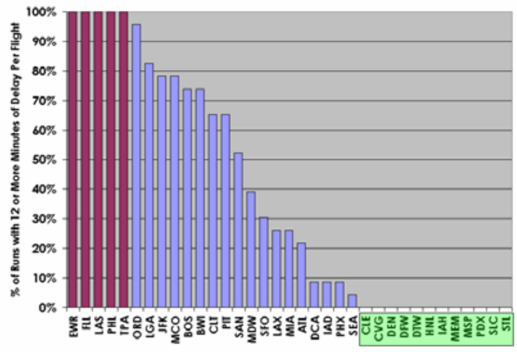

Figure 11. Percentage of Model Runs Exceeding 12 Minutes Threshold

Conclusion

Past analyses conducted to assess the anticipated performance of the NAS once the OEP is implemented have produced point estimates of expected schedule arrival delay, which can not adequately address the uncertainty that exists in demand forecasts. By producing ranges of demand consistent with deviations seen in historical observations, a range of future performance can be modeled. The range of modeled system performance provides insight into how much uncertainty in demand can impact the future performance of the system as a whole. Average schedule delays in 2015 may range from as little as 11 minutes per flight to as much as 18 minutes per flight on an annual basis across all of the 35 OEP airports. Modeling ranges of future performance also provides greater confidence in not only identifying those airports where greater improvements are needed, but also in identifying those airports that can satisfy forecast demand adequately under the existing plans. Additionally, the number of airports that may require additional improvements to keep performance at acceptable levels can be narrowed by modeling ranges of performance. The improvements planned in the OEP may leave five airports needing additional capacity to satisfy forecast demand, while 12 airports may be able to serve forecast demand with the planned improvements. Further attention can be directed at monitoring the remaining 18 airports, as demand forecasts become more certain, to ensure that planned capacity will be sufficient to maintain satisfactory performance levels.

In this study the approach to determine uncertainty ranges in future demand was only applied to the OEP airports. However, this approach could be applied to any airport which has the required historical and forecast data.

References

[1] Federal Aviation Administration, May 2006, Operational Evolution Plan Version 8.0, http://www.faa.gov/programs/oep/v8/Executive%20Summary/Executive%20Summary%20v8.pdf

[2] U.S. Department of Transportation, Federal Aviation Administration, October 2004, Airport Capacity Benchmark Report 2004, http://www.faa.gov/events/benchmarks/2004download.htm

[3] Fratar, T. J., January 1954, "Vehicular Trip Distribution by Successive Approximations," Traffic Quarterly, vol. 8, no. 1, pp. 53-65

Disclaimers

Glossary: OEP Airport Identifier Codes

ATL	Hartsfield - Jackson Atlanta International Airport
BOS	Boston Logan International Airport
BWI	Baltimore-Washington International Thurgood Marshall Airport
CLE	Cleveland Hopkins International Airport
CLT	Charlotte Douglas International Airport
CVG	Cincinnati/Northern Kentucky International Airport
DCA	Ronald Reagan Washington National Airport
DEN	Denver International Airport
DFW	Dallas-Fort Worth International Airport
DTW	Detroit Metropolitan Wayne County Airport
EWR	Newark Liberty International Airport
FLL	Fort Lauderdale-Hollywood International Airport
HNL	Honolulu International Airport
IAD	Washington Dulles International Airport
IAH	George Bush Intercontinental/Houston Airport
JFK	John F Kennedy International (New York, NY) Airport
LAS	Las Vegas McCarran International Airport
LAX	Los Angeles International Airport
LGA	LaGuardia (New York, NY) Airport
MCO	Orlando International Airport
MDW	Chicago Midway International Airport
MEM	Memphis International Airport
MIA	Miami International Airport
MSP	Minneapolis-St Paul International Airport
ORD	Chicago O'Hare International Airport
PDX	Portland International Airport
PHL	Philadelphia International Airport
PHX	Phoenix Sky Harbor International Airport
PIT	Pittsburgh International Airport
SAN	San Diego International Airport
SEA	Seattle-Tacoma International Airport
SFO	San Francisco International Airport
SLC	Salt Lake City International Airport
STL	Lambert-St Louis International Airport
TPA	Tampa International Airport