EVALUATING THE PERFORMANCE OF NEXTGEN USING THE ADVANCED CONCEPTS EVALUATION SYSTEM

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Introduction

This paper describes a delay analysis of the Next Generation Air Transportation System (NextGen), as it was envisioned in the summer of 2006, using the Advanced Concepts Evaluation System (ACES). NextGen is the plan for the transformation of the United States' National Airspace System (NAS) as outlined by the Joint Planning and Development Organization (JPDO), an inter-governmental organization with industry participation chartered to develop and facilitate an integrated plan for transforming the NAS.

Because the NextGen vision continually evolves, this analysis necessarily focuses on the vision as it existed at a single point in time—June, 2006. At that point the NextGen concept was a high-level conceptual vision, containing over two hundred specific operational improvements (OIs), an operational concept describing how the OIs work to enable a more efficient system, and a portfolio containing a time-sequenced set of OIs outlining the transformation from the current NAS to the future NextGen over a twenty-year period.

The challenge for the modeling team is to take these high-level concepts and assess the delay implications of NextGen. This analysis assumes that the NextGen concepts will perform as expected, and thus the focus of this paper is not on analysis of the concepts themselves, but rather on analysis of the performance of the NAS assuming that the concepts are implemented as described and that they work as predicted. This paper seeks to answer the question: If NextGen is implemented as envisioned, then what is the resultant performance of the NAS?

The remainder of this paper is organized as follows. In section 2, we review the relevant literature regarding performance assessment of aviation systems. Section 3 discusses the NextGen concept of operations for the configurations analyzed in this study. Section 4 discusses the specific modeling techniques and assumptions used in the analysis, and Section 5 presents the results and discusses their implications.

NAS Performance Modeling

Questions involving the performance of the NAS when various changes are introduced are important for several reasons. First, many benefits analyses, which are necessary to justify making the change, rely on estimates of the performance implications of the change, which often take the form of delay reduction. Secondly, often it is necessary to choose between several competing concepts, and performance assessment of the concepts is sometimes the deciding factor. Thirdly, performance assessment can project future demand/capacity imbalances, which drives investment decision making.

NAS performance modeling has a long and venerable history. Early researchers integrated queueing equations to estimate delays at small networks of airports [1,2]. Later these analytic models were upgraded to include all large airports in the NAS and extended to model airspace as well as airports [3]. Discrete-event simulations of NAS-wide performance began with the introduction of NASPAC in 1989 [4] and continued with such models as DPAT [5], the GMU macro model of air transportation [6], and recent entries such as Systemwide Modeler [7].

Detailed simulations of air traffic service providers in the USA, Europe, and elsewhere were developed beginning in the late 1980's. The Total Airport and Airspace Model (TAAM) [8] has been applied to numerous problems, such as identification of airport/airspace constraints [9]. The Reorganized ATC Mathematical Simulator [10], which focuses on controller workload in the enroute environment, has also been used for many benefits assessments, such as evaluating dynamic density metrics [11].

NextGen Concept of Operations

The NextGen vision is described below by enumerating the operational capabilities for "segment 3" and "segment 7" of the NextGen portfolio description. Segment 3 is an intermediate transformational state, while segment 7 is the end transformational state. The description below purposely excludes safety, environment, and security aspects of NextGen; those three areas require modeling techniques that are beyond the scope of this analysis.

The overall NextGen vision is to move from a ground-based to air and space-based communication, navigation, and surveillance systems, while increasing automation and changing responsibilities for the service providers, users, and operators of the system. While a complete description of the NextGen vision can be found in the concept of operations [12], we provide here a summary of the salient concepts.

Segment 3 Description

Segment 3 improvements include an evolution of what is currently available, plus introduction of new techniques, particularly at very large congested airports, that later become standard throughout the NAS. The paragraphs below discuss specifics of the Segment 3 plan.

Pre-flight. During pre-flight planning, traffic management initiatives containing multiple "what-if" decision support capabilities exist to help manage the four-dimensional trajectory environment. The "Go-button" is available to traffic flow managers to enable aircraft reroutes to be issued to the sector controlling the aircraft when a flow strategy is executed. Flow control managers have access to decision tools that use probabilistic weather forecasts to determine reroutes and ground delays, allowing the enroute environment to "fine-tune" traffic.

Surface. At the airport surface, there is reduced lateral and in-trail separation for converging and closely spaced parallel runways. The service provider will provide different levels of service to different operators, depending upon equipage, with preference given to operators with more advanced equipage. During taxi, the safety management system issues taxi instructions, while the aircraft move and maintain situational awareness in low visibility conditions through cockpit display of traffic information (CDTI), automatic dependence surveillance-broadcast (ADS-B), and a moving map display. During periods of instrument meteorological conditions (IMC) at large congested airports, self-separation of aircraft on final approach using these technologies allows separations close to what can be obtained during visual operations.

Terminal. In the terminal area, the vision includes RNP and RNAV routes being available in the largest airports in the NAS. These routes effectively increase the number of paths to and from runways, and assume that flights using these paths are properly equipped. Continuous descent arrivals are enabled when there is light to moderate traffic loads, with ground-based separation, metering, merging, and spacing.

Enroute. RNAV routes are available NAS-wide, which allows properly equipped aircraft to use more direct routing to their destinations. RNAV-defined "tubes" exist to/from runways and the enroute environment. Four dimensional trajectories (4D trajectories)—which consist of lists of waypoints with associated time intervals during which the aircraft will transit the waypoint—will be mandatory for all aircraft in high altitude airspace. Multiple levels of service will be provided to aircraft in terminal, enroute, and oceanic environments, essentially implying that better equipped aircraft will be given better service. Airspace will be dynamically reconfigured to meet demand, while collaborative rerouting will be used to avoid convective and other bad weather.

Segment 7 Description

In segment 7, the end-state vision for NextGen, the system has been wholly transformed into the new visions. The paragraphs below discuss the specifics of the plan.

Pre-flight. Surface, arrival, departure, and enroute status of all flights are integrated into traffic management initiatives to reduce the impact of congestion and weather on 4D trajectories. Capacity planning is expanded from single airports to metroplex-wide planning. Traffic flow management capabilities are expanded to include probabilistic weather information at all levels, to reduce impact of flow restrictions and also to reduce controller and pilot workload.

Surface. At the airport surface, reduced arrival spacing is available for very closely-spaced parallel runways at the large airports. The metroplex planning capabilities, combined with better ground transportation between metroplex airports, allows demand and capacity to be more closely balanced. Aircraft and ground vehicles have the equipment and procedures to move safely in zero-visibility conditions. Variable touchdown zones are available at large airports, and improved operations in icing conditions exist. Multiple runway occupancies can occur at large airports, and remote towers exist to manage traffic at remote, smaller airports.

Terminal. RNP routes to and from runways at all airports with commercial operations are available and used for arrival and departure procedures. Aircraft flow seamlessly from the enroute environment to the terminal area, using continuous descent arrivals with cockpit-based merging and spacing, within "tubes" defined by an RNAV route with a small RNP level. Ground control issues time-based spacing directives to aircraft that use the instructions to self-separate. Any small trajectory changes are auto-negotiated between aircraft and the ground systems. Longitudinal arrival and departure spacing is automatically changed based upon wake vortex observations

Enroute. Aircraft are automatically sequenced from enroute to terminal area. 4D trajectories are auto-negotiated between aircraft and the ground, and are also employed in autonomous airspace (where uninhabited aerial vehicles operate). Separation is reduced to less than the five nautical miles currently used through better weather forecasts and wake vortex observations. Airspace is dynamically configured to match flow volume, while self-separation, merging, spacing, and passing are allowed and routinely performed for properly equipped aircraft.

Modeling Techniques and Assumptions

The model used in this analysis is the Airspace Concept Evaluation System (ACES), build 4 [13]. ACES is a fast-time computer simulation of system-wide flights in the NAS, typically configured for a day's worth of flights. It provides a flexible and configurable simulation of the NAS useful for assessing the impact of new air traffic management tools, concepts, and architectures, especially those that are significantly different from today's operations. From [13]: "ACES accounts for terminal gate pushback and arrival, taxi, runway system takeoff and landing, local approach and departure, climb and descent transition, and cruise operations. ACES employs a multi-trajectory based modeling approach that currently models Traffic Flow Management (TFM), Air Traffic Control (ATC) and flight operations, en route winds, and airport operating conditions. . .The intent is to quantitatively describe air traffic movement resulting from the interaction of the operational and technological constructs. . .Advanced four-degree-of-freedom trajectory modeling emulates the movement of each aircraft along a four-dimensional trajectory in conformance with its current flight plan and clearance." It is important to note that ACES is not merely a queueing model like most other system-wide models of the NAS; instead, it is a physics-based simulation that is similar to, but in some ways goes beyond the capabilities of, a model such as TAAM [8]

Regardless of the degree of sophistication of a simulation, the mapping of the NextGen concept of operations to the various controls provided by a model such as ACES is as much an art as it is a science. This analysis uses modeling parameters derived from empirical studies of concepts similar to those in NextGen. In some cases, identical concepts have not yet been studied, but similar concepts have been. This section reviews and justifies the major parameter settings for the three configurations of the NAS simulated: the baseline, NextGen segment 3, and NextGen segment 7.

Demand

Central to NAS-wide simulations is the source of the demand data, that is, the flights that are flown during the analysis period (one day in this case). Because this analysis focuses on the delay performance of the NAS in each of the three configurations, it makes sense to drive each configuration with the same demand set. An argument can certainly be made that the three configurations will exist at different times—the baseline, segment 3, and segment 7 will occur at times many years apart—and thus the demand sets for the three configurations should reflect the traffic expected when those configurations are realized. But using different demand sets for different NAS configurations adds another variable—the demand set—to the analysis.

In order to isolate a single variable to study—in this case, NAS configuration—ACES was driven by the same input set, representing approximately a one-and-a-half times (1.5X) traffic increase over that observed in 2004. The

1.5X demand was derived after the Logistics Management Institute (LMI) trimmed a three times current traffic (3X) demand set down to a level that was delay-feasible for the baseline, good-weather NAS configuration. A *delay feasible demand set* means that the computed delays for the demand set and NAS configuration are within tolerable limits, as set by the highest delays observed in the summer of 2000. Because the good-weather baseline NAS configuration is delay feasible at 1.5X, the segment 3 and segment 7 good-weather configurations will also be delay-feasible. However, it is not clear *a priori* to what extent the poor weather days (discussed below) are delay feasible.

Weather

A second important analysis factor is the weather, both terminal and enroute, and how the weather is realized in ACES. The Center for Naval Analysis (CNA) completed a thorough study of weather days in 2004 [14], and from that study three days were selected: February 19th 2004 (excellent weather, visual conditions, throughout most of the continental US (CONUS)), May 10th 2004 (some weather, a "medium" value of total flight delay), and July 27th 2004 (severe weather, the highest total delay observed during 2004).

Each of these weather days has two important effects in the simulation. The first effect is that airport capacities dynamically change with weather conditions. Weather conditions were downloaded from an FAA web site [15], where airports are categorized as having visual (VMC) or instrument (IMC) conditions in fifteen-minute intervals throughout the day. The second effect is caused by enroute convective weather, for which ACES is configured with sector capacities that dynamically change with time. The dynamic change of sector capacities is modeling a convective weather front moving through the sector. To our knowledge, there has been no other system-wide NAS analysis that dynamically changes sector capacities with time. The values to which the sector capacities change are computed by a tool called ProbTFM, explained in more detail below.

It is important to note that the three weather days only affect the dynamic capacities used by ACES for both airports and airspace. The demand is not changed for these three days: the same 1.5X demand used in a good weather, all-VMC day is used for the two weather days, so that the resulting delay performance can be computed and compared across the different weather systems and NAS configurations.

Airport Capacities

Airport capacities vary depending upon which configuration of the NAS is simulated. The capacities for the baseline configuration are derived from the 2004 capacity benchmark report [16]. In that report, several capacities are listed for each airport, the second of which is the capacity of the airport when planned new runways, if any, become operational. By using the "new runway" capacities, the baseline represents a NAS configuration with planned airport improvements.

For both the segment 3 and segment 7 configurations, the capacities were derived from Boeing's airport capacity model [17]. The model represents runway complexes at the busiest airports, identifying constraints at the airport that affect its capacity—constraints such as converging runways, crossing runways, airspace, outer marker delivery accuracy, length of final approach, interarrival separation distance, and many others. These constraints are modeled as a series of equations, where the coefficients (weights) of each constraint are initially set by calibrating the equations against the 2004 benchmark report.

After calibration, the constraints can be changed to represent a future NextGen configuration. Boeing conducted an extensive analysis to determine the appropriate constraint coefficients for NextGen. Space prevents an exhaustive enumeration of the coefficients, but some examples will be illustrated. One of the constraints is the outer marker delivery accuracy—how accurately (in time) flights can pass over the outer marker. For the baseline, this constraint is set to 18 seconds, for NextGen segment 3 it is relaxed to 12 seconds, and for segment 5 it is further reduced to 6 seconds. Another constraint involves the final approach interarrival separations which are also reduced for the NextGen scenarios. For example, in IMC the baseline separation for a large jet following a heavy is 5 nm, while for segment 3 it is reduced to 2.5 nm and in segment 7 to 2.0 nm; similar reductions occur in VMC. These parameter reductions (and many others not listed here) drive some sixteen different constraint coefficients to determine the overall NextGen VMC and IMC capacities for segments 3 and 7.

Sector Capacities

Three different changes are made to sector capacities to model NextGen. The first involves dynamically changing the sector capacities to model the movement of convective weather through the area. The second involves setting parameters for RNP routes to and from the en-route airspace and the departure/arrival runway. The third involves setting sector capacities to account for workload-reducing technologies like CPDLC. We will treat each of these in turn.

Dynamic sector capacity changes. One of the most innovative features of this analysis is the changing of sector capacities with time as weather moves through the sector. For the good weather day (February 19th 2004), no time-varying capacity adjustment was made. For the two poor weather days, a tool called *ProbTFM* was used to estimate the time-varying capacities. *ProbTFM* [18] uses the actual flight tracks through a sector combined with the actual weather system to estimate reroutes around convective systems. Two parameters in *ProbTFM* are relevant to NextGen. The first varies the accuracy at which the weather is forecasted: low accuracy implies that convective weather polygons are large, while high accuracy implies that weather polygons wrap tightly around the areas of convection. The second varies the aggressiveness of the rerouting strategy: an aggressive setting will cause the flights to fly closer to the weather than a less aggressive setting.

As outlined earlier, the intent of NextGen is to improve weather forecasts and their delivery to the cockpit so that more effective decisions are made by operators. For the baseline, *ProbTFM* was configured so that both the forecasting accuracy and rerouting aggressiveness parameters were set to "low." For NextGen segment 3, these parameters were set to "medium," while for segment 7 they were set to "high." *ProbTFM* takes these parameters, the flight tracks, and the weather polygons, producing delays and/or flight reroutes that ultimately determine the maximum number of flights that each sector can handle, for each 15 minute interval of time.

An example of the ProbTFM output, for sector ZAB15 (in Albuquerque center) with the settings on "low," is shown in Figure 1. Convective weather transited the sector late in the day, but the weather did not cover the entire sector, and hence routes existed through the sector even during the period of convective weather. The resulting capacity dropped from 18 to as low as 13 during one fifteen-minute period during the day. A similar time-varying capacity reduction occurred for each sector that had convective weather during some part of the day, for the moderate and sever weather days. (For the good weather day, sector capacity remains at maximum during the entire day).

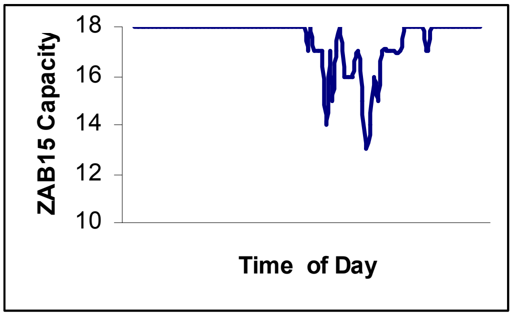

Figure 1. Dynamic sector capacity change for ZAB15 for the severe weather day.

Sector capacities in transition airspace. The second change to sector capacities involves setting them in the transition airspace, for flights that are arriving or departing certain airports. For segment 3, the settings apply only to flights to or from one of the 35 largest airports in the NAS, while for segment 7 the settings apply to all flights to or from any airport handling commercial flights. The change involves modeling the "tube" concept, in which flights are cleared from the enroute airspace into an RNAV-defined "tube" that extends down to the runway end, and similarly upon departure are cleared into a "tube" that extends up to the enroute airspace. In modeling this concept, it is important to estimate the reduction in controller workload that occurs when flights are cleared into these tubes. To do so, a literature search was conducted for relevant analyses.

The most directly relevant report was published by the FAA in December 2005 [19]. The report summarizes research done on the feasibility of pilot self-separation in the TRACON environment; the workload implications for the pilot; and the workload implications for the controller. It is the latter that we will summarize.

Most of the data obtained from the experiments is qualitative in nature, that is, controllers would report that the workload was "slightly reduced" or "reduced by a large margin" in the presence of self-separation. However, there were two experiments conducted by the Eurocontrol Experimental Center that are of particular interest. In a 2001 experiment at Eurocontrol Experimental Centre, when controllers delegated spacing authority to the pilots on approach for 60% of the traffic, communications were reduced by 20%; when it was done for 45% of the traffic, communications were reduced by 13%. The reductions occurred because controllers did not have to issue as many speed instructions because the pilots were adjusting their own speed using the CDTI avionics [19, p. 25].

In a more thorough 2003 experiment by Eurocontrol [20], 34 arrivals per hour were processed by controllers (a very high traffic level) into the Paris/Orly airport, with and without pilot self-spacing. The traffic pattern included a merge point, a high workload point for controllers. With pilot self-separation, there was a reduction of 28-48% in the number of maneuvering instructions. Those instructions were issued 30-35 nm before final (compared to 10 nm without pilot self-separation). Controller eye fixations were concentrated between 5 and 20 nm from final approach without CDTI, and between 15 and 40 nm from the fix with CDTI. It is clear that the controllers could integrate the flows earlier, and their workload was reduced substantially (Zingale 05, p. 27).

Another potential source of data for controller workload reduction is derived from User Request Evaluation Tool (URET) benefits analysis. In the mid-1990's URET went online, providing controllers with trajectory intent information more accurate than the paper flight strips that existed at the time. In addition, URET flagged potential conflicts and allowed controllers to experiment with "trial flight plans" to see if vectoring instructions would cause more conflicts.

URET is not pilot self-separation, but its effect on controller workload could be similar in magnitude. A salient study was conducted by Kerns and McFarland in 1998 [21]. Using the NASA-derived Task Load Index (TLX), they found that in high-volume unstructured (i.e. "free-flight") airspace, controller workload decreased from a TLX of 41 without conflict probe, to a TLX of 37 with conflict probe, a 10% reduction [21, p. 17]

Given this research, the sector capacities for NextGen transition airspace (tubes) are set as follows. Based upon the URET experience, a 10% reduction in controller workload is expected when "time-based metering" and "advanced sequencing and merging tools" are introduced to the controllers, which occurs in segment 3. For segment 7, extrapolating the Eurocontrol results to 100% equipage, a communication decrease of about 33% would be expected between pilots and controllers. Because each communication requires thought and prior radar scan, an overall workload reduction of 50% is assumed for segment 7.

These parameters (a 10% reduction for segment 3 and a 50% reduction for segment 7) apply only to the transition airspace, in segment 3 for flights arriving or departing one of the top 35 airports, and for segment 7 they are applied to all commercial flights. Note that flights transiting the same airspace but not going to one of the designated airports would cause the same amount of controller workload as in the baseline. Workload is adjusted by varying the amount that a flight counts towards the sector capacity; for example, a commercial flight in transition airspace in segment 7 would count only 50% towards that sector's capacity.

Controller-pilot datalink communications (CPDLC). Controller workload is reduced NAS-wide when CPDLC is introduced. At the minimum, the voice greeting and handoff is eliminated, however, many other controller actions can also be transmitted digitally. A study by the Center for Naval Analysis [22] showed approximately a 25%-35% reduction in controller workload due to a CPDLC experiment, most of the reduction during handoff.

In NextGen CPDLC-equipped aircraft are only partially available by segment 3, so sector capacities are increased by 15% across the board. Because it is assumed that by segment 7 all aircraft are CPDLC-equipped, sector capacities are increased by 30% across the board. These capacity increases are in addition to the time-varying sector capacities and the transition airspace workload reduction. For example, if the baseline time-varying sector varies from 15 to 10 and back to 15, then in segment 3 those values would be increased by 15%, and in segment 7 they would be increased by 30%.

Experimental Design

Given all these parameters, nine set of ACES runs was conducted. There are three sets of three runs each. The first set represents the baseline configuration, with the three weather days (good weather, moderate, and poor weather), using the 1.5X demand set. The second represents the segment 3 configuration, with the three weather days and the same 1.5X demand set. The third represents the segment 7 configuration, with the three weather days and the same 1.5X demand set.

Results

In this section we discuss the results obtained from the ACES experiments configured and conducted as described in the previous section.

Validation Results

First we must discuss the extent to which the experiments are valid. Separately, three ACES runs were independently validated using a 1X demand set to compare with current NAS performance statistics. Validation experiments were conducted on the good weather day—February 19th, 2004—by comparing the results from ACES with those from NASPAC, LMInet, and actual FAA recorded performance data for that day [23]. The result of the validation experiment shows that the ACES delays are approximately the same as the delays recorded by the FAA, and the delays are in line with delays computed by other models.

Validation of the two poor weather days is underway, and results from that validation are not yet available. In the remainder of this section, we are comparing the ACES results with other ACES results, with the model configured as described earlier. Because we are comparing results between two configurations of the same model, if the actual weather results have an (unknown) systematic bias, then this bias will exist in all the runs. If that is the case, the absolute numbers may or may not be trustworthy, but the trends between the numbers are comparable.

Delay Metric

The metric used to estimate NextGen performance is average delay per flight. Average flight delay is computed by comparing ACES-computed block times against ACES-computed minimum block times. Minimum block times represent ACES computation of the fastest time the aircraft can fly from origin to destination, assuming the weather conditions (winds, visibility, enroute convection) for the run, the filed flight plan (or a great circle if none exists), and the aircraft's optimal performance. Note that ACES, being a physics-based model, has the capability to compute the minimum block time given the physics of the NAS configuration being modeled. Also note that, by definition, this metric will always produce nonnegative delay numbers.

NextGen Performance

The delay performance for the three weather days is shown in Figure 2. These results suggest that NextGen decreases the average flight delay by a factor of seven for the VMC results, a factor of 14 in a moderate weather, and by a factor of about 4.5 in a poor weather day. That these results suggest that NextGen improves its performance in moderate weather by a greater factor than either good or very poor weather suggests that the combination of weather location, weather severity, and NextGen parameters as modeled herein combine most effectively when the weather is moderate.

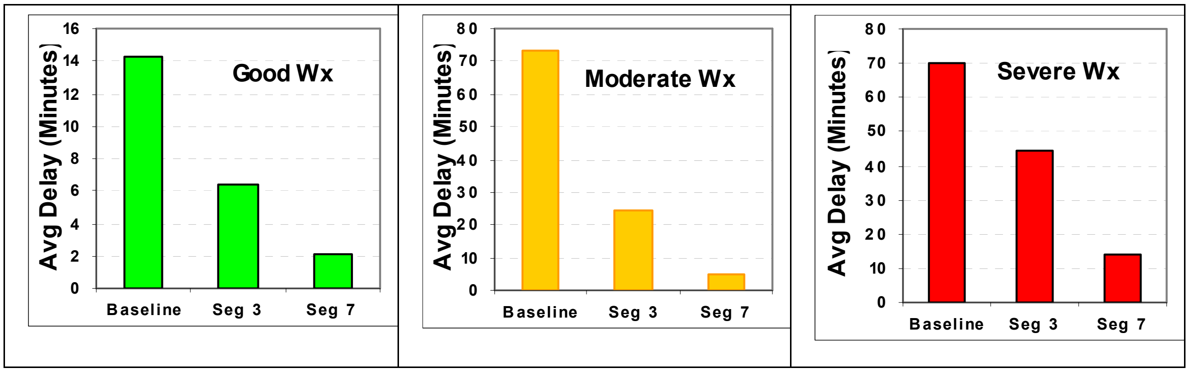

Figure 2. Average flight delay for the different weather days and NAS configurations.

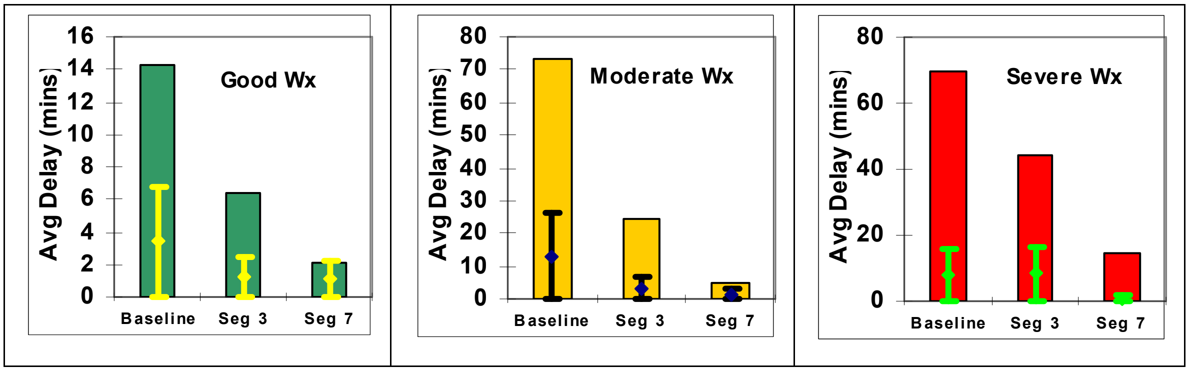

Figure 3. Average flight delay, with the interquartile range plotted.

Of additional interest is the distribution of delay around the average. Figure 3 shows the average delay is shown in the bars and is the same as in the previous figure. In addition, the interquartile range is plotted.

Fifty percent of the data fall within the interquartile range, the solid vertical lines in the figure, which represents the *middle* 50% of the range of the data—so 25% of the data fall below the solid vertical lines in the Figure 2. Thus it is apparent that 25% or more of all delays recorded by all runs are zero—the computed block time is equal to the minimum block time.

For all but the segment 7 runs, the majority of the data fall well below the mean delay—suggesting that the distribution is “fat tailed,” meaning that there is a fairly small number of very large delays. In fact, maximum delays for all nine runs fall in the 150-210 minute range; while these delays may seem excessive, the ACES simulation currently lacks an algorithm to cancel highly delayed flights.

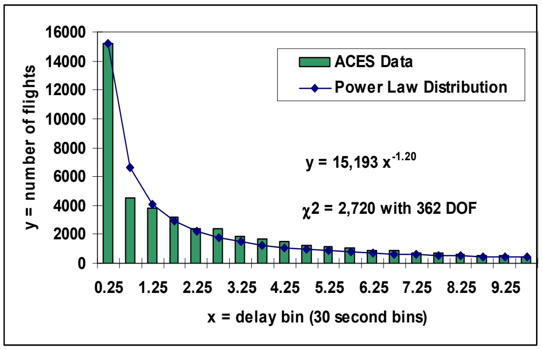

Figure 4. Delay distribution for the baseline moderate weather day.

These results beg the question as to the exact form of the delay distribution. Figure 4 shows the delay distribution for the baseline moderate weather day.

The figure plots the delays in 30-second bins. For example, the leftmost bin represents delays between 0 and 30 seconds, and the bin is labeled 0.25 minutes (15 seconds) to signify the midpoint of the bin. The histogram fits a power law distribution, that is, a function of the form $y = \alpha x^{-\beta}$. The coefficient α is set to the height of the leftmost bar in the histogram, while β is set to a value that minimizes the chi-square goodness-of-fit statistic.

Note that the power-law distribution is heavy-tailed, as noted above, meaning that there are a few flights with extraordinarily high delays. The heavy-tailed nature of the delay distribution is an important observation, as it suggests that maximum improvement in NAS performance can be obtained if NextGen policies and procedures are developed to reduce flights that are excessively delayed, i.e. those flights that are in “trouble.” Policies and procedures that are directed towards the normal operations of flights may be less effective in reducing average delay and the variance thereof.

The length of the tail is governed by the magnitude of the exponent β. Higher β implies shorter tails. While space limits the presentation of all nine histograms, Figure 5 shows the magnitude of β for each of the nine runs.

It is important to note that the data in Figure 5 indicates the degree to which the tail of the delay distribution disappears—a higher value (higher β) implies that the tail of the distribution

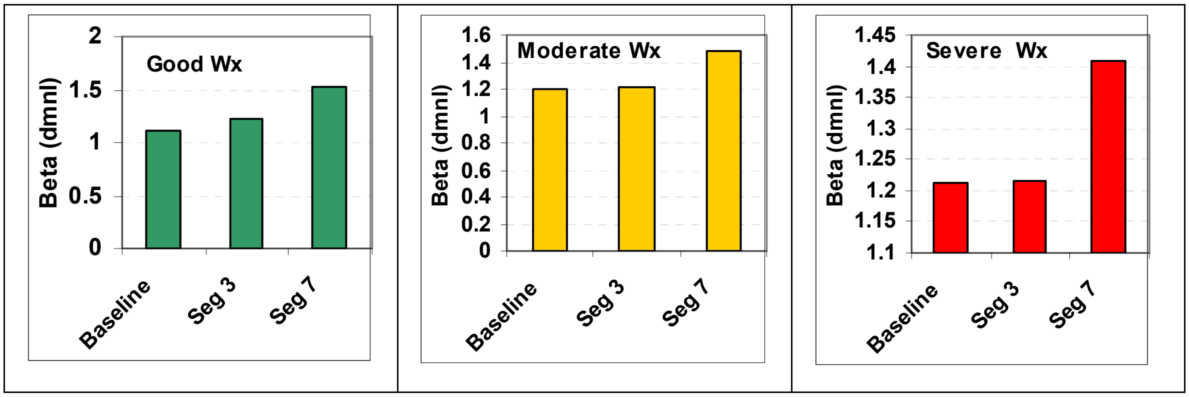

Figure 5. Investigating the tail of the delay distributions by comparing the exponent β.

disappears faster, meaning that higher β's are better. In the good weather case, β increases nicely between the three configurations. In the moderate and severe weather cases, the β is virtually unchanged between the baseline and segment 3, while it increases significantly for segment 7. The fact that the mean delay decreases between the baseline and segment 3 for the moderate and severe weather cases, but the tail behavior (the β) remains the same, suggests that the segment 3 configuration is redistributing the delays in the lower end of the distribution while leaving the very large delays (the tails) mainly untouched.

Conclusions

This study has investigated the performance of the NextGen system as embodied by a model using the ACES simulation. This analysis assumed the NextGen future vision as embodied by a series of documents published in the summer of 2006, and the analysis further assumed that the concepts outlined in those documents will be implemented and will work as expected. As noted earlier, validation of the concepts—which involves analysis, human in the loop experiments, and field trials—is yet to be done with many of the NextGen concepts. This paper, however, started with the assumption that these concepts work and explored the expected performance of the NAS should these concepts be implemented.

The results show that the average delay in good weather decreases from about 14 minutes per flight (today) to about 2 minutes per flight (NextGen segment 7), while the average decreases from 70 minutes to 5 minutes in moderate weather, and from 70 minutes to 15 minutes in severe weather. The Air Transport Association estimates that each minute of delay costs approximately $50/flight (passenger value of time is not included in that figure) [24]. As the 1.5X demand set contains approximately 87,000 flights, at $50/hour/flight, the daily delay savings is approximately $52.2 million/day in good weather, $282 million/day in moderate weather, and $239 million/day in severe weather, according to these results.

Additionally, the study discovered that the distribution of delay for this particular metric closely follows a power-law distribution, implying a few number of flights with very high delays. The behavior of the tail can be studied through the value of the exponent of the power-law distribution (the β), which shows that the tails disappear quickly as NextGen is implemented in good weather, while they disappear a bit slower in the moderate and severe weather cases.

One of the main results of this study is that the heavy-tailed nature of the delay distribution implies that, if delay mean and variance reduction is the goal of future policies, then the behavior of flights which run into "trouble" during their sojourns should be the focus of policies and procedures. If the operation of the system is tilted only towards flights which perform "normally," then it will be more difficult for future NAS configurations to reduce the mean and variance of the delay.

As the NextGen vision continues to evolve, the concepts will become clearer and concept evaluation studies will occur, providing definition and focus for the performance benefits of NextGen. This study, with its assumptions and limitations, will be extended and supplemented as necessary in the future.

Acknowledgements

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