NAS-Wide Performance: Impact of Select Uncertainty Factors and Implications for Experimental Design

Gareth O. Coville, MITRE Corporation
Billy Baden Jr., MITRE Corporation
Stéphane Mondoloni, Ph.D. Associate Fellow AIAA, MITRE Corporation
Seli Agbolosu-Amison, Ph.D. member AIAA, MITRE Corporation
David C. Millner, MITRE Corporation

Motivation

As Air Navigation Service Providers across the globe invest in and deploy operational upgrades in alignment with the ICAO Global ATM Operational Concept [1], performance justification is required for these investments [2]. Pre-deployment, these are frequently justified at a national or regional scale through modeling and simulation (M&S) activities quantifying the total performance impact of operational improvements. Often, these improvements can deliver value through relatively small changes in performance thereby necessitating M&S capabilities capable of differentiating the effect of the proposed improvement from the effect of modeling variability.

One area of modeling variability which current M&S practices attempt to compensate for is the variation in performance occurring across days [3-4]. This is typically accomplished through the use of a carefully-selected set of days seeking to be “representative” of the NAS performance across a given year. These selected days are referred to as design days. Modeling is then performed on the design days and statistics are obtained to gather the performance under a baseline and a treatment case. Current practices model each day in the set of design days once, with averaging across all design days to yield annual estimates of performance.

The concern with this process is that each design day represents one specific instance of what could have happened in the NAS on that day and does not consider the many small perturbations which impact the NAS daily (e.g. an aircraft taking off 5 minutes later due to a slow boarding process or a TRACON or tower deciding when to change runway configurations). Certain design days, such as days when bad weather conditions result in portions of the system operating at or near capacity, are expected to be more sensitive to these perturbations than other design days. With current practices averaging across design days subject to these perturbations, this paper identifies the impact on the accuracy of flight delays as a result of selecting a single sample-run per design day. It is expected that as the number of sample days is decreased, the effect of intra-day variation will increase resulting in larger uncertainty bounds on NAS-wide operational performance. Effectively, there is a limit to the magnitude of the operational effect that can be reported with confidence (as a result of these known sources of variability) unless the number of model runs is increased to sufficiently resolve the effects.

Objectives

The objectives of this report are to:

1. Determine the combinations of design days and sample runs per day required to achieve convergence of NAS-wide results within a specified level of accuracy.

2. Identify the impact that intra-day perturbations and fidelity of select input data have on NAS-wide simulation results.

Approach

The *systemwide*Modeler tool is a fast-time, discrete-event simulation developed by the MITRE Corporation to simulate air traffic and its interactions with various elements of the NAS. A typical *systemwide*Modeler simulation consists of tens of thousands of flights progressing along four-dimensional trajectories, responding to constraints imposed by capacity-limited resources like airports and en route sectors. Because *systemwide*Modeler is a deterministic model, uncertainty must be represented through changes to model inputs over a series of simulation runs. With run-times in the tens of minutes, performing a sufficient number of simulation runs to assess the impact of uncertainty on NAS performance has not been practical. Advances in multicore architectures have enabled parallel processing of simulation runs on a large enough scale to facilitate Monte Carlo analysis by varying model inputs.

Perturbations contributing to model sensitivity

This paper will examine the time impact of four factors of uncertainty upon NAS performance: (1) carrier induced delays, (2) airport called rates, (3) timing of airport configuration changes and (4) en route sector capacity. These four variables were chosen due to the impact that they could have on specific instances of the design days. This impact stems from the magnitude of their variability on any given day, or our ability to obtain the data within a level of accuracy. To represent the impact of these factors of uncertainty upon NAS performance, input parameters to *systemwide*Modeler will be varied with each simulation run. A distribution for each parameter or set of parameters will be created based on historical data sources. This may be through direct observation of historical data, such as for reported carrier-induced delays, or through an understanding of errors being introduced, such as for the timing of configuration changes as explained below.

As an example, Figure 1 below illustrates carrier induced delay distributions for selected airports which were obtained using carrier delay data from the Bureau of Transportation Statistics (BTS) databases for selected carriers. The Figure describes the carrier induced delay for those flights subject to a delay. To approximate these distributions, a NAS-wide carrier delay distribution is applied. By assuming that carrier induced delays are imposed prior to the flight pushing back, we can draw from the distribution to determine how much carrier induced delay to impose upon flights prior to the execution of the simulation. It is recognized that carrier-induced delay may occur post-pushback, but for the purposes of simulating this delay we imposed it pre-pushback in the model. The carrier induced delay to be imposed on each flight will be the result of two independent draws, one to determine if a flight is subject to a carrier delay at all, and a second to determine the delay from the distribution.

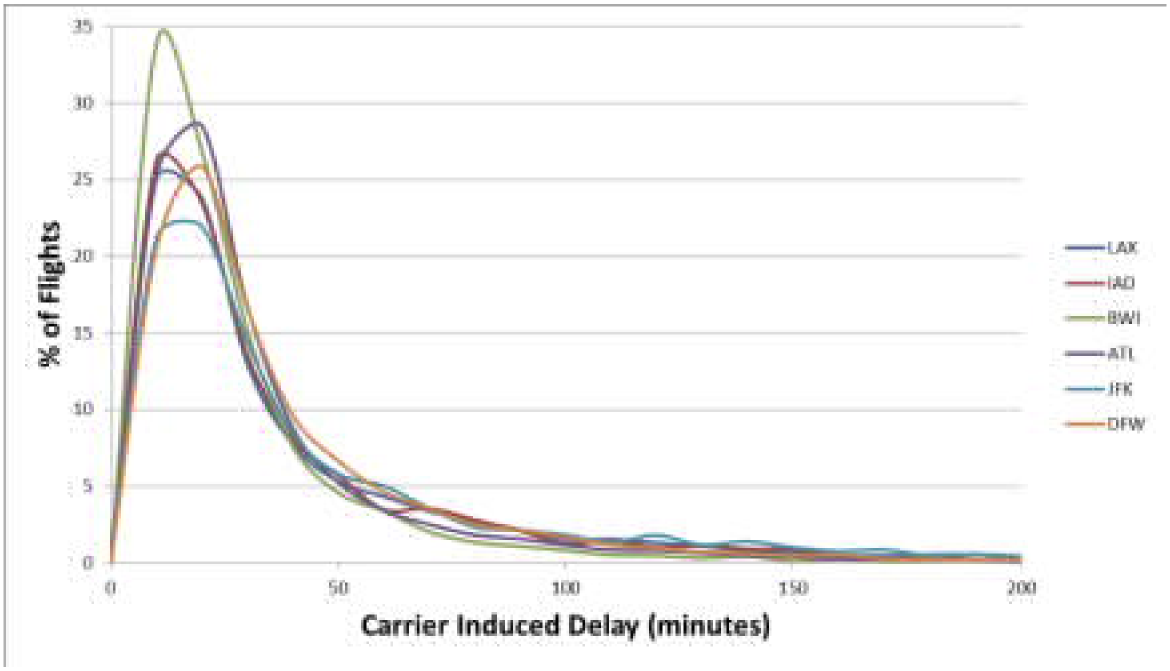

Figure 1 – Carrier Induced Delay (minutes) for Flights Subject to a Carrier Delay

Airport called rates reflect efforts to manage arrival rates into an airport and are recorded hourly in the Aviation System Performance Metric (ASPM) databases maintained by the FAA. The decision about what rates to call are made by taking into account such factors as weather, airport configuration and the corresponding arrival capacity as well as departure and arrival demand. Because called rates reflect a process involving judgment, there is uncertainty associated with called rates. Furthermore, the rates used by *systemwide*Modeler reflect only a subset of the airport configurations which may be used by the airport. In *systemwide*Modeler, the airport resource strategically manages arrival demand by publishing a called rate that the merging and spacing resource uses to time the delivery of arrival flows. To represent the uncertainty of called rates in *systemwide*Modeler, we adjust a parameter that governs the delivery rate of arrivals relative to the called rate published by the airport resource. The distribution we draw from comes from the observed difference between the called rates in ASPM and those called by *systemwide*Modeler.

The timing of runway configuration changes is important because it can have a significant impact on the airport's capacity. Airport configurations are not explicitly represented in *systemwide*Modeler. Instead, representative configurations describe the airport capacity in VMC, MMC, and IMC conditions. Ceiling, visibility, and approach information provided by ASPM is used to determine which configuration is in effect each hour. Due to the discrete nature of the data, the actual time that a runway configuration could have changed is equally likely to have happened anytime within the hour. Therefore, a uniform distribution over the hour leading up to the configuration change will be used to adjust the time of configuration changes as scheduled in *systemwide*Modeler input.

Previous studies have been conducted into the error and standard deviation of prediction of sector peak count as a function of look-ahead time [5]. Since the peak counts relative to monitor alert parameter values are used as a guide to determine when to impose upstream flow constraints, errors due to prediction can be represented in a deterministic model as the same relative error in the parameter used to control capacity. The variation in the maximum workload that air traffic controllers can handle in each sector will be varied based on results from these studies. En route capacity in *systemwide*Modeler is workload-based. Each flight entering a sector has some set of tasks that must be performed by the air traffic controller. Each of those tasks has a task time. Those task times are summed to build a profile of the work that the air traffic controller must carry out over time. When the amount of work that must be performed by the controller would exceed the capacity to do work, flights requesting to enter the sector must be delayed in an upstream sector until the controller can accommodate the workload created by that flight. The parameter governing the controller's capacity to do work will be drawn from a distribution mimicking the error in peak count prediction relative to sector capacity values used to impose flow constraints.

Model sensitivity to individual perturbations

Using *systemwide*Modeler, simulations will be conducted to test the impact of the four factors of previously described uncertainty on model results. Multiple samples of the 36-design day will be used. Charts will be presented to compare the relative impact of each perturbation with respect to one another.

Model sensitivity to all perturbations

The variables will then be varied simultaneously to replicate the impact that multiple perturbations will have on model results. The number of design days and number of sample runs for each day will be varied and the delays compared to results from a base case which does not include any perturbations. The results from this exercise will be a chart showing the relationship between design days, sample runs per day and level of accuracy in the model results. A notional example of this is provided in Figure 2 below:

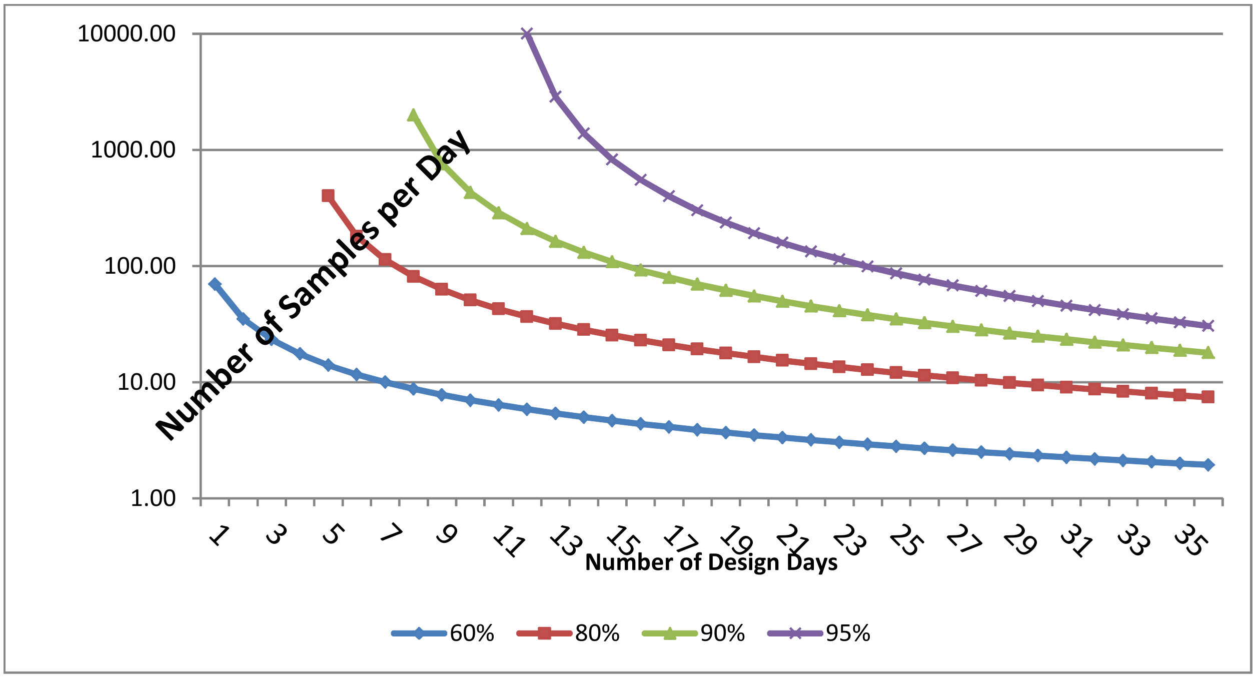

Figure 2 –Number of Runs Needed to Obtain Level of Accuracy in Model Results (Notional)

Initial Results

Research is still ongoing, however initial results have been conducted by perturbing flight pushback times by a uniform ±5 minutes. 100 iterations for each of 36 design days were conducted and the total delay from each run was analyzed. As expected, heavier delayed days are more sensitive to small changes than less delayed days as shown in Figure 3 below. If only one run is conducted for each design day, per current practices, the larger uncertainty associated with these design days will contribute significantly more to the overall error.

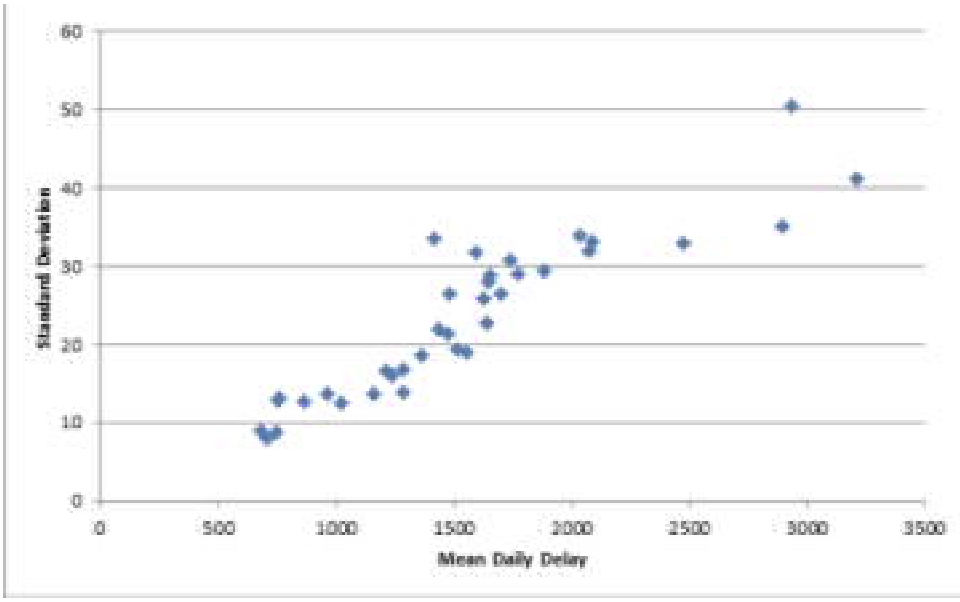

Figure 3 –System Impact to Perturbing Pushback Times by ±5 Minutes

Additionally, 10,000 simulations were then run by selecting one of the 100 runs for each of the 36 design days, summing the delays and dividing by 36 to get an average daily delay. Figure 4 below shows the results from these runs. It is important to note that in these initial results, the chosen variation was arbitrary and not based upon the uncertainty or variation expected in the system.

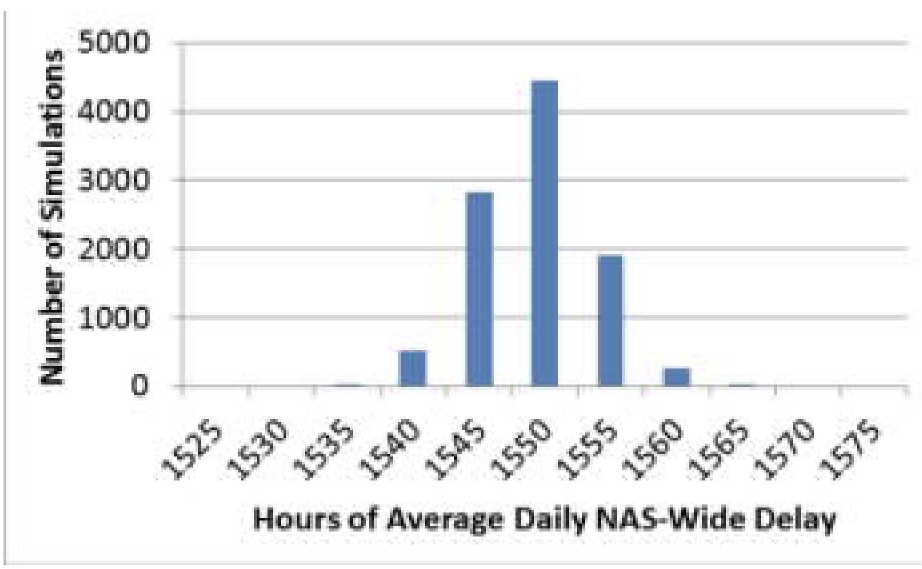

Figure 4 –Distribution of NAS-wide Delay Resulting from Perturbing Pushback Times by ±5 Minutes

Conclusions

Conclusions will be finalized once all results from this study are completed.

References

[1] ICAO, *Global Air Traffic Management Operational Concept*, ICAO Doc 9854, First Edition, 2005.

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[3] Foster, G.*, Demand Generation for System-Wide Simulation*, 2nd Annual Workshop on Innovations in NAS-Wide Simulation in Support of NextGen, Center for Air Transportation Systems Research, George Mason University, January 2010

[4] Gulding, J., ATO Future Schedule Generation, 2nd Annual Workshop on Innovations in NAS-Wide Simulation in Support of NextGen, Center for Air Transportation Systems Research, George Mason University, January 2010

[5] Wanke, C., Mulgund, S., Greenbaum, D., and Song, L., “Modeling Traffic Prediction Uncertainty for Traffic Management Decision Support”, AIAA-2004-5230, AIAA GN&C Conference, Providence, RI, August, 2004.