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Effects of Future Traffic on the National Airspace System

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I. Introduction

The capacity of the United States' National Airspace System (NAS) must grow to handle the passenger demands that are projected over the next 25 years. NASA initiated the Virtual Airspace Modeling and Simulation (VAMS) Project in 2002. The VAMS Project goals are to provide advanced air traffic management (ATM) concepts as well as develop an air space system modeling, simulation and evaluation environment. This environment, titled Airspace Concept Evaluation System (ACES) has been used to assess the advanced ATM concepts that may be used to increase the capacity of the NAS.

In addition to evaluating the specifics of the various concepts, ACES has also been used to conduct a sensitivity analysis of the major factors contributing to system performance. These factors, namely Airport Arrival/Departure Rates (AAR/ADR) and Enroute Sector Capacity have been varied to predict performance under future traffic demands. While there are many performance metrics that can be analyzed, one of the most significant is Flight Delay.

This paper presents a sensitivity analysis that was performed to evaluate key aspects of the Radio Technical Commission for Aeronautics Incorporated (RTCA, Inc) Concept of Operations (CONOPS). The analysis first assesses the changes required in the Enroute domain to meet the traffic demand predicted for 2022. The analysis then focuses on the terminal domain and assesses the impact of airport enhancements. It is shown that, although the future traffic demand doubles today's traffic, a simple homogenous doubling of NAS sector and airport capacities is not required, nor does it provide optimal benefit.

II. Assessment Goals and Objectives

An evaluation of the RTCA CONOPS utilizing ACES Build 2 was conducted to provide insight into key aspects of the concept while at the same time further validating ACES as a resource for broad application to the aerospace community. This analysis evaluated a representative sample of the RTCA "Operational Statements" [1]. The RTCA CONOPS addresses the following domain areas: NAS Management, Flight Planning and Emergency and Alerting Services, Surface, Arrival/Departure, Enroute, and International Oceanic. The ACES Build 2 functionality provided the means to evaluate three of the domains, NAS Management, Enroute, and Arrival/Departure. The assessment determined the capacity improvement benefits, measured by reduction in flight delays, offered by the operational statements. By integrating the three domains in a final analysis it was possible to assess the overall capacity of a future ATM system based on implementing key parts of the RTCA CONOPS.

RTCA optimizes resources in the NAS Management and Enroute domains through functions including improving sector management, accommodating user priorities, and improving decision support tools. As stated in the RTCA CONOPS "In contrast to the past, both demand and capacity are managed by allocating access to resources, collaborative rerouting, and by maximizing the remaining capacity through realignment of sectors and associated resources." [2]. ACES Build 2 does not include the capability to evaluate rerouting, however it does include the capability to assess reallocating sector resources. Relevant Operation Statements in the RTCA CONOPS include:

- Enhanced system wide TFM planning, problem resolution, and execution capabilities; strategic flow initiatives; contingency planning.
- Assess the impact of reducing constraints and reducing restrictions
- Airspace structure is adjusted when demand exceeds capacity

Airport Arrival/Departure enhancements envisioned by RTCA include optimizing traffic flow through decision support tools and closely spaced parallel runways. RTCA envisions that "enhanced all weather landing systems allow for multiple paths to final approach to facilitate full use of runway capacity" as well as "modifications to service provider procedures and improvements in turbulence and wake vortex avoidance facilitate a reduction in separation standards". The airport Arrival and Departure Rates (AAR/ADR) and airport operational states within ACES can be varied to assess the impact on flight delay given various traffic levels. Relevant Operational Statements include:

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- DSSs provides optimization of sequencing and spacing to airports and runways, including multi-airport arrival stream(s)
- FMS offset approaches/departures and parallel RNP/RNAV routes
- Separation standards are dynamically adjusted and applied based on accurate real-time prediction/detection/decay of wake turbulence and actual aircraft type

III. Assessment Approach

The assessment begins by investigating the performance required in the Enroute domain by removing the constraints in origin and destination airports. Once the Enroute sector capacity required for minimal flight delay is established, baseline airport capacities (AAR/ADR) are reintroduced. The AAR/ADRs are then increased to assess the impact on flight delay of various traffic levels.

A. Traffic Demand Schedules – Flight Data Sets

A traffic demand schedule (or flight data set) defines the number of aircraft operations and their distribution over a given time period. It includes the planned routes between origin and destination airports, scheduled departure times, aircraft types, and the providing air carriers. To evaluate the added value of a proposed NAS operational concept, a baseline demand schedule and at least one future demand schedule are required. For this analysis, three demand schedules were used: a baseline demand schedule that describes a typical NAS operational day in the present time frame, a "2x" demand schedule that estimates a typical NAS operational day in the future year 2022, and a "3x" demand schedule that roughly triples the number of flights in the baseline demand schedule. The baseline current day demand schedule was based on FAA Enhanced Traffic Management System (ETMS) data from Friday, May 17, 2002. The ACES Build 1 validation effort defined this day as a "high traffic" operational day with no significant Enroute weather. The ETMS data was filtered to remove flights that were incompatible with ACES and to homogenize the demand schedules for comparison purposes. The filtering operation reduced the data to a set of commercial passenger flights traveling to and from 98 domestic airports. The resulting demand schedule contained 17,875 flights.

The 2x demand schedule was developed from a transportation demand and economic forecast analysis developed for NASA by the Logistics Management Institute and GRA, Inc. in 2003 [3]. This analysis used a series of assumptions to forecast operational demand for the year 2022. These assumptions included: relatively high GDP growth, continued airline recovery, limited aviation system growth, further growth of the hub and spoke system, and a lack of substitutes for commercial aviation services. The study concluded that 2022 commercial passenger demand would be approximately double that of a baseline data set from Monday, May 12, 1997. Filtering this data as described above yielded a demand schedule containing 36,252 flights.

.A 3x demand schedule was developed by tripling the baseline demand schedule. The duplicated flights were assigned new flight Ids, and their scheduled gate departure times were postponed by a random value between 0 and 30 minutes. After elimination of conflicting operations, this demand schedule contained 53,625 flights.

B. Current Demand – Baseline Assessment Cases

The Current Day Demand file, described above, was used in order to determine the baseline from which to benchmark or compare the Future Demand results. The four cases shown in Table 1 were evaluated in order to determine the relative sensitivities of the NAS to Enroute versus airport constraints. "Current" means current sector and airport capacities. The current sector capacities range from 6 to 25, with an average of 16.9. The current airport capacities range from 31 to 141, with an average of 42. For the "Unlimited" cases, all sector capacities were set to 200 aircraft and all airport capacities to 200 operations/hour.

		Sectors	
		Current	Unlimited
Airports	Current	1	2
	Unlimited	3	4

Table 1. Airport and Sector Settings of the Four Current Demand Cases

C. NAS Management/Enroute Assessment Cases

The assessment cases for the NAS Management/Enroute enhancements envisioned by RTCA are provided below. In this evaluation, the constraints of the origin and destination airports were removed by setting all airport capacities to 200. Two Flight Data Sets were used, 2x Future Demand, and 3x Future Demand.

1. *Flight Data Set: Future Demand (2x Current)*
   For the 2x Future Demand case, Aces was first run with current sector capacities. The sectors with predicted demand exceeding capacity were identified and the capacity of these congested sectors was increased in the succeeding run. This approach continued until the number of congested sectors became near zero.

2. *Flight Data Set: Future Demand (3x Current)*
   The 3x Future Demand case analysis was conducted similar to the 2x case, increasing sector capacity until the number of sectors predicted to be congested was near-zero.

D. Arrival/Departure Assessment Cases

The effects of the enhanced airport operations were evaluated by adjusting airport acceptance and departure rates as described below. In this analysis the Enroute constraints are nearly eliminated by using the sector capacities developed in the NAS Management/Enroute Assessment cases.

1. *Flight Data Set: Future Demand (2x Current)*
   The 2x Future Demand case was initially run with current airport capacities. Similar to the Enroute analysis, we identified congested airports and then increased their capacities. The first increase raised capacities of the congested airports to the FAA's Operational Evaluation Plan (OEP) maximum optimal conditions for 2010 defined in the FAA Benchmark report of 2001[4]. The succeeding runs further raised the capacities until near-zero airport congestion alerts occurred.
2. *Flight Data Set: Future Demand (3x Current)*
   The 3x Future Demand case analysis was conducted similar to the 2x case, increasing airport capacity until the number of airports predicted to be congested was near-zero.

IV. Results

As mentioned above, the NAS Management/Enroute evaluation was conducted by removing airport constraints. The Arrival/Departure evaluation then re-introduced airport constraints and nearly removed enroute constraints by using the sector capacities determined by the previous analysis.

A. Current Day – Baseline Results

The average delay produced by each of the four Current Demand cases is shown in Table 2. As expected the current sector capacity/current airport capacity (Case 1) generated the highest average delay of 1.5 minutes. A comparison of Cases 2 and 3 indicates that the NAS is more sensitive to airport capacity than to sector capacity. Retaining airports at current capacity and removing sector constraints (Case 2) reduced the average delay by only 0.1 seconds, to 1.4 minutes. However, with sectors at current capacity and removing airport constraints (Case 3) the average delay is reduced to 0.42 minutes. When removing both airport and sector constraints (Case 4), ACES generated a residual average delay of 0.2 minutes, and this phenomenon is under investigation.

		Sectors	
		Current	Unlimited
Airports	Current	1.5 min	1.4 min
	Unlimited	0.42 min	0.2 min

Table 2. Average Delay (Minutes) of the Four Current Demand Cases

B. NAS Management/Enroute Results

The purpose of the NAS Management/Enroute analysis was to investigate the effects of increased demand to sector capacity in the presence of unconstrained Terminal domain. When sectors were kept at current capacity and demand was increased to 2X Future Demand, the average delay increased from 0.42 minutes (Current Demand Case 2) to 2 minutes. The capacities of the congested sectors were then increased in succeeding 2x Future Demand runs (while keeping airport capacities at 200). The sector capacity increase was done in a targeted fashion, increasing only those sectors that were predicted to become congested. As shown in Figure 1, a 9% increase in total sector capacity resulted in approximately 90% reduction in average delay.

The 3x Future Demand analysis was initialized using the 9% increased sector capacities from the 2x Future Demand analysis, and the average delay increased to 16 minutes as shown in Figure 1.

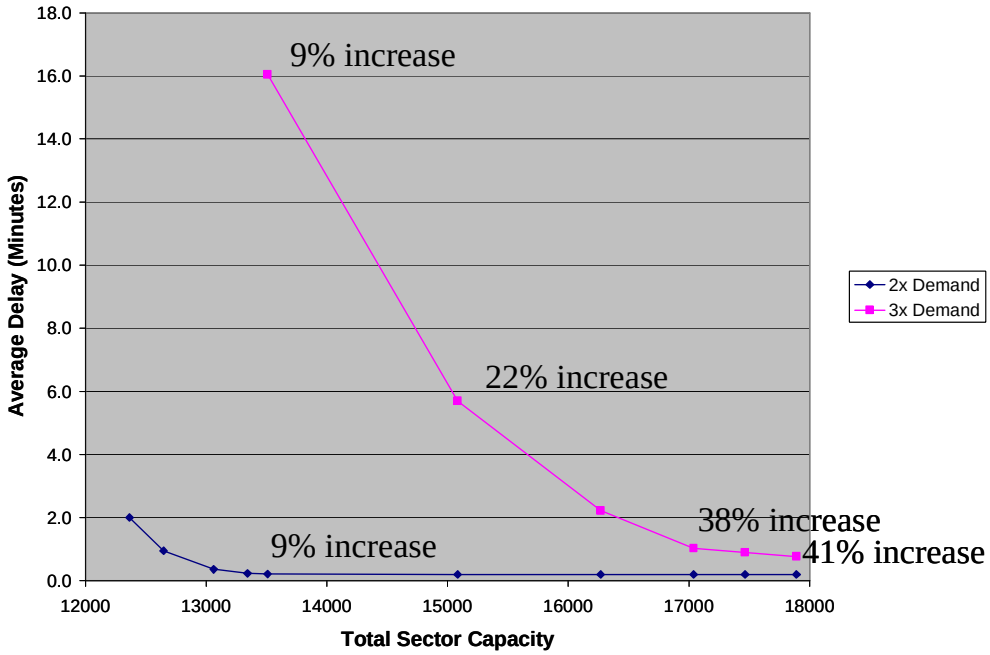

Figure 1. Average Delay vs. Total Sector Capacity for 2x and 3x Future Demand Set

Figure 2 presents this data in the standard Delay vs. Demand fashion where the curves represent various total sector capacities. The Enroute domain is relatively insensitive to 2x Demand. For example, it is observed that 1) with baseline sector capacities, the average delay is only 2 minutes and only 1.3% of all flights experience delay greater than 30 minutes, and 2) with total sector capacities increased by 9% the average delay is reduced to the 'residual' 0.2 minutes and zero flights have delay greater than 30 minutes. However, the Enroute domain is much more sensitive to 3x Demand. Sector capacities had to be increased 38% in order to produce an average delay of under one minute. In this case only 0.2% of flights experienced delay greater than 30 minutes.

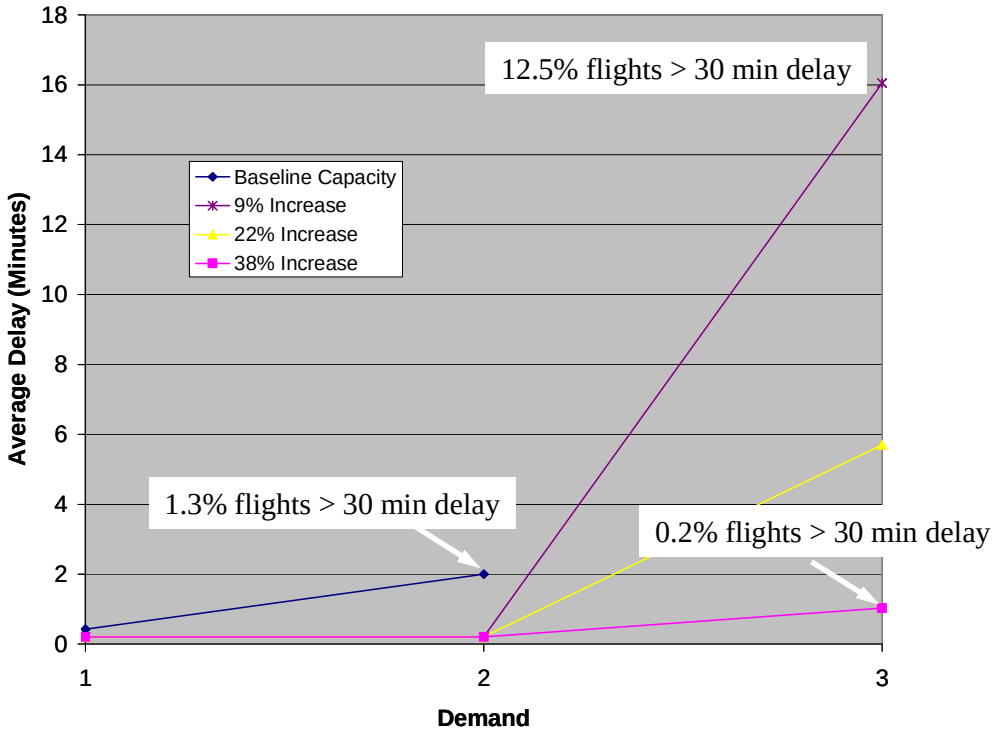

Figure 2. Delay vs. Demand for Various Sector Capacities

C. Arrival/Departure Results

The purpose of the Arrival/Departure analysis was to investigate the effects of increased demand to airport capacity in the presence of the "improved" sectors found in the Enroute analysis. For the 2x Future Demand cases sector capacities were set to the 9% increased capacities, and for the 3x Future Demand cases sector capacities were set to the 38% increased capacities.

With airports at current capacity and demand at 2x Future Demand the average delay increased from 1.4 minutes (Current Demand Case 2) to 10.8 minutes. As shown in Figures 3 and 4, with 2x demand an increase in total airport capacity of 25% was required to drop the average delay below one minute. An increase of only 10% was required such that no flights experienced delay of greater than 30 minutes. Again, the key point is that capacity was not increased across the board, but only at congested airports.

The first case analyzed with 3x demand used the OEP airport capacities. This case produced an average delay of 78 minutes, seven times larger than that created by 2x demand. Reasons for the significant delay increase with 3x demand include, congestion occurs for longer periods during the day and a larger number of airports become congested. Even with a 25% increase of total airport capacity the 3x demand produced an average delay of 21 minutes, and 14% flights experienced delay of greater than 30 minutes. Airport capacities had to be raised 66% before the average delay dropped below one minute. However, it is now believed that these capacity increases are conservative and that an improved approach to increasing airport capacity would reduce the overall capacity increase required. Such improvements will be investigated during ongoing studies.

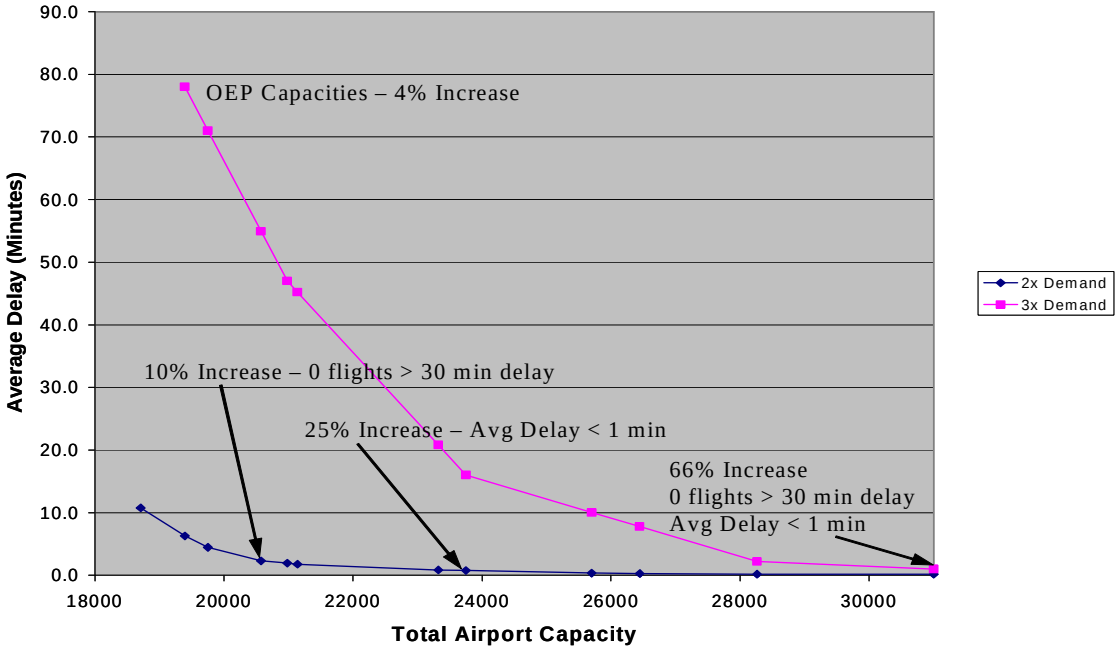

Figure 3 Average Flight Delay vs. Total Airport Capacity for 2x and 3x Future Demand Set

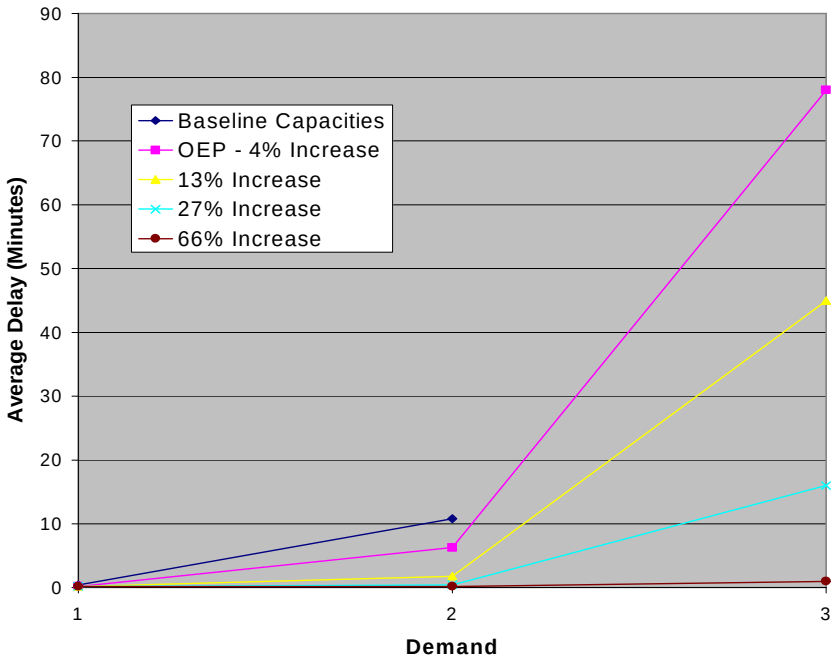

Figure 4. Delay vs. Demand for Various Airport Capacities

In addition to the NAS-wide effects presented above, individual airports were also studied with 2x Future Demand. The seven airports with highest delay are shown in Figure 5. The data points at Total Airport Capacity of 18709 are at current airport capacities, those at 19392 are the 4% increased OEP values, etc. The Las Vegas (LAS) 'outlier' at OEP capacities will be discussed in a few paragraphs.

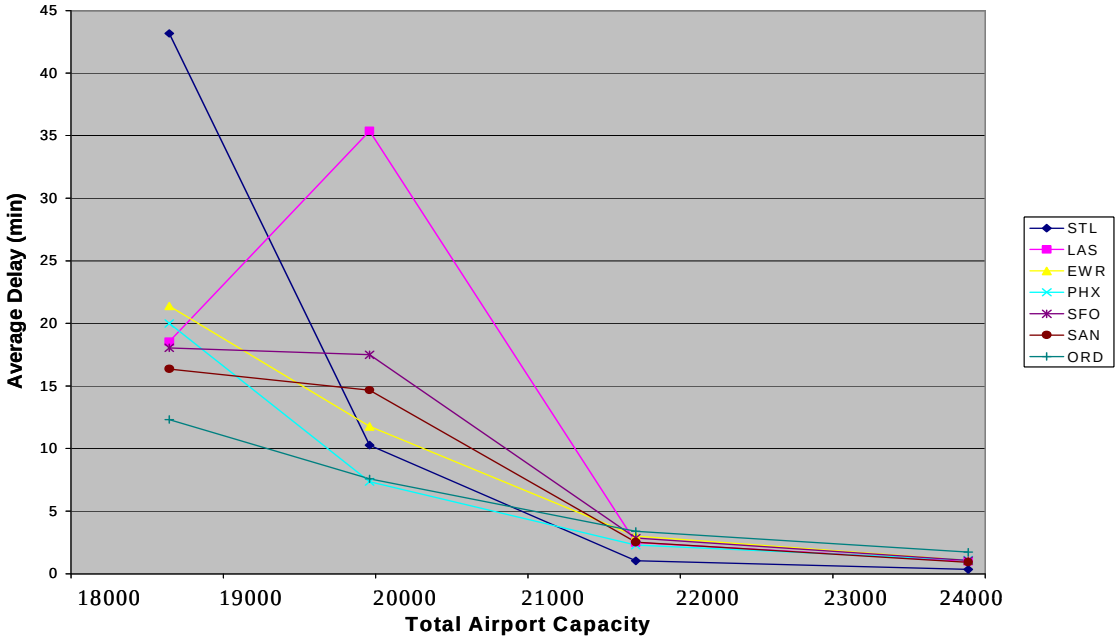

Figure 5 Average Delay vs. Total Airport Capacity for 2x Current Demand Set at Highest Congested Airports

These seven airports experienced the large majority, approximately 80%, of all delay incurred across the 98 airports modeled in this study. St Louis International (STL) had the lion's share of delay under current airport capacities and also the majority of delay greater than 60 minutes, as shown in Figure 6. This can be explained by Figure 7 which shows the Demand-over-Capacity ratio during the busiest arrival/departure hours as well as the daily average. STL lead the other airports in all categories.

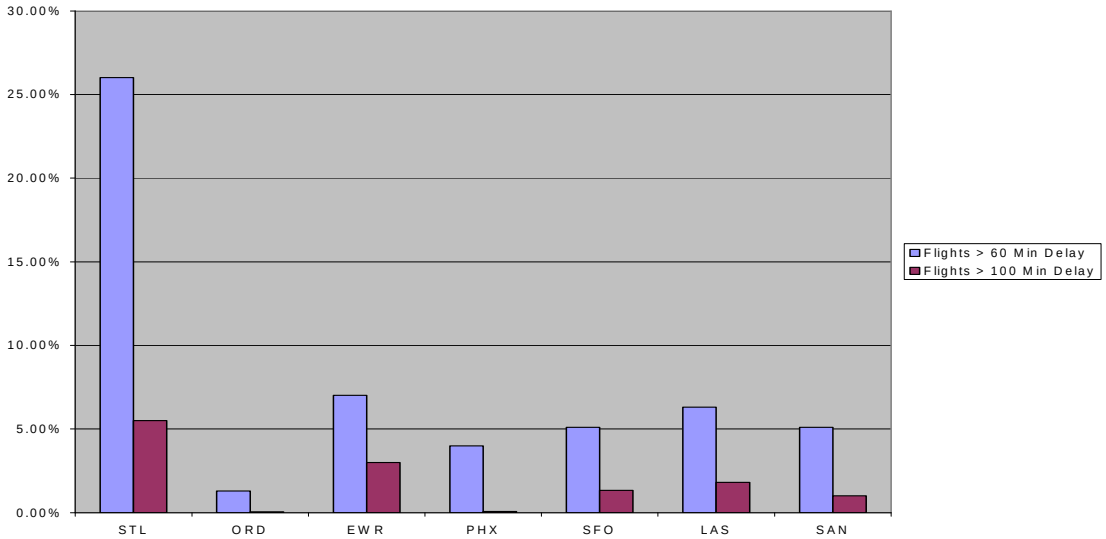

Figure 6. Percentage of Flights with Delay Greater than 60 and 100 Minutes at Current Airport Capacities and 2x Demand

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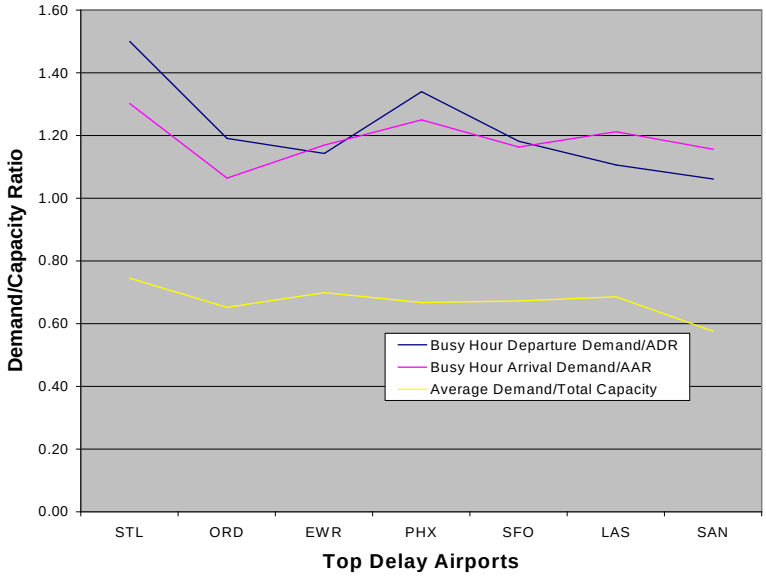

Figure 7. Demand/Capacity Ratio at Highest Congested Airports with Current Airport Capacities and 2x Demand

STL is a medium sized airport and as it turns out, it was closer to its peak operating state with Current Demand than the other airports, particularly with respect to departures. It is therefore more sensitive to the increased 2x demand. When an airport's departure demand exceeds its capacity, ACES restricts the takeoff time by producing Taxi-Out delay. STL had significant departure congestion with 2x demand and current airport capacity, so as shown in Figure 8 the majority of its delay is caused by Taxi-Out delay.

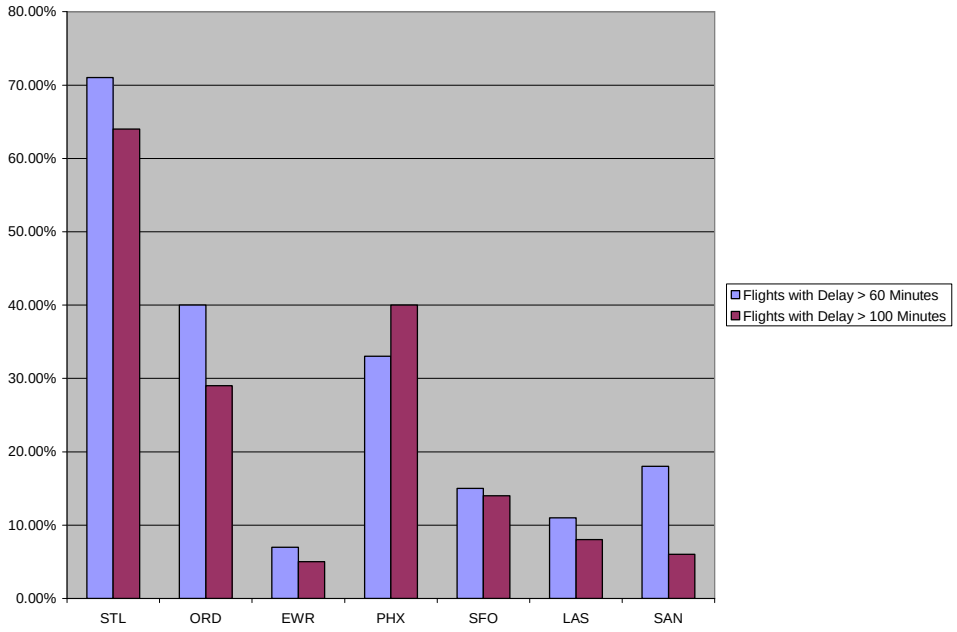

Figure 8. Taxi-Out Delay Percentages at Highest Congested Airports with Current Airport Capacities

While STL benefited greatly by the OEP operational improvements, Las Vegas (LAS) was the only airport to experience more delay when its capacity changed from current to OEP conditions. This is because LAS is the only airport out of these seven where OEP improvements are only in effect during reduced visibility (IFR) conditions. This analysis assumed optimal (VFR) conditions across the NAS so LAS capacities were not increased during the OEP run. However, under OEP conditions LAS had higher arrival demand than under current conditions since more flights were able to depart their origin airports on their way to LAS. This higher arrival demand resulted in the increased delay experienced at LAS.

V. Conclusion

This analysis provided insight into the capacity benefits and delay reduction likely to be achieved by implementing significant portions of the RTCA CONOPS. The parametric evaluation generated data that establishes the required sector and airport capacities that enhanced RTCA operations must meet to keep delays to an acceptable limit in the presence of 2x and 3x Future Demand.

This study has shown that given accurate and timely congestion prediction, adding only minimal resources can make significant reductions in NAS-wide delay. This result points to the need for techniques and technologies that enable the rapid identification and dissemination of air traffic information. For example, a network-centric information system that distributes timely and consistent information across the NAS can enable the allocation of additional resources to sectors that are predicted to become congested. Additionally, accurate traffic forecasts will enable the nation to target those airports requiring operational enhancements such as closely spaced parallel runways, and therefore minimize the cost to achieve NAS-wide performance improvements.

VI. Acknowledgements

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References

[1] Paul Abramson and Edmond Koenke, "Analysis of the RTCA Concept of Operation (CONOP) and Development of a Plan for Simulating the RTCA CONOP using ACES", Sept 30, 2003,

[2] "National Airspace System Concept of Operations and Vision for the Future of Aviation", October 29, 2002, RTCA, Inc.

[3] Wingrove, E.R., Hees, J., Oberman, J., Ballard, D., Golaszeqsi, R., "Airline Scenarios for Transportation Demand and Economic Analysis", *Final Report, NASA NS255S1 Task, Logistics Management Institute*, 2003

[4] "The Airport Capacity Benchmark Report 2001", FAA