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JPDO Case Study of NextGen High Density Operations

Yuri Gawdiak[1]
Joint Planning and Development Office, Washington, DC, 20005

Gregory Carr[2]
Sensis Corporation, Campbell, CA, 95008

and

Shahab Hasan[3]
Logistics Management Institute, McLean, VA, 22102

The Joint Planning and Development Office has organized an Interagency Portfolio and Systems Analysis Division in order to provide an analytical basis to formulate and assess the capabilities of the Next Generation Air Transportation System. In the past analysis products have been developed based on targets of opportunity and dynamic requests from the other divisions within the JPDO. The High Density Case Study was formulated as an integrated, top-down, test case to strategically align the JPDO divisions and agency partners with their respective outputs for the NextGen plan into an integrated portfolio. This case study documents the capacity-related benefits and environmental impacts of a subset of the capabilities comprising the Next Generation Air Transportation System. The analysis focused on determining the benefits of the NextGen capabilities related to the High Density or Super-Density Operations. High Density Operations are a component of the OEP Solution Set while Super Density Operations are corresponding capabilities described in the NextGen Concept of Operations. For the sake of simplicity and consistency we refer to the analysis performed as the HD Case Study.

I. Introduction

The mission, roles, and responsibilities of the Joint Planning and Development Office (JPDO) are established in Public Law 108-176, Vision 100 – Century of Aviation Reauthorization Act. The Act establishes "a joint planning and development office to manage work related to the Next Generation Air Transportation System". The principal responsibility of this office is to "create and carry out an integrated plan for a Next Generation Air Transportation System". The JPDO's plan for the Next Generation Air Transportation System (NextGen) is embodied in the NextGen Concept of Operations, the Enterprise Architecture, and the Integrated Work Plan. Together they comprise the NextGen Plan. The JPDO has organized a Interagency Portfolio and Systems Analysis Division (IPSA) in order to provide an analytical basis implemented through capability models and system-wide simulations to help formulate and assess the components of the NextGen Plan. In the past IPSA has provided analysis products based on targets of opportunity and dynamic requests from the other divisions within the JPDO. The High Density (HD) Case Study was formulated as an integrated top-down test case to strategically align the JPDO divisions and agency partners with their respective outputs for the NextGen plan into an integrated portfolio.

This case study documents the capacity-related benefits and environmental impacts of a subset of the capabilities comprising NextGen. NextGen will be the outcome of a structured and sequenced set of changes in the technology and operations of the national airspace system (NAS). The components of the NextGen transformation of the nation's air transportation system are in their early stages. The path to NextGen is being developed by a consortium of federal agencies and organizations that are collaborating through the JPDO.

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[1] Director, Interagency Portfolio and Systems Analysis Division, 1500 K St., Member AIAA
[2] Senior Systems Engineer, Sensis Corporation, 1700 Dell Avenue, Member, AIAA
[3] Program Director, 2000 Corporate Ridge, Senior Member, AIAA

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- **Step 1:** The Operational Improvements (OI's) were extracted by the Enterprise Architecture (EA) division from the EA database.
- **Step 2:** These OI's were organized into 3 different alternatives in order to generate a portfolio of options.
- **Step 3:** The 3 alternatives were run through an Integrated Modeling Suite to generate the benefits of the OI's
- **Step 4:** The Operational Improvements Initial Operational Capability (IOC) dates were adjusted by the historic policy risks.
- **Step 5:** The adjusted OI's were rerun through the Integrated Modeling Suite to generate a new set of policy risk adjusted benefits.
- **Step 6:** The results of the simulation and generated benefits were then updated into the Enterprise Architecture.

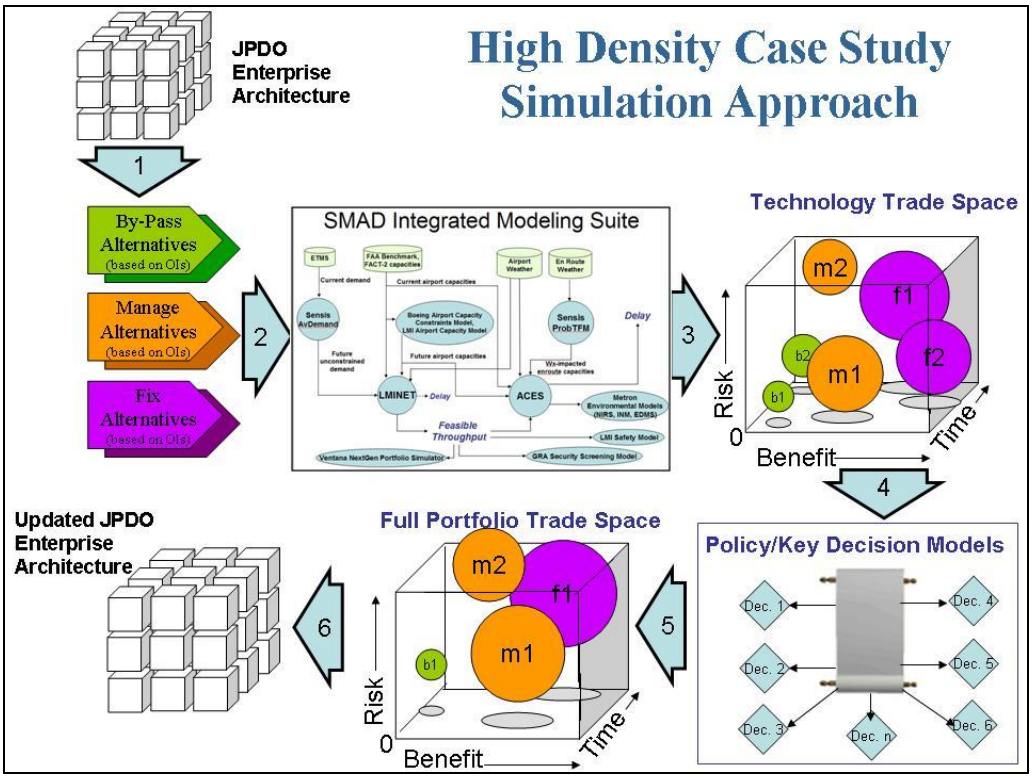

Figure 1. High Density Case Study Simulation Approach

II. Limitations

The HD Case Study is an internal process and quality check for the JPDO. The results are not meant to be used directly for investment or policy decisions. Where appropriate successful techniques and processes used in the case study may be used in the future to generate recommendations on investment and policy options for interagency NextGen issues. While this paper provides a complete framework for the NextGen benefits assessment, there are

several limitations affecting the paper's comprehensiveness that must be kept in mind. These limitations are directly related to the evolving maturity of most NextGen concepts and proposals. The JPDO Working Groups and other divisions are still developing the operational improvements (OIs) that will enable the transformation from today's NAS to NextGen. Different Working Groups are at different stages of the OI definition process and complexities related to coordinating OIs that may have implications for or correlations with other OIs have not yet been addressed.

This discussion is complicated by the fact that some OIs affect the same or similar areas of NAS operations, and the joint impact of two or more OIs may not be identical to the sum of the individual OI impacts. Many of the OI's are related; that is, they do not form an orthogonal set of improvements to the NAS—and neither should they. The OI's represent a set of improvements, some of which are related and depend upon each other, and are an attempt to present an overall plan for NAS transformation. For an analysis to isolate the effect of individual OI's, however, they would need to be orthogonal and non-interacting, else designing an experiment that isolates the contribution of a given OI becomes intractable. In theory, identifying individual OI contributions might be achievable if thousands of simulation runs are completed; because we only run dozens to hundreds of separate runs, we have too sparse a data set to identify individual OI contributions.

The process of refining operational improvement definitions and finding ways that they can be represented in existing airspace models is an ongoing joint activity between IPSA and the Working Groups that have developed the OIs. To date, IPSA has primarily included OIs related to en route airspace activity and terminal area airspace activity. IPSA has also conducted analyses of environmental constraints to assess the limitations that meeting environmental requirements may pose to NextGen capacity goals. As mentioned above, OIs are less developed in other NextGen capability areas and have not been part of IPSA analyses to date. Nevertheless, NextGen capacity goals are most intimately related to the effects from improvements in en route and terminal area airspace, and these goals may be most severely constrained by environmental requirements. As a result, although a complete assessment has not yet been possible, initial IPSA analyses have addressed important aspects of the performance of NextGen.

III. Approach

The initial work for the NextGen High Density Test Case focused on developing feasible alternatives to modernize air transportation that could be evaluated and modeled by IPSA. Consideration of alternatives is required by the Office of Management and Budget (OMB), which requires a cost/benefit estimate of three alternatives and the status quo for an Exhibit 300 test case. Meetings were held to discuss possible scenarios and alternatives for evaluation based on establishing some common factors and potential constraints in the air transportation system. The JPDO decided to use the following three alternatives for the High Density Test Case: fixing the congestion problems to enable smooth high density operations, managing operations by making incremental gains to control root causes, and bypassing the problem by using policy and other means to accommodate future increases in air traffic.

The IPSA and other divisions of the JPDO reviewed the NextGen Concept of Operations (ConOps), the Enterprise Architecture (EA) and other documents and references to identify the scope and capabilities related to High Density Operations (HDO, term used in the EA) and Super Density Operations (SDO, term used in the ConOps). From the ConOps and EA, we extracted the definitions and mechanisms associated with SDO and HDO, respectively. Alternative Development Teams were named to construct the scenarios and assumptions for the three alternatives. Construction of the alternatives entailed defining common characteristics and assumptions and determining which Operational Improvements (OIs) apply to each alternative. For example, determining to what extent technology is needed to provide a solution for each alternative was a critical distinction.

The results of the modeling activity are combined with appropriate cost factors and estimates to document the business case for NextGen and to generate certain metrics. It was vital for the cost analysts and the benefits modelers to keep each other informed of the framework being used for cost and performance projections, the assumptions involved, and the cost and performance parameters needed and how they would be combined. This coordination was effected by having these groups serve as liaisons, by periodic meetings on topics of common interest, by having cross-division representation at weekly IPSA meetings, and by reviewing each other's products. These activities have the goal of maintaining compatible frameworks and assumptions for cost and performance and producing timely and responsive modeling results and cost estimates that can be suitably combined for the business case and other purposes.

IV. NAS-Wide Modeling and Simulation

A. Baseline and NextGen Alternative Analysis

We accomplished this analysis using the NAS-wide modeling and simulation tools that have been brought together from a number of organizations for use in the IPSA (see Figure 2). For each alternative, the performance benefits that might result from the NextGen capabilities were estimated on a relative basis compared with the estimated performance of a "baseline" NAS that does not include NextGen capabilities. The analytical process used for this initial evaluation comprised five major steps: 1) estimation of the impact of NextGen operational improvements on airport and airspace capacities (OI abstraction), 2) development of future demand scenarios based on the FAA Terminal Area Forecast (TAF), 3) evaluation of baseline NAS performance for different levels of future traffic), 4) evaluation of the NextGen performance for different levels of future traffic, and 5) comparison of the NextGen performance and the baseline performance for each alternative.

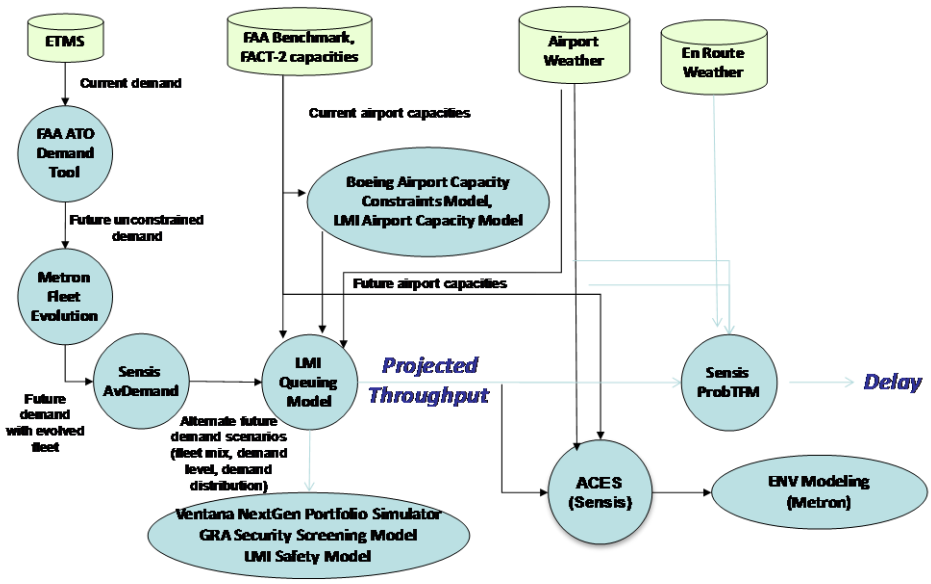

Figure 2. IPSA Integrated Modeling Tools

The focus of the NAS-wide demand/capacity analysis of HD Case Study was to estimate the performance benefits as measured by the number of flights that can be accommodated while maintaining reasonable levels of delays in good weather. Prior analyses have shown that if future demand is allowed to grow at a pace that outstrips the planned growth in capacity, the delays that would be experienced in the NAS would become unrealistically large. We therefore utilized a method of constraining future demand by trimming flights from the projected demand in order to maintain reasonable levels of delay in the NAS. In this manner we were able to quantify the future shortfall in NAS capacity by measuring the number of flights that must be removed from the projected or unconstrained demand. We then compared the capacity shortfall for the future baseline NAS with the capacity shortfall of a future NAS using assumed increases in airport and airspace capacities to represent the operational impact of the NextGen capabilities. The NextGen capabilities should reduce the capacity shortfall and enable the NAS to accommodate a greater number of flights while maintaining a reasonable level of delay – i.e., the projected throughput should increase under the NextGen alternatives.

In addition to estimating the performance benefits related to NAS capacity in good weather, we evaluated the performance of each alternative as measured by average flight delays in poor weather, the environmental performance of the NextGen alternative, as well as the potential impact of policy decisions on system performance. As previously mentioned, a major goal of the modeling activity is to support the JPDO business case that will include estimates of benefits and costs of NextGen alternatives. In the HD Case Study, the benefits are represented by operational performance impacts in terms of metrics such as projected NAS throughput and average NAS-wide delays. In order to support a comparison of the benefits and costs of NextGen, these operational performance impacts will need to be monetized.

B. Throughput vs. Delay Tradeoff and Projected Throughput

It is often said that air system capacity and air system delay are two sides of a single coin, linked by the amount of load or user activity within the system. For example, if capacity is held constant and load on the system (throughput, or user activity in the form of flights) is increased, then average system delay increases. Conversely, if system delays are to be held roughly constant in the face of increasing load on the system (throughput), capacity must increase by an appropriate amount in some way. The users of the system ultimately decide, through their scheduling practices, at which point the system operates along the delay/throughput curve. In addition to such a curve associated with the current system, a new curve can be envisioned associated with the capacity enhancement provided by NextGen or any other NAS investment. The investment provides benefit, assuredly, but that benefit can be taken as additional throughput, reduced delay, or some combination of the two. These concepts and curves are depicted in Figure 3 below.

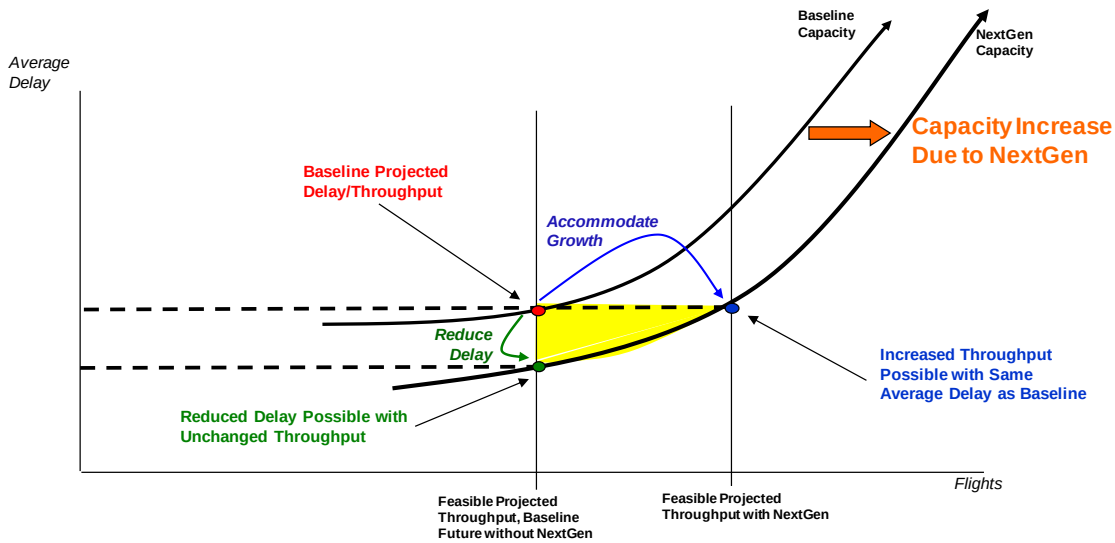

Figure 3. Graphical Depiction of Delay/Capacity Tradeoff

Many traditional NAS benefits analyses have focused on the delay reduction aspect of the tradeoff. But for more transformational changes to the system, we believe the additional throughput aspect may be more appropriate. Future demand forecasts such as the FAA TAF represent unconstrained demand; i.e., there is no accounting for airport and airspace capacity limitations. Our thesis is that at a certain saturation point, some of the demand would go unsatisfied in order to keep delays at tenable levels. We reasonably assume that the airlines, being in the business of providing reliable transportation, will not schedule a service if its expected delay exceeds some delay tolerance. Therefore, as a composite capacity metric, we use the concept of "projected throughput." This is the daily number of flights that can be accommodated by the system given (1) an airport-specific demand/capacity ratio (explained further below); (2) a sector-specific maximum airspace capacity; and (3) assumptions about the airline business model (e.g., scaled-up current system, business shift to alternate airports, introduction of large numbers of Very Light Jets (VLJs)). Projected throughput thus measures how much of forecasted demand can actually be accommodated by the system.

The demand/capacity (D/C) ratio is typically used to characterize an airport's ability to serve the traffic demand (number of operations) placed upon it given its total runway capacity (also measured by number of operations). This metric is measured over a period of time (e.g., an hour or a day); it is not typically used to measure en route performance. Queuing theory, backed by quantitative data analysis, indicates that for efficient operations an airport's D/C ratio must be under 1.0, otherwise delays build up exponentially which would severely compromise an airline's ability to maintain schedule integrity. The D/C ratio can exceed 1.0 only for short periods of time. In recognition of this, we limit each airport's D/C ratio to 1.2 for each 15-minute epoch and to 0.9 for each rolling hour. Our model computes the D/C ratio throughout the day, at each airport, for both arrival and departure queues. If the ratio exceeds our tolerances, we reduce the demand to conform to this constraint.

For the airspace, we use the FAA's sector Monitor Alert Parameter (MAP) to represent each sector's maximum capacity. Flights are selected for elimination one flight at a time based on criteria that measures the flight's total impact on congestion at the airports and in the airspace (sectors) in which that specific flight operates. Finally, when the new constrained schedule (in which flights have been eliminated to satisfy our airport D/C and airspace MAP value constraints) has been created, we compute various traffic measures for benefits, such as flight operations, available seat miles, and revenue passenger miles. These measures are what we refer to as the projected throughput.

We realize that flight elimination is an extreme method of handling capacity constraints. Alternatively, flights could be shifted to other times and/or take different routes. However, these strategies are airline coping mechanisms (using larger aircraft is another strategy). Flight elimination, and the concept of projected throughput in general, is an analytical construct meant to measure the shortfall between capacity and demand; this construct assumes that airlines operate the way they do currently for rational reasons and would seek to preserve that operating mode. The possible coping mechanisms all have costs and tradeoffs associated with them.

In this analytical process we have introduced some terms and concepts which may lead to some confusion since these terms are similar (but distinct) from terms used in other fields of study within the air transportation domain. Therefore, we take this opportunity to provide some further context for the terminology we have employed. The flight eliminations from a future forecasted schedule that we estimate are entirely distinct from the flight cancellations, which occur in the daily operation of the NAS due to disruptions such as inclement weather. Here in our method, the flight eliminations we compute to estimate projected throughput simply mean that some of the projected future traffic growth cannot be realized because of the capacity limitations. To further clarify the difference, it is useful to remember that our method is related to the "macro" level dynamics of flight scheduling across the aggregate airline industry which is done for future quarters or even years. This type of planning is affected by long-term factors such as the chosen business strategy (e.g., hub-and-spoke vs. direct service) and, as is the focus of our analyses, existing and anticipated NAS capacity constraints, which prevent all the demand from being satisfied. This contrasts with the "micro" level operation of the schedule on any single day, which can be affected by various traffic flow management (TFM) initiatives in response to inclement weather or other disruptive events such as equipment breakdowns.

The flight trimming is performed using LMINET. LMINET is a NAS-wide model that simulates flights among a set of airports by linking queuing network models of the airports with sequences of ATC sectors. The demands, delays and capacities at airports and sectors are determined by the flight schedules, flight trajectories, airport runway configurations and airport weather conditions. LMINET considers all flights, both commercial and general aviation, in the U.S. The arrival and departure delays are computed for the top 110 airports; these airports comprise over 95% of all enplanements in the U.S. All ATC sectors are considered.

C. Weather Modeling and Delay Analysis

We evaluate the benefits and impact of improved NextGen weather capabilities using the ProbTFM NAS-wide simulation. ProbTFM includes trajectory based operations, forecast uncertainty and NextGen probabilistic decision making. ProbTFM uses the actual flight tracks through a sector combined with the actual weather system to estimate reroutes around convective systems. ProbTFM takes parameters related to the accuracy of weather forecasts and the aggressiveness of re-routing strategies, the flight tracks, sector and airport capacities, and the weather polygons, producing delays and/or flight reroutes that ultimately determine the flow of flights through the enroute system. ProbTFM is used to assess the NextGen improvements related to pre-flight and in-flight rerouting strategies around enroute convective weather systems as well as severe enroute congestion caused by excessive traffic load.

We evaluate NextGen weather capabilities according to the Operational Improvements (OIs) at the interim steps as well as the target NAS end state. We use the Initial Operating Capability (IOC) dates listed in the Integrated Work Plan (IWP) for the OIs as the basis for when performance improvements will be realized. The calendar years at which we project and evaluate the NAS system performance are 2014, 2018, 2025, 2086. And when we assess similar or overlapping OIs, the analysis depends on the sequence of when those capabilities are introduced. In such cases of overlapping OIs, the traceability of benefits to OIs can be complicated. We give credit to the first OI in the entirety of the benefit that it provides. Subsequence OIs that overlap are credited only with the additional improvements that are added sequentially.

The NextGen benefits analysis for weather focuses on a finite set of days, characterizing different types and levels of traffic inclement weather. For instance, we include traffic demand from holidays and weekends as well as weekdays. And we include weather days ranging from light to medium to heavy weather, and from different seasons. In addition to the observed weather data, we include in our evaluation weather forecasts and weather effects on both airports and the en route environment.

Our detailed NAS-wide simulations include flight rerouting and delays (and long delays can be interpreted as cancellations). For simulating the impact of inclement weather at airports, the airport capacity model translates meteorological phenomena into IMC and VMC capacities and other reduced capacity factors (such as the impact of surface winds). For the en route environment, the observed reflectivity data are translated into reduced airspace capacity. And for both the airports and airspace, meteorological forecasts of these phenomena are used to model forecasted capacities. The detailed NAS-wide simulations use both the weather and traffic forecasts, as well as the observed data, to drive the decision making and evaluate the performance

D. Baseline and Future Demand

For the HD Case Study, baseline and future demand data was provided by the FAA ATO-P office. The inputs necessary to the NAS-wide simulators include a flight schedule containing information such as flight origin and destination, flight routing, aircraft type, (desired) flight altitudes and desired times of departure and arrival. The "baseline seed day" is a day of actual NAS activity, chosen as "representative" and is used to develop the input data sets. Once the baseline day is selected, flight plans for the traffic that flew on that day are obtained from the FAA's Enhanced Traffic Management System (ETMS) archive. This database captures all messages from the real-time ETMS system, which includes a record for each flight plan filed for every IFR flight. Because the ETMS archive only contains records for IFR traffic the ATO-P office developed a method of estimating VFR traffic counts based on OPSNET data. The ATO-P baseline demand set includes actual traffic data for IFR flights as well as estimated traffic data for VFR flights. It should be noted that the IFR traffic in the baseline demand set is represented as flights (O/D pairs), while the VFR traffic data is represented as a discrete set of arrival and departure operations (not flights).

Developing demand levels for future years involves "scaling up" the daily NAS traffic levels that occurred during the baseline seed day. The seed day traffic level is scaled up according to the rates of system activity growth forecast by the FAA in its Terminal Area Forecast (TAF) document, which is updated and published annually. The TAF forecasts are based on past airport activity levels and on socio-economic and institutional factors, especially for the larger airport forecasts. It is important to note that when scaling up current traffic levels to represent future demand, the traffic is grown heterogeneously across the NAS based on TAF growth projections for individual airports. The FAA ATO-P office uses a demand generation tool that employs widely-accepted numerical techniques such as the Fratar algorithm to generate future or projected demand data based on the historic or baseline seed day data.

The FAA ATO-P office provided demand data for the baseline seed day of July 13, 2006 as well as projected demand data for the years 2014, 2018, 2025, 2040, and 2086 (intended to represent approximately 3X the current level of operations). Table 1 includes a summary of the baseline and future demand data used in the HD Case Study.

Table 1. Summary of Demand Set Data for the HD Case Study

Year	IFR Commercial Flights	IFR General Aviation Flights	VFR General Aviation Flights	Total Flights
2006	40,792	12,798	25,352	78,942
2014	49,249	14,297	30,075	93,621
2018	53,862	14,971	31,697	100,530
2025	62,781	16,427	35,170	114,378
2040	83,151	19,612	42,539	145,302
2086	145,791	28,937	65,292	240,020

V. Assessment of NextGen Fix and Bypass Alternatives

Due to time and resource constraints, the alternatives evaluated in the HD Case Study were limited to the Fix (or NextGen) alternative, and the Bypass alternative. The Fix alternative attempts to change the NAS so that the congestion and delay problems around the high density airports are, in fact, "fixed" (as the name implies). This alternative is the more comprehensive of the two studied, in that it incorporates all of the OIs that pertain to a high

density airport. This option applies OIs, associated infrastructure, and required policies to meet the NextGen forecast demand characteristics.

The Bypass alternative seeks to balance demand to capacity by using policy based incentives and regulatory measures to shift demand to regional, underutilized facilities.. For the HD Case Study, we assume that the Bypass Alternative makes use of existing runways at secondary airports – shifting demand to regional airports surrounding the OEP airports. The Bypass Alternative does not depend on NextGen technologies in order to enable the utilization of existing runways at regional airports surrounding the OEP airports. We therefore don't associate any NextGen Operational Improvements with the Bypass Alternative.

We evaluate the performance of the NextGen (Fix) alternative and the Bypass alternative for projected levels of future demand, and we compare this with the performance of the Baseline NAS for the same projected levels of future demand.The Baseline case represents the capacity of the current NAS and assumes no future increases in NAS capacity.

For the sake of brevity we focus on describing the results related to the evaluation and comparison of NextGen and Baseline performance in terms of projected NAS throughput and NAS-wide delays in all weather conditions.

A. Fix Alternative – Projected Throughput

As described earlier, our primary metric of interest is the number of flights that the NAS could accommodate while conforming to our rules for airport demand/capacity ratio and airspace capacity; we call this "projected throughput". Table 2 shows the number of flights per day that are projected to be accommodated by the NAS.

Table 2. Summary of Projected Daily Throughput – Fix Alternative

Scenario	Projected Throughput (Daily Flights)
2014 Baseline	88,878
2014 Fix	91,428
2025 Baseline	102,245
2025 Fix	110,297

The results show that in 2014, the NextGen Fix alternative enables the NAS to accommodate an additional ~2500 flights per day compared with the baseline case. In 2025, the NextGen Fix alternative enables an additional ~8000 flights per day to operate in the NAS. This represents a significant increase in the future capacity of the NAS beyond currently planned improvements.

The purpose of NextGen is to enable system capacity to grow, allowing the NAS to accommodate the growing demand that will accompany a growing economy, and to avoid supply and demand pressures that could constrain system growth, or at least to reduce their effect. Thus, while our primary metric is the projected throughput, as reported above, it is also useful and illustrative to show the results in terms of the percentage of demand growth accommodated (Table 3).

Table 3. Summary of Percentage of Demand Growth Accommodated

Scenario	% Demand Growth Accommodated, NAS-wide	% Demand Growth Accommodated, OEP 35 Airports
2014 Baseline	68 %	40 %
2014 Fix	85 %	73 %
2025 Baseline	66 %	40 %
2025 Fix	89 %	82 %

We see that the NextGen Fix alternative allows a much greater amount of system growth to be accommodated and that the difference between the NextGen Fix alternative and the baseline is even more dramatic when looking only at the OEP 35 airports where congestion is more of a problem. In both 2014 and 2025, while the baseline fails to accommodate over half of the projected growth in demand, the NextGen Fix alternative is able to accommodate almost three-quarters of the projected growth in demand in 2014 and over 80% in 2025.

B. Fix Alternative – Delays

NextGen benefits analysis for weather focused on three actual days to evaluate the impact on NAS operations – Good Weather Day (VMC, VFR), Bad Weather Day 1 (IMC, IFR), and Bad Weather Day 2 (IMC, IFR). These days were evaluated for the Baseline scenario as well as in the NextGen Fix scenario. An "all-VMC" day was analyzed as a reference day, showing how NextGen will perform when weather is absent. Two days with significant weather in the Northeast and Midwest were also analyzed. The first day is based upon the actual weather that occurred on November 12, 2006. On that day, there was significant convective activity in the northeast, especially in the New York TRACON area. The second day is based upon the actual weather that occurred on November 17, 2006, during which there was convective weather in the Midwest and the upper northeast (Boston through Maine). These dates were used because the data was readily available and configured based on previous studies

We use the ProbTFM tool to evaluate the performance of the NexGen Fix alternative compared with the performance of the Baseline NAS. Bad weather affects both the airports and en route airspace, and we model the impacts on both airport and airspace capacities. For simulating the impact on airport capacities, the ProbTFM airport capacity model produces IFR and VFR capacities by assessing how weather impacts operations at each airport and determines which airport would operate in IMC vs. VMC conditions. For simulating bad weather en route, ProbTFM model computes more efficient bad weather re-routes.

Figure 4 summarizes the results of the Wx analysis for the NextGen Fix alternative. We see that for both the 2014 and 2025 future demand scenarios, NextGen outperforms the NAS baseline in both good weather and bad weather. It should be noted that for each future demand year, we are actually testing the performance of the NextGen capabilities using a higher level of demand than that used in the Baseline scenario for each year. Specifically, referring to the projected throughput results provided earlier, in the 2014 demand year the NextGen scenario is run with approximately 3,000 more flights than the baseline. And in the 2025 demand year, the NextGen scenario is run with approximately 8,000 more flights than the baseline scenario.

Results for the 2014 demand year show that in the Baseline scenario, the average NAS-wide delay increases in the two bad weather days when compared with the good weather day. We also see that for the NextGen Fix scenario, the average NAS-wide delay decreases substantially when compared with the Baseline Scenario. In fact, the results show that for each of the three sample weather days, the NextGen capabilities modeled are able to reduce the average NAS-wide flight delay by approximately 65% when compared with the Baseline scenario. In addition, the NextGen results show less variability or sensitivity to the impacts of weather on the NAS. This could provide for enhanced schedule reliability in future operations under NextGen.

We see similar results for the 2025 demand year. Again, the NextGen capabilities represented in the Fix scenario far outperform the Baseline scenario. Even with 8,000 more daily flights accommodated, the NextGen scenario shows an almost 90% reduction in average NAS-wide delays when compared with the Baseline scenario. And, as in

the 2014 demand year, the NextGen results show reduced variability or sensitivity to the impacts of weather on NAS performance. One expected benefit of NextGen weather capabilities is to be able to maintain the good-weather performance of the NAS in bad weather.

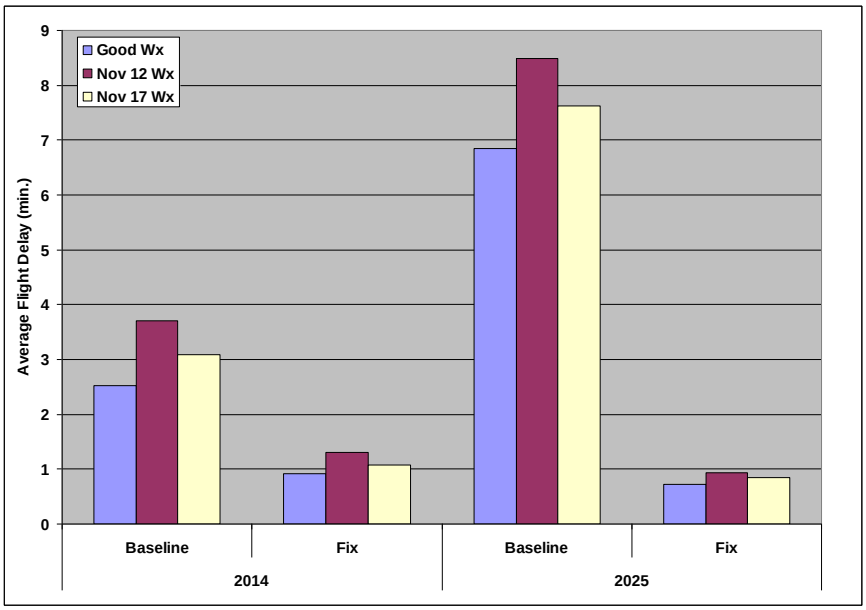

Figure 4. Summary of Delay Analysis for 2014 and 2025 Fix Alternative

C. Bypass Alternative – Scenario Construction

As previously mentioned, we assume that the Bypass Alternative makes use of existing runways at secondary airports – shifting demand to regional airports surrounding the OEP airports. We also assume that the Bypass Alternative is not dependent on NextGen technologies in order to enable the utilization of existing runways at the regional airports. As a result there are no HD Operational Improvements that are abstracted in order to represent the Bypass alternative. Instead, the Bypass alternative is modeled by altering the characteristics of the input demand data sets to redistribute a portion of the scheduled traffic from OEP airports to a specified set of regional airports surrounding the OEP airports. In this manner the Byass alternative represents an analysis of NAS demand and capacity where existing NAS capacity is more effectively utilized by shifting a portion of the demand away from the OEP airports to arguably underutilized regional airport surrounding the busy hub airports.

The set of candidate regional airports is constructed based on several selection criteria including an airport's geographical proximity to an OEP CONUS airport, minimum runway length, and a history of commercial service. We define a "catchment area" of 70 nautical miles around each of the 34 OEP CONUS airports intended to capture candidate airports that could serve as alternative destinations to the original OEP airport airports (the 70 nm criterion has been used in previous metro-area analyses by the FAA). Each candidate airport must have at least one paved runway with a minimum runway length of 6, 000 ft in order to accommodate the kinds of smaller, jet aircraft currently used by carriers (Regional Jets). Finally, requiring that a candidate airport have a prior history of commercial service limits the set of candidate airports to those that have previously overcome some of the common hurdles associated with the initiation of commercial service such as startup costs and community acceptance. Based on these airport selection criteria we construct a list of candidate bypass airports for each of the 34 OEP CONUS airports. Table 4 summarizes the candidate airports identified. Note that no candidate airports meet the selection criteria for PDX, and SAN. Note also that OEP airports are not considered as candidate reliever airports for one another (the inclusion of DCA was an oversight – but the results were kept intact).

Table 4. Table of OEP Airports and Associated Bypass Airports

OEP Airport	Bypass 1	Bypass 2	Bypass 3	Bypass 4	Bypass 5	Bypass 6
ATL	MCN					
BOS	ORH	BED	PVD	PSM	CEF	MHT
BWI	MDT	ILG	DCA			
CLE	MFD	YNG	CAK	BKL		
CLT	GSP	INT				
CVG	DAY	LEX	ILN	LUK		
DEN	COS	FNL	AKO			
DFW	FTW	ADS	DAL	AFW		
DTW	FNT	YIP	TOL	LAN	PTK	
EWR	SWF	ISP	HPN	FRG	ABE	TTN
FLL	PBI	OPF				
IAD	CHO	DCA				
IAH	EFD	CLL	BPT			
JFK	SWF	ISP	HPN	FRG	TTN	
LAS	HND	IFP				
LAX	LGB	MHV	ONT	VCV	BUR	
LGA	SWF	ISP	HPN	FRG	TTN	
MCO	DAB	SFB	LAL	MLB		
MDW	RFD	MKE	SBN	GYY	DPA	
MEM	NQA	MKL	UTA			
MIA	PBI	OPF				
MSP	STC	RST				
ORD	JVL	RFD	MKE	GYY	DPA	
PHL	ILG	RDG	ABE	ACY	TTN	
PHX	GYR	IWA				
PIT	LBE	CAK	YNG	AGC		
SEA	BFI	PAE				
SFO	MRY	OAK	SJC	SCK		
SLC	OGD					
STL	SUS	ALN	BLV			
TPA	LAL	SRQ	PIE			

The airport selection criteria are intended to provide an operationally plausible basis for the analytical approach taken in modeling the shifting of flights to regional airports. However, the analysis is not intended to evaluate the operational feasibility of the shifting of flights.

In addition to specifying a set of candidate regional airports, we develop a set of criteria to determine which flights can be shifted from the OEP airports to the candidate regional airports. In practice the shifting of flights to regional airports would be based on a number of complex economic, operational, and policy considerations. For the HD case study, we make a number of simplifying assumptions and the primary consideration is to maintain reasonable demand-capacity ratios at the OEP airports by shifting high-frequency flights to the regional airports with available capacity. The flights to the OEP hub airports that are shifted to surrounding regional airports are first 'broken up' into multiple flights using smaller aircraft. This is done in recognition of the differing runway capabilities that exist at the regional airports. Many of the regional airports have shorter runways that the major hub airports and cannot accommodate some of the large aircraft that operators typically use at the major hubs. We therefore substitute multiple flights using an aircraft type with operating characteristics appropriate for the regional airport to which a flight has been shifted. As a result of this flight substitution, the number of flights in a given future demand year will be higher in the Bypass alternative than in the other alternatives which are based solely on TAF growth rates.

While we do not have the capability to model the complex economic, operational, and policy considerations that would drive the shifting of flights to regional airports, we do attempt to capture the net effect of some of these considerations by defining two distinct scenarios for analysis within the Bypass alternative: a "Market" scenario and a "Regulatory" scenario. The Market scenario is intended to represent an alternative distribution of demand assuming that the carriers actively seek to shift flights to regional airports. The Regulatory scenario is intended to represent an alternative distribution of demand in which the government compels carriers to shift a portion of their flights from the OEP hubs to regional airports. For the Market scenario we assume that the carriers would tend to shift smaller aircraft servicing shorter flight lengths to regional airports. For the Regulatory scenario we assume that the carriers would be compelled to shift flights with longer stage lengths and larger aircraft to regional airports. We

then use flight length and aircraft size as a proxy for the "value" of a flight with the carriers attempting to preserve their high-value flights at the OEP airports in the Market scenario, but being forced to shift a greater number of high-value flights under the Regulatory scenario. In our modeling, the two scenarios are differentiated by the rules used that determine which flights are candidates for shifting, and what size/aircraft type is used when flight substitution is required. Following is a summary of the rules used for flight shifting and substitution in both the Market and Regulatory scenarios:

Market Scenario

- Flights with a great circle distance less than 750 nm are considered for shifting.
- If a flight has a seat capacity of 60 or less, shift the flight as-is to the regional airport.
- If a flight has a seat capacity of 61 or more, change the aircraft type to a Regional Jet with a seat capacity of 60, and add extra flights to capture at least the number of seats in the original flight.

Regulatory Scenario

- Flights with a great circle distance less than 1500 nm are considered for shifting.
- If a flight has a seat capacity of 99 or less, shift the flight as-is to the regional airport.
- If a flight has a seat capacity of 100 or more, change the aircraft type to a Regional Jet with a seat capacity of 100, and add extra flights to capture at least the number of seats in the original flight.

Using the previously described rules for flight shifting and flight substitution, we use a software demand generation application to create demand data sets representing the resulting distribution of traffic for both the Market and Regulatory scenarios for the years 2014 and 2025. Each Bypass scenario demand set is based on the 2014 and 2025 baseline demand set data provided by the FAA-ATO-P office. Table 5 summarizes the resulting number of total flights, IFR flights, and VFR flights in each of the demand data sets for the Bypass alternative. Note that for any given demand year, the number of flights in the Bypass scenarios increases over that in the baseline demand set because of the flight substitution rules. In addition, note that the number of VFR flights remains unchanged between the baseline and the alternative demand sets. This is because we assume that only IFR or scheduled traffic would be shifted from the OEP airports to the regional airports. More flights are generated in the market scenario because of the smaller average aircraft size limit used in shifting traffic.

Table 5. Summary of Bypass Demand Scenario Flight Counts

Demand Scenario	Total Flights	IFR Flights	VFR Flights
2006 Baseline	78,470	53,590	24,880
2014 Baseline	93,081	63,547	29,534
2014 Bypass-Regulatory	95,096	65,562	29,534
2014 Bypass-Market	96,426	66,892	29,534
2025 Baseline	113,815	79,210	34,605
2025 Bypass-Regulatory	118,257	83,652	34,605
2025 Bypass-Market	120,519	85,914	34,605

D. Bypass Alternative – Projected Throughput

Our primary metric for project throughput is measured in number of flights. For the Bypass alternative, however, this unit of measure may be misleading because the alternative itself creates additional flights in order to spread the demand from congested hub airports to proximate airports with available capacity. Therefore, we instead report the projected throughput in terms of available passenger seats because the number of seats is preserved when the Bypass demand scenarios are generated. The benefit of the Bypass alternative, then, is measured by how many seats are made available when the flights are added/shifted, as compared to the Baseline, and also the same data expressed as the amount of demand growth accommodated. Table 6 contains the results and includes the Fix alternative results expressed using number of seats (rather than number of flights) to allow comparison across the alternatives as well as relative to the Baseline scenario.

Table 6. Summary of Projected Throughput and % of Demand Growth Across Alternatives

Scenario	Projected Throughput (daily seats)	% Seat Demand Growth Accommodated, NAS-wide
2014 Baseline	4,426,602	73 %
2014 Fix	4,606,300	89 %
2014 Bypass Market	4,551,226	85 %
2014 Bypass Regulatory	4,573,806	87 %
2025 Baseline	5,409,299	66 %
2025 Fix	6,074,700	91 %
2025 Bypass Market	5,649,272	77 %
2025 Bypass Regulatory	5,727,221	80 %

We see that the Bypass scenario, in both the Market and Regulatory versions, allows over 100,000 additional daily seats to be accommodated in 2014 and over 200,000 additional daily seats in 2025. In terms of demand growth accommodated, the Bypass alternative accommodates more than 10% additional demand growth which is a significant economic benefit. The Bypass alternative does not perform quite as well as the Fix alternative which is expected given that the Fix alternative enjoys the benefit of the NextGen operational improvements. While more flights shift in the market scenario than the regulatory one, more seats shift in the regulatory scenario because the aircraft shifted are larger.

E. Bypass Alternative – Delays

In addition to modeling the good weather performance of the Bypass alternative, we also model the performance of the Bypass alternative for the same two weather days that were used in the analysis of the Fix Alternative: November 12 and November 17. Figure 5 summarizes the performance for both the Bypass Regulatory and Bypass Market Scenarios compared with the Baseline Scenario for the 2014 and 2025 demand years. Results show that in both future demand years (2014 and 2025) the Bypass alternative scenarios do not outperform the future Baseline system performance in terms of average NAS-wide delays per aircraft. For each of the Weather days and Bypass Scenarios analyzed, the Baseline system had lower average NAS-wide delays per aircraft than either the Bypass-Regulatory, or Bypass-Market scenarios.

While the feasible throughput metric computed in the previous sections shows improvement in the Bypass scenarios when compared with Baseline performance, the delay metric actually shows a performance degradation (increased delays) for the Bypass scenarios. This is attributable to the NAS-wide models showing increased congestion in the airspace surrounding the OEP airports from which flights are shifted in the Bypass scenarios. It is important to note that for the Bypass scenarios, no terminal area airspace redesign is performed as part of the analysis. In addition we make a number of simplifying assumptions regarding how/when flights can be shifted from the OEP airports to surrounding airports. In this sense, the Bypass Alternative can be considered an evaluation of an alternative distribution of demand compared with the current distribution of demand represented by and large by hub-and-spoke type operations. Given these limitations, it is not possible to draw definitive conclusions regarding the operational feasibility or performance of the Bypass scenarios in terms of increasing NAS-wide throughput while maintaining or reducing delays. However, we can assert with confidence that the efficacy of an alternative solution such as a Bypass scenario would be strongly dependent on factors such as successful redesign of airspace and procedures to accommodate additional traffic within a metroplex or metropolitan region without increasing airspace congestion.

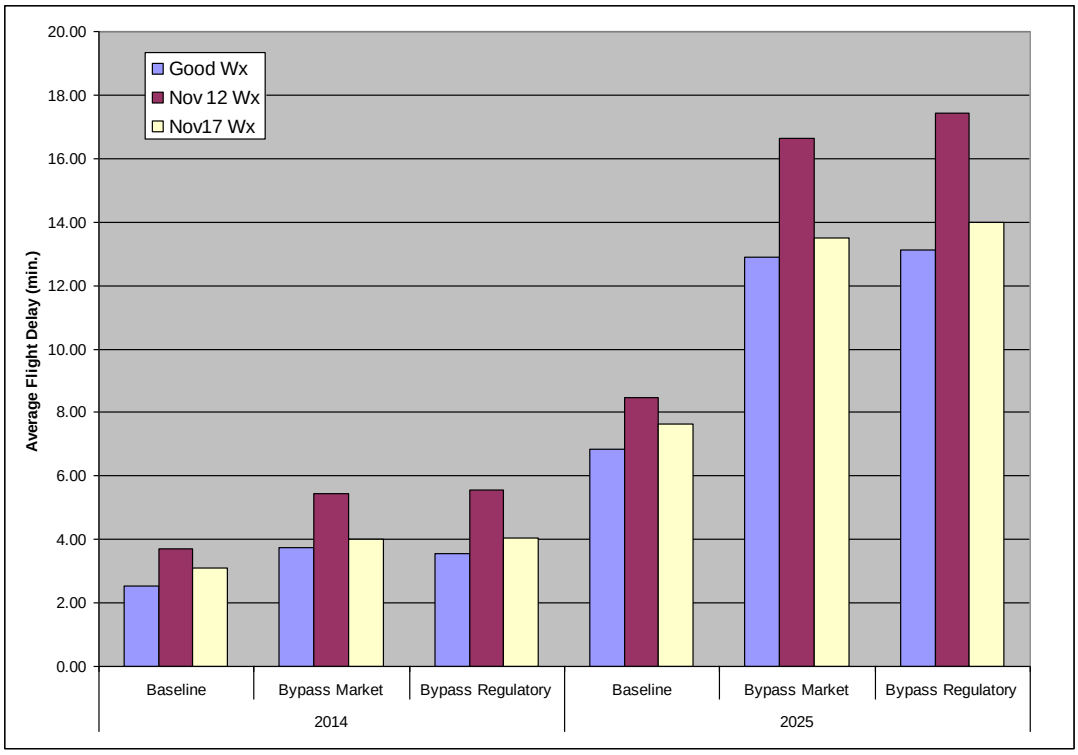

Figure 5. Summary of Delay Analysis for 2014 and 2025 Bypass Alternative Scenarios

VI. Summary Assessment of NextGen Performance Benefits

In addition to estimating the performance benefits related to NAS capacity in good weather, and the performance of each alternative as measured by average flight delays in poor weather, we also estimated the environmental performance of the NextGen alternatives, as well as the potential impact of policy decisions on system performance. As previously mentioned, a major goal of the modeling activity is to support the JPDO business case that will include estimates of benefits and costs of NextGen alternatives. The environmental impacts and policy impacts will be key drivers in estimating both the costs and benefits of NextGen. Following is summary of the performance benefits of the Fix and Bypass alternatives (relative to the performance of the Baseline or current NAS) for demand levels projected for the year 2025 including the evaluation of environmental impacts and policy impacts.

- Increased system-wide throughput
  - The NextGen Fix alternative accommodates 91% of the growth in demand for seats in 2025.
  - The Bypass alternative accommodates up to 80% of the growth in demand for seats in 2025.
  - The Baseline NAS accommodates only 66% of the growth in demand for seats in 2025.
- Reduced delay
  - The NextGen Fix alternative reduces average delay by almost 90% compared to the Baseline NAS.
  - The Bypass alternative actually increases average delay by up to 105% compared with the Baseline NAS.
- Greater fuel efficiency
  - The NextGen Fix alternative which includes CDA, less delay, more optimal routings, and vehicle improvements all of which contribute to a greater than 10% improvement in fuel efficiency when compared to the Baseline NAS. Although improved, the fuel efficiency target of 1% per year was not achieved.
  - The Bypass alternative improved fuel efficiency by 6% when compared to the Baseline NAS.
- Reduced Noise
  - The NextGen Fix Scenario exposes 60% fewer people to >65 dB DNL when compared to the Baseline NAS despite 40% traffic growth. The introduction of new aircraft technologies achieved the original noise goal of 1% reduction per year, however the current goal of 4% reduction was not met.
  - The ByPass alternative reduced the number of people exposed to >65 dB DNL at the OEP airports but the area exposed to >65 dB DNL at reliever airports grew by over 20%.

- Policy Impacts
  - Conservative estimates based on historical performance show that policy impacts could postpone realization of up to 40% of NextGen's benefits beyond 2025.

VII. Conclusions and Recommendations

A number of conclusions can be drawn from the High Density Case study both in terms of the interpretation of the analytical results, and in terms of lessons-learned based on the overall process/approach applied.

- Systems modeling of well defined Operational Improvements in the NextGen Enterprise Architecture consistently predict significant improvements over the current operations capabilities.
- Policy dynamics have potentially very large system effects that could significantly alter expected return-on-investments because of delays to initial operational capability dates. Additional validation of these early results is underway.
- Assessing performance of the NextGen technologies still faces several modeling challenges:
  - Current system productivity points/characteristics and inefficiency profiles
  - Safety & Security Risk Exposure
  - Collaboration behaviors, marketing strategies and business rules of the airlines & other NextGen stakeholders
  - Complex Airport Terminal & Airport Surface Operations
  - Policy Dynamics
  - System-Wide Information Effects
- The JPDO NextGen Enterprise Architecture still needs additional details to enable full performance modeling as well as costing analysis.

Based on the HD Case Study the JPDO divisions have exercised an integrated workflow between the divisions and the FAA partners which will enable them to formalize and implement a comprehensive performance management plan that will fit the federal planning lifecycles. This plan will focus on providing performance valuations including sensitivity analysis at the Enterprise Architecture Capability levels with associated costing at the system component levels. The case study has also helped to establish a consistent approach between the FAA and JPDO on scope, initial settings, metrics calculations, and baselining procedures. The process results of this collaboration will be extended to the other JPDO partners in order to have an integrated and coherent product.

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Name	**Organization**
Yuri Gawdiak	NASA, JPDO
Gregory Carr	Sensis Corporation
George Hunter	Sensis Corporation
Fred Wieland	Sensis Corporation
Kris Ramamoorthy	Sensis Corporation
Alex Huang	Sensis Corporation
Shahab Hasan	Logistics Management Institute
Jeremy Eckhause	Logistics Management Institute
Robert Hemm	Logistics Management Institute
Dou Long	Logistics Management Institute
Jerry Creedon	Old Dominion University
Monica Alcabin	Boeing Commercial Aircraft
Mike Graham	Metron Aviation
Terry Thompson	Metron Aviation
Stephen Augustine	Metron Aviation
John DiFelici	Metron Aviation
Tyler White	Metron Aviation
David Ballard	GRA, Inc.
Rich Golaszewski	GRA, Inc.
George Price	Crown Consulting
EJ Spear	Mitre CAASD
Debby Kirkman	Mitre CAASD
Sylvie Volel	Booz Allen Hamilton
Amit Kumar	Booz Allen Hamilton
Kevin Foley	Booz Allen Hamilton
Kent Duffy	Booz Allen Hamilton
Mike Marcolini	NASA Langley Research Center
Dan Goldner	Ventana Systems