PERFORMANCE-BASED AIR TRAFFIC MANAGEMENT:
EVALUATING OPERATIONAL ACCEPTABILITY

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Abstract

The Joint Planning and Development Office (JPDO) has released its vision and integrated plan for the Next Generation (NextGen) air traffic control system. NextGen represents a quantum leap forward in air traffic management, integrating aircraft, automation and humans into a net-centric and collaborative environment based on precise operation of aircraft and common information sharing.

The Federal Aviation Administration (FAA) needs to develop strategies and plans to evolve the present day Air Traffic Management (ATM) system into tomorrow’s NextGen system in an affordable and harmonious manner. By 2015, air traffic is expected to increase by 25-30 percent overall and more than that in certain areas of the country. [1] There is also an increased need to hire new air traffic controllers due to pending retirements that will put stress on workforce management during the next 10 years.

MITRE’s Center for Advanced Aviation System Development (CAASD) in partnership with the FAA developed an approach to address this mid-term challenge called Performance-Based Air Traffic Management (P-ATM). P-ATM is a set of capabilities and an operational concept that is firmly aligned with the NextGen vision and represents an affordable and realistic path.

Through 2006, CAASD has engaged a group of Front Line Managers from en route and terminal Air Traffic Control (ATC) facilities in evaluating the operational acceptability of the concept and in estimating its productivity benefits by analyses and Human-In-The-Loop (HITL) evaluations. This document summarizes the evaluation results and outlines the P-ATM capabilities and concepts.

Introduction

The JPDO has developed a high-level vision to communicate the key operating principles and characteristics of the NextGen. [2, 3] The goals for NextGen are aimed at significantly increasing the capacity, safety, efficiency, and security of air transportation operations and through doing so, improve the overall economic well being of the country. These benefits are achieved through a combination of new procedures and advances in the technology deployed to manage passenger, air cargo, and air traffic operations. In many cases, this vision and plan builds on work done by international aviation organizations that represent a globally harmonized set of concepts for the future. [4, 5, 6, 7]

The FAA’s strategy will evolve operations toward NextGen in a way that integrates proven technologies, can be scaled for the future, and couples advanced ground automation systems and advanced aircraft capabilities. CAASD has developed P-ATM as a mid-term step toward NextGen (around 2015), while meeting the FAAs need for capacity and productivity benefits.

Performance-Based ATM

P-ATM integrates advanced capabilities that will provide vastly improved surveillance, navigation, data communications, and automation for ground and airborne systems with changes in service provider roles and responsibilities. Key aspects of P-ATM are:

- Consistent and up-to-date information describing flights and air traffic flows are available system-wide, supporting both user and service provider operations.
- Data Communication is used between the ground and aircraft to improve the accuracy of trajectories, provide precise clearances to the flight, and exchange information without controller involvement.
- The basis for all operations is an accurate four-dimensional trajectory that is shared among all of the aviation system users.
- Area Navigation (RNAV) operations remove the requirement for routes to be defined by the location of navigational aids, enabling the flexibility of point-to-point aircraft operations.
- Required Navigation Performance (RNP) operations introduce the requirement for onboard performance monitoring and alerting. A critical characteristic of RNP operations is the ability of the aircraft navigation system to monitor its achieved navigation performance for a specific operation, and inform the air crew if the operational requirement is being met. This
onboard monitoring and alerting capability enhances pilot situational awareness.

- En route controllers rely on automation to identify conflicts and propose resolutions allowing them to focus on providing improved services to the users.
- The ability of cockpit automation to fly the aircraft more precisely and predictably reduces routine tasks of controllers.
- Performance-based services that require minimum flight performance levels are provided in designated airspace.
- Flow management automation will use probabilistic decision-making to propose incremental congestion resolutions that will maintain congestion risk at an acceptable level, using flight-specific alternative intent options to the extent possible. [8]
- Time-based metering that coordinates arrival flows for high traffic airports.

**P-ATM Evaluations**

During 2006, evaluations were conducted to assess the operational feasibility, acceptability, and benefits of P-ATM in the en route and terminal domains. The HI TL evaluations provided the opportunity to identify new components in the concept, as well as to identify areas that need further refinement. A secondary objective of the HITLs was to estimate the productivity improvements that can be realized with P-ATM operations. Through the collection of quantitative and qualitative data, the evaluations sought to determine the degree to which the improved automation capabilities and operational changes affect: the time required for controllers to perform certain tasks (e.g., resolving a potential conflict), the frequency of tasks, perceived controller workload, and ultimately, sector capacity (i.e., the maximum number of aircraft the controller can manage in a safe and sustainable manner during a specified time interval).

**En route HITL Evaluations**

The en route HITL evaluations were conducted using high fidelity prototypes of operations for today’s en route automation (the baseline) and P-ATM in the 2015 timeframe. They were conducted in a controlled manner that enabled the direct comparison of results between the baseline automation and P-ATM operations.

Today’s baseline automation consists of an emulation of the Host and User Request Evaluation Tool (URET) functionality displayed on a Display System 20x20 inch display and a 20 inch diagonal plat panel. All of the primary Computer-Human Interface (CHI) capabilities were provided so that the Front Line Managers could use their expertise in handling traffic to the same level as in the fielded en route system. Figure 1 shows the typical setup for the en route HITLs.

For P-ATM operations, mixed levels of aircraft performance and air crew authorizations are expected. High-performance aircraft will be capable of flying RNAV routes, accurately conforming to their route of flight, supporting data communications, communicating requests and aircraft state and intent information electronically with the ATC automation, and receiving clearances and other messages electronically from the ATC automation.

It is anticipated that some en route airspace, referred to as High-Performance Airspace, will be designated for high-performance aircraft only, allowing the ATC system to engage operations that fully leverage the capabilities of those aircraft. [9] In High-Performance Airspace, aircraft will communicate state and intent information to the ATC automation and closely follow their intended routes of flight. As a result, the automated problem prediction and resolution capabilities will be able to maximize user benefits by supporting user-preferred flight plans, minimizing changes to those plans as aircraft traverse the National Airspace System (NAS), and improving services provided (such as providing automated clearances for some situations).

The controller’s primary responsibilities will be to respond to problems predicted by the ATC automation, and to maintain accurate flight information in the ATC automation. Predicted problems will include

- Aircraft to aircraft conflicts
- Aircraft to special use or other types of restricted airspaces
- Aircraft to severe weather forecast areas
• Aircraft to metering constraint problems including Miles-in-Trail restrictions.

The aircraft’s capability to accurately fly its cleared route of flight, coupled with the state and intent information sent from the aircraft to the ATC automation, will increase the accuracy of trajectory modeling and problem prediction. The controller will not be required to monitor the sector airspace display to predict potential problems; rather the automation will be responsible for predicting all problems and providing operationally acceptable resolutions.

The P-ATM automation supporting the HITLs contained capabilities that simulated a possible future environment. The problem detection capability of the URET [10] was augmented with problem resolution automation from Problem Analysis, Resolution, and Ranking (PARR) [11]. PARR calculates a set of possible operationally acceptable resolutions then ranks those resolutions to find a Highest Ranked Resolution (HRR). The HRR is presented to the position that controls the aircraft to be moved in the HRR. Controller actions in sectors that are not the evaluation sector are emulated so that the HRR is accepted. RNAV capabilities were simulated by reducing the buffers used for conflict detection in the lateral direction presuming an RNP-1 capability for all aircraft. Data communication was assumed for all flights so that very little voice communication was required to deliver clearances and change radio frequencies between sectors. The transfer of control was done automatically between sectors so that there was no controller actions required.

The CHI was consolidated onto the 20x20” display. An Action List was created that contained entries whenever the controller was required to take an action to resolve a conflict or approve a pilot request. The Situation Display data blocks were reduced to just the callsign since the controller was not required to project the flight path of all flights to detect conflicts. Flight data, resolution information, and trail planning data were available to the controller on request.

Several types of data were collected both during and after the simulation runs. Subjective measures included workload and operational acceptability ratings. Debriefing sessions allowed an open flow of impressions and ideas. The Air Traffic Workload Input Technique (ATWIT) is a workload rating scale designed for use in air traffic control studies. [12] With this technique, controllers rate their workload, while controlling traffic, on a scale from 1 (low workload) to 7 (very high workload). For this experiment, the ATWIT was administered approximately every five minutes using a touch-screen window displaying the scale accompanied by an audible prompt for controller input.

The National Aeronautics and Space Administration Task Load Index (TLX) is a widely-used, general-purpose workload rating scale consisting of multiple subscales. [13] With the TLX, participants provide a rating from 1 to 10 for each subscale, with 10 being the highest possible rating. The ratings are then averaged to provide a composite workload rating. Following each operational trial, participants rated the workload of the entire run using the TLX. In summary, the TLX ratings provide an estimate of the average workload for the entire trial, whereas the ATWIT ratings provide estimates of workload levels as they changed throughout the trial.

Operational environment acceptability was assessed after each trial with the Controller Acceptance Rating Scale (CARS). [14] The CARS was developed as a measure of controller acceptance of various operational environments and has been used in the development of air traffic automation systems.

The en route HITLs focused on High Performance Airspace operations to show the potential of the concept. Two different en route sectors were selected for inclusion in the evaluation. These two sectors have varying levels of complexity, operations, and traffic flow patterns.

• Indianapolis ARTCC Sector 75 (defined as FL310 to FL350) is a high altitude sector with predominantly proximity and transition complexity. The conflicts within this airspace are diverse and often involve Chicago departures.
• Washington ARTCC Sector 72 (defined as FL340 and above) is a high altitude sector that handles predominantly southwest bound traffic. It is characterized by very high transition activity, with departures from Washington airports climbing into departures from New York airports. The merging of these transitioning aircraft creates a fair amount of complexity.

Scenarios were built to represent traffic levels expected in 2015, about a 25-30 percent increase over today’s traffic. [1] Traffic for a busy day in the NAS was used as a starting point with additional flights added. The scenarios did not include severe weather or traffic flow initiatives, nor were there exceptions or failures of equipment either in the ground or airborne systems. The routes and constraints present in the current system were retained in order to assess how the baseline automation case compared to the P-ATM automation and procedures. Evaluations were
conducted with 12 Front Line Managers operating the baseline system and P-ATM operations thus allowing for comparisons of performance.

Figure 2 shows the composite results for the Indianapolis Sector 75 scenario, showing the average of the flights under control of the sector over the time of the simulation and the ATWIT ratings taken at the same times. The traffic increased to 14 aircraft under control of the sector in both cases. The perceived workload increased to the maximum level during the baseline case. For several of the Front Line Managers, the workload became unmanageable and they terminated the scenario before it had run to completion. During the P-ATM run, the workload remained at the lowest level and all participants completed the 45-minute scenario.

Figure 2. En Route Results for ZID 75 Sector

The FAA Front Line Managers noted that their workload was reduced dramatically under P-ATM operations. They consistently rated their workload as very high in the simulation of today’s baseline automation environment and as very low in the simulation of P-ATM. While this was primarily due to the introduction of data link and automated problem prediction and resolution capabilities, several other features also contributed to this reduction, including automated transfer of control and the automatic approval of problem-free pilot requests.

Expanded volume experiments were also conducted under the P-ATM concept, whereby the sector ceiling was raised and the floor lowered. While managing traffic during these scenarios, the FAA Front Line Managers were responsible for more airspace volume and an increased number of aircraft. The results of these expanded volume scenarios, as depicted in Figure 3, shows that with P-ATM the controller could handle at least double the traffic with a very low level of workload.

Figure 3. En Route Results for Expanded Sector

Results for the ZDC Sector 72, baseline vs. P-ATM scenario and an expanded sector scenario had similar results to the ZID sector scenarios.

When asked to describe their thoughts on the this concept after conducting the HITL evaluations, all the FAA Front Line Managers were unanimous in advocating the operational feasibility and acceptability and moving forward to making this concept real. All the participants agreed that they could effectively manage traffic and perform their required roles and responsibilities in the new operating environment. Furthermore, they suggested that given the expected growth in air traffic over the next ten years, the implementation of the concept and supporting automation enhancements was essential.

Terminal HITL Evaluations

HITL evaluations were conducted to assess the operational feasibility and to measure the workload impact of the P-ATM operations in terminal radar approach airspace. The HITL evaluations focused on three radar positions (Feeder approach, final approach, and departure), and was performed using terminal Front Line Managers. Workload and acceptability were assessed using three conditions:

- The baseline condition was composed of current air traffic levels and controller tools.
- A combined baseline condition was created by combining a larger area of airspace to create increased traffic levels, still using current controller tools.
- The P-ATM environment was applied to the increased traffic combined baseline condition.

The P-ATM terminal environment encompasses tower and Terminal Radar Approach Control (TRACON) operations. Mixed levels of aircraft performance and air crew authorizations are expected in future terminal environments. In low-traffic terminal areas, a range of aircraft performance will be accommodated, but it will be necessary to specify aircraft performance
requirements for access to the high-traffic terminal environments.

In high-traffic terminal areas, routes will be restructured to organize traffic into well-defined, segregated flows that provide access to primary airports, satellite airports, and overflights. These routes will accommodate a wide range of aircraft performance, optimizing vertical profiles wherever possible for both arriving and departing flights. Pre-defined routes will be developed to accommodate all expected flows and to provide flexibility to handle upset conditions, such as convective weather that prevents the use of normal routing. All of the routes in high-traffic terminal areas will require RNAV capability, and some might require RNP to ensure accurate route following (particularly in turns) and to reduce terminal controller workload.

Improved Traffic Flow Management is a key element of the future terminal environment. Arrival metering that coordinates all the arrival flows for high-traffic airports will greatly reduce the need for extensive vectoring in the TRACON. Minor adjustments to the timing of arrivals will be facilitated by controller decision support capabilities that identify the need for speed control or pre-planned maneuvers. Improvements in departure sequencing and better coordination of departures with surface and en route operations will ensure less surface congestion and smoother departures. Finally, automation enhancements to support merging and sequencing can be provided when traffic levels reach the point where controller workload in the terminal area is a limiting factor.

While all aircraft in high-traffic terminal areas must be capable of flying RNAV routes, few other capability requirements are likely. Data communications will be leveraged, as available, to deliver route clearances and information, with voice radio communications available for those aircraft that are not capable of data communications. It is expected that a large percentage of the aircraft in high-traffic terminal airspace will be capable of data communications as a result of the requirements for high performance en route airspace operations.

The evaluations were conducted in the CAASD laboratory using a medium fidelity simulation of terminal radar approach control automation. No additional automation tools were used during the terminal evaluations, although data communication and metering tools were assumed to be present. Acceptability and workload assessments used ATWIT, TLX, CARS, and debriefing sessions similar to en route evaluations.

RNAV and RNP arrival and departure routes were developed for these evaluations. These routes consist of waypoints that define the lateral path, altitudes at waypoints, and speed assignments at waypoints. RNP operations introduce the requirement for the aircraft’s navigation system to conduct on board performance monitoring and crew alerting. This onboard monitoring and alerting capability increases the pilot’s situation awareness and can enable closer route spacing without the need for controller intervention. [15] These arrival and departure routes were simulated for all flight paths in the P-ATM condition with controllers instructed to intervene as needed for efficiency and safety.

The evaluation scenarios were taken from current operations at Atlanta and Houston TRACONS. Current operations were compared with P-ATM operations to assess the acceptability and workload even when traffic levels are high and operations are complex. Several combinations of the feeder, final, and departure were simulated. The results of the Atlanta feeder/final combination are described below as representative of the results.

The areas of control responsibility for the Atlanta airport arrivals were divided between the north and south airport complexes. For each arrival runway operating in a busy period, two Radar Controller positions are required; a feeder and final approach. Figure 4 shows the north feeder position airspace in yellow and the final airspace in blue. In the simulation, the team evaluated whether a single controller could manage traffic in both the feeder and final airspace with P-ATM.

![Figure 4. Atlanta Feeder Final Combination](image)

Figure 5 presents the real-time workload responses of the Feeder-Final participant as the simulation progressed for each scenario test condition. Because there was a reduced traffic rate for the first 15-minutes of every simulation, workload inputs were generally low for the time period. Traffic began to ramp up after the initial 15-minute period. The Baseline Uncombined condition provides a reference of current workload experienced with today’s operations. The Baseline Combined condition continues to steadily increase, almost maximizing the ATWIT scale, suggesting an
unsafe workload level. Workload levels are drastically reduced with the application of P-ATM and never elicited a controller response greater than: 1. Several upset events were introduced into the scenario such as loss of RNAV and convective weather blocking the use of a primary arrival corridor. That caused a temporary increase in workload while that event was handled.

Figure 5. Feeder Final Controller Workload

When examining the number of communication transactions between baseline and P-ATM operations in the terminal domain, it is evident from the results as depicted in Figure 6, the significant impact P-ATM operations has on controller workload in terms of time on frequency. There is a reduction of regular voice transaction from over 300 in the baseline case to under 100 for the P-ATM case. Using data communication for hand-offs, reduces those transactions further.

Figure 6. Communications by Controller

Data was captured during the HITLs showing the tracks flown during the simulation for the various evaluation runs. Figure 7 shows the tracks for the Atlanta feeder baseline combined simulation and Figure 8 is the matching P-ATM run. For the baseline condition, controllers managed traffic normally, descending aircraft on the arrival route, turning aircraft to the downwind, and using speed control as required. For P-ATM, flights were assigned RNAV/RNP routes where the lateral, longitudinal, altitude and speed were defined at all waypoints. The aircraft normally complied with the route constraints. In P-ATM, controllers monitored for procedure compliance and intervened if they could provide more efficiency to the user. For the baseline, the aircraft were cleared onto the final arrival procedure and departed through the departure gate as is done today with the track dispersion shown in Figure 7. For P-ATM, the tracks were flown much more precisely with some final adjustments on turning to the final arrival procedure.

Figure 7. Track images for Baseline Combined simulation

Figure 8. Track images for P-ATM operations

Based on the concepts validated during the terminal HITL simulations of operations of Atlanta and Houston, CAASD is continuing to enhance the application of the concept to other terminal environments.
Conclusion

Through 2006, CAASD has evaluated P-ATM through analyses and HITL evaluations. Results showed that the en route and terminal concepts are feasible and provide significant benefits in service provider workload reduction. The amount of time spent on both routine and complex tasks was reduced. The amount of traffic safely and efficiently handled with the same or fewer controllers was increased. This assessment of concept feasibility and productivity gains was conducted for a subset of operational conditions.

CAASD will continue to work with FAA and other government, industry, and academic organizations to complete the assessment of P-ATM and evolve into this new set of operations. Operational concept evaluation activities will focus on understanding the viability of P-ATM with respect to the following:

- Efficiency of user operations
- Balance between automation capabilities and human responsibilities
- Safety considerations under normal and degraded operating conditions.
- Transition issues

CAASD will continue to evaluate the critical capabilities that will enable these operational shifts, and perform detailed analyses to further the definition of P-ATM, with the objective of informing the FAA’s planning for NextGen, as well as operational and system evolution.

References


Joe Celio joined The MITRE Corporation in 1978 working with the FAA on the modernization of Air Traffic Control systems. He has worked on several programs including the Advanced En Route ATC project and the User Request Evaluation Tool that performed research into new tools that would provide conflict detection and resolution information to en route controllers. Since 1995, he has managed different aspects of the en route
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Elly Smith joined MITRE in 2004 and has worked on Area Navigation implementation and user and controller benefits analysis as well as the development and evaluation of the terminal Performance-based Air Traffic Management operational concept. Her educational background is in aerospace engineering and human factors engineering. She previously worked for Boeing Commercial Airplane Division and Continental airlines before joining MITRE.