Paradigm Changes Related to TSAS Viewed Through the Perspective of the FAA/NASA Operational Integration Assessment

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Introduction

In May 2015, NASA and the FAA conducted the Operational Integration Assessment (OIA) at the FAA's William J. Hughes Technical Center (referred to here as the Tech Center). The OIA was an operational assessment of a NASA-developed prototype technology, Terminal Sequencing and Spacing (TSAS, formerly known as TSS), planned for operational deployment in April 2019. The main objective was to identify risks that need to be addressed prior to transitioning TSAS from the laboratory to the National Airspace System (NAS). Key to the OIA was integrating TSAS with recently deployed Next Generation Air Transportation System (NextGen) technologies that the FAA expects TSAS to interoperate with when it becomes operational, such as the En Route Automation Modernization (ERAM) platform and newer Time Based Flow Management (TBFM) capabilities such as Extended Metering and Ground-based Interval Management for Spacing (GIM-S). The National Air Traffic Controllers Association (NATCA) controllers and traffic management coordinators (TMCs) from several Air Route Traffic Control Centers (en route) and Terminal Radar Approach Control (terminal) facilities participated in the OIA, and are critical to identifying risks when transitioning TSAS to an operational system. We discuss the OIA, including expected paradigm changes necessary to realize the full benefits of TSAS. Two of the paradigm changes are operational and one relates to testing and evaluation.

We start by briefly discussing the impetus for TSAS, followed by its main background components. Next, we discuss the motivation for the OIA, its objective, and key attributes. We then proceed with a section discussing three important and expected paradigm shifts related to TSAS. We end by briefly discussing some representative observations and feedback from the OIA related to the paradigm shifts.

Motivation

Performance Based Navigation (PBN) is a key capability of the NextGen [1]. Airlines investing in avionics upgrades to leverage PBN routes and procedures expect to save fuel by flying required area navigation (RNAV) optimized profile descents (OPDs). For aircraft equipped with advanced avionics, required navigation performance (RNP) approach procedures enable more efficient approaches relative to standard instrument landing approaches. RNAV OPD arrival routes at airports with established RNP approaches offer efficient, predictable and precise routing that reduce the workload of controllers and pilots. Unfortunately, not all aircraft are equipped with the same avionics capabilities even for aircraft within the same weight class. Controllers vector aircraft to sequence and maintain the required separation. Vectoring degrades PBN conformance by interrupting the OPD and/or the established RNP approach procedure. Degraded PBN conformance results in additional fuel burn, emissions, and controller and pilot workload. Increasing arrival demand exacerbates the issue, creating more opportunities for inefficient, albeit safe, operations in the terminal area. Figure 1 illustrates the degraded PBN conformance by showing the ground tracks of dozens of aircraft from an Air Traffic Management Technology Demonstration #1 (ATD-1) human-in-the-loop simulation in which the controllers did not use TSAS [2,3]. Instead, they used conventional techniques to sequence and maintain safe separation, resulting in vectoring and extended downwinds.

Background

In an effort to improve terminal area operations, NASA partnered with the FAA and industry partners to develop an enabling technology called TSAS that can increase PBN conformance and reduce controller workload without reducing runway throughput [3]. TSAS is a ground-based automation system developed under NASA's ATD-1 subproject, and the technology was transferred to the FAA with deployment to the first site planned for April 2019. Figure 2 shows the ground tracks of aircraft captured from the same past ATD-1 simulation shown in Figure 1. Conditions were exactly the same as those in Figure 1, except that the terminal controllers used TSAS information to assist them in merging mixed equipage multiple streams of aircraft in a complex airspace environment, resulting in less vectoring and increased PBN conformance. TSAS generated an arrival sequence that minimized inter-arrival spacing at the runway threshold that resulted in maintaining, and often times, increased runway throughput.

TSAS expands two FAA platforms: TBFM, and the Standard Terminal Automation Replacement System (STARS). TBFM is a scheduling tool that is the evolution of the Traffic Management Advisor (TMA) system developed by NASA in the early 1990s [4]. TBFM enables the use of time based metering, allowing airlines to execute fuel-efficient RNAV OPDs. Aircraft that have been metered to absorb all or nearly all of their TBFM assigned delay prior to entering the RNAV OPD arrival phase of the flight are more likely to have an uninterrupted descent. Newer TBFM releases contain functionality to enable metering of aircraft up to several hundred miles away from the arrival airport with the use of Extended Metering and GIM-S [5]. GIM-S is a speed advisory displayed to en route controllers on adapted ERAM systems. Extended Metering and GIM-S are recent NextGen capabilities in their early deployment stages, and are expected to increase the opportunities to fly OPDs, reduce vectoring, and increase delivery accuracy to metering constraint satisfaction points.

TBFM release 4.2.3, a recent release containing Extended Metering and GIM-S, was enhanced by NASA to enable metering inside the terminal area, and to precisely model PBN procedures, resulting in a higher fidelity schedule than the operational TBFM. Delay in the terminal area that cannot be absorbed with speed adjustments alone is allocated to the en route center. We refer to the TSAS-enhanced TBFM as the prototype TBFM.

STARS is the latest terminal automation platform, and includes various hardware and software components being deployed through the FAA's Terminal Automation Modernization and Replacement program. Terminal controllers interface with STARS through terminal controller workstations to manage traffic. Radar screens are part of the terminal controller workstations, and display each arriving aircraft's flight data block (referred to here as data block), containing the aircraft's ground speed, altitude, and call sign, as shown in Figure 3.

The Raytheon Corporation (Raytheon), through a contract with NASA, enhanced a STARS ELITE Release 2 Drop 7 build to interface with the prototype TBFM and display additional information on the terminal controller workstation radar screen. This will assist the controller in meeting the higher fidelity schedule generated by the prototype TBFM. Six to seven new information elements were added to the data block for each aircraft, depending on the scheduled approach procedure, including the runway assignment and sequence number. Figure 4 shows a prototype of the TSAS data block, commonly referred to as the TSAS computer human interface (CHI). We refer to the TSAS-enhanced STARS as the prototype STARS. The prototype TSAS system is comprised of the prototype TBFM and the prototype STARS.

OIA Purpose, Objective, and Key Aspects

Recognizing that previous NASA-developed prototype technologies such as TMA took nearly a decade to be implemented in the NAS, NASA and the FAA developed a strategy to better facilitate the transfer of TSAS from the laboratory to an operational environment with the expectation that this would accelerate deployment. NASA and the FAA established a Research and Transition Team to align the ATD-1 research and development with the FAA's NextGen commitments and constraints. In the beginning of the ATD-1 subproject, NASA's strategy reflected the approach used for the TMA in the 1990s that relied on operational field tests at an airport [6]. Subsequently, the FAA and NASA agreed on a new approach—the OIA [7]. At its core, the OIA was a large and complex risk *identification* activity, with the objective of identifying risks that need to be addressed prior to transitioning TSAS from the laboratory to the NAS. It focused on including operational characteristics that were unavailable or limited in scope during the research and development of TSAS, but were expected for the eventual testing, evaluation, and deployment of TSAS. The spectrum of risks was broad and includes, but was not limited to, technical, policy and procedures, training, TSAS robustness, TBFM command and control, TSAS CHI, and TSAS interoperability with other NextGen technologies such as ERAM and Extended Metering/GIM-S.

Each agency agreed to specific roles and responsibilities for the OIA. The FAA took responsibility for the en route airspace configuration, including Extended Metering and GIM-S adaptation, testing, training, as well as overall scenario development. The FAA provided the controller and pseudo-pilot participants, in addition to en route and terminal subject matter experts (SMEs). Managers at the Tech Center coordinated and provided the required laboratories, typically used once or twice weekly. Tech Center engineers integrated the various platforms, using the appropriate interfaces when required.

NASA was responsible for transitioning TSAS from NASA Ames to the Tech Center, and ensuring it performed properly. Raytheon coordinated the transfer of the prototype STARS. NASA installed the prototype TBFM on a workstation, referred to as TBFM in-a-box, and shipped it to the Tech Center where it remains today on loan. NASA led the OIA, including defining milestones, providing functional tests, identifying risks to the data collection human-in-the-loop simulation (referred to as the Run for Record), and developed risk mitigation strategies. NASA provided the specifications for the traffic scenarios such as the number and type of aircraft and weather files. Human Solutions, Inc. (HSI) SMEs trained the controller participants on the en route and terminal airspaces, in addition to TSAS. Human factor specialists from NASA and MITRE developed and administered questionnaires. NASA, MITRE, and HSI stationed observers throughout the various laboratories to record controller and TMC participant comments and feedback. NASA and MITRE collected data that is currently being analyzed and a comprehensive report is expected this Fall [8].

The OIA leveraged PBN arrival routes and procedures to the Phoenix Sky Harbor Airport (Phoenix Airport) used in past ATD-1 simulations, which included arrival airspace in Phoenix Terminal, Albuquerque En Route, Denver En Route and Los Angeles En Route [3,9]. Extended Metering/GIM-S became operational at Albuquerque En Route in 2014, and is expanding to include Denver En Route airspace. The Phoenix Airport has the requisite environment necessary for TSAS such as established PBN routes and procedures and the terminal automation system (STARS). It is the first site planned for TSAS deployment.

The Run for Record required about 20 pseudo-pilots, 12 NATCA controllers and three NATCA TMC participants, working in three different laboratories. ERAM Test Bed 4 supported a one or two site configuration; selecting the Albuquerque/Denver configuration enabled the Extended Metering/GIM-S for the eastern arrivals. Eight en route controllers managed the traffic into two northern and two southern Phoenix Terminal arrival gates. GIM-S advisories were available at five of the eight controller positions. When GIM-S speed advisories were not available, conventional metering techniques were employed. Controllers exclusively used conventional metering techniques at three of the eight positions. TBFM delay times displayed to the controllers were changed from minutes resolution used at Albuquerque En Route to tens-of-seconds resolution to facilitate delivering the aircraft within +/- 30 seconds to each meter fix (the +/- 30-second meter fix delivery accuracy differs from that in the FAA Order JO 7111.65 and will be discussed later). Controllers in the ERAM Test Bed 4 laboratory worked every position at least once, ensuring maximum workforce exposure to the newer Extended Metering and GIM-S technologies.

Four terminal controllers used TSAS in the STARS String 11 laboratory. Two feeder controllers metered the northern and southern Phoenix Terminal arrivals using the slot markers and other TSAS information elements before handing off to their respective final controller. For the most part, the terminal controllers worked the same position throughout the Run for Record.

In the Target Generation Facility laboratory, about 20 pseudo-pilots each staffed a workstation. After a pseudo-pilot received an instruction from a controller, the pseudo-pilot first identified the correct aircraft from a list of several aircraft, and then entered the appropriate command into a terminal window. Pseudo-pilots did not “fly” the same aircraft throughout a simulation run. Instead, he/she handed control of the aircraft over to the next pseudo-pilot, using the same airspace sector and frequency scheme as the controllers.

The OIA simulation runs included a set of planned events causing one or more aircraft to deviate from the schedule; an aircraft that executed a missed-approach was one example. For convenience, we refer to these planned schedule disruption events as off-nominal events. They were strategically initiated to impact the terminal and/or en route operations. Although controllers and TMCs routinely manage off-nominal events, TSAS research that included off-nominal events was sparse and limited in scope [10]. Including off-nominal events in the OIA provided an opportunity to examine the robustness of TSAS and potential TBFM command and control issues. The TMCs were expected to coordinate as needed with their controllers and each other to resolve the disruption. Two NATCA TMCs staffed the Albuquerque and Denver TMC positions in the ERAM Test Bed 4 laboratory. A third NATCA TMC staffed the Phoenix Terminal TMC position in the STARS String

11 laboratory. Each TMC position included a TBFM schedule display, and each TMC participant could adjust the schedule.

NATCA participated early and often in the OIA. Over the course of two preparation simulations and the Run for Record, 16 en route controllers from seven en route centers and nine terminal controllers from five terminal facilities participated in the OIA. None of the Run for Record controllers had participated in any of the previous simulations, and all were from facilities other than Phoenix Terminal, and Albuquerque and Denver En Route Centers. Four TMCs, each from a different facility, participated. Three of the four TMCs began participating months before the Run for Record. Two of the four TMCs attended a human-in-the-loop simulation at NASA Ames tailored for them to gain a familiarity with TSAS and to identify their OIA roles and responsibilities. Their continuous participation through all the simulations, including the Run for Record, was critical to the success of the OIA.

Shifting Paradigms

Identifying all possible risks was beyond the scope of the OIA. Likewise, discussing each of the previously mentioned risks in the context of the OIA is beyond the scope of this paper. Instead, we frame the discussion in terms of three interdependent paradigm shifts expected in order to realize the maximum benefits of TSAS: (1) expanding metering operations; (2) TBFM command and control; and (3) testing with multiple platforms. Each paradigm shift is naturally a risk. We choose to discuss these three because the research of TSAS could not evaluate these three paradigm shifts, making the OIA an invaluable experience.

Operations, Paradigm Shift 1: Expanding Metering Operations and TSAS

Currently, en route controllers manage aircraft to meet a schedule. The common technique is miles-in-trail or metering, depending on the en route facility and the airport demand/capacity. Terminal controllers do not meter aircraft in today's NAS—they sequence the aircraft, assign runways and approach procedures, and maintain the required separation.

As the FAA continues transitioning from miles-in-trail to metering as the preferred technique to manage arrival demand, a new metering paradigm for en route and terminal operations is expected to enable the higher PBN conformance representative of Figure 2. For en route operations, this new metering paradigm is expected with advanced TBFM capabilities that are in the early deployment stages: Extended Metering and GIM-S. With Extended Metering, delay allocation can be extended to 600 miles or even greater from the meter fix, allowing delay to be distributed over more airspace, possibly extending into the airspace of adjacent en route centers. GIM-S compliments Extended Metering by providing speed advisories to the en route controllers to more efficiently meet meter times by trading heading adjustments for speed adjustments.

TSAS is expected to usher in the new metering paradigm for terminal operations. For the first time, terminal controllers will be able to continue the metering schedule generated by TBFM, providing continuity in managing aircraft demand from en route to the runway. Slot markers are expected to be the primary tool used by the controllers to manage the aircraft. As a result, TSAS generates the arrival sequence and runway assignments, while taking into PBN procedures such as RNP approaches. The terminal controllers are still responsible for separation. Because terminal controllers have less time and distance to meter aircraft relative to their en route controller counterparts, preconditioning the arrivals before entering the terminal area will be important so that remaining delay in the terminal area can be absorbed primarily with just speed adjustments.

Extended Metering and GIM-S are expected to be key technologies that will allow more accurate preconditioning of the arrival aircraft to the terminal area. Past TSAS studies have shown that TSAS performs best when aircraft are delivered to the meter fix within +/- 30 seconds; twice as accurate as the current +/- one-minute requirement specified in FAA Order JO 7110.65 [11]. To facilitate this increased delivery accuracy, meter fix delay times displayed with tens-of-seconds resolution are expected rather than minutes resolution used at most facilities.

Operations, Paradigm Shift 2: TBFM Command and Control

In today's NAS, en route TMCs typically manage schedule adjustments using TBFM. When necessary, TMCs coordinate actions with TMCs from other affected facilities. The amount a terminal TMC interacts with TBFM varies across facilities. Schedule changes tend to be coordinated with an en route TMC since they typically are the ones that manage TBFM. With Extended Metering and GIM-S, command and control restrictions are implemented in TBFM to add an additional level of protection from unintended changes to the TBFM schedule.

When TSAS is operational, the terminal facility will have a tool to manage aircraft to meet a schedule in the terminal area, and adjust the schedule when necessary. Some of these schedule adjustments have the potential to impact en route metering operations, whereas others do not. Because an en route and terminal TMC will likely need to make schedule adjustments using TBFM, coordination will be important. In the near future, a new command and control paradigm will be necessary; additional TBFM scheduling functionality may or may not be required.

Testing and Evaluation, Paradigm Shift 3: Testing With Multiple Platforms

Testing and evaluation of technologies at the Tech Center tends to require simulating operations in the terminal airspace or the en route airspace. Consequently, such testing requires just a few platforms, and limits the scope of required PBN procedures. For example, GIM-S testing and evaluation required ERAM and TBFM, but not the STARS platform, because testing required simulating aircraft in the en route environment. Testing and evaluation that does not require using all of the operational platforms at the Tech Center experience fewer laboratory scheduling conflicts and require fewer SMEs, controllers, pseudo-pilots, and test engineers. These smaller-scale test and evaluations also reduce the opportunities to develop and improve simulating PBN procedures in the phase of flight that is not included in the test.

Many NextGen technologies have inherent interdependencies with other NextGen technologies. These technologies are often contained within different system platforms and, because of dependencies, require connections between multiple platforms for adequate testing. In the future, testing and evaluation of NextGen technologies requiring the interoperability of multiple platforms is expected to become more commonly required. As metering expands and requires airspace of multiple en route centers, testing will require multiple ERAM site configurations, possibly requiring multiple ERAM laboratories. Because TSAS affects en route and terminal operations, the eventual testing and evaluation will likely require multiple connected platforms such as TBFM, STARS, ERAM, and the Target Generation Facility, and a corresponding increase in SMEs, test engineers, controllers, and pseudo-pilots. Increasing the scope and continuity of simulated PBN procedures across en route and terminal airspace will also be required. To facilitate testing, even in a laboratory environment, a strategy for TBFM command and control is necessary. Eventually, TSAS testing and evaluation will transition from the TBFM in-a-box used at the OIA to the TBFM platform in the corresponding laboratory at the Tech Center.

Some Representative Observations and Feedback

Finalizing TSAS CHI requirements for the operational version is an on-going effort, and findings from the OIA are expected to influence these requirements. Preliminary results indicate that the terminal controller participants thought the sequence produced by TSAS was reliable; however, they found the organization of new information in the data block somewhat confusing. Further analysis is needed to provide more insight about the possible sources of confusion.

We observed TSAS robustness to off-nominal events to be inversely proportional to the magnitude of the schedule disruption. For three simulation runs impacted by highly disruptive off-nominal events, the terminal TMC elected to turn off the TSAS information. Later in the run, the terminal TMC utilized a trial-and-error procedure to determine when the TSAS information elements should be turned back on. Further research is required to determine the appropriate times to toggle TSAS off/on.

Some Observations and Feedback, Paradigm Shift 1: Expanding Metering Operations and TSAS

In general, en route controller participants delivered aircraft within 30 seconds to the meter fix, with more variability than in past ATD-1 simulations. Feedback was mixed on the viability of achieving this potential new requirement at their respective facilities. Some controllers stated that they issued more clearances to achieve the accuracy than they would typically issue at their facility.

En route controller participants confirmed that they would like to see the delay times displayed in tens-of-seconds resolution, regardless of the required metering accuracy. Their main reason for preferring ten-of-seconds resolution was seeing the trend as the delay counted down or up. Fine-tuning is needed, however, as sometimes the delay times jumped and this skitter was magnified in the tens-of-seconds display, which the controllers found distracting.

Some Observations and Feedback, Paradigm Shift 2: TBFM Command and Control

The TMC participants coordinated with each other and with the controllers regarding schedule adjustments; however, not all schedule adjustments were coordinated, and there were instances where a lack of coordination caused major disruption to the operations. More research is needed to determine the workload impacts to the TMC role due to TSAS, possibly prescribing processes and procedures for the terminal and en route TMCs because both will be cognizant of the same schedule. Additional TBFM scheduling restrictions may be a requirement for command and control.

Some Observations and Feedback, Paradigm Shift 3: Testing With Multiple Platforms

Testing required scheduling and reserving time for the required laboratories and engineers to start up and connect all the platforms, even if the objective of the test was limited to a single platform. The availability of the different laboratories was very limited, and mostly reflected the availability of ERAM or STARS. Sometimes laboratories were lost to higher priority activities. On average, about 10% of the reserved laboratory time was lost due to laboratory availability changes. TSAS scenario development necessarily requires assessing and adjusting delay distributions using TBFM, and is inherently iterative, requiring more laboratory and personnel time than were available.

The OIA was the first opportunity for simulating some important PBN procedures such as RNP approaches using the Target Generation Facility. Observations and participant feedback indicated that accurately simulating PBN procedures was not at the desired level of performance. Accurately simulating PBN procedures is an important aspect of TSAS testing, and improvements are expected for future testing and evaluation events.

Summary

NASA and the FAA partnered to conduct a successful integrated operational assessment, the OIA, of TSAS with other NextGen technologies that are at different deployment stages. NATCA controllers and TMCs participated in the OIA at the FAA's Tech Center. This paper described three paradigm shifts that are expected to maximize the benefits of TSAS when it becomes operational, and discussed some of the observations and feedback of each in the context of the OIA. Examination of these three paradigm shifts had not been performed until the OIA, making the OIA an invaluable activity to identify key risks when transitioning TSAS from the laboratory to the NAS.

NASA and the FAA plan to capture lessons learned from the OIA, expecting to improve the process of future NASA to FAA technology transfers. Early involvement of the TBFM operations team is expected to be a lesson learned.

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