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Assessment of Delivery Accuracy in an Operational-Like Environment

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In order to enable arrival management concepts and solutions in a Next Generation Air Transportation System (NextGen) environment, ground-based sequencing and scheduling functions were developed to support metering operations in the National Airspace System. These sequencing and scheduling tools are designed to assist air traffic controllers in developing an overall arrival strategy, from enroute down to the terminal area boundary. NASA developed a ground system concept and protoype capability called Terminal Sequencing and Spacing (TSAS) to extend metering operations into the terminal area to the runway. To demonstrate the use of these scheduling and spacing tools in an operational-like environment, the FAA, NASA, and MITRE conducted an Operational Integration Assessment (OIA) of a prototype TSAS system at the FAA's William J. Hughes Technical Center (WJHTC). This paper presents an analysis of the arrival management strategies utilized and delivery accuracy achieved during the OIA. The analysis demonstrates how en route preconditioning, in various forms, and schedule disruptions impact delivery accuracy. As the simulation spanned both enroute and terminal airspace, the use of Ground Interval Management – Spacing (GIM-S) enroute speed advisories was investigated. Delivery accuracy was measured as the difference between the Scheduled Time of Arrival (STA) and the Actual Time of Arrival (ATA). The delivery accuracy was computed across all runs conducted during the OIA, which included deviations from nominal operations which are known to commonly occur in real operations, such as schedule changes and missed approaches. Overall, 83% of all flights were delivered into the terminal airspace within +/- 30 seconds of their STA and 94% of flights were delivered within +/- 60 seconds. The meter fix delivery accuracy standard deviation was found to be between 36 and 55 seconds across all arrival procedures. The data also showed when schedule disruptions were excluded, the percentage of aircraft delivered within +/- 30 seconds was between 85 and 90% across the various arrival procedures at the meter fix. This paper illustrates the ability to meet new delivery accuracy requirements in an operational-like environment using operational systems and NATCA controller participants, while also including common events that might cause disruptions to the schedule and overall system.

I. Introduction

NASA, the Federal Aviation Administration (FAA), and the MITRE Corporation performed an Operational Integration Assessment (OIA) of the Terminal Sequencing and Spacing (TSAS) functionality at the William J. Hughes Technical Center (WJHTC) in May 2015. The main objective of the OIA was to identify operational risks, including technical, policy, procedures, computer-human interface, and training. Given an operationally realistic environment, the OIA provided an opportunity to test events outside of nominal operations, such as configuration changes and missed approach events.[15,16] In addition, the OIA enabled the integration of TSAS with existing FAA metering capabilities from the enroute to the terminal areas.

TSAS was developed as an advanced arrival management capability for terminal controllers to enable increased use of performance-based navigation (PBN) arrival procedures during periods of moderate and high traffic demand.[8,12] This technology enhances FAA operational systems by adding terminal metering capabilities to TBFM and controller spacing tools to the Standard Terminal Automation Replacement System (STARS). These technologies were developed under NASA's Air Traffic Management Technology Demonstration-1 (ATD-1) research and development activity.[1-4,11] ATD-1 combines advanced arrival scheduling, controller decision support tools, and aircraft avionics to enable efficient arrival operations in high-density terminal airspace.[1,11]

This paper first describes the TSAS technology and then the details of the OIA human-in-the-loop simulation (HITL). The report then details the delivery accuracy analysis and findings from the OIA.

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II. Background

A. Terminal Sequencing and Spacing

In today's operations without TSAS, TBFM generates an arrival schedule and provides advisories for enroute controllers to maintain schedule conformance. TBFM uses 4-D trajectory predictions to determine runway assignments, arrival sequences, and scheduled times-of-arrival (STAs). Runway assignments are selected to minimize total arrival delay. Arrival sequences and STAs are computed for meter fixes located near the terminal boundary and at the runway threshold. TBFM schedule information is not directly available to terminal controllers, so they manually assign runways, sequence the aircraft for landing, and ensure separation primarily using vectors and step-down descents without knowledge of the TBFM runway schedule.[8]

In 2011, NASA initiated its ATD-1 research and development activity, extending earlier NASA work in this domain.[1,8] The primary ATD-1 objectives are to (1) develop fully functional operational prototypes of the ground and airborne spacing technologies, (2) demonstrate the integrated ATD-1 concept of operations in a series of evaluations, and (3) transfer the mature technologies to the FAA and industry stakeholders.

ATD-1 integrates time-based scheduling across the entire arrival phase of flight with ground-based tools for terminal controllers and an airborne spacing capability for equipped aircraft.[8] A prototype version of TBFM enhanced with TSAS builds upon the FAA's existing TBFM system by performing detailed modeling and scheduling of the terminal portions of the arrival procedures. The controller-managed spacing tools provide textual and graphical representations of the arrival schedule and speed advisories and are displayed on the STARS controller displays.

TSAS reflects a maturation of existing capabilities that enable use of PBN arrival procedures in moderate and high traffic demand, and implementation in operational prototype software. The ATD-1 concept of operations, from Ref. 8, describes the TSAS tools and explains their support of increased PBN utilization. TBFM with TSAS includes more sophisticated scheduling in the terminal area than the currently deployed TBFM, and provides advisories for terminal controllers to maintain schedule conformance. In addition to the meter point's schedules that are already computed in TBFM, arrival sequences and STAs are computed for additional terminal meter points where traffic flows merge. At these merge points, the STAs are computed to allow aircraft to remain on their assigned PBN arrival procedures.

B. Operational Integration Assessment

The objective of the OIA was to identify risks of integrating TSAS in an operational environment, which need to be resolved prior to the transition of TSAS to the NAS. This included assessing the risk of the technical integration of TBFM enhanced with TSAS, with En Route Automation Modernization (ERAM) and prototype STARS systems. The OIA also explored potential risks associated with policies, procedures, and training. In addition, the FAA was specifically interested in exploring the impact of TSAS interoperability with other NextGen technologies in various stages of deployment such as Extended Metering and controller speed advisories of Ground Interval Management – Spacing (GIM-S).[5]

III. Methodology

The OIA was conducted May 12-21, 2015 at the WJHTC. Participant training was performed exclusively over the first two days and followed by six days of data collection. Nineteen total simulation runs were completed during the data collection days.

A. Simulation Environment

Three separate labs within the WJHTC were used to conduct the OIA, to simulate terminal area operations, enroute operations, and generate aircraft targets. Terminal controllers staffed positions in the available STARS laboratories. Traffic was simulated using the Tech Center's on-site Target Generation Facility (TGF), which included an interface for pseudo pilots. The STARS lab, ERAM lab, and pseudo pilot workstations were in physically separate areas of the building. Pseudo pilots interacted with controllers in both the STARS lab and ERAM lab via a voice communication system, and controllers were also able to communicate between the STARS lab and ERAM lab via the same audio system. TBFM timelines and plan view displays were located at Traffic Management Coordinator (TMC) workstations located adjacent to the STARS lab and the ERAM lab, with a Terminal Radar Approach Control (TRACON) TMC present in the STARS lab and two enroute TMCs present in the ERAM lab. These TMCs were able to directly interact with the controllers in their respective areas by walking over and speaking with them, and TMCs could communicate with each other across the audio system.

B. Participants

The OIA was staffed by twelve FAA Certified Professional Controllers. The FAA enroute and terminal controllers who participated in the OIA data collection simulations had no prior experience using TSAS and did not participate in previous TSAS simulations. The eight enroute controllers were from six enroute facilities (Boston, Indianapolis, Atlanta, Memphis, Minneapolis, and Washington Centers). Four terminal controllers from two terminal facilities (Seattle and Houston TRACONs) participated; the two terminal controllers from Seattle TRACON were familiar with RNP approaches and profile descents. None of the controller participants had prior experience with Albuquerque Center, Denver Center or Phoenix TRACON operations.

The OIA also included FAA Traffic Management Coordinators (TMC). The three enroute traffic managers were from the FAA's TBFM Operations Team, and worked at Memphis, Cleveland, and Denver Centers. The TRACON TMC was from Houston TRACON. With the exception of the traffic manager from Denver Center, none of the FAA participants had prior experience with Albuquerque Center, Denver Center or Phoenix TRACON operations, which were the focus of the test scenarios. Two of the traffic managers, the enroute TMC from Memphis and the TRACON TMC from Houston, had used TSAS in prior OIA testing leading up to data collection. All FAA controller and TMCs were selected and authorized to participate by the National Air Traffic Controller Association (NATCA). Representatives from NATCA were present during the OIA to provide operational expertise during preparation activities and to observe the simulation.

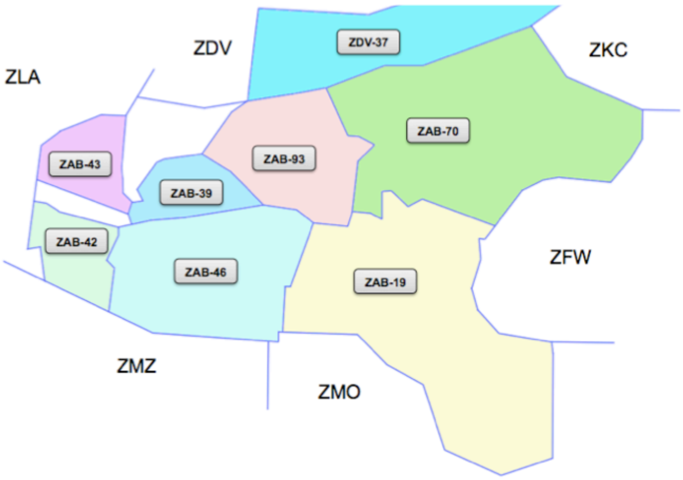


Figure 1. Enroute Airspace Configuration

Between twenty and twenty four pseudo pilots participated each day of the OIA. The exact number of pseudo pilots varied each day depending upon the traffic scenarios being simulated. Each pseudo pilot was responsible for controlling multiple aircraft in a single sector (i.e., they interacted with a single controller during a simulation run). Prior to the OIA data collection simulations, the pseudo pilots had participated in the OIA shakedown simulations, during which various preparation, system integration, and training activities took place. The pseudo pilots were considered confederates for this simulation, so data are not reported regarding their performance.

C. Routes and Airspace

The OIA operations consisted of arrivals to the Phoenix Sky Harbor International Airport, whose operations are conducted in Phoenix TRACON, Albuquerque Center (ZAB), and portions of Los Angeles Center (ZLA) and Denver Center (ZDV). See Figure 1 for an airspace overview.

1. Enroute Airspace Configuration

Eight enroute airspace sectors were simulated, seven in ZAB and one in ZDV (see Figure 1). With the exception of ZAB-42, all sectors were a combination of two or more operational sectors. ZLA airspace was delegated to ZAB-42 and ZAB-43. The EAGUL-6 and PINNG-1 arrival routes were adapted for extended metering which spanned approximately 400 miles. The HYDRR-1 and BRUSR-1 arrival routes were simulated in single sectors and spanned approximately 160 miles including delegated airspace from ZLA.

For the EAGUL-6 Arrival, ZDV-37 and ZAB-70 metered and sequenced aircraft to the extended meter points[3] (XMPs) and fed ZAB-93. ZAB-93 metered and sequenced aircraft to the coupled meter point (CMP) and fed sector ZAB-39. ZAB-39 metered and sequenced aircraft to the meter fix (MF). For the PINNG-1 Arrival, ZAB-19 metered and sequenced aircraft to the CMP and fed ZAB-46. ZAB-46 metered and sequenced aircraft to the MF. For the BRUSR-1 Arrival, ZAB-43 metered and sequenced aircraft to the MF.[14] For the HYDRR-1 Arrival, ZAB-42 metered and sequenced aircraft to the MF.

GIM-S is a NextGen capability that provides enroute controllers with speed advisories in higher altitude sectors to help precondition aircraft in an arrival flow. For this simulation GIM-S was adapted for the EAGUL-6 and PINNG-1 turbojet arrivals to PHX. No delay was allocated to ZAB-39 and 46 sectors, which passed back all known delay to the upstream CMPs and XMPs. The BRUSR-1 and HYDRR-1 arrivals were not adapted for GIM-S.

For the EAGUL-6 Arrival, ZAB-70 and ZDV-37 were adapted for GIM-S cruise advisories to XMPs (ZAB-X1 and ZDV-X1) and ZAB-93 was adapted for GIM-S cruise advisories to the CMP (PHXSLDR).

For the PINNG-1 Arrival, ZAB-19 was adapted to provide GIM-S cruise advisories to the CMP (PINC-1). ZAB-46 was adapted to provide GIM-S cruise and descent advisories to the BRDEY MF.

2. *Terminal Airspace Configuration*

In the P50 Terminal airspace, the airport configuration was west flow into PHX on runways 26 and 25L; the configuration of the airspace is shown in Figure 2. The primary landing runway for turbojets on the EAGUL-6 and BRUSR-1 was runway 26. The primary landing runway for turbojets on the PINNG-1 and HYDRR-1 was runway 25L. The primary landing runway for turboprops from all directions was runway 25L.

The Apache sector fed turbojet aircraft to the Freeway sector on the EAGUL-6 and BRUSR-1 Area Navigation (RNAV) arrivals and turboprops on the conventional COYOT-2 and JESSE-1 arrivals. The Quartz sector fed turbojet aircraft to the Verde sector on the HYDRR-1 and PINNG-1 RNAV arrivals and turboprops on the conventional ARLIN-3 and SUNSS-7 arrivals.

Turboprop arrivals required radar vectors and altitude assignments from the feeder and final controllers. Procedures for crossovers from BRUSR-1 and EAGUL-6 to runway 25L and HYDRR-1 and PINNG-1 to runway 26 were also in place.

The RNP approach procedures, which include RF turns to final, are illustrated in Figure 3. These procedures are not currently used for arrivals into PHX, but were adapted for the purposes of the simulation. Participants were trained to utilize the RNP Established concept. The concept considers aircraft on an RNP approach established and therefore not required to maintain radar separation with aircraft on the approach course to an adjacent parallel runway. Consequently, there is no need for altitude separation for aircraft that are turning to final at the same time.

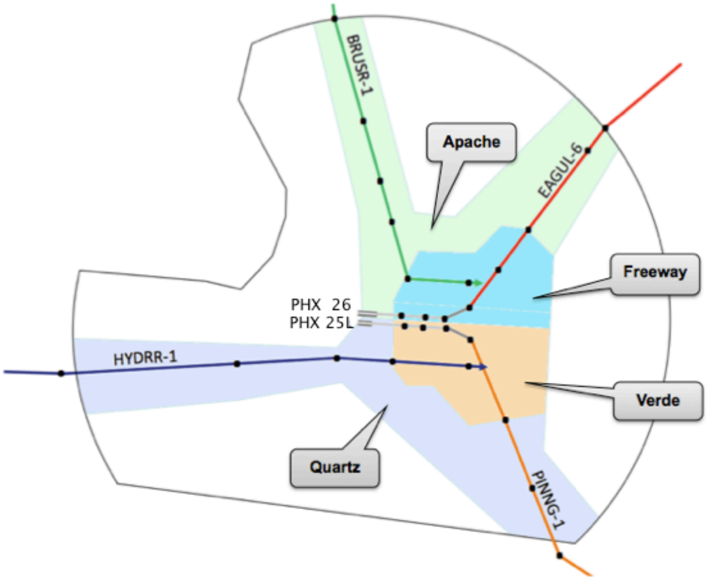


Figure 2. Terminal Airspace Configuration

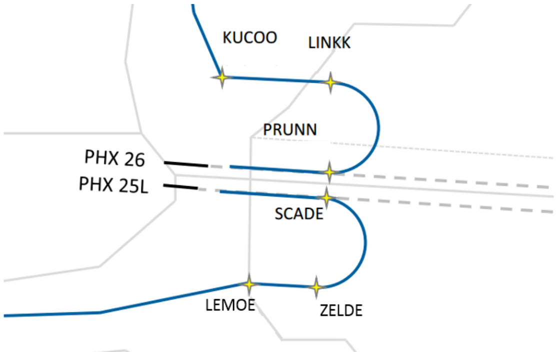


Figure 3. RNP Approach Procedures

D. Simulation Scenarios

Two variables are focused on in this analysis: Airport Demand (low versus high arrival demand) and specific planned off-nominal events. Other variables and events that were explored during the OIA simulation that are not discussed in this paper. These include metering usage (metering on vs. off), TSAS tools usage, and initial airport arrival configuration. Due to simulation difficulties and schedule constraints, these variables were not represented with sufficient regularity and quantity to be included in the data analysis.

Each traffic scenario ran about 75 minutes, with peaks and valleys of arrival demand. The low demand scenario represents current day staggered operations into PHX while the high demand scenario represents typical current PHX visual flight rules (VFR) operations. The traffic composition was approximately 90 aircraft per scenario with 75% RNAV-equipped jets, 22% RNP-equipped jets, and 3% unequipped turboprops. The OIA scenarios did not include departures or overflight traffic. There were a total of nineteen runs performed for the OIA data collection.

1. *Delivery Accuracy*

Controllers targeted a metering accuracy of ± 1 minute for metering restrictions upstream of the meter fix for the eastern sectors, consistent with current-day operations, and as required of enroute controllers specified in FAA Order JO 7110.65. Past simulations performed by both NASA demonstrated that TSAS performs best when aircraft are delivered to the meter fix within ± 30 seconds of their STA (Swenson, et al., 2011). During the OIA, the enroute controllers were trained to deliver aircraft to the meter fix within ± 30 seconds in order to assess the potential delivery accuracy requirement changes. The delay countdown timers (DCTs) were displayed with tens-of-seconds resolution in order to enable the more precise delivery. Some facilities already use tens-of-seconds DCT resolution, but one-minute resolution is more common, and is currently used at Albuquerque Center.

2. *GIM-S Configuration*

Extended metering and speed advisories are a part of GIM-S, recently deployed as a NextGen capability that is expected to improve the preconditioning of the arrivals to terminal airspace. GIM-S cruise speed advisories were available to help precondition the high altitude aircraft along the EAGUL-6 (from the northeast) arrival flow in ZAB and ZDV. The low-altitude enroute controller responsible for delivering the aircraft to the northeast meter fix used conventional metering techniques. The GIM-S implementation on the EAGUL-6 was consistent with current-day ZAB operations.

For PINNG-1 arrivals from the southeast, GIM-S cruise and cruise/descent speed advisories were provided, which deviated from present-day ZAB operations. New phraseology was created to issue clearances for aircraft with GIM-S cruise/decent advisories. The low-altitude enroute controller responsible for delivering aircraft to the southeast meter fix used conventional metering techniques for those aircraft that did not have GIM-S cruise/descent advisories available.

For the HYDRR-1 and BRUSR-1 arrivals from the west and northwest, controllers used conventional metering techniques to manage the arriving aircraft.

3. *Off-Nominal Events*

The term “off-nominal” is used to describe events that cause disruptions to the arrival schedule of one or more aircraft. Eight specific off-nominal events were planned to be evaluated in the OIA:

- Go-around/Missed approach
- Unscheduled internal departure
- RNP-equipped aircraft unable to execute the RNP approach
- Runway assignment change
- Priority aircraft
- Swap aircraft STAs in enroute airspace prior to the meter fix
- Runway configuration change: simultaneous arrivals to staggered arrivals
- Future change in runway spacing matrix buffer

Table 1. Delivery Accuracy Across Runs with No Global Off-nominal Events

Off-nominal Condition	# of Runs
No Event	2
Planned – Local event	8
Planned – Global event	1
Planned – Global with Local	4
Unplanned – occurred naturally	4

The frequency of these off-nominal events, in actual operations, is quite variable between the different events. For example, enroute controllers might swap aircraft several times per hour, but only handle one or two missed approaches per day. Within the planned off-nominal events, some events were considered “local,” which primarily originated with one aircraft (for example, a pilot requesting a missed approach or a priority status) or “global,” which originated from the Traffic Managers (for example, a change to the overall TBFM schedule such as a runway spacing matrix buffer change, or airport landing reconfiguration). However, as noted above in Table 1, additional unplanned off-nominal events were found to occur naturally as a result of simulation conditions.

IV. Analysis Methodology

To enable delivery accuracy analysis and computation of other metrics, a toolset was developed by MITRE for the purpose of parsing, processing, and storing the various objective data outputs for post analysis. This toolset was developed within the commercial software package MATLAB®, a numerical computing environment. Log files from each of the operational systems, including TBFM, ERAM, and TGF, were parsed for relevant information, and post-processed data was stored for each run in a central repository within MATLAB. Where necessary, data formats and time formats were aligned so that analyses could be performed across various data sources and systems.

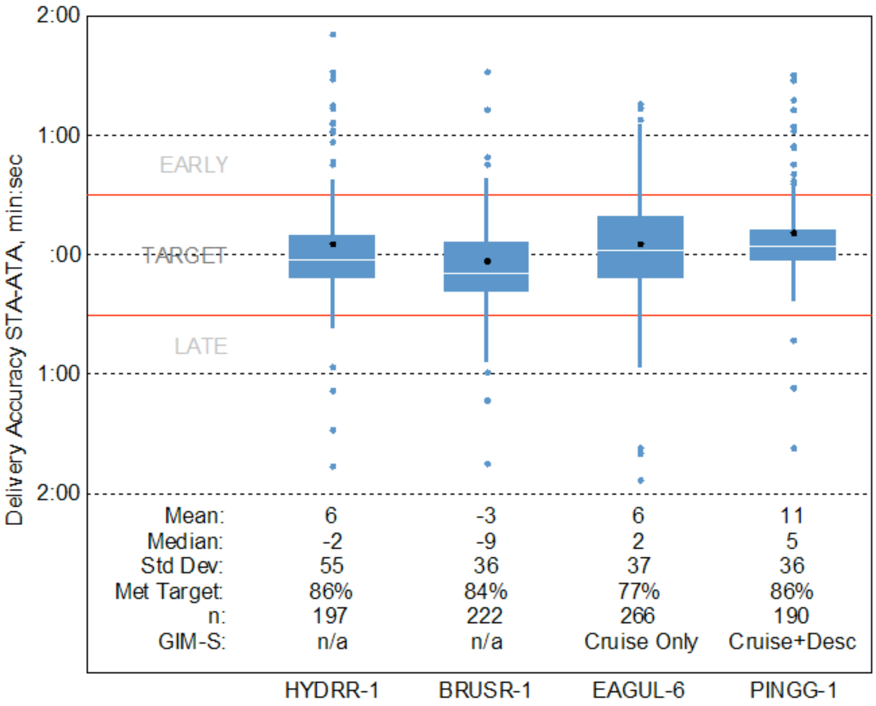
Delivery accuracy was measured as schedule conformance at each of the four meter fixes and the metering arcs. It was defined as difference between the scheduled time of arrival (STA) and the actual time of arrival (ATA). A positive delivery accuracy value indicates the flight arrived at the meter fix early while a negative value indicates that the aircraft arrive later than scheduled. As described earlier, the delay was displayed on ZAB controller scopes with a resolution in tens-of-seconds.

V. Delivery Accuracy Results

The delivery accuracy analysis provides insight into the ability of controllers to deliver aircraft to the desired tolerance of ± 30 seconds to the meter points, using GIM-S speed advisories and extended metering in an operationally realistic environment. The delivery accuracy was assessed across all runs when metering was utilized for the meter points and the extended metering arcs. In addition, the impact of global off-nominal scenarios is shown, as well as the impact of GIM-S configuration and advisory type.

A. Delivery Accuracy to Meter Points

The delivery accuracy to each meter fix across runs in which metering occurred, which includes runs 1-15 and 18, is shown in a box plot in Figure 4. Runs 16, 17, and 19 were excluded from this analysis as no enroute metering was used.



	HYDRR-1	BRUSR-1	EAGUL-6	PINGG-1
Mean:	6	-3	6	11
Median:	-2	-9	2	5
Std Dev:	55	36	37	36
Met Target:	86%	84%	77%	86%
n:	197	222	266	190
GIM-S:	n/a	n/a	Cruise Only	Cruise+Desc

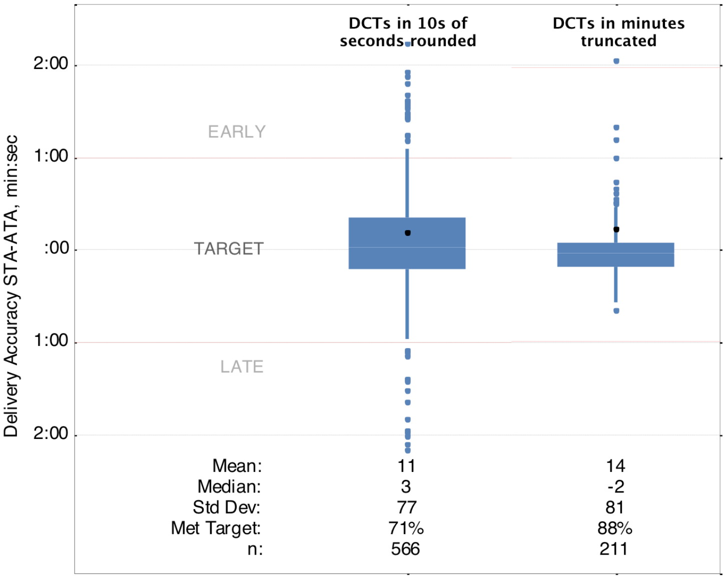
Figure 4. Delivery Accuracy to Meter Points Across All Runs

Overall, 83% of aircraft that were delivered within ± 30 seconds of their STA (shown in the figures as "Met Target") with variation between 77% to 86% depending on the arrival procedure; 94% of all flights were delivered within an wider window of ± 60 seconds at the terminal boundary. The standard deviation for meter fix delivery across these runs ranged from 36 to 55 seconds.

B. Delivery Accuracy to Extended Metering Arcs

For the sectors beyond the corner posts, enroute controllers were asked to meet a tolerance of +/- 1 minute to the metering arcs PHXSLDR, PINC1, and ZABX1 in the ZAB ARTCC, with DCTs displaying tens of seconds, as well as ZDVX1 in the ZDV ARTCC, which displayed in minutes truncated due to a different adaptation setup for ZDV. GIM-S was enabled to provide both cruise and descent speed advisories to the BRDEY corner post, and cruise-only speed advisories to PHXSLDR, PINC1, ZABX1, and ZDVX1.

Figure 5 shows the delivery accuracy for the extended metering arcs grouped into two categories; the first grouping contains the metering arcs with a ± 1 minute tolerance and DCTs displayed in tens of seconds and a second group contained the metering arc with a larger tolerance and with DCTs displayed in minutes truncated.



	DCTs in 10s of seconds rounded	DCTs in minutes truncated
Mean:	11	14
Median:	3	-2
Std Dev:	77	81
Met Target:	71%	88%
n:	566	211

Figure 5. Delivery Accuracy to Extended Metering Arcs Across All Runs

C. Impact of Global Off-Nominal Events

Global off-nominal events during the OIA allowed the study of events that may affect operations in both the terminal and enroute airspace. The global off-nominal events included changing from independent to staggered approaches and implementation of future spacing matrix changes. These global off-nominal events illustrated impacts of an integrated TSAS system in the terminal area with GIM-S tools in enroute.

In Figure 6 and Figure 7, the delivery accuracy for runs with no global off-nominal events versus runs with global off-nominal events , are grouped and illustrated.

Figure 6 shows the delivery accuracy of runs with no global off-nominal events and either no or some local off-nominal events, which includes 10 runs. The percentage of aircraft delivered within ± 30 seconds for runs with no global off-nominal events varied between 85% and 90% depending on arrival procedure. The meter fix delivery standard deviation ranged from 23 to 26 seconds.

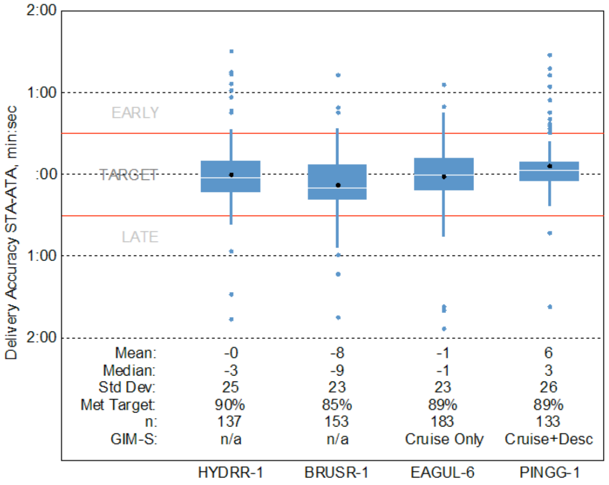


Figure 6. Delivery Accuracy Across Runs with No Global Off-nominal Events

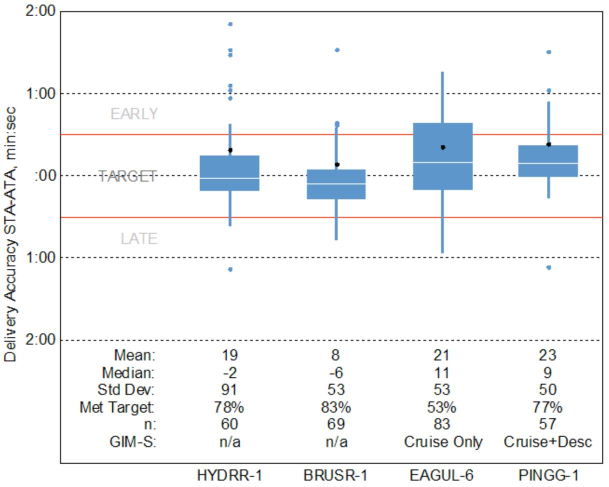


Figure 7. Delivery Accuracy Across Runs with Global Off-nominal Events

Figure 7 shows the delivery accuracy of runs with global off-nominal events, or off-nominal events that affected the enroute and terminal area as described above. These data in the figure includes 5 runs. The percentage of aircraft delivered within ± 30 seconds for runs with global off-nominal events varied from 53 to 83% depending on arrival procedure. The meter fix delivery standard deviation ranged from 50 to 90 seconds

Figure 7 illustrates runs that required global reschedules, in which the disruption caused a change in the overall arrival schedule. Due to the integrated nature of the TSAS schedule with the enroute schedule, changes to the schedule typically have a big impact on the STAs of aircraft in enroute airspace. With large disruptions, controllers lose the ability to meet the updated STAs, especially when traffic levels are high, and the overall conditioning of the stream into the terminal is impacted. However, it should be noted the difference in sample size between the two conditions is large and may impact the met target values as well as standard deviation seen in Figure 7.

1. Investigation of Two Runs with Different Demands and Global Off-nominal Events

One global off-nominal event of note is when the airport changes to staggered arrivals. This can drastically reduce the throughput to the airport and impact enroute metering times. Two scenarios were run to simulate this type of event, both of which called for a change to stagger midway through the run, the first occurring during a low traffic scenario and the second occurring during a high traffic run.

During the first scenario where a change to staggered arrivals occurred, run 10, the change was made to the schedule 33 minutes into the scenario, with the scenario lasting just over an hour. The demand on the airport was low, so when the airport capacity was reduced, overall delay increase in the sector was manageable. The following plots focus on the southeast arrival flow, but the effects here are representative of the behavior of all enroute sectors during the stagger off-nominal event.

Figure 8a shows the delivery accuracy to each of the meter fixes and Figure 8b the cumulative delay for sector ZAB 19 throughout the run. The reschedule event can be seen midway through, when the cumulative delay (in light blue) jumps up to over 8 minutes. However, this delay is reduced through controller action fairly quickly, and the delivery accuracy is not significantly impacted. Aircraft are still delivered over the various arrival streams with at least 70% or higher met target values, however the standard deviations are much larger, ranging from 11 to 181 seconds.

Run 11 included a change to staggered arrivals in a high traffic scenario. The impact in enroute due to the reduction in airport throughput was significant. The delivery accuracy across the meter points and the cumulative delay is shown in Figure 9a and Figure 9b. Figure 9b shows the cumulative delay in ZAB 19 on the right, for the

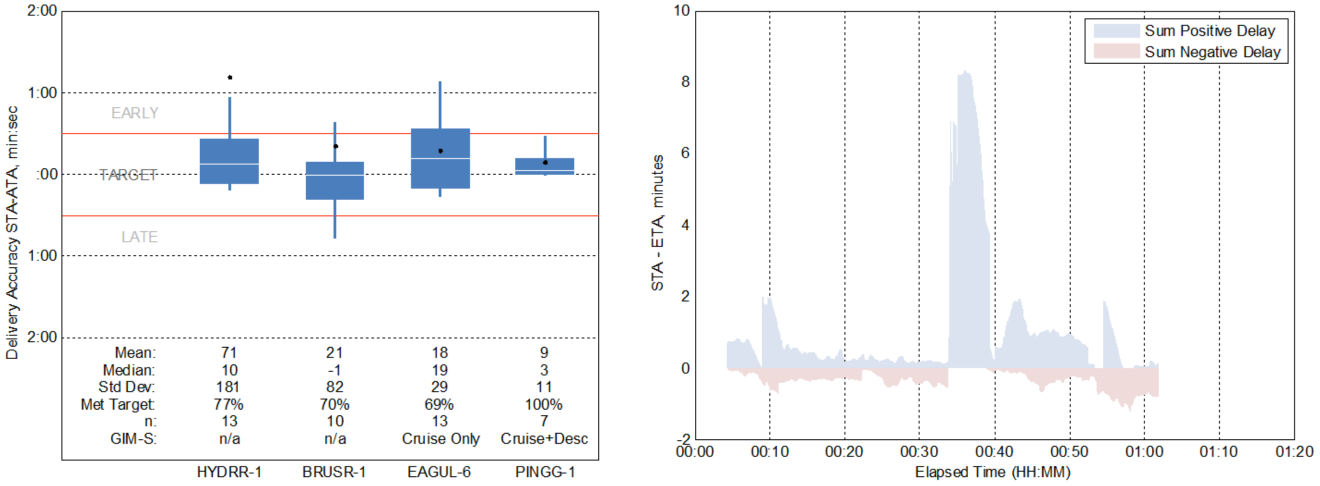


Figure 8a. Delivery Accuracy and Figure 8b. Cumulative Delay for Run 10

high traffic scenario.. The cumulative delay initially hovered around 2 to 3 minutes for the first half of the scenario, but when the global off-nominal event occurred 28 minutes into the scenario, the cumulative delay for all eleven flights in the sector at that time jumped to over 140 minutes.

When comparing the cumulative delay plots in Figures 8 and 9 (on the right side), note the change in the span of the y-axis, which shows that Run 11 with high traffic had drastically more cumulative delay after the reschedule than Run 10 with lower traffic. The average delivery accuracy into the terminal over BRDEY for run 12 was 88 seconds early, with an 89 second standard deviation. Feedback received from enroute controllers for this run was that the workload resulting from this off-nominal event was extremely high as additional vecotoring was required to account for the jump in delay values.

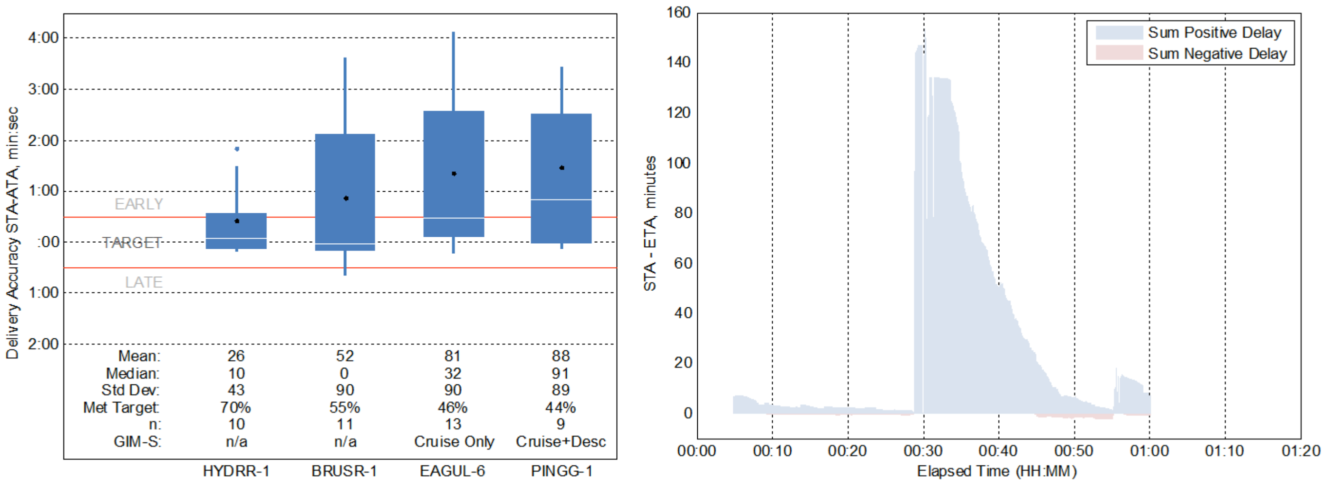
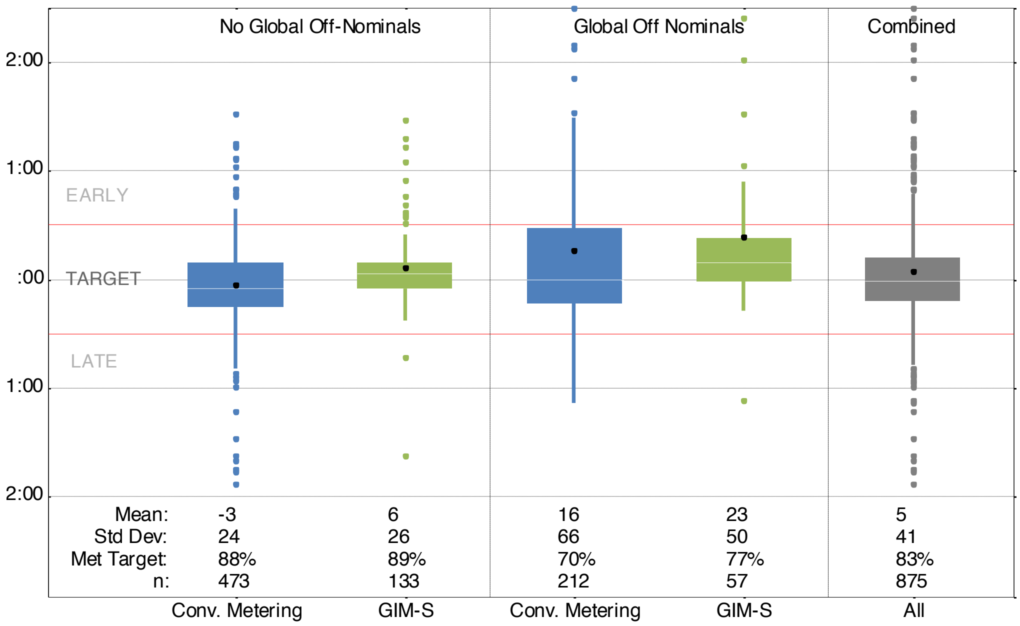


Figure 9a. Delivery Accuracy and Figure 9b. Cumulative Delay for Run 11

D. Impact of GIM-S Configuration and Advisory Type

The impact of GIM-S speed advisories was also investigated, as noted in previous sections. GIM-S speed advisories in cruise were available to help precondition the high altitude aircraft along the EAGUL-6 (from the northeast) arrival flow in ZAB and ZDV, which was consistent with current-day ZAB operations. For PINNG-1 arrivals from the southeast, GIM-S speed advisories for both cruise and descent were provided, For the HYDRR-1 and BRUSR-1 arrivals from the west and northwest, controllers used conventional metering techniques to manage the aircraft arriving from the west.

The delivery accuracy results shown in Figure 10 are grouped across arrival streams using conventional metering versus those with GIM-S speed advisories. In addition the groupings are further broken down to distinguish runs that did not include any global off-nominal events and those that did. This was done as the previous section indicated the significant impact of global off-nominal events on delivery accuracy results.



	Conv. Metering	GIM-S	Conv. Metering	GIM-S	All
Mean:	-3	6	16	23	5
Std Dev:	24	26	66	50	41
Met Target:	88%	89%	70%	77%	83%
n:	473	133	212	57	875

Figure 10. Summary of Delivery Accuracy with GIM-S and Conventional Metering and the Presence of Global Off-Nominal Events

Broken down by runs with and without global off-nominal events, the runs with no global off-nominal events and using GIM-S speed advisories are shown to meet their delivery accuracy target 89% of the time with a standard deviation of 26 seconds. The runs with no global off-nominal events with conventional metering met the delivery target 88% of the time with a standard deviation of 24 seconds. With the introduction of global off-nominal events, the arrival streams using GIM-S speed advisories met the delivery accuracy target 77% of the time, but with conventional metering the proportion that met the target drops to 70%.

In addition to the presence of GIM-S speed advisories, the impact of the various types of advisories was also investigated. Figure 11 illustrates a breakdown of delivery accuracy and initial delay based on GIM-S advisory type. The initial delay is shown on the left side, computed as STA minus ETA at the time when the STA was frozen. Delivery accuracy is shown on the right, computed as the STA minus ATA at the time the aircraft crossed the meter point or arc. GIM-S informed controllers using two advisory types, or an absence of an advisory. An aircraft that is estimated to meet its STA within the 60 second tolerance at the extended meter arc would not be given a GIM-S advisory, and is referred to below as "None Required." If the aircraft fell outside that 60 second tolerance, the system would attempt to compute a GIM-S advisory based on a range of allowable speeds for that airframe at its present altitude. If it is able to compute a speed, then that advisory would be displayed to the controller in the form of a cruise Mach speed or, in the case of PINNG-1 arrival not shown in this plot, both a cruise Mach speed and descent speed in IAS. The controller had the option of accepting and issuing that advisory, but was not required to do so. If no solution could be found to meet the STA using the allowable speeds for that airframe, then message is displayed to the controller indicating that they must meet the STA without the help of a GIM-S speed; these are referred to as "No Advisory" in this analysis.

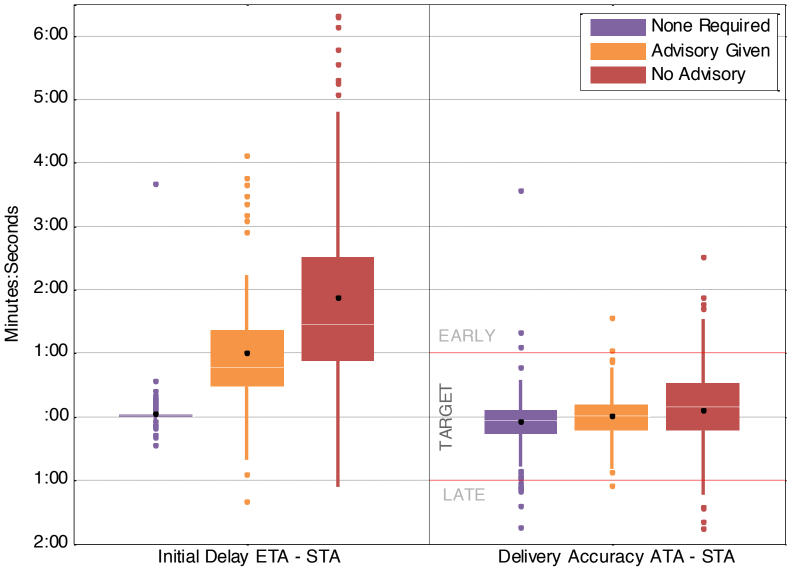


Figure 11. Intial Delay and Delivery Accuracy to the Extended Meter Arcs By GIM-S Advisory

The initial delay figures show that in general, a delay value close to zero will result in a GIM-S advisory not being required, since the aircraft is already on its way to meeting the STA on its current trajectory. GIM-S advisories are generated when a greater amount of delay is allocated to a flight. At very high amouts of delay, an advisory sometimes cannot be computed, especially under certain airspace conditions including short flight distance the meter arc, high altitude, certain airframes, or particularly strong tail winds,. Under these conditions, a controller will likely need to resort to maneuvers beyond speed change alone, such as vectors or altitude changes, to meet the STA. Flights with a GIM-S speed advisory were delivered to their extended meter arc with a similar accuracy to those flights which absorbed no delay; 98% of flights given a GIM-S advisory met their delivery requirement at the extended meter arc, compared to 96% which did were deemed to not require an advisory. Those flights which received a “No Advisory” message and required greater maneuvering at the controller’s discretion met their delivery requirement 89% of the time.

VI. Discussion

The OIA simulation performance data offered an opportunity to investigate a single integrated schedule to examine enroute and terminal area continuity. These data were measured by performance on two different delivery accuracy tolerances that the enroute controllers were instructed to meet: ± 30 seconds at the four meter fixes, and ± 1 minute to the metering arcs. The overall percentage of aircraft that were delivered into the terminal airspace within in ± 30 seconds of their STA was between 85% and 90%, including scenarios where there was a local off-nominal event. However, when a scenario included a global off-nominal event with a local off-nominal event, between 53% and 83% met their delivery accuracy target of ± 30 seconds, and the variability increased as well. The difficulty that enroute controllers may have in meeting the ± 30s performance requirement at the meter fix in the presence of disruptive global off-nominal events represents a possible risk to TSAS deployment. Two individual runs were described during which a global off-nominal occurred that caused a major schedule change. The runs had different arrival rates, low and high; a global off-nominal at a high arrival rate was shown to significantly impact delivery accuracy and the amount of cumulative delay in one enroute sector during the run. The scenario which included staggered arrivals and a high arrival rate was shown to increase cumulative delay values in a single sector to above 140 minutes compared to a 8 minute jump in the low arrival rate scenario. These two examples from the OIA suggest that strategic reschedules by TMCs during global off-nominal events should be done carefully so as to mitigate the amount of delay and vectoring required by enroute controllers in order to limit the impact of global off-nominal events. However, the data analyzed in this paper only reflects a comparison of two scenario conditions and a single set of controllers. To determine the full impact of strategic reschedules further investigation on a larger data set is required.

In addition to the impact of global off-nominal events on a realistic operational environment, the OIA allowed the investigation of the impact of GIM-S advisories on delivery accuracy and preconditioning of the arrival streams in comparison to conventional metering. The delivery accuracy of the two arrival sreams with GIM-S advisories was not found to produce considerable differences during runs with no global off-nominal events; however, during runs with global off-nominal events, the GIM-S advisories helped controllers to meet their delivery accuracy target of ± 30 seconds 77% of the time, compared to 70% using conventional metering techniques. In addition, the standard deviation was reduced from 66 seconds with conventional metering to 50 seconds with GIM-S speed advisories. The type of GIM-S speed advisory given was also investigated and it was shown that among flights for which a GIM-S speed advisory was successfully generated and shown to the controller, 98% met their delivery requirement at the extended meter arc.

Based on the experimental conditions that were tested, the operational risks of integrating TSAS in an operational like environment were determined to be manageable in terms of delivery accuracy implications and integration with existing NextGen technologies, such as GIM-S. Enroute controllers demonstrated that a higher delivery accuracy target could be achieved during local off-nominal events. In the presence of disruptive global off-nominals delivery accuracy performance is degraded and requires research as to the timing of actions from a TMC to mitigate and resolve schedule disruptions. It should be noted that the data considered for this paper was collected in a simulated environoment under prescribed conditions, to fully quantify the impact of global off-nominals and GIM-S integration further investigation on a larger data set is required.

VII. Conclusion

The primary objective of the OIA was to identify technical and operational risks that need to be addressed prior to transitioning TSAS from the laboratory to the National Airspace System (NAS). The risks ranged from the technical integration of the software and hardware components to identification of policy and procedures needed for operational use. The key variables investigated in the simulation were off-nominal events (none, global event, or combined) in two arrival rate scenarios.

The OIA simulation enabled analysis of delivery accuracy at the metering points in a realistic operational environment. The delivery accuracy for ± 1 minute accuracy at the metering fix was consistently high; however, the variability of the delivery accuracy when trying to achieve ± 30 seconds accuracy may present challenges, particularly during off-nominal events. The data also illustrates minor differences in standard deviations of aircraft using the different GIM-S advisories when no schedule disruptions occurred. In addition, the different types of GIM-S advisories were examined, and it was shown that the advisories helped controllers achieve the target delivery accuracy of ± 30 seconds into the terminal. This paper demonstrates controllers’ ability to meet new delivery accuracy requirements in an operational like environment using operational systems, while also including common events that might cause disruptions to the schedule and overall system.

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