



# Controller Initiation and Monitoring of a Relative Spacing Task during Closely Spaced Parallel Runway Operations

## Interval Management Paired Approach Human-In-The-Loop Experiment

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## Executive Summary

The Federal Aviation Administration's (FAA) Next Generation Air Transportation System leverages new technology and concepts to improve efficiency and enhance safety in the National Airspace System. One such concept is Interval Management (IM) which refers to an application suite, enabled by Automatic Dependent Surveillance – Broadcast (ADS-B), providing greater air traffic system throughput and efficiency by improving inter-aircraft spacing precision. IM avionics (termed flight deck-based IM [FIM] Equipment) provide speed commands to the flight crew enabling them to manage a desired spacing relative to another aircraft. IM is a tactical capability used to manage spacing based on a separation standard, miles-in-trail restriction, or any air traffic control spacing objective. The closed-loop nature of IM allows for more accurate speed adjustments to achieve the desired spacing for a given flight segment than can be provided by a ground system.

IM Paired Approach (PA) is intended for dependent approaches to Closely-Spaced Parallel Runways (CSPRs) (i.e., separated by less than 2,500 feet). This application provides a means for CSPR approach and landing operations to continue in weather conditions where visual separation cannot be maintained. IM PA maximizes arrival throughput in Instrument Meteorological Conditions (IMC) by minimizing the in-trail spacing between successive arrivals without compromising safety.

An IM PA aircraft pair consists of a *Lead Aircraft*, equipped with ADS-B Out avionics, and a *Trail Aircraft* equipped with ADS-B In FIM Equipment on the CSPR. A Collision Safety Limit (CSL) is defined between the two aircraft such that the risk of collision is less than  $10^{-9}$  in the case that either aircraft deviates laterally from its approach path into the adjacent path. A Wake Safety Limit (WSL) defines the risk the Trail Aircraft encounters the wake vortices from the Lead Aircraft at a rate no worse than current operations. All IM PA operations require a CSL; however, the need for a WSL is based on aircraft weight category and crosswind conditions. The FIM Equipment provides speeds to the Trail Aircraft flight crew to manage spacing relative to the Lead Aircraft and keep the Trail Aircraft inside the safety limits for the entire approach to its runway threshold. A new separation standard is envisioned for IM PA operations and it will likely be based on allowable safety limit values as implemented at each airport.

The FAA, National Aeronautics and Space Administration (NASA), The MITRE Corporation's Center for Advanced Aviation System Development (CAASD), and others have been conducting research on various aspects of PA for over two decades. In 2016, RTCA Special Committee 186 (SC-186) Working Group 4 decided to make PA an IM application and include it in the updated FIM Equipment requirements. Through this process, stakeholders determined controllers must be able to monitor the operation relative to a separation standard. This requires controllers to be able to assess separation within an IM PA pair and take effective action before separation is lost. Therefore, the IM PA concept was changed to move the safety limit monitoring function from being a flight crew responsibility and FIM Equipment capability to a ground capability, likely to be hosted in the Standard Terminal Automation Replacement System.

The FAA's Surveillance Broadcast Services (SBS) Program Office tasked MITRE CAASD to develop and execute a Human-In-The-Loop (HITL) simulation experiment to validate IM PA concept changes, address open controller acceptability and feasibility questions, provide input to air and ground system requirements, and mitigate technical risks associated with the revised PA

concept. The primary goal of this HITL simulation was to examine new controller monitoring functions. A secondary goal was to examine acceptability and information requirements for IM PA initiation.

Addressing the primary goal included an evaluation of the terminal controller monitoring task for IM PA aircraft pairs established on final approach, especially with respect to both minimum and maximum separation values that change over the course of the approach, and for lateral deviations. Related to this goal was the acceptability of a single Monitor controller to manage Lead and Trail Aircraft, or whether separate monitors should be required. The experiment also included an evaluation of prototype display features to facilitate this monitoring task. These features were developed by MITRE CAASD for the FAA's Closely Spaced Parallel Operations Program Office in coordination with SBS and the FAA's Operational Concepts, Validation, and Requirements office in 2017.

Data collection occurred in April 2018 and twelve currently certified Air Traffic Controllers participated in the simulation. Four controllers were from the Northern California Terminal Radar Approach Control facility and had experience in the areas being simulated. Eight controllers were from other terminal facilities with parallel runway approach operations. The controller participants managed scenario traffic that included IM PA operations in both Final Approach and Final Monitor positions. Two pseudopilots controlled and responded as all aircraft. Two confederate controllers served as Local controllers.

After initiating and monitoring IM PA operations with varying supporting IM PA (display) Tool configurations, monitor configurations, and off-nominal deviations, results suggest given the appropriate tools and training, the IM PA longitudinal and lateral separation monitoring task should be feasible and acceptable to controllers. IM PA pair-wise separation assurance appeared to be a straightforward task for controllers as only a single violation was observed within an IM Trail Aircraft and IM Lead Aircraft pairing, despite the introduction of far more off-nominal deviations than would be expected in actual operations. This instance involved a controller appearing to attempt to manually manage an IM PA Trail Aircraft's speed. It was not a result of the controller failing to notice a developing situation.

Separation was also examined between other aircraft combinations (e.g. between the trail aircraft of a leading pair and the lead aircraft of a following pair). Twelve total instances of separation violations were observed between aircraft pairs not performing IM PA. It was unclear if this was due to the presence of IM PA in the operational environment or was related to controllers in the simulation not having current separation tools such as Automated Terminal Proximity Alert available to them. Although these violations occurred in the context of simulation events that were designed to stress test the concept and ground tools, their presence still suggests that tools and procedures need to be fully integrated to ensure that separation between aircraft pairs not performing IM PA can be maintained while IM PA operations are in progress. In addition, IM PA setup spacing requirements should ensure that between-pair separation can be sufficiently maintained during compression on final.

Controller participants on average reported: low and acceptable workload; acceptable tasks in each of the monitoring positions; acceptable levels of traffic awareness for all types of aircraft; comfort in allowing the IM Trail Aircraft to manage their own speeds; and confidence they could assess whether the separation between the IM Trail Aircraft and Lead Aircraft would be

maintained. They also agreed IM PA is operationally desirable and compatible with terminal approach operations, though real-world facility and airspace integration may be challenging. Controller participants appeared to be comfortable monitoring IM PA when both safety limits (CSL and WSL) that changed over the course of an approach were active at the same time.

Due to the potential logistical and operational challenges certain facilities may have employing two Local controllers, the HITL experiment examined whether a single, combined Monitor controller can effectively provide separation for two CSPR final approaches involving IM PA operations. Results suggest under nominal conditions, a single, Combined Monitor controller is likely to be able to effectively and acceptably provide separation within and between IM PA pairs. However, further study is recommended to examine whether separate monitors may ultimately be required for safety to manage extreme off-nominal lateral deviation situations.

The simulation also produced several findings and recommendations with respect to the IM PA Tool display elements. Graphic depiction of the safety limits were preferred to numeric distances presented in the Trail Aircraft data block. As the WSL only became active late in the approach, controllers found a preview feature helpful in indicating whether an aircraft would eventually require it. Alerts were introduced to direct controller attention to aircraft that were starting to encroach on either limit and controllers found these useful.

For the lateral monitoring task, a 4:1 aspect ratio Final Monitor Aid display was found to significantly help controller lateral deviation assessment; however, questionnaire responses did not appear to suggest it should be a minimum requirement. A Warning was introduced to inform controllers when a lateral deviation occurred and IM PA needed to be terminated. Controllers found it useful and offered suggestions to increase its saliency.

Most controllers reported a Final Monitor controller is the most appropriate position to monitor IM PA operations, though this may ultimately depend on the facility. They also expressed a strong preference to provide speeds manually to the IM Trail Aircraft when they observed a spacing situation start to develop. However, the practicality of this may depend on whether a Final Approach controller or dedicated Monitor controller is providing separation within and between IM PA pairs. Controller manual PA speed management must be balanced with the potential for undesirable frequency overrides and workload, which may make it highly challenging to implement.

With respect to the experiment's secondary goal to evaluate the IM PA initiation task, controller participants on average agreed Final controllers: can acceptably initiate the IM PA operation; can acceptably ensure separation during IM PA operations before transferring aircraft to the Local controller given the appropriate training and tools; and were comfortable with the IM Trail Aircraft managing speed to achieve the spacing goal. However, concerns were raised regarding the phraseology, available CSL and WSL information at the time of initiation, and the available time and airspace to perform the initiation task as simulated.

Overall results suggest given the appropriate tools and training, the IM PA longitudinal and lateral separation monitoring and initiation tasks should be acceptable to controllers. In a related IM PA flight deck features evaluation performed in 2018, pilots also found IM PA to be generally acceptable, even after experiencing significant lateral deviations by the Lead Aircraft. The current IM PA concept appears feasible and MITRE CAASD recommends the FAA continue its development.

This study provided initial findings on the initiation and monitoring of an IM PA operation. The results are intended to provide concept validation for the avionics standard development activities and A-IM Concept of Operations, as well as specific recommendations for the FAA IM Initial Program Requirements document with respect to controller information needs and supporting ground tools. These results and recommendations should be considered by RTCA SC-186, FAA SBS Program Office, FAA Aircraft Certification, and FAA Flight Standards as IM PA proceeds through concept maturation.

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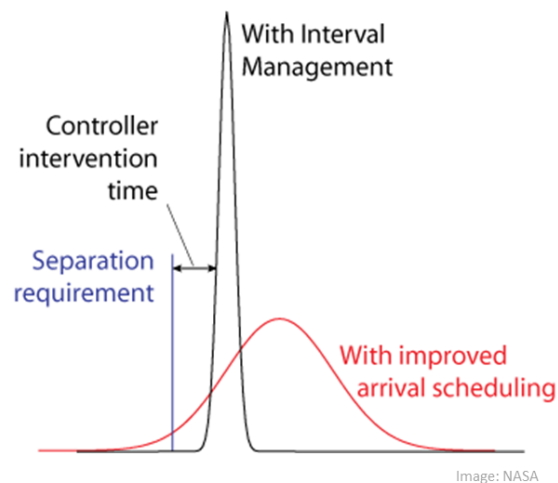
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# 1 Introduction

The Federal Aviation Administration’s (FAA) Next Generation Air Transportation System (NextGen) leverages new technology and concepts to improve efficiency and enhance safety in the National Airspace System (NAS). These include improvements in communication, navigation, and surveillance systems, such as the deployment of Automatic Dependent Surveillance-Broadcast (ADS-B), and expanded use of trajectory based operations (TBO), including time-based aircraft spacing and scheduling. New traffic management concepts based on the confluence of these technologies are intended to mitigate the potential for increased delays in the NAS and projected airport capacity shortfalls.

One such concept is Interval Management (IM) which refers to an application suite, enabled by Automatic Dependent Surveillance-Broadcast (ADS-B), providing greater air traffic system throughput and efficiency by improving inter-aircraft spacing precision. IM is a tactical capability used to manage spacing based on a separation standard, miles-in-trail restriction, or any air traffic control (ATC) spacing objective. Or, as it relates to TBO, to the metering schedule.

IM avionics (termed flight deck-based IM [FIM] Equipment) provide speed commands to the flight crew enabling them to manage a desired spacing relative to a *Lead Aircraft*. The closed-loop nature of IM allows for more accurate speed adjustments to achieve the desired spacing for a given flight segment than can be provided by a ground system. As shown in Figure 1-1, this leads to improved inter-aircraft spacing precision and allows aircraft to be consistently spaced closer to the separation standard or metering constraints, thus increasing throughput in capacity-constrained airspace. IM is primarily being developed to increase arrival throughput at metered airports; however, it is also expected to enable more efficient spacing during high traffic periods at other facilities as well.



**Figure 1-1. Improved Spacing Consistency with IM**

An initial set of avionics standards supporting a limited set of IM operations were published by RTCA Special Committee (SC) 186 Working Group (WG) 4 in 2015 (RTCA, 2015). Three years later, an FAA Systems Engineering Working Group (SEWG) developed an Advanced IM (A-IM) Concept of Operations (ConOps) for IM during arrivals and approaches, and en route and terminal merging operations (FAA, 2017b). In conjunction with that activity, RTCA SC-186 WG4

group is currently updating the Flight-deck Interval Management (FIM) Safety and Performance Requirements (SPR) (DO-328A) (RTCA, 2019a) and the FIM Minimum Operational Performance Standards (MOPS) (DO-361) (RTCA, 2019b) documents to enable the A-IM operations included in the ConOps. This includes enabling more complex route geometries, such as an IM and Lead Aircraft arriving to parallel or crossing or converging dependent runway configurations. In addition, these updates improve the utility of IM operations through further integration with data communications, leveraging air/ground trajectory synchronization, and better performance from the use of higher fidelity wind data.

There are many possible applications of IM with varying operational objectives, desired spacing behavior, and operating environments. One of the advanced concepts supported by the new standards and ConOps is IM Paired Approach (PA), which is intended for use on dependent approaches to Closely-Spaced Parallel Runways (CSPRs) (i.e., separated by less than 2,500 feet [ft]). IM PA provides a means for CSPR approach and landing operations to continue in weather conditions where visual separation cannot be maintained. IM PA maximizes arrival throughput in IMC by minimizing the in-trail spacing between successive arrivals without compromising safety. For example, IM PA may be able to preserve two runway operations at San Francisco International Airport (SFO) to applicable Category (CAT) I minima for the approaches in use Stassen, et al. (2013).

The FAA, National Aeronautics and Space Administration (NASA), The MITRE Corporation's Center for Advanced Aviation System Development (CAASD), and others have been conducting research on PA as a separate ADS-B concept for over two decades. In 2016, RTCA SC-186 WG4 decided to make PA an IM application and include it in the updated FIM Equipment requirements. Through this process, stakeholders determined controllers must be able to monitor the operation relative to a separation standard. This requires controllers to be able to assess separation within an IM PA pair and take effective action before separation is lost. Therefore, the IM PA concept was changed from that described in Stassen, et al. (2013), to move the safety limit monitoring function was move from being a flight crew responsibility and FIM Equipment capability to a ground capability, likely to be hosted in Standard Terminal Automation Replacement System (STARS).

To validate the revised PA concept, the FAA's Surveillance Broadcast Services (SBS) Program Office tasked MITRE CAASD to develop and execute a Human-In-The-Loop (HITL) simulation experiment to address open controller acceptability and feasibility questions, provide input to air and ground system requirements, and mitigate technical risks associated with the revised PA concept. This HITL simulation helped define the controller's role in IM PA and informed the design of new ground tools needed to enable the operation. These features were developed by MITRE CAASD for the FAA's Closely Spaced Parallel Operations (CSPO) Program Office in coordination with SBS and the FAA's Operational Concepts, Validation, and Requirements office in 2017. The results and recommendations should be considered by RTCA SC-186, FAA SBS Program Office, FAA Aircraft Certification, and FAA Flight Standards as IM PA proceeds through concept development.

This document presents the findings of the simulation and has seven main sections including this one. *Section 2— Background, Concept Description, and Prior Research* provides an overview of CSPR arrival operations, the IM PA concept, and summarizes relevant past work. *Section 3— Research Goals, Questions, and Hypotheses* presents the main research questions and

hypotheses for this study. *Section 4—Experiment Methodology* describes how the simulation was conducted. *Section 5—Results* summarizes the results of the data collection, including the statistical analyses. *Section 6—Discussion* reviews the major findings and puts them in an operational context. *Section 7—Conclusions and Recommendations* reviews the key findings and provides recommendations for continued IM PA development and future research.

## 2 Background, Concept Description, and Prior Research

This section provides an overview of the CSPR operational environment, describes the IM PA concept including its potential implementation at SFO, and summarizes past PA and IM research that is relevant to this study.

### 2.1 Closely Spaced Parallel Runway Arrival Operations

Parallel runways spaced closer than 2500 ft are defined as closely spaced parallel runways (CSPRs). Current separation minima require that such runways be treated as one for arrivals and departures, unless other types of separation (e.g. visual or 7110.308C) are used in place of standard radar separation. To maximize throughput for CSPRs, facilities employ simultaneous visual approaches whenever possible. During simultaneous visual approach operations to CSPRs, maximum arrival throughput relies on the use of pilot-provided visual separation between two arrival aircraft. This effectively allows two streams of traffic to the CSPRs. However if aircraft cannot provide its own visual separation relative to a lead aircraft on the CSPR, one of the aircraft is broken out of the flow. This results in a single runway operation<sup>1</sup> and loss of throughput.

As described in FAA (2017a), the application of visual separation is relatively straightforward in good Visual Meteorological Conditions (VMC) when conditions exceed visual approach minima. Visual approach minima are required to be at least MVA+500, where the MVA is the Minimum Vectoring altitude. In actual operations, the minima to which Terminal Radar Approach Controls (TRACONs) will conduct visual approaches vary greatly from airport to airport, depending on the airspace and the airport operations. At SFO, for example, visual operations can be conducted with relative ease for ceilings and visibilities exceeding 5000 ft and 10 miles. However, pilot-applied visual separation is more difficult in Marginal Meteorological Conditions (MMC). At SFO, for example, these consist of a ceiling of ~4000 ft and 5-7 miles visibility.

Pilot-applied visual separation is impossible in IMC with ceiling and visibility less than 1000 ft and 3 miles, respectively. When simultaneous visual approaches to the CSPRs cannot be conducted, the airport operations change from a two-runway operation to a single runway operation, with a consequent significant loss of throughput<sup>2</sup>. To regain some of this lost throughput, reduced separation standards and procedures have been developed for airports with CSPRs in MMC and IMC operations. The following describes the various available CSPR operations in each type of meteorological condition.

**“Good” VMC.** Side-by visual approaches at CSPR airports can be conducted down to visual approach minima. Controllers vector aircraft, or procedures are developed, to deliver aircraft to their respective final approach courses separated with 1000 ft vertical or 3 nautical miles (NM) lateral separation. When the trail aircraft can provide and maintain visual separation with the parallel traffic, vertical or lateral separation is discontinued and each aircraft is cleared for an approach<sup>3</sup>. Any weight class (excluding Super) may be the lead of a pair; the only requirement is

<sup>1</sup> Except for the 7110.308C operation, which is described later, and which does not quite fill the throughput gap.

<sup>2</sup> At SFO, the two runway visual operations rate is 54, and the single runway rate is 32. However, SFO can also use 7110.308C which allows them to use staggered approaches down to Cat I minima, with a rate between 34 and 36.

<sup>3</sup> At SFO, to facilitate departures, arrival aircraft may be paired (i.e., they are ‘side-by’ or nearly so) so that arrivals may cross the runway thresholds within 0 - 0.25 NM of each other.



Precision Runway Monitors (PRMs) or Final Monitor Aid (FMA) to monitor aircraft position relative to the NTZ, and must use an override frequency for communications. If an aircraft deviates from its final approach course toward the NTZ, the controller must advise the flight crew that they are off course and to return to the final approach course. If the aircraft does not comply and enters the NTZ, the other aircraft of the pair is issued a traffic alert and is vectored away from the deviating aircraft. In the event of such a time-critical PRM “breakout” instruction, the Monitor controller overrides the Final controller on the PRM frequency. Therefore, these operations require flight crews to tune their radios to both the final approach frequency and a second monitor frequency.

**IMC.** When weather conditions do not allow visual separation or SOIA procedures between arrivals on CSPRs, aircraft must land single-file to one runway or they may be staggered to each of the parallel runways. While both runways are used in this configuration (by alternating arrival runways, for example), the resulting arrival throughput is effectively the same as if operating to a single runway. However, FAA Order 7110.308C allows for reduced diagonal separation on the parallel final approach course if certain weather and weight restrictions are met (FAA, 2018b).

For the 7110.308C procedure, as with the VMC and MMC procedures, aircraft are delivered to their respective final approach courses separated by the standard 1000 ft or 3 NM. Once established on their respective courses, each aircraft is cleared for an approach and standard lateral and vertical separation are discontinued. The diagonal separation for this dependent pair can be as low as 1 NM at certain airports. Standard radar or wake turbulence separation must be provided to the next aircraft to follow a dependent pair. These approaches may be conducted down to CAT I minima; however, a Super, Heavy, or B757 may not lead a dependent pair. No Monitor controllers are required for these dependent approaches.

Though helpful, the 7110.308C and SOIA procedures have restrictions that limit how often they can be used and how close the aircraft can get from each other. The 7110.308C operation is currently only available at eight airports<sup>4</sup> in the NAS, the leading aircraft must be a large or small weight category, and the closest possible intra-pair diagonal spacing is 1 NM. The SOIA operation requires specialized ground equipment, NTZ monitoring, an offset approach, special flight crew training, and a visual segment during the final portion of the approach. The visual maneuver with SOIA involves first a bank towards the parallel final, followed by a bank away from the parallel final. During this time, aircraft structure can interfere with the flight crew’s ability to maintain visual contact with the aircraft on the parallel final. SOIA is currently only available for SFO and Cleveland-Hopkins International Airport (CLE). At SFO, it is authorized for use down to a ceilings and visibility of 1400 ft and 4 miles. However, the SOIA procedure at SFO has been replaced with 7110.308C procedures, which are more predictable, deliver about the same aircraft arrival rate, and requires fewer controllers and less specialized equipment. SFO is able to attain an arrival rate of 36 with 7110.308C, which is still a considerable decrement from its rate of 54 for visual operations. The IM PA operation is intended to help close this gap.

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<sup>4</sup> The airports are: BOS, CLE, EWR, MEM, PHL, SEA, SFO, and STL. They are in regular use at SFO, though their use at the other airports is not as prevalent.

## 2.2 Concept Overview

PA is one of several applications of IM. This section first summarizes the general concept of IM. Then, the specifics of the IM PA application are discussed in greater detail.

### 2.2.1 Interval Management

IM is intended to enable an increase in the reliability and accuracy of the spacing interval between an IM Aircraft and its Target Aircraft than is possible from a ground system alone. A more accurate and reliable spacing interval can support a decrease in spacing buffers, which in turn increases throughput during high-demand arrival operations (Bone & Mendolia, 2018). Other advantages include increased predictability of the overall arrival flow, which should increase the number of aircraft that remain on their RNAV arrival procedures. This also reduces the number of speed assignments needed to manage the arrivals, thereby reducing communications and workload. An overview and history of IM is available in Barmore, et al. (2016).

As described in Penhallegon & Stassen (2018), a general IM operation involves an air traffic controller, assisted by automation as needed, clearing an IM-capable aircraft to manage a desired time or distance-based spacing interval (termed Assigned Spacing Goal), relative to a specified Target Aircraft. Two types of spacing goal behavior have been defined by RTCA (2019b). The first, termed Achieve, has the IM Aircraft achieve the Assigned Spacing Goal by a desired location, termed the Achieve-by Point (ABP), within  $\pm 10$  seconds (sec) across 95% of IM Achieve operations. The second behavior, termed Maintain, has the IM Aircraft manage its speed to stay within  $\pm 10$  sec of the Assigned Spacing Goal for at least 95% of the operation on a specified route segment.

When the flight crew receives the IM Clearance, they enter its information into their on-board Flight-deck IM avionics (termed FIM Equipment), which then starts providing speed guidance (termed IM Speeds) to help them achieve and/or maintain the desired spacing. The flight crew then follows the IM Speeds until the IM operation is terminated either by a controller or at specified location, termed the Planned Termination Point (PTP).

An IM operation begins immediately after a controller provides all the IM Clearance information at once and the flight crew accepts. Alternatively, a controller may issue a Partial IM Clearance. A Partial IM Clearance contains all required IM Clearance information except the Assigned Spacing Goal. This allows a flight crew to prepare the FIM Equipment before IM is intended to begin. For terminal IM operations, this should allow an en-route controller to transmit IM information using Controller Pilot Data Link Communications (CPDLC) possibly during a less busy phase of flight for the flight crew. Then, at the desired start of the IM operation, a terminal controller provides the Assigned Spacing Goal over voice. Flight crew acceptance of this second message constitutes acceptance of the IM Clearance and IM begins. A Partial IM Clearance can be provided to an IM Aircraft already executing an IM operation; however, only a single Partial IM Clearance can be accommodated by the FIM Equipment at a time (RTCA, 2019a).

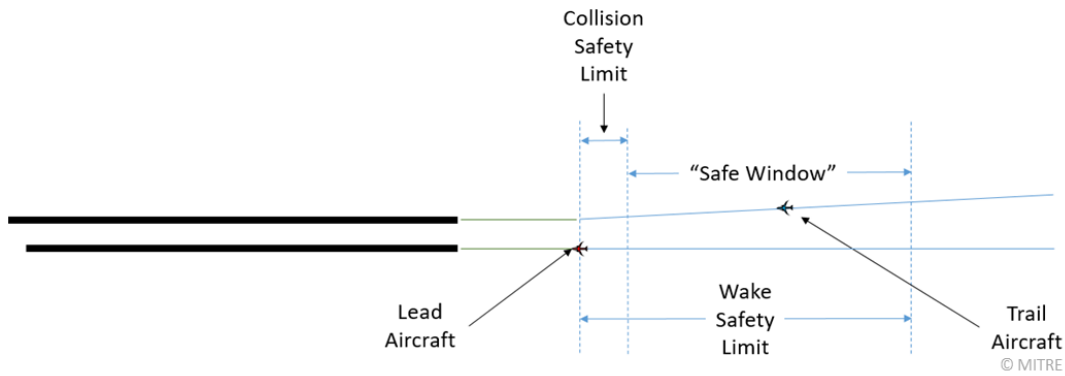
Introducing a relative spacing task to the flight deck will require additional training for both controllers and flight crews. Though IM operations will not change the separation responsibilities of ATC, they are intended to be used in the context of a variety of types of

operations, governed by a variety of separation standards. In most cases, the increased spacing accuracy IM provides enables a reduction in the buffers added to the applicable separation standard. IM can also reduce buffers and increase accuracy when the spacing objective exceeds the separation requirement, such as when spacing between successive arrivals is increased to allow for departures in the intervening time.

## **2.2.2 IM Paired Approach**

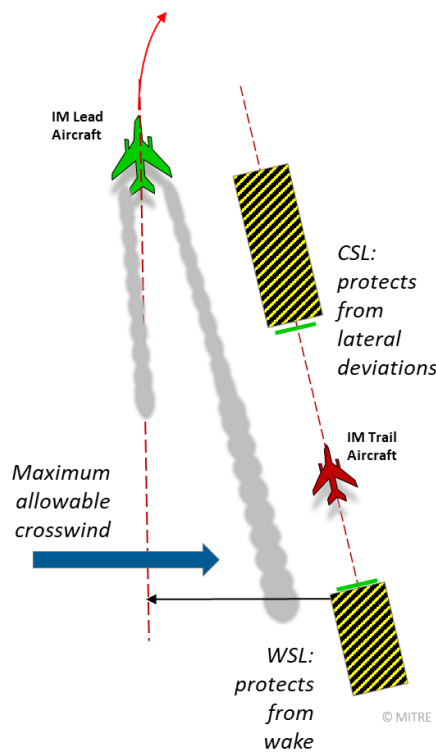
The IM PA application provides a means for CSPR approach and landing operations to continue in weather conditions where visual separation cannot be maintained. IM PA maximizes arrival throughput in IMC by minimizing the in-trail spacing between successive arrivals without compromising safety. The concept combines beneficial aspects of both 7110.308C and SOIA operations, while mitigating some of their restrictions. In its fully developed state, IM PA operations are envisioned to be available in weather conditions down to the applicable CAT I minima for the approaches used. The ability to support operations independent of wake category and/or crosswind components along the approach is still being determined. Benefits and feasibility analyses performed by the FAA, MITRE, and other stakeholders suggest IM PA is likely to result in significant throughput increases and reduced delays, especially during IMC Stassen, et al. (2013), (Penhallegon, Stassen, Elliott, & Gryphon, 2016), (FAA, 2018a). In addition, ground delay programs and airspace flow programs can be modified to ensure an appropriate flow of additional aircraft is available to increase throughput at the terminal facility conducting IM PA operations (FAA, 2017b). Airports that may benefit from IM PA include: Boston, Cleveland, Newark, Chicago Midway, Philadelphia, San Francisco, and San Jose (Mendolia, et al., 2016).

An IM PA aircraft pair consists of an IM Lead Aircraft, equipped with ADS-B Out avionics, and an IM Trail Aircraft equipped with ADS-B In FIM Equipment. A Collision Safety Limit (CSL) is defined between the two aircraft such that the risk of collision is less than  $10^{-9}$  in the case that either aircraft deviates laterally from its approach path into the adjacent path. As shown in Figure 2-2, the CSL ensures the aircraft do not collide in the event of a flight path deviation by providing enough spacing so the deviating aircraft can pass through the other aircraft's approach path. A Wake Safety Limit (WSL) defines the risk the Trail Aircraft encounters the wake vortices from the Lead Aircraft at a rate no worse than current operations. It ensures the IM Trail Aircraft remains close enough longitudinally so the IM Lead Aircraft's wake turbulence passes behind the trail aircraft. These safety limits provide the time needed for controllers to detect and mitigate potential exceedances before they occur. All IM PA operations require a CSL; however, the need for a WSL is based on aircraft weight category and crosswind conditions.



**Figure 2-2. IM PA Safety Limits**

The IM Trail Aircraft is protected from collision by the CSL in case of an inboard lateral deviation by the IM Lead Aircraft as shown in Figure 2-3. Additionally, by staying forward of the WSL, it is protected from the IM Lead Aircraft’s wake even under unfavorable crosswind conditions.



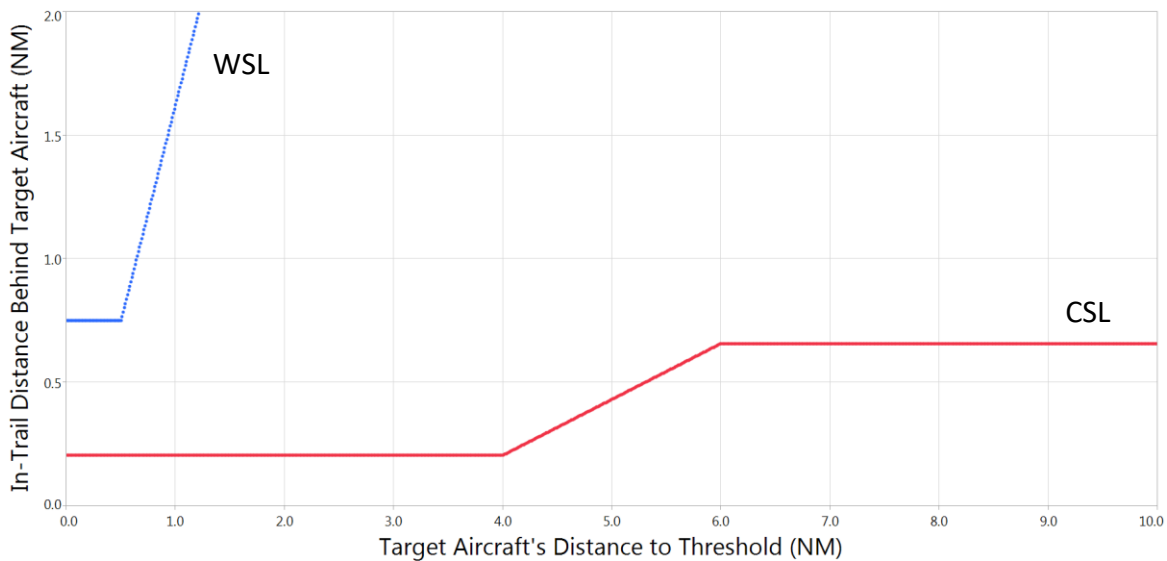
**Figure 2-3. IM Trail Aircraft between WSL and CSL**

In the IM PA procedure, the Assigned Spacing Goal is designed to keep the IM Trail Aircraft inside the safety limits for the entire flight to the runway threshold. IM PA begins when a terminal controller clears an IM Trail Aircraft to pair behind an IM Lead Aircraft, and to capture and maintain a desired Assigned Spacing Goal by flying the IM Speeds generated by the FIM Equipment. This continues until the PTP which in most cases is expected to be collocated with the FAF. After this point, the IM Speed guidance is terminated, and the IM Trail Aircraft begins configuring to its final approach speed. The Assigned Spacing Goal therefore represents the desired spacing between the two aircraft at the PTP and is a function of a variety of factors.

These include the approach geometry and the difference in IM Trail Aircraft and IM Lead Aircraft predicted flight times between the PTP and the runway threshold, which is largely a function of the difference in landing speeds.

The IM PA operation depends on the ability of ground automation to compute an Assigned Spacing Goal that keeps the IM Aircraft within the safety limits, with time for controllers to respond to any developing encroachment of the CSL and WSL. Separation will need to be ensured by the controller until the IM Lead Aircraft crosses its runway threshold; therefore, the Assigned Spacing Goal must be attainable before termination of speed guidance at the PTP and still allow for the compression or expansion that may occur during the final phase of the approach.

As described in the FAA A-IM ConOps (FAA, 2017b), the CSL and WSL are airport-specific and will change over the course of a typical IM PA operation. The notional example in Figure 2-4 illustrates how the CSL (lower, red line) moves closer to the IM Lead Aircraft on a six-mile final in the vicinity of the FAF and the PTP. Therefore, to increase throughput by reducing the spacing interval at the runway threshold, some amount of compression is desirable after the PTP. This suggests that whenever possible, controllers and/or ground automation should select the aircraft with the higher landing speed as the IM Aircraft in an IM PA operation.



**Figure 2-4. Notional IM PA Example Safety Limits**

In some cases, it may be operationally desirable to allow the faster aircraft to lead in an IM PA operation, such as when the effort associated with exchanging the lead and trail positions on the approach leads to a greater loss of throughput than the expansion that would otherwise occur after the PTP. However, the amount of expansion that can be tolerated is limited by the WSL (if required, the upper, blue line in Figure 2-4). For the geometry shown in the figure, anything more than a small amount of expansion would lead to exceedance of the WSL on short final. Therefore, the ability of the IM PA operation to tolerate a faster leading aircraft depends on the runway spacing, winds, and WSL.

### **2.2.3 PA Separation**

IM PA will require a new dependent parallel runway separation standard. Though the FAA has not yet begun to define this standard, it will likely be based on allowable CSL and WSL values as implemented at specific airports. In order to define an IM performance requirement for PA, safety limit values at various facilities with CSPR, including SFO, are being considered by RTCA SC-186, WG4, based on FAA Flight Standards (AFS) analyses (Williams & Wood, 2017) and empirical wake data provided by Volpe (unpublished). These safety limits were designed to accommodate some amount of normal aircraft crosstrack error from the approach path centerline. However, lateral deviations beyond the design limits (e.g. blunders) may result in the CSL and WSL no longer being adequate to ensure the required level of safety. Therefore, to indicate to controllers when lateral deviations exceed the CSL and WSL design error assumptions, inboard and outboard lateral boundaries for each aircraft in an IM PA pairing could be part of the separation standard.

As described further in Section 4.2.1, the PA separation standard assumed for the HITL experiment that is the subject of this paper was informed by SC-186 WG4 safety limit calculations for SFO (Williams & Wood, 2017). The HITL further assumes that controllers will not be required to detect lateral deviations and break out an IM Trail Aircraft for collision protection before one aircraft in an IM PA crosses the path of the other. However, they will need to be informed as to when an aircraft's crosstrack error may result in the CSL and WSL no longer providing the required protection from collision or wake risk. Research in this area is still on-going, especially with respect to air versus ground deviation detection and appropriate response procedures. Many unknowns remain with respect to what will be required for PA separation and therefore the limits, assumptions, and procedures used in this HITL may not ultimately match the FAA's final PA separation standard design.

In addition, a full IM PA operation may not necessarily need to be implemented all at once. Some consideration has been given to a potential evolutionary approach which supports building experience with more benign operations before progressing to more challenging implementations. For example, initial implementations that limit allowable wake category pairings and operate to higher approach weather minima could be considered in advance of a PA-specific separation standard being finalized (Bateman, et al., 2017). IM PA separation and implementation may not be fully understood until after the completion of a full safety process, separation standard design, and determination of facility-specific adaption parameters.

### **2.2.4 IM PA Setup**

The IM PA procedure is contained within the terminal area and can only be executed once both aircraft are established on their final approach courses. IM PA would function equally well within metered and non-metered flows. The two domains differ mainly in the way aircraft are delivered to the approach and their initial spacing controlled to ensure success. These differences are shown in Table 2-1.

**Table 2-1. IM PA Setup in Metering and Non-Metering Environments**

	<b>Metering Environment</b>	<b>Non-Metering Environment</b>
<b>Flight Paths</b>	<b>Continuous RNAV routes</b>	<b>Vectors and/or RNAV routes</b>
<b>Identification of pair, ASG* &amp; IM Clearance(s)</b>	<b>Time-Based Flow Management (TBFM) (possibly 2 IM operations)</b>	<b>Coordinator controller (aided by automation)</b>
<b>Initial Aircraft Delivery</b>	<b>Aided by IM or Terminal Sequencing and Spacing (TSAS)</b>	<b>Vectors and/or speed assignments</b>
<b>Start of PA operation</b>	<b>Once both aircraft are established on final</b>	

\*Assigned Spacing Goal

In a TBFM environment, en route and terminal time-based metering automation can provide speed guidance to controllers to position the aircraft pair with a suitable starting interval at the start of the IM PA operation. Or, when available, IM PA can be set up by another IM operation that is initiated en route. This other IM operation delivers the IM PA pair to their final approach segments in position to transition to an IM PA procedure. A scenario that illustrates both cases is summarized in Penhallegon & Stassen (2018).

When metering is not available, controllers must manually set up a “tactical” IM PA operation, possibly with the support of unique IM PA tools. This involves the identification of aircraft pairs, Assigned Spacing Goals, and establishing the aircraft on their final approaches with the appropriate initial spacing as described in Stassen, et al. (2013) and FAA (2017b). ATC HITL research involving controllers from Northern California TRACON (NCT) suggests this is feasible (Domino, Tuomey, Stassen, & Mundra, 2014), though somewhat challenging if a 15 NM or longer final is an absolute minimum requirement (Mendolia, et al., 2016).

General setup conditions and procedures for either the metering or non-metering (tactical) case are not further described in this paper as they are not directly relevant to the findings. However, potential concepts for setting up IM PA for SFO arrival operations are described in Section 2.3.3.

## **2.2.5 Planned Final Approach Speed**

In any arrival and approach operation, it is important to understand the speed profile of successive arrivals late in the approach to maximize buffer reduction. As described in Stassen, Priess, & Weitz (2016), factors such as final approach speed have a bearing on the evolution of the spacing interval late in the approach. Because of this, the PA concept has traditionally assumed the need for Planned Final Approach Speed (PFAS) as input to the spacing goal calculation Stassen, et al. (2013). One implication is that if the relative difference in PFAS between the IM Trail Aircraft and IM Lead Aircraft changes beyond a certain threshold, the Assigned Spacing Goal may need to be recalculated and sent to the IM Trail Aircraft. It is not known if it will be necessary to consider changes in PFAS in real time once the aircraft have

been cleared for their approaches. It may ultimately be decided to allow the aircraft to be broken out only if it appears that either the CSL and WSL will be exceeded.

The requirements for providing PFAS and managing revisions are still being determined. Due to the lack of definition around the alternatives and trade space, the research scope for this study did not include an examination of the human factors issues associated with relative PFAS changes and Assigned Spacing Goal updates.

## 2.3 Application of IM PA to NCT and SFO Operations

Implementation of the IM PA procedure is highly dependent on the facility and operational environment. As this HITL simulation examined an IM PA operation at NCT/SFO, this section provides an overview of the relevant airspace, then summarizes how IM PA operations could possibly be incorporated into NCT and SFO arrival operations in both metering and non-metering environments.

### 2.3.1 NCT/SFO Airspace Overview

As shown in Figure 2-5<sup>5</sup>, NCT manages three main flows into SFO airspace, worked by a variety of positions. The DYAMD flow is worked by the Cedar High Feeder, Niles Low Feeder and Foster Final. The SERFR flow is worked by the Laguna High Feeder, Boulder Low Feeder and Woodside Final, and the BDEGA flow is worked by the Boulder Low Feeder and Woodside Low Final (landing Runway 28L) or Foster Final (landing Runway 28R). The approximate balance of traffic on these three routes is 50 percent on DYAMD, 25 percent on SERFR, and 25 percent on BDEGA. A small number of satellite airport operations (Oakland, San Carlos, San Jose) and tailored oceanic arrivals (PIRAT) occur in the airspace. In addition, vectoring airspace floors are established to accommodate Moffet Federal Airfield operations.

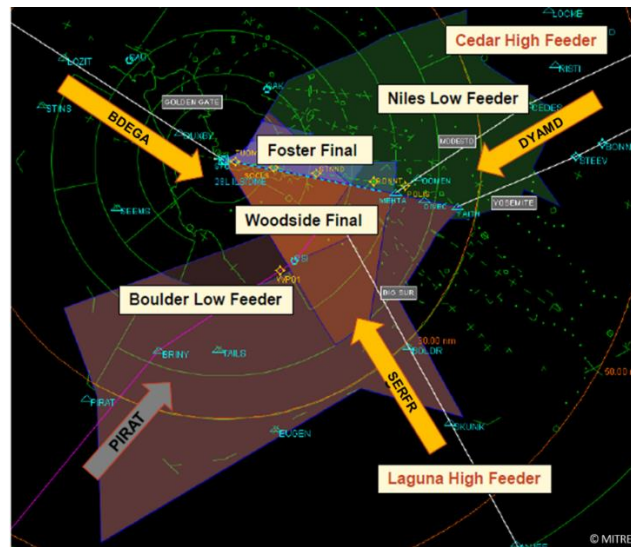
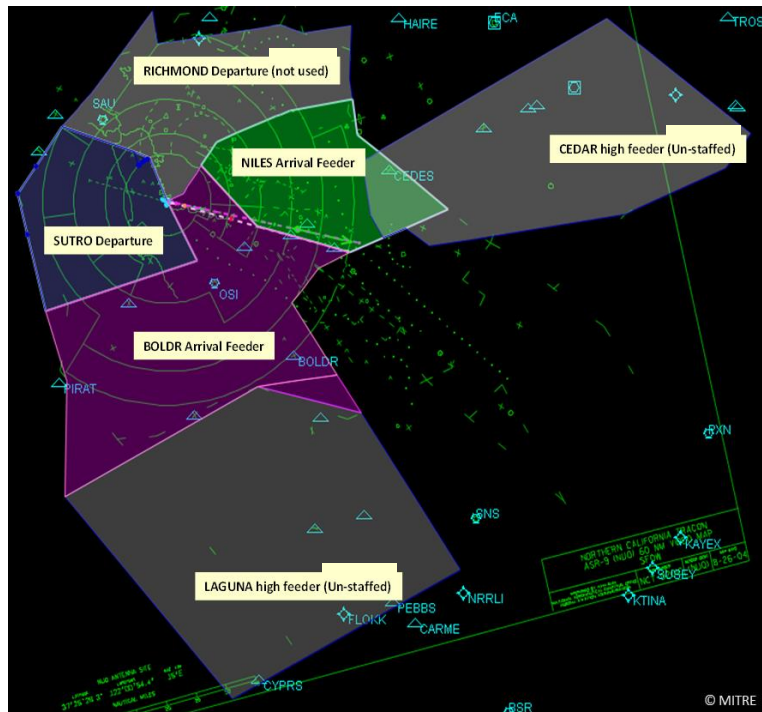


Figure 2-5. SFO Traffic Flows and ATC Positions

The SFO arrival and departure sectors are depicted in Figure 2-6. Four arrival positions normally manage the inbound flows to SFO. The low altitude arrival positions are NILES and BOULDER

<sup>5</sup> Several of the figures in this section are adapted from Mendolia, et al. (2016).

and the high-altitude positions are CEDAR and LAGUNA. All breakouts are handed off to the departure sector SUTRO.



**Figure 2-6. NCT/SFO Arrival and Departure Sectors**

The two Final Approach sectors, FOSTER and WOODSIDE, are shown in Figure 2-7.

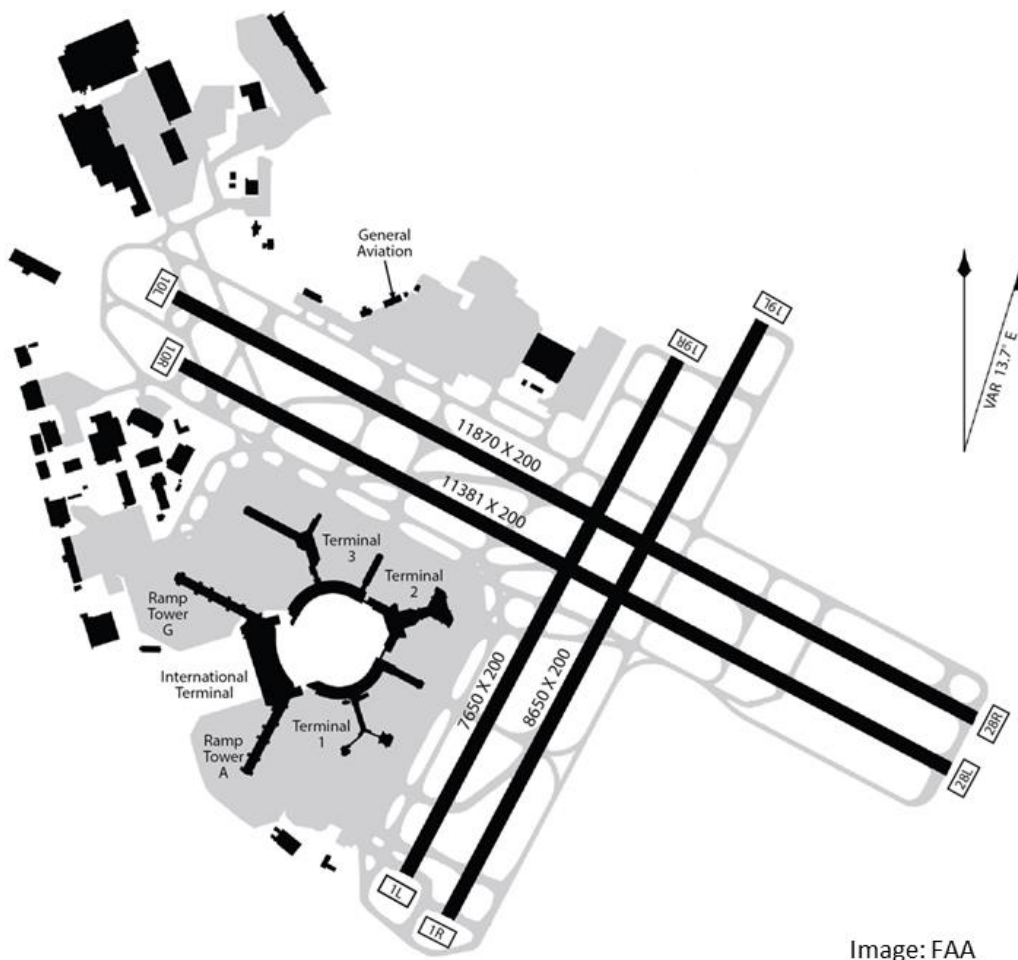


**Figure 2-7. NCT/SFO Final Approach Sectors**

### 2.3.2 IM PA Monitoring at NCT/SFO

Requirements for separation monitoring and controller roles and responsibilities for IM PA at NCT and SFO must be generally compatible with the facility’s arrival operation and equipment

capabilities. Due to its dual intersecting runway configuration shown in Figure 2-8, SFO currently employs a single Local controller (plus a radar assist) to manage arrivals and departures on the 28 Left (L)/28R runways and 1L/1R runways. During SOIA operations, FAA Order 7110.65X requires separate monitor controllers, each with transmit / receive and override capability for their assigned runway on the local control frequency (FAA, 2017a). In the case of SFO and NCT, a waiver was granted to allow the monitoring of SOIA arrivals at NCT on Woodside’s and Foster’s frequencies which eliminates the possibility of the monitors blocking critical transmissions on SFO Local frequency. This is possible at SFO because SOIA procedures allow for separate left/right (L/R) Final Approach controllers to work the finals until the aircraft are 3.3 mile from the runway. Only then are they handed off to the Local controller. The trailing aircraft then navigates visually for the last portion of the approach. At this point, the aircraft no longer require monitoring and are transferred to the single Local controller.



**Figure 2-8. SFO Airport Map**

IM PA is intended for operations in IMC and does not require the use of visual separation during the final portion of the approach. Implementing separate L/R Monitor controllers, as would be required by current 7110.65X rules, may not be practical or feasible at SFO since that would also require separate Local controllers and frequencies, one for each arrival runway. This could introduce significant coordination challenges managing the airport’s four runway intersections

and runway crossings for arrival aircraft. However, past research results suggest that similar to SOIA, dedicated Monitor controllers would be the preferred implementation at NCT/SFO to provide IM PA separation (Mendolia, et al., 2016). Due to the challenges this would introduce at facilities such as SFO, the feasibility and acceptability for a single monitor controller to provide IM PA separation needed to be examined.

### 2.3.2.1 Lateral Deviations

The SFO monitor display consists of a PRM display with 4:1 lateral expansion and 1 second update, an NTZ region that aircraft are not allowed to penetrate, and NTZ alerting that indicates if one does penetrate or is predicated to penetrate the NTZ located between the two runways. The NTZ for SOIA requires straight-in approaches until the visual segment (FAA, 2017a). The SOIA monitoring task requires that controllers take action if an aircraft enters the NTZ region. At SFO the NTZ consists of a rectangle that is 2000 ft wide, beginning at the point where vertical separation would be lost, and ending approximately 3.3 NM from the runways. At that point the distance between the respective approach courses is the required 3000 ft, which provides a 500 ft buffer to the end of the NTZ. After this point, monitoring ends as the aircraft transition to visual separation approximately 3.3 NM from the runway for the Lead and 3.4 NM from the runway for the Trail.

An IM PA RNAV approach path to SFO Runway 28R will likely involve a 3 degree angled offset to reduce the risk of a wake encounter<sup>6</sup>. The offset also permits increasing the space between the IM PA safety limits. As shown in Figure 2-9, the existing SOIA NTZ cannot be directly applied to the IM PA operation, because the RNAV PA 28R approach path would pass through it. The lateral deviation monitoring task for IM PA and supporting display features implemented for the HITL experiment are described in Section 4.2.8.

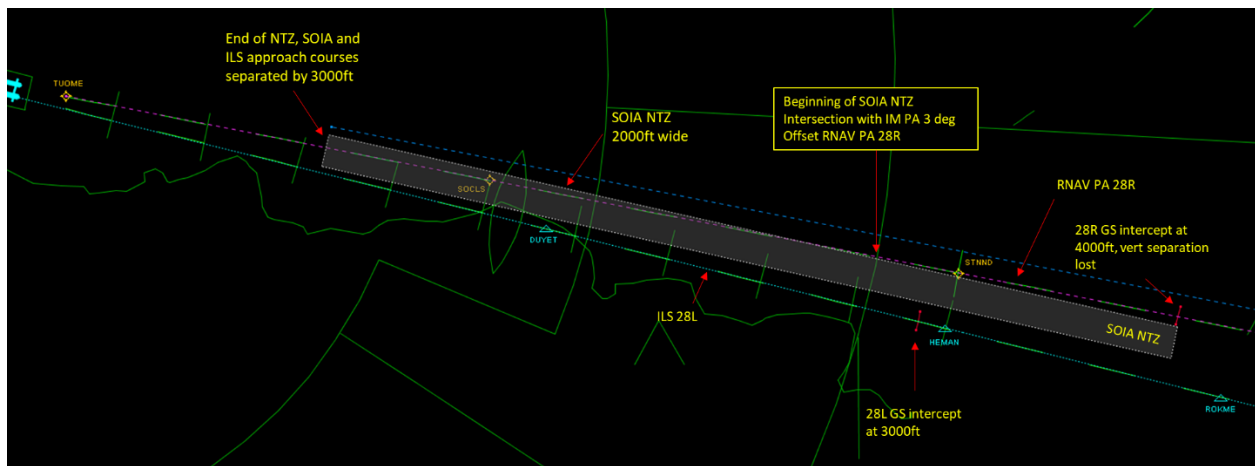


Figure 2-9. SFO 28R IM PA Approach Path Penetrates SOIA NTZ

<sup>6</sup> The offset is also required to overcome navigation overlap and to enable the design of the IM PA safety limits.

### 2.3.2.2 Automated Terminal Proximity Alert

Automated Terminal Proximity Alert (ATPA) Phase 1 functionality is available at NCT and would also be available during IM PA operations. ATPA Phase 1 alert timing served as the basis for the development of the IM PA monitoring tools and is summarized here for background.

The ATPA becomes active in a facility-specified zone along the final, approximately 10 to 12 NM from touchdown. When an aircraft enters the zone and meets ATPA eligibility criteria, ATPA begins monitoring proximity with the aircraft ahead and tracks closure rates to alert the controller if a separation violation is predicted to occur. Controllers may toggle the display of a cone ahead of the aircraft which indicates the minimum authorized separation (Figure 2-10). Under nominal conditions (no alerts), the cone is blue and radiating outward from a trailing aircraft with separation limits displayed. In addition, the distance to lead is displayed in the data block. The cone and the data block distance both turn amber (“warning” state) when a separation violation is predicted to occur in 45 seconds. The cone and data block distance turn orange (“alert” state) if a violation is predicted to occur in 24 seconds.



Figure 2-10. ATPA Symbology from Bone and Mendolia (2018)

ATPA is an important tool at NCT for monitoring separation along final. However, the use of ATPA with IM PA, and integration of display features and potential alerting has not been considered. Therefore, to avoid a potential confound from tools that may not be well integrated, the HITL did not include ATPA functionality. However, the IM PA alerting is based on the ATPA alert construct, as described in Section 4.2.7.

### 2.3.2.3 NCT/SFO IM PA Monitoring Summary for the HITL

The HITL design team made the following eight assumptions with respect to the implementation of the IM PA operation in NCT/SFO airspace. More detail for each can be found in the referenced sections.

1. The 28R Final controller will initiate IM PA once the Trail Aircraft is established on final, and then transfer it to the Local controller at approximately 15 to 20 NM (see Section 4.4.1).
2. IM PA separation responsibility within an IM Trail Aircraft and IM Lead Aircraft will rest with a Monitor controller, who will monitor all arrival aircraft on their respective Local controller’s frequency. Monitoring will be required until the IM Lead Aircraft crosses its runway threshold. This also avoids flight crews being required to make a frequency

change from final to local (i.e., Tower) during the mid or late stages of the operation (see Section 4.4.3.3).

3. The Monitor controller will also provide the appropriate separation between the aircraft pairs (see Section 4.4.3.3).
4. Collision protection is assured by taking action if the IM Trail Aircraft is expected to violate the CSL (see Section 2.2.2).
5. In the event of a lateral flight path deviation by the IM Lead Aircraft, controllers are not required to break out the IM Trail Aircraft before the IM Lead Aircraft crosses its path (see Section 4.4.3.2).
6. Monitor controllers will be required to provide separation in the event of a lateral deviation by any aircraft in their airspace (see Section 4.2.8).
7. The HITL will evaluate the IM PA monitoring task against both Combined 28R/L and Separate Monitor controller configurations (see Section 4.4.3.3).
8. The HITL will not include ATPA functionality; however, IM PA alerting was based on the ATPA alert construct (see Section 4.2.7).

### **2.3.3 IM PA Setup at NCT/SFO**

Based on FAA (2017b), this section summarizes the overall setup and chronology for how an IM PA operation could be scheduled and initiated at NCT/SFO, in both terminal (tactical) and en route (metering) environments. Chronology and details for the IM PA setup specifically assumed for the HITL are described in Section 4.3.1.

#### **2.3.3.1 Tactical Setup**

Tactical IM PA operations are designed to be planned and executed entirely within terminal airspace. RNAV routes connecting to the instrument approach procedure to be used may or may not be available. In the case of NCT/SFO, the assumption has been that a continuous RNAV path would be available for arrivals to runway 28R (the IM Trail Aircraft) and that vectoring would be used to deliver the IM Lead Aircraft to 28L.

A scenario for a generic tactical IM PA operation is detailed in FAA (2017b). Based on that and a scenario for a tactical operation from the earlier IM PA concept detailed in Stassen, et al. (2013), a possible chronology of events for a tactical IM PA operation at SFO could be as follows. First, the candidate IM Trail Aircraft and IM Lead Aircraft check in on frequency with their respective Feeder Controllers and both aircraft report PFAS. Each Feeder Controller annotates the reported speed in the secondary scratchpad. A Coordinator Controller observes the speeds, compares flying miles to the runway, and evaluates the speeds for compatibility. If the aircraft pair is suitable for an IM PA operation, the Coordinator Controller uses automation or another method to compute an Assigned Spacing Goal and then populates the IM Spacing List. The Coordinator Controller then coordinates with the Feeder and Final controllers to ensure that the pairings are acceptable.

The Feeder Controllers inform the candidate IM Trail Aircraft of the planned IM PA operation, providing the IM Clearance Type (IM PA) and IM Lead Aircraft Flight Identification. They do not

yet provide the Assigned Spacing Goal. The flight crew of the IM Trail Aircraft initializes the FIM Equipment entering the information they have been provided. The Feeder Controllers provide speed assignments and vectors as necessary to deliver the aircraft to the Final controllers such that their spacing targets can be achieved. The Woodside (Final Approach) Controller vectors the IM Lead Aircraft in front of the IM Trail Aircraft, targeting an in-trail spacing between 1 and 2 NM. The Foster (Final Approach) Controller provides the IM Trail Aircraft its Assigned Spacing Goal once both aircraft are established on the final approach course, which initiates the IM PA operation. The flight crew of the IM Trail Aircraft enters the Assigned Spacing Goal into the FIM Equipment and begins following the IM Speeds. The Final Approach controllers clear the aircraft for their approaches and instruct the aircraft to change to the Local controller frequency. Monitor controllers monitor separation with respect to the CSL and WSL (if applicable) until the IM Lead Aircraft crosses its runway threshold.

For tactical IM PA operations, terminal automation may be required to: 1) Identify candidate IM Trail and IM Lead Aircraft (possibly through filed flight plans); 2) Calculate an Assigned Spacing Goal based on PFAS inputs; 3) Display IM PA information to Final and Monitor controllers; 4) Accept controller inputs indicating initiation and termination of the IM PA operation.

### **2.3.3.2 Metering Setup**

When IM PA is conducted in a metering environment, the aircraft are likely to be scheduled for an IM PA operation while still in en route airspace. TBFM is expected to identify suitable aircraft pairs and, optionally, define an IM operation that precedes the IM PA operation to ensure that the aircraft are delivered to the final approach course with suitable spacing. The required IM information is then forwarded to the terminal controllers' displays (e.g., STARS), as appropriate. A scenario for an IM PA operation in a metering environment is detailed in FAA (2017b). That scenario suggests a chronology of events associated with IM PA in a metering environment at SFO which includes both IM operations and is summarized below.

First, all aircraft landing at SFO report PFAS at an appropriate point in en route airspace. This may be accomplished using some form of digital communications (e.g., CPDLC), or other means. TBFM captures the PFAS information, assesses the traffic flow, identifies aircraft pairs for IM PA operations, and builds a runway schedule based on IM PA capability. TBFM then creates two IM Clearances: (1) an Achieve-by then Maintain clearance that ends when the aircraft arrive on the final approach course, and (2) a Pair (PA) IM Clearance that begins when the first clearance is planned to end. (Alternatively, the Achieve-by then Maintain Clearance could be amended to a Pair Clearance by a terminal controller at the appropriate time.)

TBFM proposes both IM clearances to the en route controller, who evaluates and accepts the clearances. The en route controller, via voice or CPDLC (if available) sends both clearances to the IM Aircraft, withholding the Assigned Spacing Goal for the PA IM Clearance. The IM Aircraft flight crew accepts the Achieve-by then Maintain Clearance, enters the information into the FIM Equipment, and begins their spacing. They then enter the PA IM Clearance as a Partial IM Clearance and wait for the IM PA Assigned Spacing Goal to be provided. TBFM forwards the clearance information to STARS.

As the aircraft enter terminal airspace, the IM Trail Aircraft continues to execute its Achieve-by then Maintain IM Clearance. Once the IM Trail Aircraft reaches its ABP (on the extended final

approach course), the Foster (Final Approach) Controller consults the IM Spacing List and issues the Assigned Spacing Goal to the IM Trail Aircraft.

The flight crew enters the Assigned Spacing Goal into the FIM Equipment, which terminates the Achieve-by then Maintain IM operation and initiates the IM PA operation. The Foster Controller reflects the change in IM Clearance state on STARS. The Final controllers clear the aircraft for their approaches and instruct them to change to the Local controller frequency. Monitor controllers monitor separation with respect to the CSL and WSL (if applicable) until the IM Lead Aircraft crosses its runway threshold.

Based on this scenario, the key controller actions, locations and agents for an NCT/SFO IM PA operation in a metering environment are summarized in Table 2-2.

**Table 2-2. Key Functions for NCT/SFO IM PA Operation with Metering**

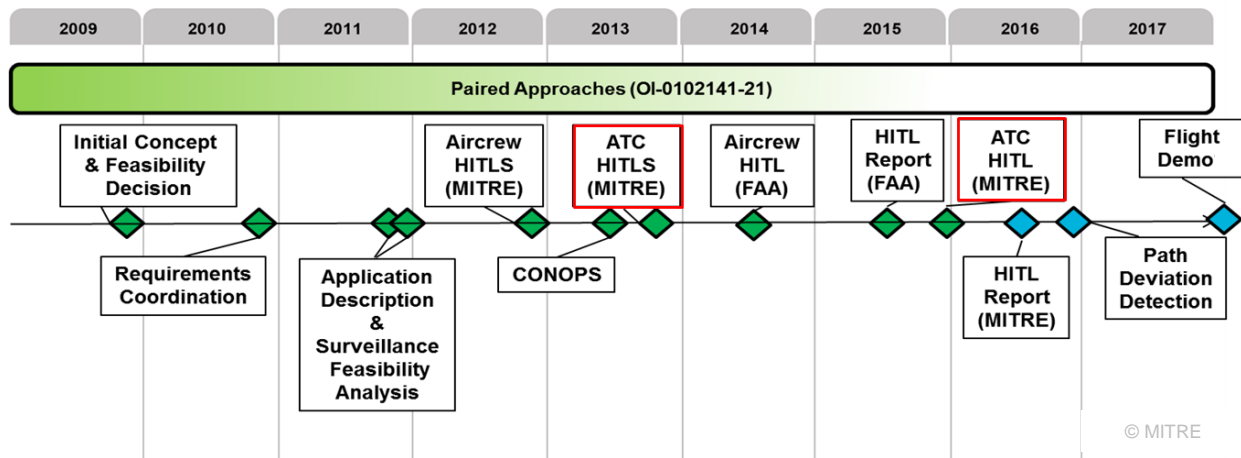
	<i>Aircraft are in ...</i>	
	<i>Performed by ...</i>	
	<b>Tactical PA</b>	<b>Metering PA</b>
<b>Identification of Pairs</b>	Cedar, Laguna, Niles, Boulder	En route
	Coordinator Controller	TBFM
<b>IM Clearance Definition / ASG* Computation</b>	Cedar, Laguna, Niles, Boulder	En route
	Coordinator Controller	TBFM
<b>Provision of First IM Clearance</b>	N/A	En route
	N/A	TBFM/En route Controller
<b>Placing Aircraft on Final / Initial Spacing</b>	TRACON	En route/TRACON
	Mainly Boulder/Woodside	TBFM/TSAS/IM
<b>Provision of ASG* (PA IM Clearance)</b>	Foster	Foster
	Foster Controller	Foster Controller
<b>Updating IM Spacing List</b>	Foster	Foster
	Foster Controller	Foster Controller
<b>CSL/WSL Monitoring</b>	Foster/Woodside	Foster/Woodside
	Monitor Controllers	Monitor Controllers
<b>Re-computation of ASG* (if needed)</b>	Foster/Woodside	Foster/Woodside
	Monitor Controller	STARS/TBFM

\*Assigned Spacing Goal

## 2.4 Related PA and IM Research

Flight crew and ATC HITL research on PA has been performed for more than two decades, with one of the earliest concept studies being performed in 2001 (Bone, Mundra, & Olmos, 2001). More recently, MITRE and the FAA have conducted several flight deck and ATC HITL experiments to mature the IM PA concept, as shown in Figure 2-11. The PA concept tested in these HITLs was not yet part of IM and assumed that safety limit monitoring would be a responsibility of airborne equipment and flight crews. Though this has changed for the current IM PA concept examined in this paper, several aspects of these HITLs remain relevant to the current work. Selected results from the 2013 and 2015 ATC HITL experiments and another

recent, relevant IM HITL are summarized in this section. An extensive review of past IM research can be found in Bone & Mendolia (2018) A review of PA flight deck research from the recent aircrew-based HITLs can be found in Lewis, Bone, Mendolia, & Nguyen (2019).



**Figure 2-11. Recent PA HITLs**

The 2013 and 2015 ATC HITL experiments were performed by MITRE and developed in coordination with NCT and included controller vectoring to set up the aircraft. The 2013 HITL focused on mainly on nominal operations and involved Niles and Boulder Feeder controllers and Foster and Woodside Final Approach controllers (Domino, Tuomey, Stassen, & Mundra, 2014). The 2015 HITL included both nominal and off-nominal operations and was expanded to include TRACON Feeder, TRACON Monitor, and Tower controllers (Mendolia, et al., 2016). In these HITLs, ATC remained responsible for separation between all other aircraft and for managing the overall arrival flow to the airport to ensure that both arrival and departure operations were conducted efficiently. The ATC task was to deliver the PA pair onto a long final approach with between 1 and 2 NM longitudinal (in-trail) spacing.

At the time, the PA concept required controllers to communicate the PFAS of the IM Lead Aircraft to the IM Trail Aircraft. The task of obtaining the leading aircraft’s PFAS and entering it into the data block scratch pad was given to the High Feeder Controller. This position would also advise which approach they would expect to fly, if known. In the 2013 ATC HITL, this position was not staffed with a participant therefore these communications were assumed to happen upstream and were not directly included in the study. The HITL procedures also did not distinguish between a “PA operation” and “PA approach” and therefore did not require separate clearances. In the HITL, the clearance for the RNAV (Required Navigation Performance [RNP]) PA runway (RWY) 28R approach constituted clearance to perform the PA operation (D. Domino, personal communication, 02/28/2019). For the south and Modesto north arrivals (see Section 2.3.1), staffed low feeder positions provided the Lead Aircraft’s PFAS to the trailing aircraft. For the Golden Gate north arrivals, the Final controller was responsible for soliciting and entering PFAS data in the arrival data block. The Boulder Low Feeder position did this in 2013 for the PYE (at that time prior to BDEGA implementation) and PIRATs.

This general procedure was the same for the 2015 study, except that an IM PA operation was initiated via a separate IM Clearance. The Final Approach controller positions provided the IM Clearance, including the Lead Aircraft’s PFAS, to each candidate Trail Aircraft. The Low Feeder

controllers advised aircraft to “expect” the IM PA procedure, as described further in Section 2.4.2.

The following two sections provide more detail with respect to these two IM PA ATC HITL experiments and results. Section 2.4.3 describes the general IM initiation task and display features that provided a foundation for the current HITL simulation.

### **2.4.1 2013 ATC Initial Feasibility HITL Experiment**

As described in Domino, Tuomey, Stassen, & Mundra (2014), the objective of 2013 ATC Initial Feasibility HITL was to perform initial ATC acceptability and feasibility assessments of the original PA concept under nominal conditions (i.e., no blunders) and determine potentially achievable arrival rates under IMC at CAT I limits with varying levels of PA equipage. It also examined whether controllers could deliver the required initial interval for candidate IM PA pairs. The NCT airspace was simulated for this study with PA operations to SFO’s runways 28L and 28R. NCT controllers provided subject matter expertise during the development of the HITL, aiding the researchers both in creating a sufficiently representative simulated environment and in refining key conceptual details. Five other controllers and supervisors from NCT participated in the data collection.

The simulation design tested three levels of PA equipage and three levels of allowable PFAS differences. A “Pair List” was implemented to display eligible pairs and display the PFAS value of the Lead Aircraft. Trail and Lead capability was also included in the data blocks along with their reported PFAS values. Results data consisted of hourly achieved arrival rates, pair interval at turn on, and questionnaire subjective data including workload.

Results suggested that controllers found that their tasks, including querying for PFAS, entering it into the data block scratchpad, and communicating it to the trail aircraft, were feasible, acceptable, and could be performed by the average controller at NCT. Controllers indicated that the procedure was possible using voice communications and there was no indication that the phraseology used in the HITL posed a problem at any of the simulated traffic levels (D. Domino, personal communication, 02/27/2019). The controllers also suggested that the procedure did not require new ground automation for pairing aircraft and that the PA procedure was similar to SOIA. Finally, the STARS Pair List was reported to be an effective way to advise the pair assignments.

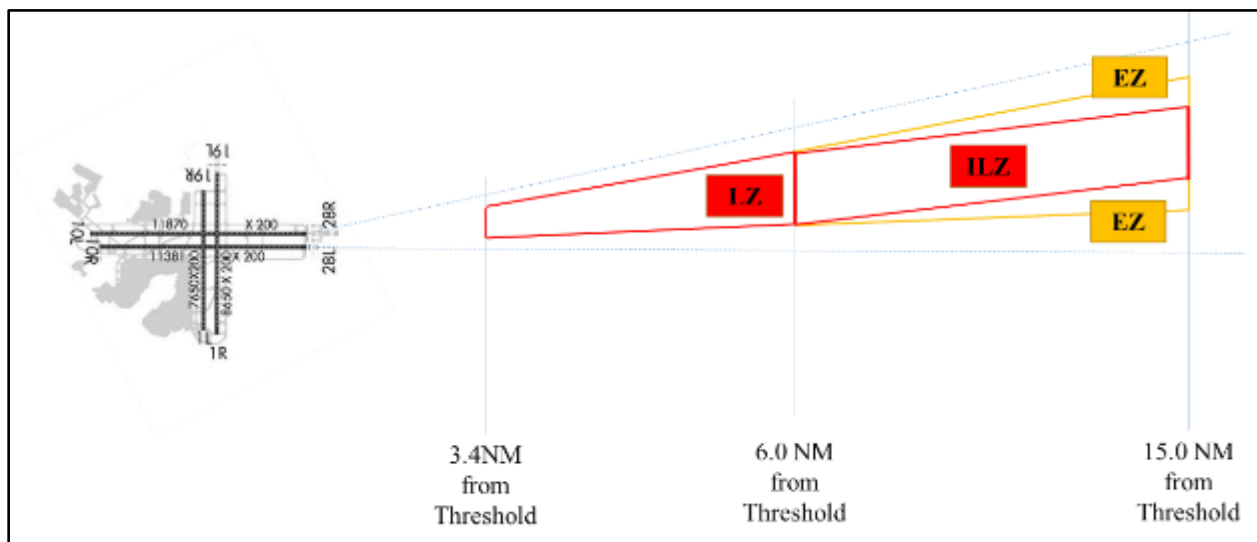
In the HITL, controllers were able to deliver the required initial spacing interval of 1-2 NM, with 1000 ft altitude separation, on a 15-17 NM long final. They also achieved arrival rates of 34 to 46 aircraft depending on the equipage level of the scenarios (34 for 30% equipage; 46 for 100% equipage), exceeding SFO’s single runway capacity at the time of 30 aircraft per hour, or 36 with a SOIA operation. Workload was consistently rated higher than a baseline scenario consisting of SOIA operations, but decreased with experience and was still reported on average as acceptable for all control positions.

### **2.4.2 2015 ATC Off-Nominal HITL Experiment**

As described in Mendolia, et al. (2016), the 2015 ATC HITL experiment was conducted to examine PA operations at both the TRACON and Tower (i.e., NCT and SFO). SFO Tower and NCT controllers provided subject matter expertise during the development of the HITL, and

participants included two SFO Tower (Local) controllers and five NCT controllers. Staffing included two Final positions (Woodside and Foster), two Arrival Feeder positions (Boulder and Niles), and one Departure position (Sutro) (see Section 2.3.1 for an overview of the airspace).

The HITL involved a lateral deviation monitoring task with a custom-designed Non-Normal Zone (NNZ), based on an NTZ, and associated caution and warnings designed to assist aircraft in avoiding wake encounters. It accommodated the 3 deg offset for the 28R RNAV approach and extended from approximately 15 NM to 3.4 NM from the runway threshold. As shown in Figure 2-12, three separate zones were created at different locations along the NNZ, each with an associated Caution or Warning for aircraft encroachment. These alerts were not predictive and appeared only when an aircraft entered one of the alerting zones. In the Early Zone (EZ), controllers had the option of bringing a deviating aircraft back into compliance. In the Imbedded Late Zone (ILZ) and Late Zone (LZ), controllers were required to issue warning alerts and provide appropriate break out instructions. Alerts were displayed via flashing, color-coded text indication in the deviating aircraft's data block along with a color-coded ATPA-like cone that was displayed in a direction that corresponded with the deviating aircraft's current track.



**Figure 2-12. NNZ Parameters and Alerting Zones from Mendolia, et al. (2016)**

Two controller configurations were evaluated: 1) dedicated Separate Monitor positions for each approach in which they were alerted to any intrusion into the NNZ on a 4:1 aspect ratio FMA display with a 4.8 sec surveillance update, and 2) a configuration where the NNZ and deviation alerts were displayed to Final controllers on a normal STARS 1:1 aspect ratio display with 1 sec updates. Final controllers had the option of toggling the NNZ on or off and changing its brightness. When off, the alerts still automatically indicated that an aircraft was entering one of the alerting zones. If the NNZ was displayed, its outline brightened until the aircraft exited the alerting zone. Also, when an alert was triggered, a flashing text string indicating the type of alert was displayed in the deviating aircraft's data block line 0 until the alert was no longer active. For the FMA display, the entire data block changed color to indicate the alert. For the Final controller display configuration, the data block remained green and only the alert text was color-coded.

The HITL included nominal and non-nominal scenarios, though the research emphasis was on Tower feasibility and off-nominal (e.g., blunder) events. Off-nominal events occurred any time after both aircraft were established on final, and included: a gate breakout (i.e., a Trail Aircraft exceeds a safety limit), a Lead Aircraft executing a missed approach, an overtake (i.e., the Lead Aircraft of a second pair overtakes the Lead / Trail Aircraft of the first pair), a late departure take-off, lateral deviations into the NNZ, and pairs modified or abandoned the IM PA procedure in response to (for example) a surveillance or algorithm failure, or disqualifying adjustment to PFAS.

Controllers used the same Pair List and data block implementations as Domino, Tuomey, Stassen, & Mundra (2014) to view proposed IM PA pairings and PFAS information. Figure 2-13 shows the Pair List as implemented in Mendolia, et al. (2016).

Paired Approach List				
	28L	FAS	28R	FAS
1	UAL261	P28	ASA382	P30
2	SKW342K	P38	UAL250	P36
3	SKW5623	P31	SKW6264	P35

Figure 2-13. Pair List from Mendolia, et al. (2016)

IM Clearance and PFAS communications were generally as described in Section 2.4. First, candidate Trail Aircraft were assumed to have been informed by High Feeder controllers (not staffed) to expect an RNAV Runway 28R Approach and to perform an IM PA operation. Then they were reminded by Low Feeder controllers (staffed) that they would be performing an IM PA operation and were given the Lead Aircraft’s identification, runway assignment, and PFAS. Example phraseology consisted of: “United 123, expect Paired Operation with United 345 on ILS 28L, planned final approach speed 140 knots.” The 28L Final controller vectored the Lead in front of the Trail Aircraft and targeted 1–2 NM spacing and cleared it for the approach. The 28R Final sector controller then issued the Trail Aircraft the IM Clearance: “United 123, cleared Paired Operation with United 345.” This HITL assumed that coupled approaches would be required for IM PA, and so the approach clearance phraseology to both aircraft also included a reminder to “check autopilot on” as an additional safety check for the prevention of blunders.

The human factors-related simulation findings were generally positive. Controllers indicated that the procedure was acceptable, desirable, and expressed confidence that other controllers could conduct the operation. They understood their roles and responsibilities during the operation. The majority of workload responses were on the “low” side of the scale. The few higher ratings were mainly attributed to the extension of the final approach course and high frequency of off-nominal events. The Local controllers reported no difference in PA workload as compared to CSPR 7110.308 and SOIA operations currently used at SFO. However, the Arrival Controllers reported that PA “somewhat increases” or “increases” their workload.

All controllers indicated a need for modification to the phraseology employed in the HITL and routinely commented that the communications were too long. They emphasized removing the PFAS from the IM Clearance and eliminating the “autopilot on” check. They also suggested putting as much information as possible on the approach chart or Attention All Users Page. The

majority of participants did not identify any issues with using third party flight identification as part of the clearance.

The lateral deviation detection scenarios were included in the HITL as an initial study to enable recommending future research direction. Several controllers in the lateral deviation scenarios indicated issues with the breakout procedure, citing confusion with what to do with the non-compliant aircraft when it penetrated the EZ. Participant agreement as to the acceptability of the Lateral Deviation scenarios appeared variable. Three of the four arrival controllers indicated a preference for separate dedicated FMA monitor position as opposed to a non-FMA configuration where the final arrival controllers are responsible for detecting and responding to deviations into the NNZ. The study recommended additional research with respect to controller detection of lateral deviations.

Participants in the study were able to maintain average arrival and departure rates above 40 operations per hour. The arrival rate ranged between 41 and 44 during nominal scenarios. Controllers were, on average, able to deliver an intra-pair spacing of 1.55 NM during initiation as required, though they were not able to consistently meet the 15 NM distance to threshold requirement. At the simulated arrival rates, this requirement was reported to require significant vectoring to achieve the required sequencing.

### **2.4.3 2017 IM TSAS HITL Experiment**

In 2017, MITRE conducted an IM HITL experiment in the TRACON environment to determine the feasibility and operational acceptability of the integration of TSAS and IM spacing to both flight crews and controllers (Bone & Mendolia, 2018). Though the HITL experiment did not involve IM PA operations, IM arrival spacing in the terminal area was evaluated and relevant results from this aspect of the simulation are summarized here. In addition, IM Spacing List and data block tools developed for this HITL were used for the IM PA HITL that is the subject of this paper, and are therefore also summarized here.

The 2017 IM TSAS HITL had several ATC-based objectives. The first was to evaluate information and communication needs, and the associated procedures, from a human factors perspective. The HITL was also intended to support the definition of IM's integration with TSAS and determine desirable initiation points (i.e., en route, early terminal, feeder to final transition, and final approach). Finally, the HITL determined and validated controller information needs, including IM situation awareness and progress monitoring.

Similar in purpose to the Pair Lists developed for the PA ATC HITLs described earlier, a prototype STARS IM Spacing List, shown in Figure 2-14, was developed to provide IM Clearance and IM Status information. The text was coded in white when proposing an IM Clearance, green if the IM Clearance was active, and yellow if the IM Clearance was terminated or an issue existed. The order of the text was presented to reflect how it would likely be issued by the controller in a voice clearance.

Trail AC	Clearance Type	Spacing Goal	Lead AC (sector)	ABP	Lead AC Route	Term Pt	Status
AAL503	Achieve	76 sec	SCX607	FINAP	HYDRR1		Eligible
SCX607	Capture	83 sec (87)	UAL644				Active
SWA515	Achieve	100 sec	SWA3414	FINAP	HYDRR1		Terminated
DAL334	Achieve	93 sec (87)	ASA514 (V)	FINAP	HYDRR1		Active

Figure reprinted from: Bone and Mendolia (2018)

**Figure 2-14. Prototype STARS IM Clearance Window from Bone and Mendolia (2018)**

An IM Clearance was only proposed when specified conditions were met. These included, for example, times when the IM Trail Aircraft and IM Lead Aircraft were on appropriate route geometries for the clearance type and both aircraft were qualified to act in their respective roles. In addition, the IM Lead Aircraft needed to be directly ahead of the IM Trail Aircraft for the same runway, the Assigned Spacing Goal needed to be between 75 and 240 seconds, the IM Lead Aircraft needed to be in surveillance range of the IM Trail Aircraft, the IM Trail Aircraft could not be beyond the ABP, and a speed-only spacing solution needed to be available. After an IM Clearance was proposed, it could be rejected by the controller. It then remained in the list for 30 seconds, so the rejection could be retracted if desired.

Bone and Mendolia (2018) developed and tested a prototype design for providing IM Information in the data block for the IM Trail Aircraft and IM Lead Aircraft. The IM Trail data block design is shown in Figure 2-15 and the IM Lead data block design is shown in Figure 2-16.

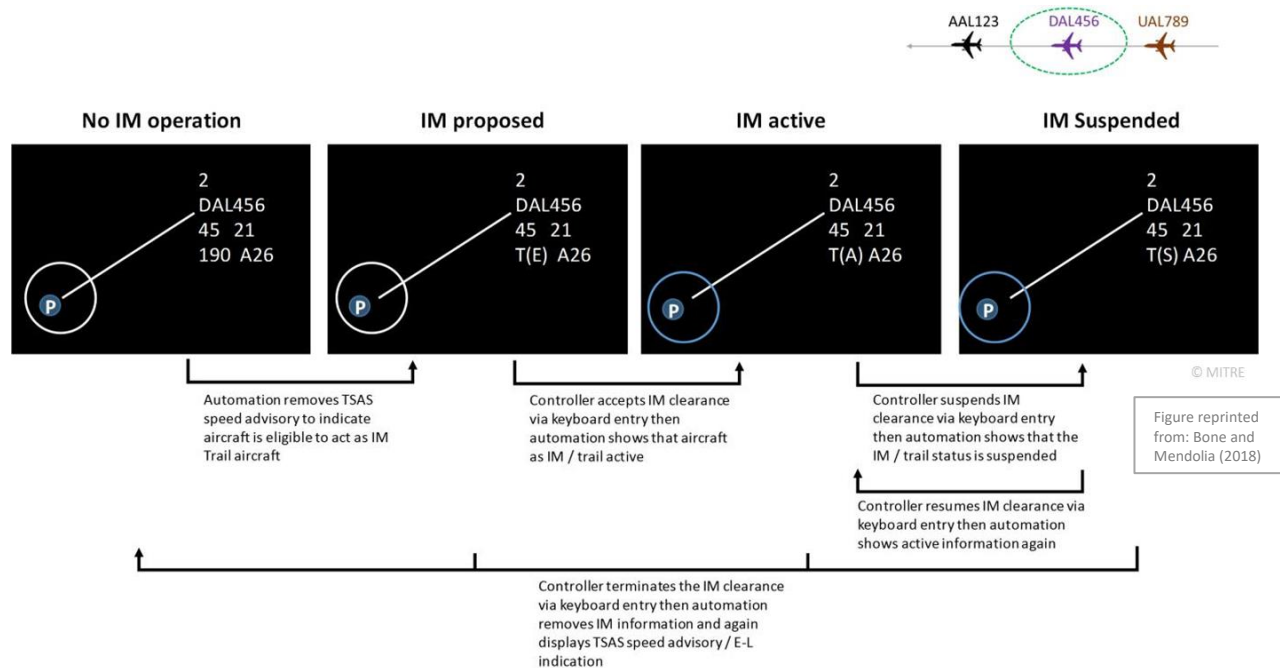
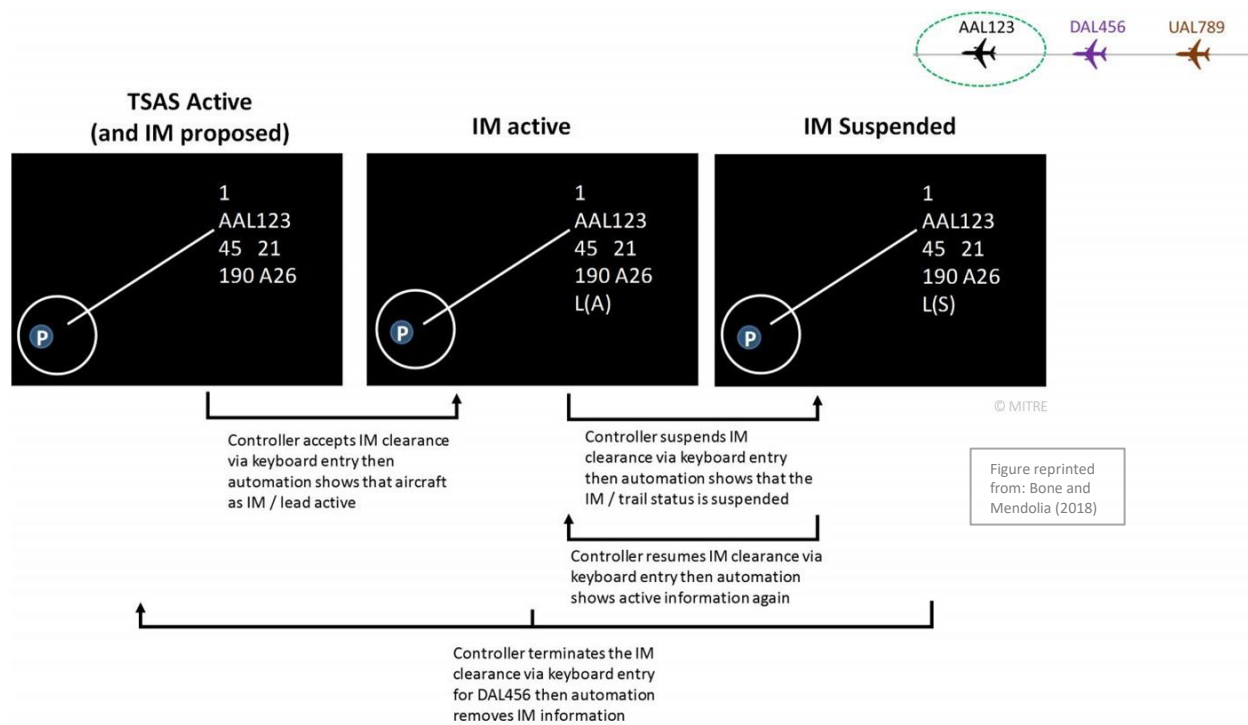


Figure reprinted from: Bone and Mendolia (2018)

**Figure 2-15. Prototype IM Information in Data Block, IM Trail Aircraft from Bone and Mendolia (2018)**



**Figure 2-16. Prototype IM Information in Data Block, IM Lead Aircraft from Bone and Mendolia (2018)**

The researchers reported that when asked whether the information in the IM Spacing List was helpful for IM, the majority of controllers agreed that in general, the IM elements were helpful for IM operations / Aircraft. Controllers also specifically found the IM Status information to be helpful for IM operations / Aircraft.

For the data block IM elements, IM Trail Aircraft and IM Lead Aircraft status indicators were reported as helpful by a majority of controllers. Controllers appeared to favor maintaining the display of IM Status in the data block and not just in the IM Spacing List. They did not want IM Status to be removed from the data blocks near and on final.

## 3 Research Goals, Questions, and Hypotheses

### 3.1 IM PA Concept Evolution and Research Gaps

The “Legacy” PA concept evaluated in the HITL experiments described in Section 2.4 assumed that safety limit monitoring would be a responsibility of the airborne equipment and flight crews. The controller’s role was to establish alternate separation in the event of a PA Equipment-commanded breakout. As PA began to be incorporated into the FIM Equipment standards process in RTCA, stakeholders determined that the concept needed to change to ensure that controllers explicitly maintain separation responsibility and therefore must be able to monitor the operation relative to a clear separation standard. This requires controllers to be able to assess aircraft pair PA separation such that they can take effective action before separation is lost. The flight crew task should become speed guidance conformance, as with the other IM applications. Therefore, the concept was changed to move the safety limit monitoring function from being a flight crew responsibility and FIM Equipment capability to a ground capability, likely to be hosted in STARS.

The updated IM PA concept introduces two new aspects to the controller separation assurance task. First, controllers today typically monitor aircraft against a single minimum separation value. With IM PA, however, controllers will likely be required to monitor some aircraft pairings with respect to a minimum limit (CSL) and a maximum limit (WSL). Second, current separation minima are usually static; i.e., they are a known value that remains fixed for a given set of conditions. For IM PA, however, the distance allowed between the aircraft and both limits will change as a function of the distance to the runway, as illustrated in Figure 2-4.

Due to IM PA’s minimum and maximum safety limits that change over the course of an approach, and the close inter-aircraft pair distances, stakeholders expected that controllers would likely require new ground tools to detect and act on potential exceedances of the safety limits. Also, these tools would be required to allow controllers to provide a timely response to an aircraft deviation in either the longitudinal (along-track) or lateral (i.e., blunder) dimensions. Neither the new monitoring task and nor the potentially enabling tool set has yet been examined in a HITL environment.

In addition, due to flight crew workload in preparing the FIM Equipment, nominal IM PA setup should be possible in en route or feeder airspace, possibly via a Partial IM Clearance (as described in Section 2.2.1). Although prior PA ATC research assumed the use of an “expect” message to provide setup information before the operation was to begin (see Section 2.4), the use of a Partial IM Clearance as described in FAA (2017b) and RTCA (2019a) to prepare an IM PA operation has not yet been examined in a HITL activity.

### 3.2 Research Goals

Prior PA HITL research such as Domino, Tuomey, Stassen, & Mundra (2014) and Mendolia, et al. (2016) examined controller tactical setup and separation monitoring as a flight crew responsibility. The results regarding tactical setup are expected to still be generally relevant to the IM PA concept as currently defined. Therefore, the primary goal of this HITL was to examine

the updated IM PA concept with a focus on the new controller monitoring functions. This included an evaluation of the terminal controller monitoring task for IM PA pairs established on final, especially with respect to minimum and maximum separation limits that change over the course of an approach. Related to this is whether it is acceptable for a single monitor controller to manage IM Lead and IM Trail Aircraft on both approaches, or whether separate monitors would be required. It also included an evaluation of alternative supporting display features to facilitate this monitoring task. A secondary goal was to examine the use of a Partial IM Clearance procedure to initiate IM PA operations on final.

This HITL experiment was not intended to comment on the feasibility of tactical or metering IM PA setup procedures, beyond having the Final Approach controller initiate the operation, nor was it intended to precisely replicate SFO airspace and operations and draw specific conclusions with respect to a mature IM PA implementation at that facility. Additionally, this HITL did not suggest any final design criteria with respect to a future PA separation standard or any final IM PA ground tool interface or display requirements (although recommendations are made for consideration by the appropriate design groups).

The results of the HITL are intended to provide concept validation for the avionics standard activities and A-IM ConOps, as well as specific recommendations for the FAA IM Initial Program Requirements document with respect to controller information needs and supporting ground tools.

### 3.3 Research Questions and Hypotheses

Based on the research goals and past studies, six research questions and corresponding hypotheses were developed. These are listed below:

RQ1: Is it feasible and acceptable for controllers to monitor PA separation with respect to both minimum and maximum separation limits?

The controller separation assurance task includes spacing and separating among in-trail aircraft within flows and on approaches. In these situations, controllers today must ensure that a given aircraft maintains appropriate spacing from an aircraft ahead as well as an aircraft behind. Though IM PA introduces a minimum and maximum limit with respect to a single leading aircraft, the task of keeping an aircraft within a forward and aft boundary should be a simple extension of this basic controller task. Therefore, it is hypothesized that controllers will find IM PA safety limit monitoring both feasible and acceptable.

*H1(RQ1): Given an appropriate tool set, controllers will find it acceptable and feasible to monitor IM PA operations with respect to both minimum and maximum separation limits.*

RQ2: Is it feasible and acceptable for controllers to provide PA separation with respect to values that change over the course of an approach?

Controllers today have experience with separation minima that can change for a given pair of aircraft depending on conditions. For example, an aircraft pair turning onto final may initially be separated via Minimum Radar Separation (MRS) of 3 NM or 1000 ft vertical. Then, when aircraft are within 10 NM of the airport on final, pairs may be allowed to close to 2.5NM per Section 5-5-4 in FAA (2017a). In another example, at certain facilities aircraft may be transitioned to a 7110.308C operation and allowed to close to within 1 NM diagonal (FAA, 2018b). Aircraft

separation on approach may be further complicated at some facilities due to MRS applying to certain aircraft pairs and new Wake Recategorization (RECAT) Separation minima required for other combinations (FAA, 2016). Controllers are therefore used to managing complexity in applying the appropriate separation standards to pairs of aircraft. However, clear rules are required to govern which standard applies for any given aircraft pairing, operation, and set of conditions.

A PA separation standard should therefore also be manageable, even if it changes over the course of an approach, as long as the required separation distance minimum is clear at any given time and the trend is generally predictable. As this can be incorporated in the design of a ground tool, it is therefore hypothesized that if done correctly, controllers can find it acceptable and feasible to provide PA separation with respect to separation values that change over the course of an approach.

*H2(RQ2): Given an appropriate tool set, controllers will find it acceptable and feasible to provide PA separation with respect to separation values that change over the course of an approach.*

RQ3: What information elements and tools may be required for Monitor controllers to longitudinally monitor IM PA operations?

As described above, it is expected that controllers will need to know the required separation distance for an IM PA pair at any given time. This may be in the form of a graphical indicator or numeric indicator. It is hypothesized that one form will be required by controllers, but not both. In addition, to ensure the acceptability of a standard that involves limits that change over the course of an approach, the changes must be generally predictable and manageable. As the WSL only applies to certain aircraft pairings, and even then, only in the last portion of the approach, there is the potential for controllers to be surprised by a pop-up WSL value. This surprise could be mitigated by a preview or pre-activation feature; however, the underlying WSL should be predictable over time and therefore this additional display feature could be considered display “clutter” by controllers. It is therefore hypothesized that a WSL pre-activation feature may be useful, but not a minimum requirement.

*H3(RQ3): Controllers will find a WSL Pre-Activation indication and distances to the CSL and WSL useful, but not minimum requirements.*

As the IM PA inter-pair spacing will be smaller than what controllers are used to today, and because the controller will be required to take action before an IM PA Aircraft longitudinally encroaches on either the WSL or CSL, it is expected that alerting will be helpful to controllers to indicate when an intervention is required. Based on the fielded ATPA Phase 1 alert implementation described in Section 2.3.2.2, it is hypothesized that a similar IM PA two-level alerting scheme will be acceptable to controllers.

*H4(RQ3): A representation of the safety limits and an alert when the IM Trail Aircraft begins to encroach on the limits will be useful to Monitor controllers.*

RQ4: What types of information and display features will controllers need to monitor IM PA operations for lateral deviations from the intended flight path?

Past research results suggest that similar to SOIA, the lateral monitoring task is enhanced by an NTZ-like area and associated alerting to indicate when controller action is needed to resolve a lateral deviation (Mendolia, et al., 2016). As noted in Section 2.2.3, the CSL and WSL were

designed to accommodate some amount of normal aircraft crosstrack error from the approach path centerline. Although controllers are not required to detect lateral deviations and break out one of the aircraft in an IM PA pair before the other crosses its path, they are expected to find it helpful to be informed as to when an aircraft's crosstrack error may result in the CSL and WSL no longer providing the required protection from collision or wake risk. Therefore, as with SOIA operations and their associated NTZ, controllers are hypothesized to find useful a display element to indicate when they need to take action based on a lateral deviation. Also, controllers are hypothesized to find useful an automated warning to draw their attention to the deviation.

*H5(RQ4): Controllers will find features such as Lateral Boundaries and an Exceedance Warning useful to alert them to IM Lead Aircraft and IM Trail Aircraft lateral path deviations.*

RQ5: Can a single, combined Monitor controller effectively monitor an IM PA operation?

Past research results suggest that similar to SOIA, dedicated Monitor controllers providing IM PA separation would be the preferred implementation at NCT/SFO (Mendolia, et al., 2016). As described in Section 2.3.2, current operations such as SOIA require separate Monitor controllers, each with transmit / receive and override capability on the respective final approach frequency, to ensure aircraft do not penetrate the depicted NTZ. This is possible at SFO because separate L/R Final Approach controllers work the finals and aircraft are navigating visually for the last portion of the approach. At this point, the aircraft no longer require Monitor controllers to provide separation and are transferred to the single Local controller.

IM PA, however, is intended for operations in IMC and may not be able to accommodate visual separation during the final portion of the approach. Implementing separate L/R Monitor controllers, as would be required by current 7110.65 rules (FAA, 2017a), may thus not be practical or feasible at SFO. It is therefore of interest to determine whether a single, combined Monitor controller can effectively provide separation for CSPR finals involving IM PA operations over a relatively long final approach segment.

Facilities with dependent parallel runway operations typically employ separate L/R Final Approach controllers due to the workload involved in vectoring aircraft to final and other intensive tasks. Today's Monitor controller workload, however, is much reduced as they are only required to take action if an aircraft penetrates the NTZ. Workload for the IM PA concept as tested in the HITL may be higher, as the Monitor controllers must provide separation for all aircraft on the approach, including within and between IM PA pairs, and must monitor for lateral deviations. However, IM PA will likely involve alerting to tell controllers when to take action for an impending loss of IM PA separation. Therefore, if vectoring to final (or managing aircraft on RNAV paths that connect to the final) remains the responsibility of Final Approach controllers, it is hypothesized that a single Monitor controller can effectively and acceptably Monitor separation for IM PA and non-IM PA aircraft over the course of a long final approach segment.

*H6(RQ5): Though the workload may be increased, a single, combined Monitor controller can effectively and acceptably provide separation for CSPR finals involving IM PA operations, including separation between successive PA pairs.*

RQ6: Is it feasible and acceptable to use Partial IM Clearance procedures to initiate an IM PA operation?

Prior PA HITL research such as Domino, Tuomey, Stassen, & Mundra (2014) and Mendolia, et al. (2016) examined the use of an “expect” message to provide IM PA setup information before the operation was intended to begin. Controller results suggested that clearance formulation in this manner was acceptable, though issues were raised with respect to the length of the phraseology as described in Section 2.4.2. The use of “expect” was modified during concept development to the use of a Partial IM Clearance summarized in Section 2.2.1. More fully described in FAA (2017b) and RTCA (2019a), the intent of the Partial IM Clearance was generally the same as the expect message and the sequence of communications and information transfers is similar. It is therefore hypothesized that Final controllers will find the IM PA initiation task, including the use of Partial IM Clearance procedures, acceptable.

*H7(RQ6): Final controllers will find the IM PA initiation task, including the use of the Partial IM Clearance, acceptable.*

## 4 Experiment Methodology

The purpose of this HITL experiment was to evaluate the terminal controller monitoring task for IM PA pairs established on final, especially with respect to minimum and maximum separation limits that change over the course of an approach. In addition, it evaluated alternative supporting display features to facilitate this monitoring task and the use of Partial IM Clearance procedures to initiate IM PA operations on final. This section details the simulation environment, prototype ground tools developed for the evaluation, IM PA concept implementation as tested including controller roles and responsibilities, and the experimental design.

### 4.1 Simulation Environment

The HITL was conducted in the MITRE Aviation Integration Demonstration and Experimentation for Aeronautics (IDEA) Laboratory at the MITRE McLean campus. The simulation utilized controller and pseudopilot workstations that incorporated new display features as necessary for this evaluation. An overview of the capabilities and workstations are provided below.

#### 4.1.1 Controller Workstation

The ATC interface consisted of a representative 2K display that hosted an interface similar to the currently fielded STARS system. The display contained an SFO terminal map and the same display and features were available to both the Monitor controller(s) and Final Approach controller and is shown in Figure 4-1. Some of the IM PA features are depicted in the figure and are described in Section 4.2. ATPA and Wake RECAT aircraft categories were not available to controllers on the display; however, other tools such as “bats” and Predicted Track Lines (PTLs) could be toggled on or off. The workstation contained the majority of the basic STARS functionality and used a typical STARS keyboard and trackball. Special keyboard entries were programmed to serve as unique IM PA functions (described in Section 4.2.2).



Figure 4-1. STARS Display used in the HITL Experiment (with IM PA Display Features)

MITRE

## 4.1.2 Pseudopilot and Confederate Controller Workstations

Aircraft in the HITL were “piloted” by pseudopilots, which allowed the controller participants to interact normally with the traffic. The pseudopilots input the controller participant instructions into an interface termed Simpilot as shown in Figure 4-2<sup>7</sup>, which allowed for the simultaneous control of multiple simulated aircraft. The HITL scenarios also required the use of a confederate to act as a Local (Tower) Controller. This Confederate Controller communicated directly with the pseudopilots on the voice frequency, which the participant Monitor controllers could listen to and override as needed. HITL scenarios involved different roles and configurations for the participant controllers. This required different configurations and communications loops for the pseudopilots and confederate controllers as described in Section 4.1.3.

<sup>7</sup> This figure first appeared in Mendolia, et al. (2016).

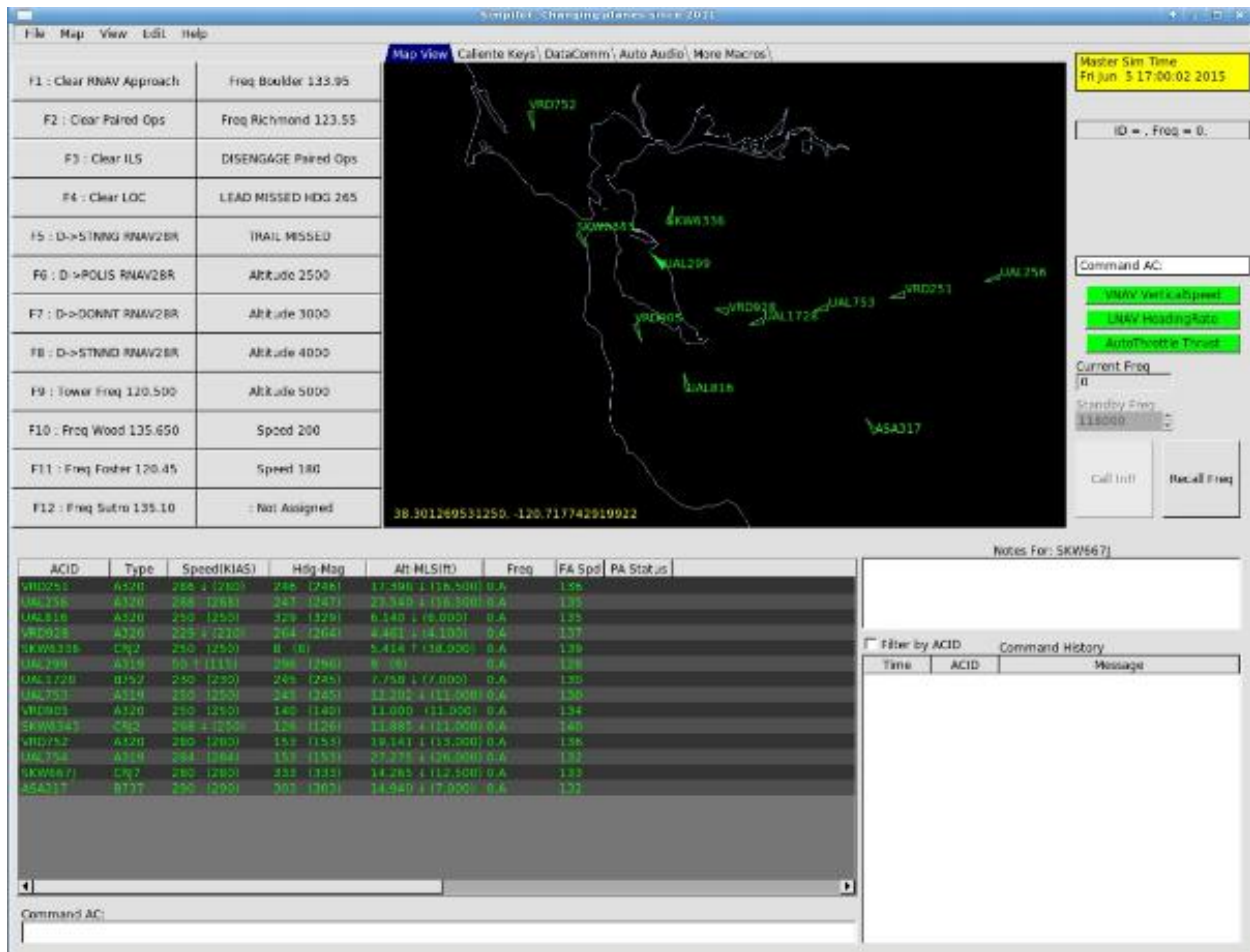
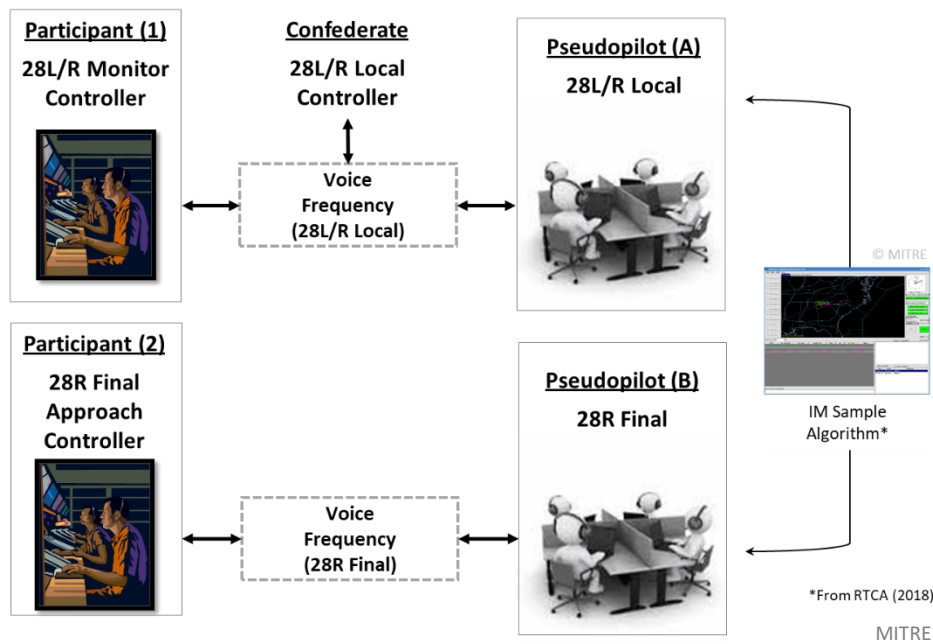


Figure 4-2. Pseudopilot Interface (Simplot)

MITRE

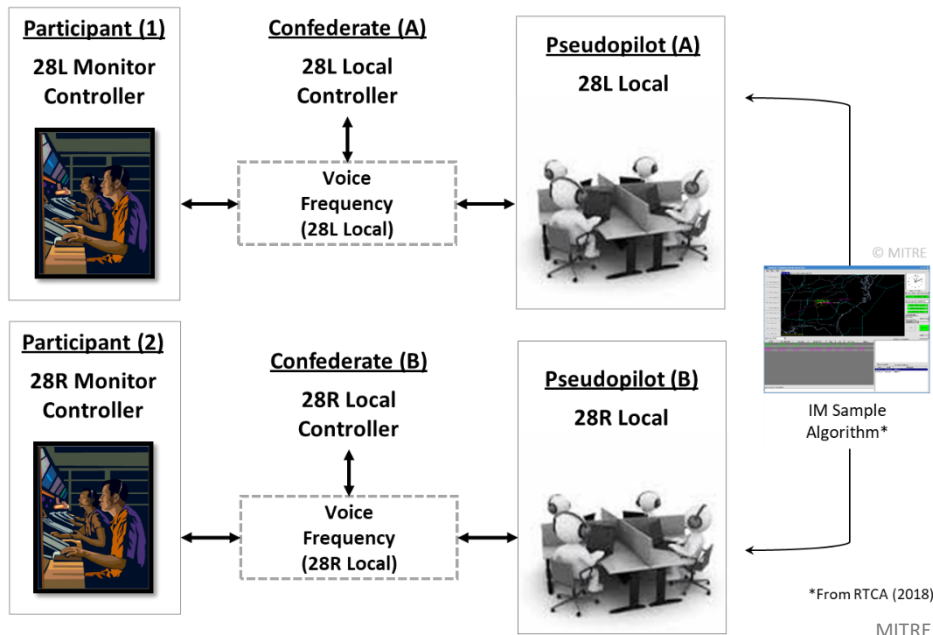
### 4.1.3 Communications Environments

Various communications configurations were used during the HITL, depending on whether participant controllers managed traffic as combined or separate monitors, as described in Section 4.3. Figure 4-3 shows the communications environment for the Combined Monitor configuration. Two separate loops were created: the first for the 28L/R Combined Monitor controller (participant), who monitored the frequency with a Combined 28L/R Local controller and the pseudopilot managing the traffic arriving to both runways. The second was the 28R Final controller, who communicated directly with a pseudopilot.



**Figure 4-3: Combined Monitor Configuration Communications Environment**

Figure 4-4 shows the communications environment for the Separate Monitor configuration. Two separate loops were created: the first for the 28L Monitor controller (participant) who monitored the frequency with a 28L Local controller and the pseudopilot managing the traffic arriving on 28L. The second was the 28R Monitor controller, who monitored a frequency between the 28R Local controller and the corresponding pseudopilot managing arrival traffic to 28R.



**Figure 4-4. Communications Environment: Separate Monitor Configuration**

The communications configuration shown in Figure 4-5 was used for the Combined Monitor Alert Timing and Lateral Deviation Combined Monitor Scenarios, as described in Section 4.5.

Only one loop was created: a 28L/R Combined Monitor controller (participant) monitored the frequency with a Combined 28L/R Local controller and the pseudopilot managing the traffic arriving to both runways. Two versions of this configuration were run at the same time, independent and in parallel.

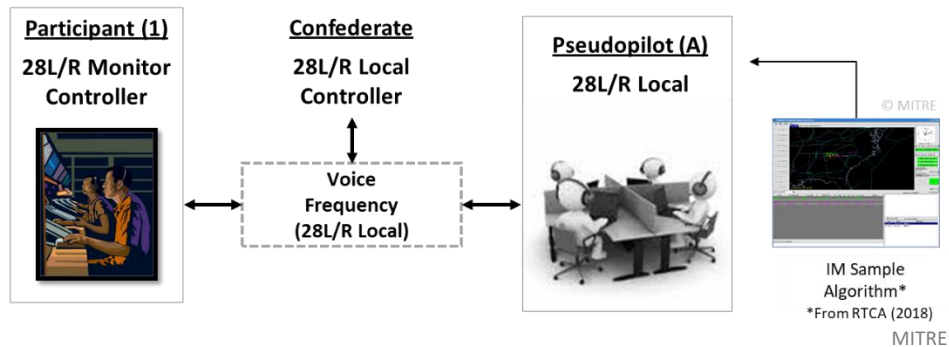


Figure 4-5. Single Participant Configuration Communications Environment

## 4.2 IM PA Ground Tools

As discussed in Section 3.1, new ground tools are expected to be required to allow controllers to provide a timely response to an aircraft deviation in either the longitudinal (along-track) or lateral (i.e., blunder) dimensions. Several new display features were therefore introduced and evaluated in the HITL to support IM initiation and monitoring functions. The following list summarizes the new display features and notes the sections of this report in which the features are described:

- IM Spacing List with IM PA Initiation Information (Section 4.2.1).
- Data Block Display of IM Status and the Distances to the CSL and WSL (Section 4.2.3).
- Line Representing the CSL (Section 4.2.4).
- Line Representing the WSL (Section 4.2.5).
- WSL Preview Line (WSL-P) (Section 4.2.6).
- Safety limit Predictive Alert and Caution Alert (Section 4.2.7).
- Lateral Boundaries and Exceedance Warning (Section 4.2.8).

The IM Spacing List and Lateral Boundary features were developed by MITRE through research supported by the FAA's SBS and ANG-C1 organizations. The other, IM PA-specific monitoring tools were developed by MITRE and supported by the FAA's CSPO Program Office. Tool design depends on the PA Separation Standard assumed for the HITL, so those assumptions are detailed in the following section. Detailed description for each of the IM PA tools is then described in the sub-sections that follow.

### 4.2.1 PA Separation Standard Assumed for the HITL

As described in Section 2.2.3, IM PA will require a new dependent parallel runway separation standard. The FAA has not yet begun to define this standard, however, so one needed to be assumed for the HITL experiment to inform: 1) suggested controller tasking and procedures, and 2) the design of the supporting monitoring tools and display features.

Previous research (Stassen, et al., 2017) suggests that although wind-independent IM PA operations at SFO requiring a WSL are likely infeasible, wake-free IM PA operations (that do not require a WSL) may be possible for more than 80% of the potential IM PA operations. As one of the primary objectives of the HITL is to examine controller monitoring with respect to both safety limits being active at the same time, it will assume that the implementation includes IM PA pairs that require a WSL. Therefore, the key PA separation standard characteristics assumed for the HITL experiment included:

- The PA separation standard is defined by the safety limit values and guarantees protection from collision in the event of a deviation by either the IM Trail Aircraft or IM Lead Aircraft and from a hazardous wake encounter.
- The safety limit values are dependent on facility geometry and independent of avionics capability. An IM termination does not automatically mean that PA separation is lost.
- No single safety limit value applies to a pair of aircraft for the entirety of the approach. Both the forward standard and aft standard change as a function of the Lead Aircraft's proximity to its runway threshold. Some aircraft pairings do not require a WSL.

For the purpose of the HITL, controllers were informed that separation is assured if the IM Trail Aircraft remains within the safety limits. The CSL values used in the HITL experiment are shown in blue in Figure 4-6, and were based on AFS, Flight Technologies Division, Flight Systems Lab (AFS-450) Monte-Carlo simulations at SFO and provided to RTCA SC-186 WG4 (Williams & Wood, 2017). The Monte-Carlo simulations examined longitudinal spacings between IM and Target Aircraft until an acceptable collision probability was found ( $1 \times 10^{-9}$ ).

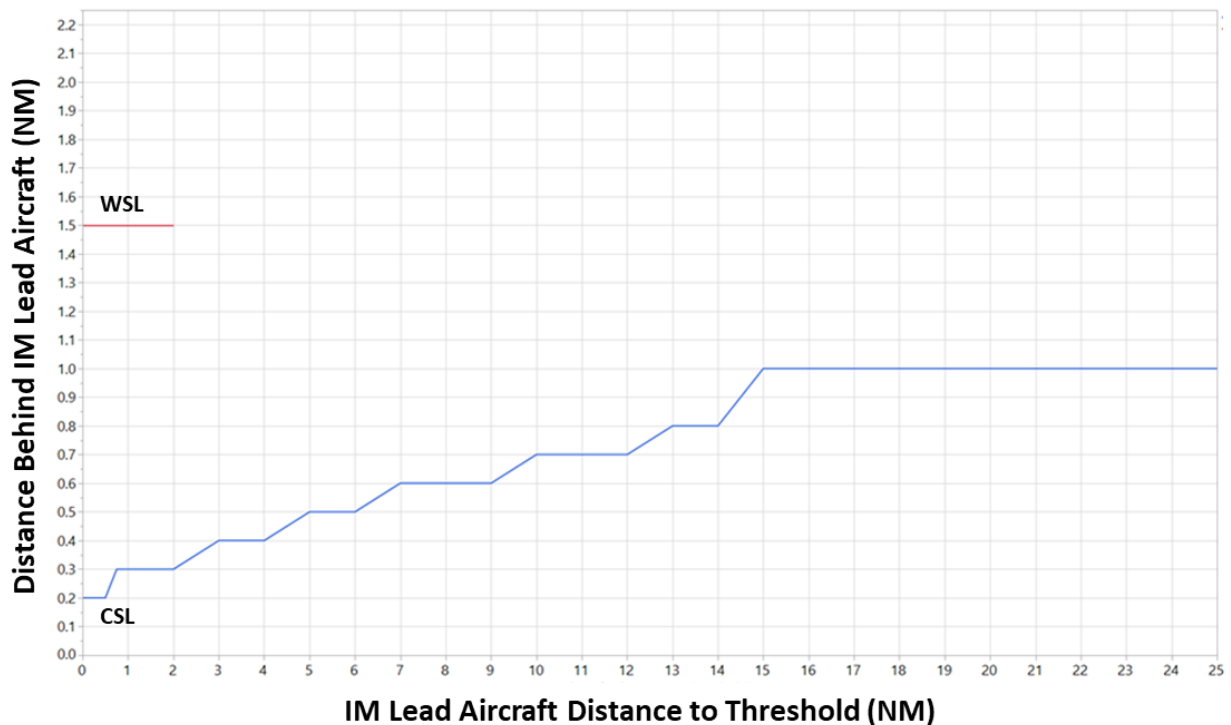


Figure 4-6. CSL and WSL Values Used in the HITL

A WSL value of 1.5 NM, starting when the IM Lead Aircraft was 2 NM from the runway threshold, was assumed for IM PA pairs involving a heavy category aircraft as the lead. This is shown as the red line in Figure 4-6.

Collision protection from a lateral deviation (i.e., blunder) is assured by the controller being required to take action to keep the IM Trail Aircraft from crossing the CSL. There is no expectation that controllers provide lateral deviation protection beyond this, therefore no “early” detection and protection requirements were assumed. However, because the CSL and WSL comprise the PA separation standard for the HITL, it was assumed that the controller participants need to know how much lateral deviation the limits have been designed to accommodate. If either aircraft then goes beyond that amount in either direction (left or right), then PA separation would no longer apply. Therefore, controllers were informed that the PA separation standard (CSL and WSL) applies as long as the IM Lead Aircraft and IM Trail Aircraft remain within defined lateral boundaries. Though the general concept for these boundaries was discussed and agreed upon by FAA stakeholders and operational experts, the implementation in this HITL, as described in Section 4.2.8, was the first attempt at a specific design.

#### 4.2.2 IM Spacing List with IM PA Initiation Information

The IM Spacing List provided the necessary information to enable the 28R Final controller to initiate the IM PA operation. The list was also displayed to the Monitor controller and provided IM Status information and an interface to the automation to indicate when IM PA was terminated early. The IM Spacing List design was based on that used in the 2017 IM TSAS HITL reported in Bone & Mendolia (2018). An example IM Spacing List is depicted in Figure 4-7 and controllers could position it as desired on the STARS display.

IM INFORMATION						
TRAIL AIRCRAFT	CLEARANCE TYPE	SPACING GOAL	LEAD AIRCRAFT	ABP	LEAD AIRCRAFT ROUTE	STATUS
FFT234	PAIR	38	UAL668		ILS28L	TERMINATED
UAL814	PAIR	35	JBU1084		ILS28L	ACTIVE
UAL718	PAIR	35	AAL451		ILS28L	ACTIVE
DAL216	PAIR	39	DAL669		ILS28L	ELIGIBLE
UAL671	PAIR	35	UAL864		ILS28L	ELIGIBLE

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Figure 4-7. IM Spacing List with IM PA Initiation Information

The IM Spacing List display included a list of proposed aircraft pairings, associated Assigned Spacing Goals, and status (i.e., eligible, active, terminated). The order of the text was presented to reflect how the IM Clearance would likely be issued via voice. The IM Spacing List also included an “accept” or “reject” function, which enabled the controller to indicate to the automation that the IM PA operation had been successfully initiated or not. Final controllers used the STARS keyboard keystroke sequence [MULTI FUNC]-[T]-[A]-SLEW (Lead+Trail Selection) to “accept” an IM Clearance. This triggered the automation to activate and display, as appropriate, the IM PA monitoring tools, including changing the Status field in the IM Spacing List to “Active.” To terminate an IM operation, Final or Monitor controllers used the STARS keyboard keystroke sequence [MULTI FUNC]-[T]-[T]-SLEW (Trail Selection). This removed the IM PA information from the radar display and changed the Status field in the IM Spacing List to “Terminated.” The text in the IM Spacing List was colored based on the status: white if eligible, green if active, and yellow if terminated.

The proposed IM PA pairs consisted of a variety of weight categories and initial spacings. An IM PA “feasibility check” was assumed to prevent the automation from proposing pairs for IM PA that arrive outside of the initial spacing window and thus are unlikely to remain within the safety limits. It was not assumed, however, that this check was sufficient to predict all possible infeasible operations. For example, scenarios included off-nominal conditions in which IM PA operations were proposed where an IM Trail Aircraft arrived near the CSL at the start of the approach and subsequently could not slow down quickly enough to remain behind the CSL.

As this list would likely be the same across the Feeder, Final, and Monitor controller positions, eligible IM PA pairs were displayed before they entered the Final controller’s area. It was assumed that any flight crew “rejection” of the initial Partial IM Clearance message would happen in feeder airspace. Therefore, Final controllers could assume that eligible pairs appearing on the IM Spacing List had already accepted the Partial IM Clearance.

### 4.2.3 Data Block Display of IM Status and CSL and WSL Values

The data block provided an indication of the IM Trail Aircraft and IM Lead Aircraft IM Status to the controllers and was incorporated into the data blocks similar to Bone & Mendolia (2018). For the IM Trail Aircraft, a T(E) symbol in Line 3 indicated a proposed IM Clearance (Trail Eligible), as shown in Figure 4-8. A T(A) symbol indicated an active IM Trail Aircraft (Trail Active). For the IM Lead Aircraft, L(A) indicated an active IM Lead Aircraft (Lead Active) as shown in Figure 4-9.



Figure 4-8. IM Trail Aircraft IM Status

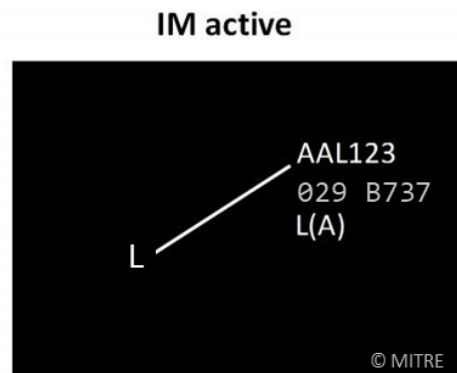


Figure 4-9. IM Lead Aircraft IM Status

The data block also was able to display CSL and WSL distance, which provided controllers with a numeric indication of the distance *from* the IM Trail Aircraft *to* each safety limit. In cases where a WSL was not yet active, the data block indicated whether it would eventually apply to the aircraft pair by displaying a “W” with no corresponding numeric value.

Figure 4-10 provides an annotated representation highlighting the CSL and WSL elements in the data block. Figure 4-11 shows the data block elements as displayed on the controller’s screen during the simulation. In summary, the data block line 3 information elements included the following four items:

1. In the first field, the IM Trail Aircraft Status was displayed.
2. In the second field, the distance to the CSL (in NM) was displayed, coded with a “C”.
3. In the third field, when a WSL applies to that pairing, the distance to the WSL (in NM) is displayed, coded with a “W”. Before the WSL applies in these cases, only the “W” was displayed as a “pre-active WSL indication.”
4. If no WSL applies to that pairing, only the IM Trail Aircraft Status and CSL distance value are displayed.

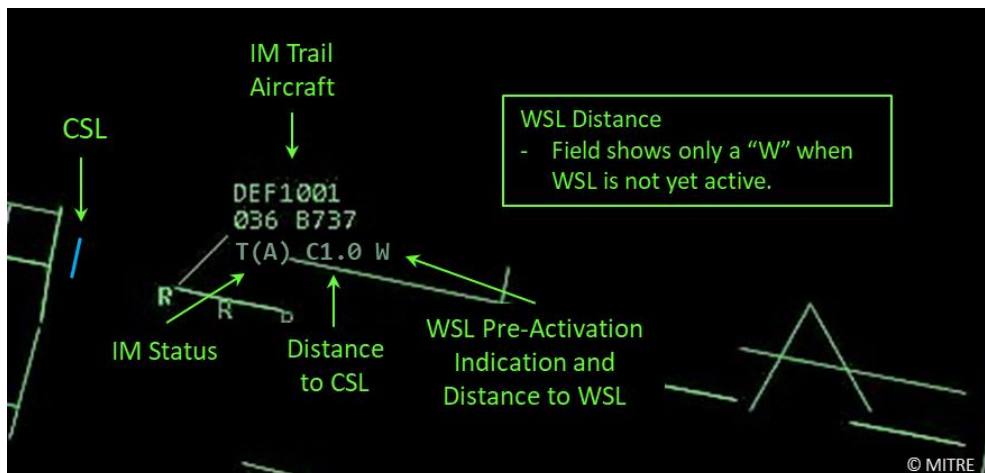


Figure 4-10. Annotated Display of CSL and WSL Data Block Elements



Figure 4-11. Data Block Elements, as Displayed in the HITL

As described in Section 4.5.4, the Data Block Distances to the CSL and WSL were investigated as an independent variable. They were either turned on or off for the Monitor controllers, depending on the scenario.

#### 4.2.4 Line Representing the CSL

A line was introduced on the display to provide a graphical indication of the minimum limit of the PA separation standard which, for the HITL, was set to the CSL value. Controllers ensured separation by keeping the IM Trail Aircraft behind this line. The CSL was represented by a cyan line on the IM Trail Aircraft's path as depicted in Figure 4-12, and moved with the IM Lead Aircraft's progression along its path. The CSL line represented the values shown in Figure 4-6.

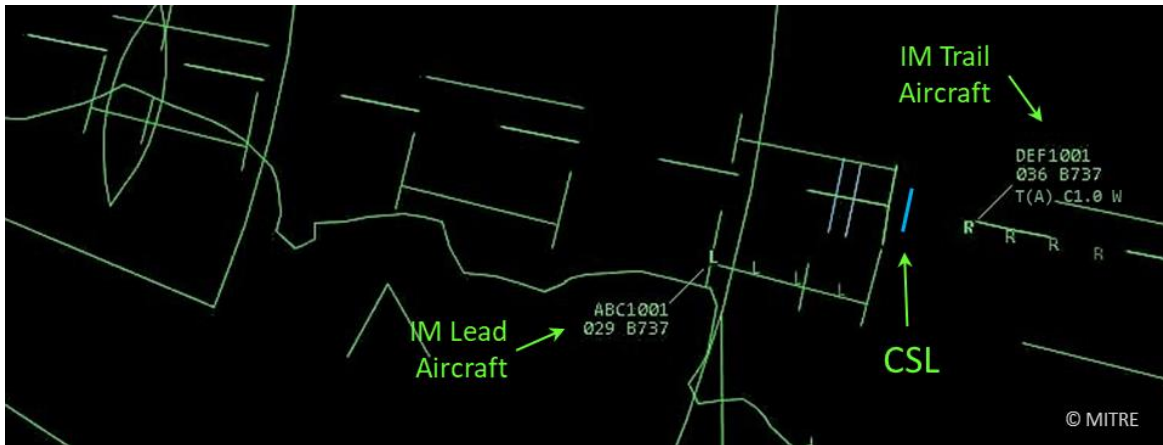


Figure 4-12. Cyan Line Representing the CSL

#### 4.2.5 Line Representing the WSL

A second line was introduced on the display to provide a graphical indication of the maximum limit of the PA separation standard which, for the HITL, was set to the WSL value. Controllers ensured separation and wake protection by keeping the IM Trail Aircraft forward of this line. The WSL was a cyan line on the IM Trail Aircraft's path as shown in Figure 4-13, and moved with the IM Lead Aircraft's progression along its path. When a WSL was applicable, it became active when the lead was 2 NM from the runway as shown in Figure 4-6.



Figure 4-13. Cyan Lines Representing the CSL and WSL

## 4.2.6 WSL Preview Line

When a WSL applied to an aircraft pair, it was only active for the last 2 NM of the final. Therefore, to avoid surprising controllers with a sudden display of the WSL, it was hypothesized that it would be useful to provide controllers with an advance indication that a WSL would eventually apply and its relative location at that time to the IM Trail Aircraft. Therefore, a WSL-P was implemented to provide an advance indication of where the WSL will appear when it becomes active. It was represented by a grey line at the location where the WSL would eventually appear, as shown in Figure 4-14.



Figure 4-14. Grey WSL-P

Although a WSL shape could theoretically change over the course of an IM PA operation, only one preview limit was displayed during the simulation to represent the initial wake separation limit that would come into effect. The behavior of the WSL-P remained continuous as it transitioned to reflect the compression of the aircraft pair. When the WSL became a requirement, the display then changed to the active state symbology (i.e., the cyan WSL line described in Section 4.2.5).

During its development, at least two potential issues were identified with the WSL-P that needed additional investigation. First, it does not indicate *when* a WSL would become active; it only indicates that at some point a WSL *will* become active. Second, at greater groundspeed differentials between the IM Trail Aircraft and IM Lead Aircraft, the WSL-P can first appear in front of the IM Trail Aircraft's current position. Then, as the IM Trail Aircraft caught up, it crosses over the WSL-P. It is possible that this may prove confusing and undesirable to controllers and was therefore included in the scenarios.

In the HITL, the WSL-P was first displayed when the IM Trail Aircraft was approximately seven NM from the runway threshold. Therefore, the WSL-P was not expected to be useful for the Final controller. As described in Section 4.5.4, the usefulness and acceptability of the WSL-P was investigated as an independent variable and it could thus be turned on or off for the Monitor controllers, depending on the scenario.

## 4.2.7 Longitudinal Alerting

As noted in Section 2.3.2.2, ATPA Phase 1 alert timing served as a foundation for the development of the IM PA alerting. The objectives of the IM PA alerts were to indicate to the controller when: 1) an IM Trail Aircraft was potentially at risk of encroaching on either of the

safety limits, and 2) when the controller must take an action (e.g., aircraft breakout) to maintain separation.

Two levels of longitudinal alerting were implemented in the simulation:

1. A *Predictive Alert* was displayed in yellow when crossing a limit boundary was predicted to occur within  $\langle X \rangle$  seconds. Here, the controller may still have had time to intervene by contacting the aircraft and confirming that the flight crew was still following the IM Speeds. This was a situation awareness advisory and controller action was not required.
2. A *Caution Alert* was displayed in orange when a limit boundary would be crossed within  $\langle Y \rangle$  seconds. When receiving this alert, the controller was required<sup>8</sup> to break out the IM Aircraft and establish an alternate form of separation.

The two alerts shared the same logic; only the timing values were different. The default Predictive / Caution alert timings were the same as those implemented for ATPA: 45 seconds and 24 seconds, respectively. Alternate Timings investigated in the HITL included: 35 seconds / 20 seconds and 25 seconds / 15 seconds. This was intended to examine whether lower alert timings than those chosen for ATPA remain acceptable to controllers for the IM PA monitoring task. Reduced timings may ultimately be used to mitigate against nuisance alerts (which would occur more frequently with greater timings).

Prior to the HITL, training emphasized that the predictive advisories do not necessarily require an action and that controllers should not break out aircraft prematurely to avoid one. The alerts apply to both the CSL and WSL, and it was possible to receive a WSL alert before the WSL was active as described in Figure 4-15.

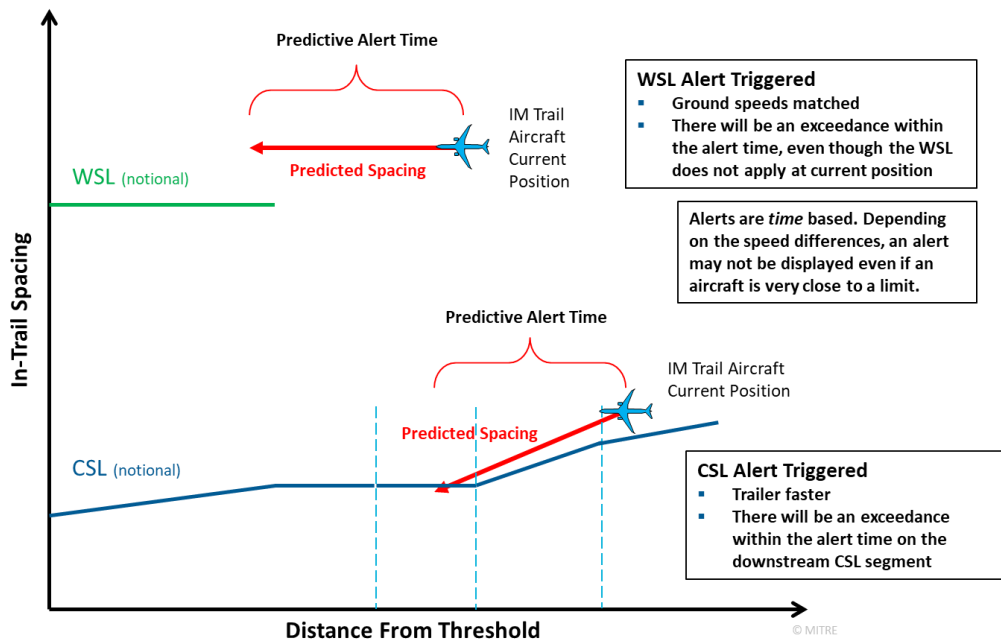
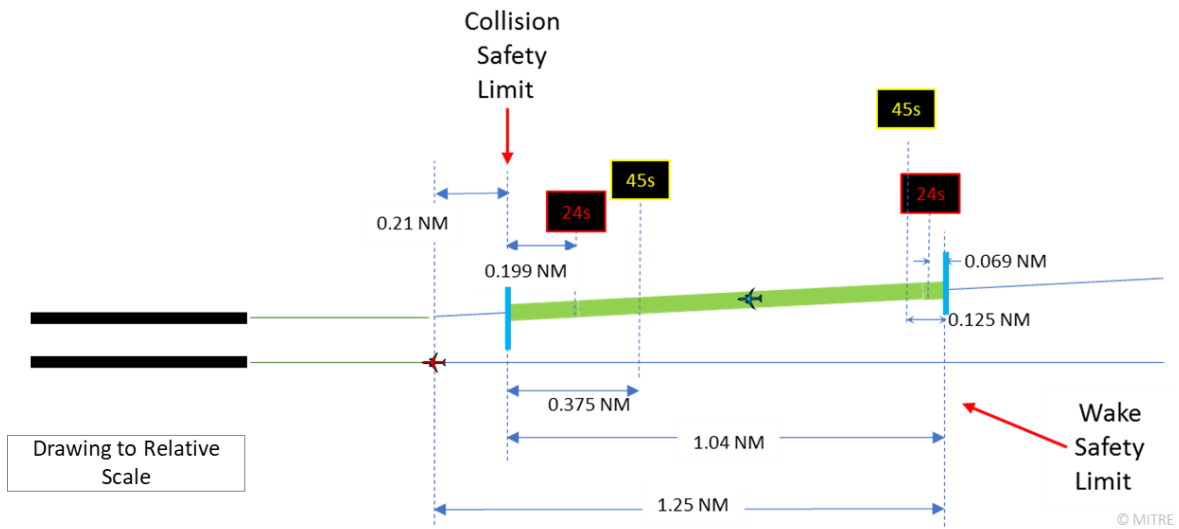


Figure 4-15. Predictive Alerting Logic

<sup>8</sup> The terminology for these alerts is consistent with those used for ATPA. These are, however, departures from industry standard definitions for Caution and Warning, in which a Caution is only an advisory and a Warning requires an action.

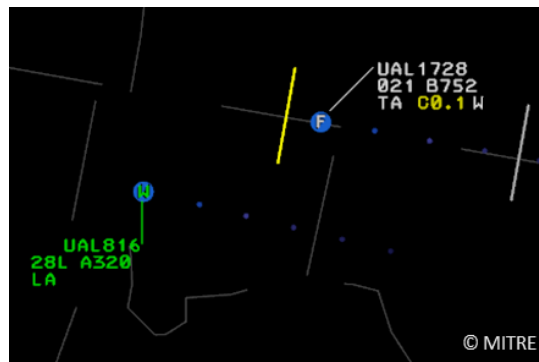
Figure 4-16 provides an example of the default alert timing distances. In the figure, the CSL and WSL are illustrated for operations inside 2 NM from the threshold. The CSL alert distances are based on a hypothetical 30 knots (kt) faster trail aircraft. The WSL alert distances are based on a hypothetical 10 kt faster Lead Aircraft. The Predictive Alert Timing is 45 seconds and the Caution Alert Timing is 24 seconds.



**Figure 4-16. Default Alert Timing Distance Example**

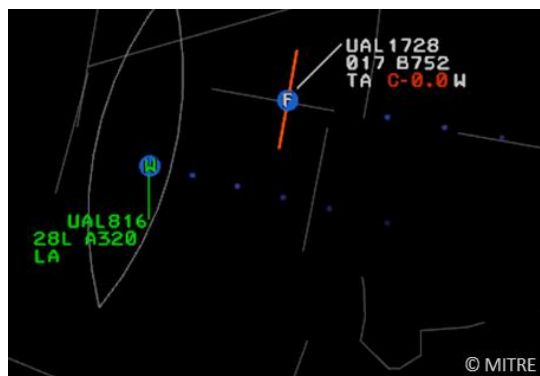
The alerts were active with respect to both the CSL and WSL. When the alerts were triggered, the CSL or WSL display, and the CSL/WSL Data Block Distance value (if displayed) changed color according to the level of alert and which limit was being encroached upon.

Figure 4-17 depicts the IM PA Predictive Alert relative to the CSL. The CSL display and Data Block Distance value are color-coded yellow to indicate the Predictive Alert state.



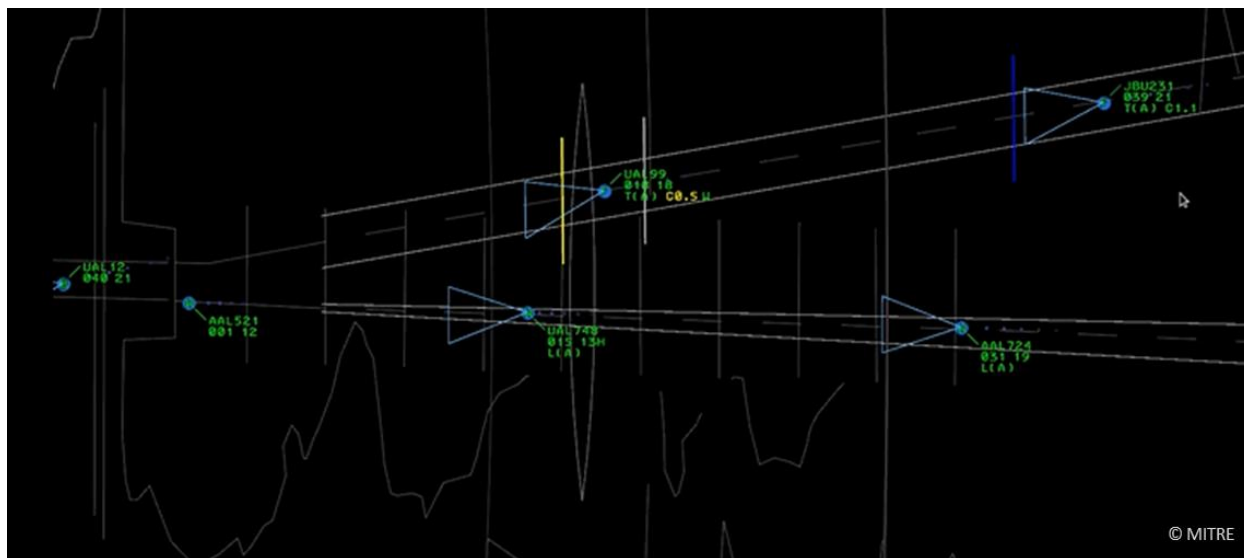
**Figure 4-17. IM PA Predictive Alert Relative to CSL**

Figure 4-18 depicts the IM PA Caution Alert relative to the CSL. The CSL display and Data Block Distance value are color-coded orange to indicate the Caution Alert state.



**Figure 4-18. IM PA Caution Alert Relative to CSL**

Some scenarios involved the use of a 4:1 FMA display for IM PA monitoring in a simulated FUSION mode which provides a one-second update rate. Figure 4-19 shows a Predictive Alert depiction on this display, relative to the CSL. The figure also depicts the Lateral Boundaries, which are described in Section 4.2.8. Note also that the controller is using the (optional) STARS “bats” to track aircraft ground tracks relative to the approach paths and to quickly detect deviations.



**Figure 4-19. Predictive Alert Depiction on the 4:1 FMA Display Relative to the CSL**

## 4.2.8 Lateral Boundaries and Exceedance Warning

The lateral monitoring task and associated procedures and requirements for IM PA operations are still in the early stages of development. As described in Section 2.4.2, Mendolia, et al. (2016) examined a lateral deviation monitoring task with a custom-designed NNZ, based on an NTZ, and associated caution and warnings. Its purpose was to assist aircraft in avoiding wake encounters as it assumed that collision protection was afforded by keeping aircraft aft of the CSL.

The lateral monitoring task, however, evolved for the current HITL due to the new IM PA requirement that controllers are responsible for separation and therefore must be able to

monitor the operation relative to a clear separation standard. As described in Section 4.2.1, the PA separation standard for the HITL was defined by the CSL and WSL. It was thus assumed that controllers needed to know how much lateral deviation was permitted before the limits were no longer valid. If either aircraft then deviated beyond those values in either direction (left or right), PA separation would no longer apply and another form of separation would be required. The lateral monitoring task was therefore different from that in Mendolia, et al. (2016) and the NNZ and alerting design needed to be reconsidered to help controllers determine whether observed lateral flight path deviations were within the allowable normal variability, or whether they were large enough to render the CSL and WSL invalid.

This section describes the design assumptions behind the Lateral Boundaries and Exceedance Warning as implemented. Procedures suggested to the controller participants for managing aircraft deviations across any of these boundaries are described in Section 4.3. The Lateral Boundaries and procedures are notional constructs developed specifically for the HITL simulation. Procedures and tools for managing IM PA operations across the range of possible lateral deviation geometries require further development.

#### **4.2.8.1 Lateral Boundary Configurations**

Due to the revised lateral monitoring task, an inner and outer boundary is required for each approach path. To inform this work, the HITL examined two Lateral Boundary configurations based on the navigation error assumed in deriving the CSL (Williams & Wood, 2017):

1. A configuration based on the most constraining Total System Error (TSE) accommodation for current NTZ implementations for independent runway operations. This consists of a 500 ft distance from the approach path to each boundary, for both approaches. This was the default condition and used during the Nominal (Section 4.5.5.1) and Alert Timing scenarios (Section 4.5.5.2).
2. A configuration that assumes the 500 ft TSE for 28R (as with Configuration #1), and three times the standard deviation of TSE assumed by Volpe in the wake research for the ILS 28L approach (unpublished). This configuration was examined only during the Lateral Deviation scenarios (Section 4.5.5.3).

The boundaries for both configurations extended from the start of the approach (15 NM final) to approximately 2 NM from the runway threshold. Inside of 2 NM, a deviation allowance of 75 ft was assumed. As boundaries at that distance are not realistically distinguishable from the approach path centerlines on the radar display, no attempt was made to display them. Therefore, from 2 NM to the runway, the controller task was to monitor deviations by ensuring the center of the target symbol remained on the approach path centerline. Unlike the NNZ described in Mendolia, et al. (2016), the Lateral Boundaries could not be toggled on or off or changed in brightness. For the Lateral Deviation scenarios, this lateral monitoring task was evaluated against both the standard 1:1 STARS display and a 4:1 FMA display. Both operated in a simulated FUSION mode with a one-second surveillance update rate.

Configuration #1, with 500 ft for both runways, was used for all HITL scenarios except for some Day 3 Lateral Deviation cases. A scaled depiction of the lateral boundaries for this configuration is illustrated in Figure 4-20.

PA Maneuvering Bounds - Fixed 500 feet

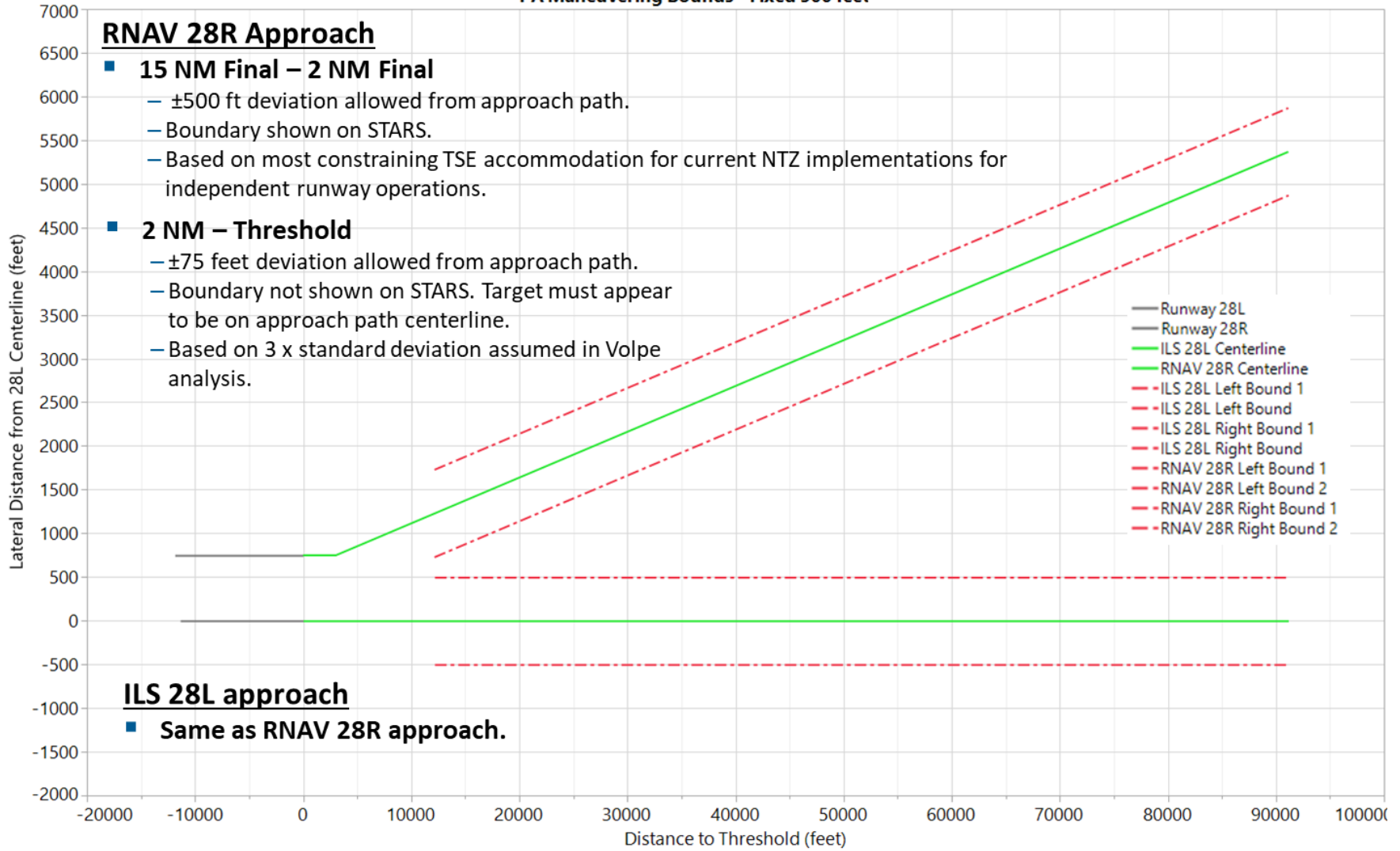
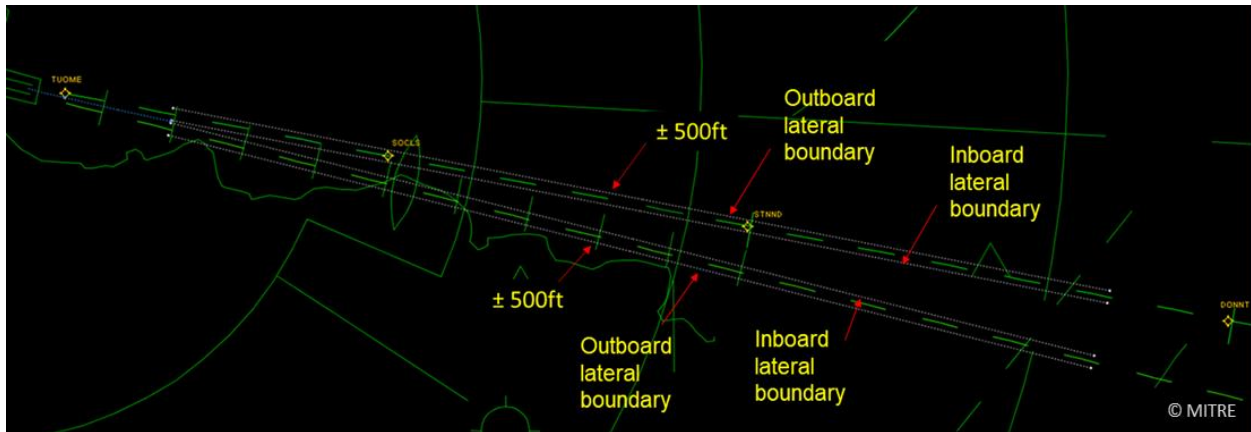


Figure 4-20. Scaled Depiction of Lateral Boundaries for Configuration #1

Figure 4-21 shows a scaled representation of the Lateral Boundaries in TARGETS with the elements labeled. Figure 4-22 contains scaled depictions of the Lateral Boundaries for Configuration #1 as implemented in the simulation.



**Figure 4-21. TARGETS Depiction of Configuration #1**



**Figure 4-22. Configuration #1 on Standard STARS Display**

Configuration #2 (500 ft for 28R and ILS for 28L) was examined in some of the Day 3 Lateral Deviation scenarios. A scaled depiction of the lateral boundaries for this configuration is illustrated in Figure 4-23.

PA Maneuvering Bounds - RNAV Fixed 500 feet - ILS Angular

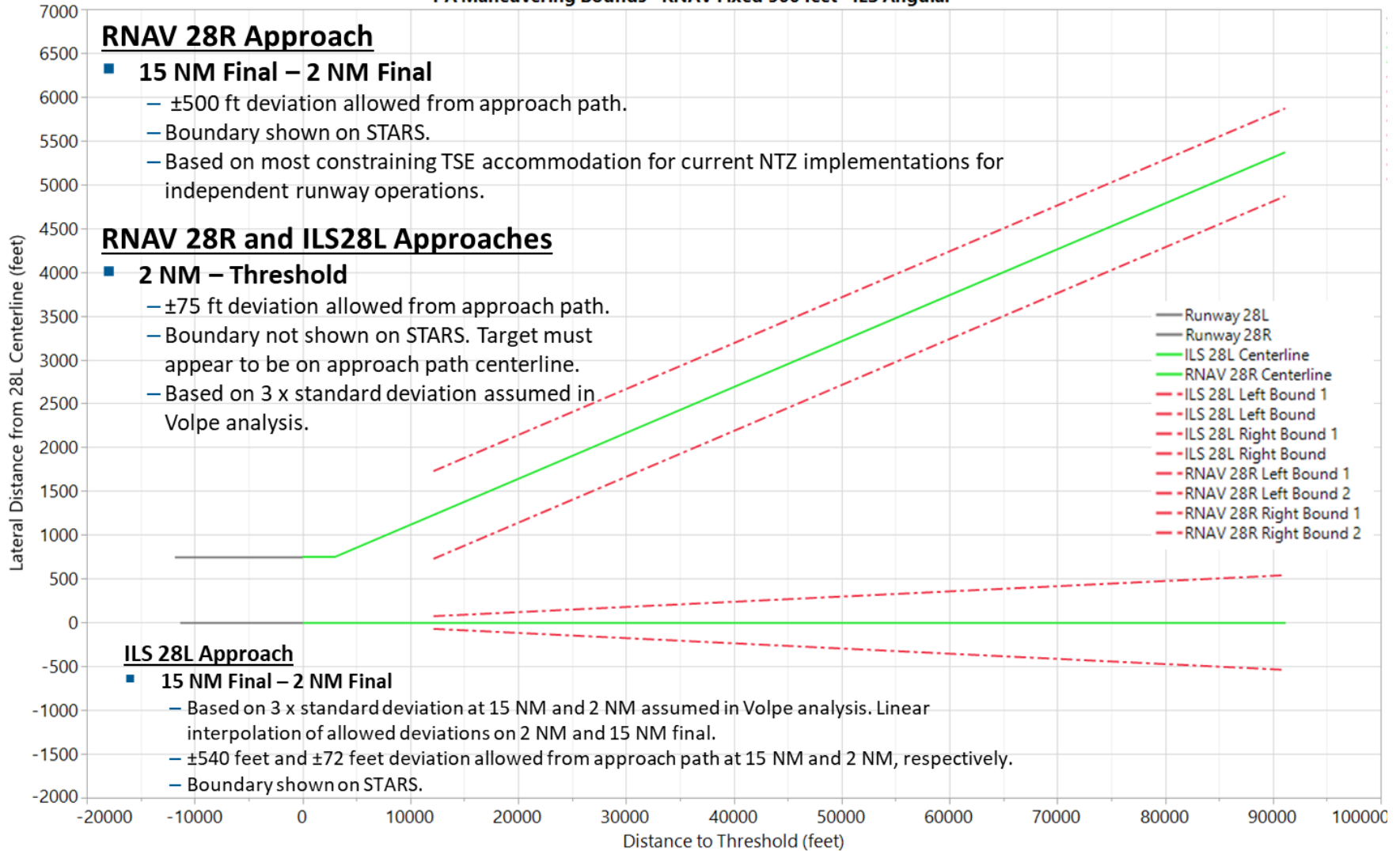


Figure 4-23. Scaled Depiction of Lateral Boundaries for Configuration #2

Figure 4-24 shows Configuration #2 on the standard STARS display. Figure 4-25 shows how Configuration #2 appeared on the 4:1 FMA display.

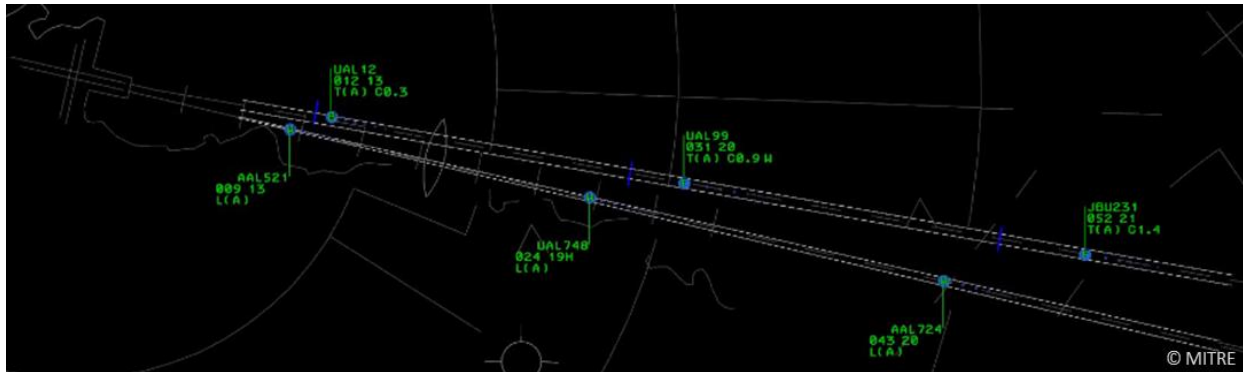


Figure 4-24. Configuration #2 on Standard STARS Display

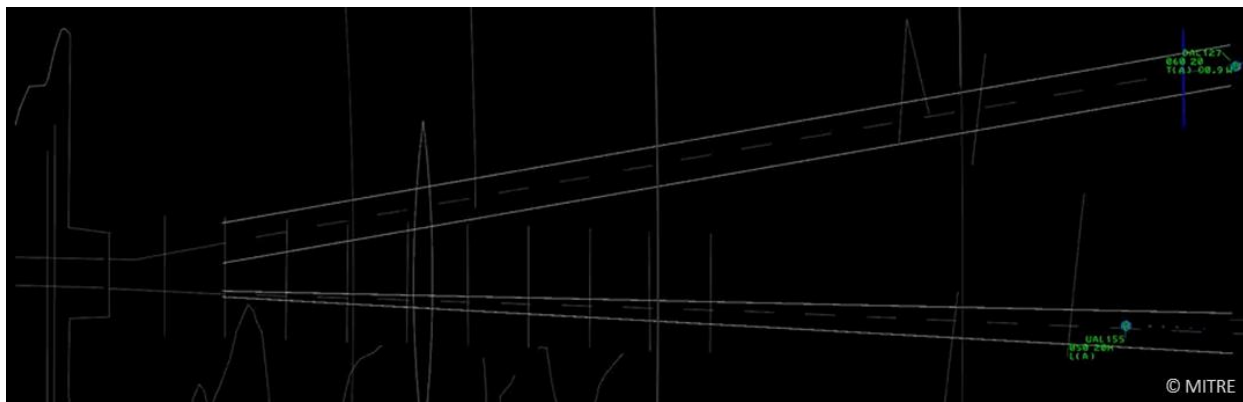
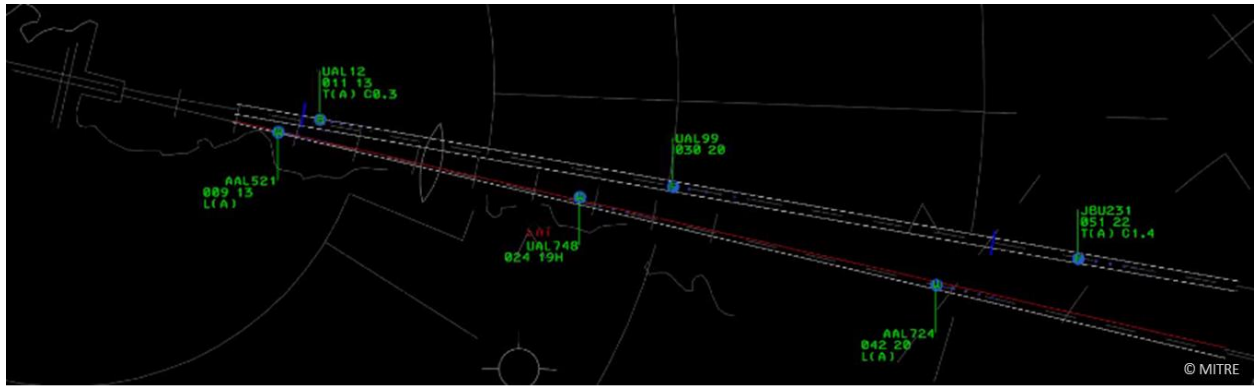


Figure 4-25. Configuration #2 on the 4:1 FMA Display

#### 4.2.8.2 Lateral Boundary Exceedance Warning

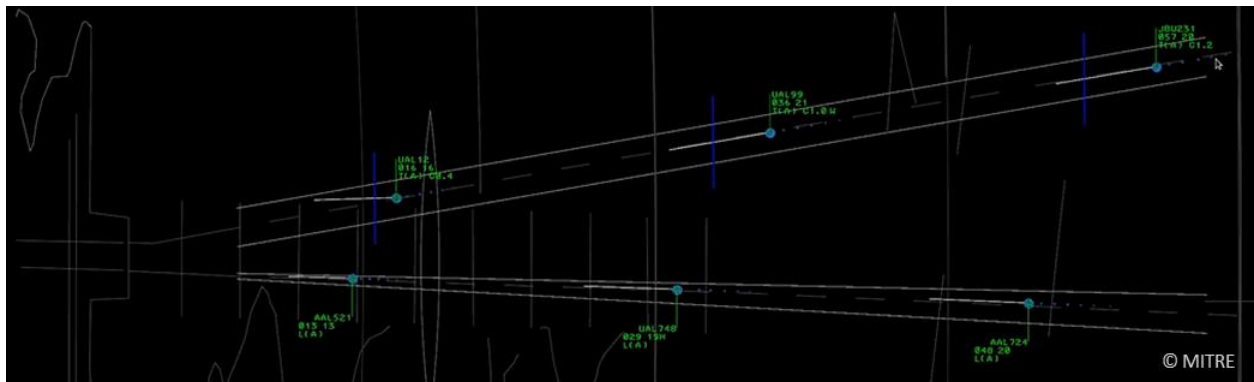
Under nominal conditions, the Lateral Boundary outlines were depicted in white on the display. When an aircraft crossed either of its respective boundary lines, an Exceedance Warning was presented to the controller. This consisted of two elements: 1) the inboard or outboard boundary line that was crossed turned red, then 2) a lateral “LAT” indication was displayed in the deviating aircraft’s data block line 0, similar to the zone alert text string indications in Mendolia, et al. (2016). Unlike in the prior study, it did not flash while active nor did the entire data block change color on the FMA display to indicate the alert.

When a lateral deviation occurred, the IM PA operation automatically terminated and the related IM PA display features (other than the Lateral Boundaries) were removed. The Lateral Boundary line remained red until the deviating aircraft was greater than 3000 ft past it. The line then returned to its former white color. Arrival aircraft not involved in IM PA operations would not trigger the Exceedance Warning. Figure 4-26 illustrates an Exceedance Warning for United (UAL) 748 crossing the inboard Lateral Boundary. The 28L Inboard Boundary is red, and a red “LAT” is displayed in Line 0 of its data block.



**Figure 4-26. Exceedance Warning for UAL748 Crossing Inboard Lateral Boundary**

Controllers could use existing STARS tools such as the PTLs and ground track bats to help detect lateral deviations on both the STARS and FMA displays. Figure 4-27 shows how PTLs appeared against the lateral boundary on Configuration #2 (500 ft for 28R and ILS for 28L) on the FMA display. In this scenario, UAL12 has just begun an outboard deviation but has not yet crossed the boundary.



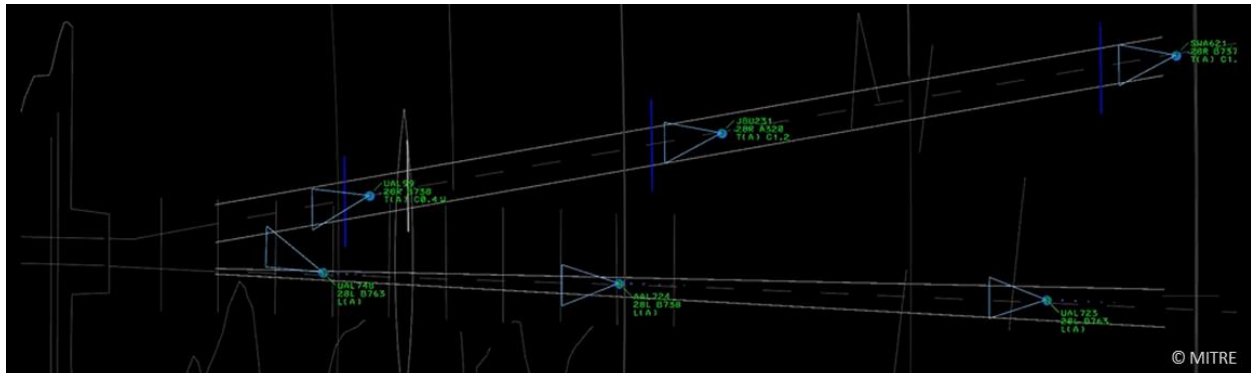
**Figure 4-27. PTLs on Configuration #2 on the FMA Display**

Figure 4-28 shows ground track bats on Configuration #2 (500 ft for 28R and ILS for 28L) on the 4:1 FMA display.

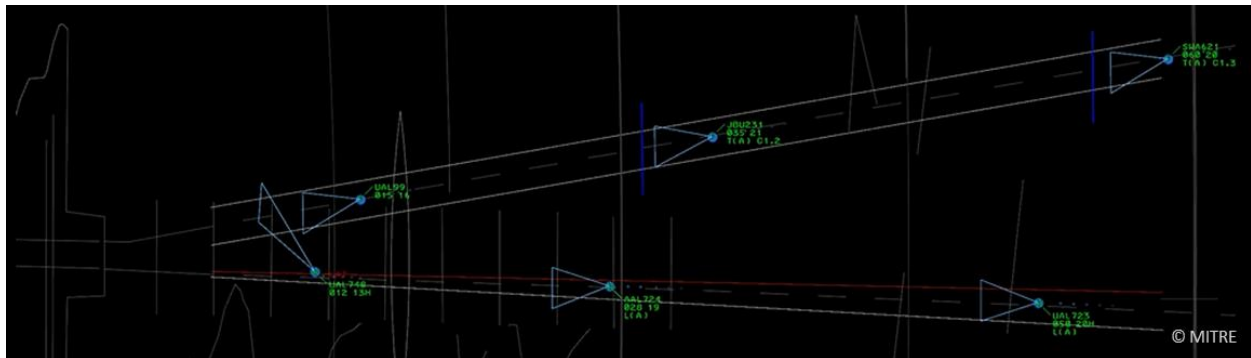


**Figure 4-28. Heading Bats on Configuration #2 on the FMA Display**

Figure 4-29 and Figure 4-30 show a lateral inboard deviation by an IM Lead Aircraft, UAL748, on the 4:1 FMA display when ground track bats were active. In the former, UAL748 started the deviation but has not yet crossed the boundary. In the latter, UAL748 has crossed the boundary, triggered the Exceedance Warning, and had its IM PA display information automatically removed.



**Figure 4-29. Start of UAL748 Deviation, Before Crossing the Inboard Lateral Boundary**



**Figure 4-30. UAL748 Crossing the Inboard Lateral Boundary**

As with the zone warnings described in Mendolia, et al. (2016), the Exceedance warning only appeared when an aircraft crossed one of the boundaries. There was no Predictive Alert capability for lateral deviations. Unlike the three different zone warnings shown in Figure 2-12, the current study design only involved a single Exceedance Warning for the entire length of the approach. This was because of the changes to the monitoring task as described in the beginning of Section 4.2.8.

## 4.3 Scenarios

This section provides an overview of the simulation scenarios, including the setup assumptions, airspace, and traffic flows.

### 4.3.1 IM PA Setup and Simulated Airspace

Each traffic scenario consisted of streams of arrival aircraft to SFO 28L and 28R parallel runways (see Figure 2-8). The flows contained a mix of aircraft separated via the PA and Single Runway

Spacing (SRS) standards. Wake turbulence RECAT separation standards (FAA, 2016) were applied and are discussed in more detail in Section 4.3.3.

Based on current airspace and RNAV procedures at SFO, a significant amount of vectoring would be needed to support the IM PA operation being evaluated in this HITL simulation. Aircraft landing on 28L generally approach the final approach course from the south, following vectoring from Boulder. These final sectors reach only to 5000 ft mean sea level. Most aircraft operating into SFO will be above that altitude and therefore under the control of an overlying sector when they enter the lateral extent of the sector. It is typically not until the aircraft nears the final approach course that they descend into Final controller airspace.

However, the simulation was not scoped to examine IM PA setup in feeder airspace. The initial positioning of the aircraft in the arrival stream was therefore assumed to have been accomplished at the start of each scenario, before the aircraft arrived in the participant controllers' airspace. The HITL did not take a position on whether this initial spacing was accomplished manually or with metering, a separate (non-PA) IM operation, or some other means.

The simulation used RNAV routes, as depicted in Figure 4-31, to ensure that aircraft were delivered to the final approach courses in a consistent, reproducible manner. The aircraft entered Final controller airspace on modified base legs, approximately 25 NM from the runway, with the desired initial spacing, and separated in altitude by 1000 ft. A lengthened, straight-in RNAV arrival to runway 28L was designed to allow aircraft pairs to enter Final controller airspace having been already established on extended final. IM Trail Aircraft joined a (new) RNAV procedure to 28R that included a 3-degree angled offset joining the final at 0.5 NM. IM Lead Aircraft turned to join the Instrument Landing System (ILS) to 28L. These procedures were developed for the HITL and are not currently in place at SFO. However, they may approximate procedures for a future metering environment.

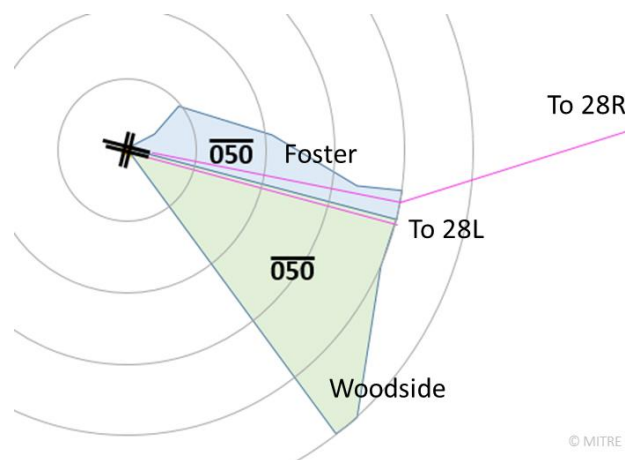


Figure 4-31. Simulation Airspace and Extended Arrivals

## 4.3.2 Traffic and Arrival Flows

All aircraft in the simulation were equipped with ADS-B Out and were thus capable of acting as IM Leads. Aircraft types in the simulated traffic flow were similar to those in Mendolia, et al. (2016) and included: Airbus A319, Airbus A320, Boeing 737-700, Boeing B737-800, Boeing

747-400, Boeing 747-800, Boeing 757-200, Boeing 767-300, B777-200, B777-300ER, CRJ-200, and CRJ-700. The 28L approach consisted of mostly heavy category aircraft such that WSLs would often be required. The simulated final approach speeds were appropriate set to the types, but were varied in each scenario. Aircraft liveries were primarily domestic, but also included some international carriers.

Aircraft were vertically separated when established on the extended final. At that point, the Final Approach controller provided the Assigned Spacing Goal and received flight crew acceptance. This initiated the IM PA operation and the controller then activated the IM PA operation via the automation<sup>9</sup>. PA Separation could then be applied. The Final Approach controller then gave the approach clearance and the IM Trail Aircraft could start descending. Controllers then monitored the IM PA operation and non-IM PA traffic (using Wake Turbulence and MRS minima discussed in Section 4.3.3) until landing. The SFO traffic flows developed for the HITL are depicted in Figure 4-32.

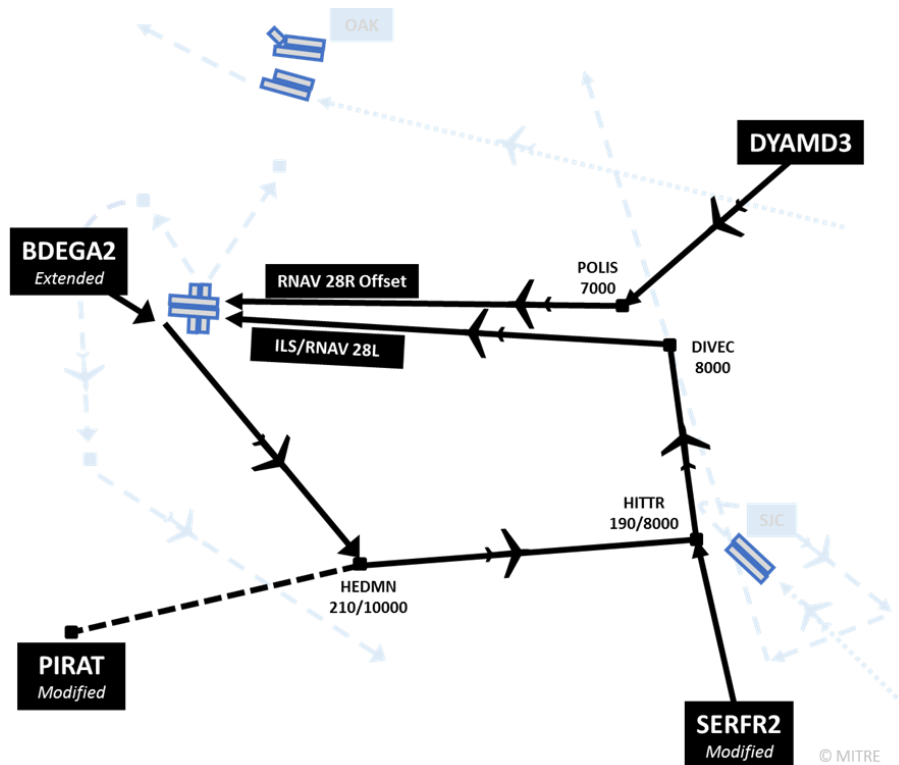


Figure 4-32. SFO Traffic Flows used in the HITL

The SFO arrival traffic in the HITL generally consisted of:

- 50% of total traffic from the east (DYAMD3 28R).
- 25% of total traffic from the north (BDEGA2 28L).
- 20% of total traffic from the south (SERFR2 28L).

<sup>9</sup> At the time of the experiment, it was thought that controllers should wait to receive flight crew acceptance of the IM Clearance before changing the IM PA status in the automation. This was intended to ensure that they would not change the status but then forget to give the IM Clearance in case of distraction. The HITL used this procedure; however, it should likely be modified based on results described in Section 5.3.

- 5% of total traffic from the ocean (PIRAT 28L).

In addition, SFO departures occurred via 1L/1R (10 for the scenario).

Some Oakland International Airport (OAK) arrival and departure traffic was also included:

- Arrivals to runway 30 (approximately 16 for the scenario).
- Departures to the north and east (approximately 15 for the scenario).

San Jose International Airport (SJC) arrival and departure traffic was also included:

- Departures to the northeast.
- Arrivals to 30R.

### 4.3.3 Wake Turbulence and Minimum Radar Separation

Wake Turbulence and MRS was required for aircraft on same and adjacent approach courses. The participants in the HITL were instructed to follow Wake RECAT On Approach separation minima by aircraft category (FAA, 2016), and were provided the separation minima shown in Table 4-1.

Table 4-1. FAA JO 7110.659C Wake Turbulence Separation on Approach

		Follower					
		A	B	C	D	E	F
Leader	A		5 NM	6 NM	7 NM	7 NM	8 NM
	B		3 NM	4 NM	5 NM	5 NM	7 NM
	C				3.5 NM	3.5 NM	6 NM
	D						4 NM
	E						
	F						

MRS is 3 NM for terminal operations and applies to pairings for which Table 4-1 does not specify wake turbulence separation. As an example, Figure 4-33 depicts the Wake RECAT and MRS separations that apply for the specified aircraft categories. In the HITL, 2.5 NM separation within 10 NM of the runway was allowed as it is in use in several facilities in the NAS (though not at SFO).

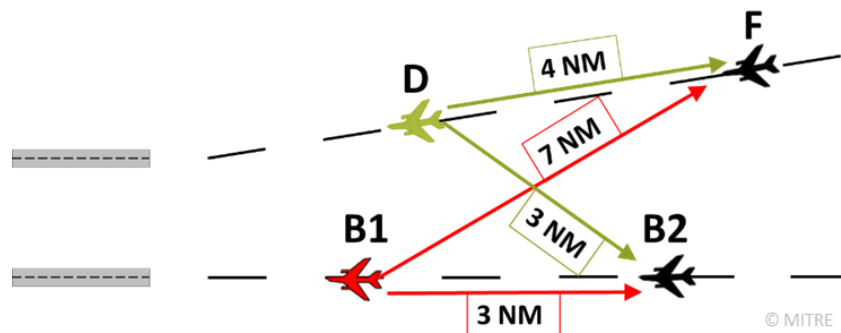


Figure 4-33. Application of Wake RECAT and MRS Standards

The aircraft types used in the scenarios correspond to the aforementioned categories and are shown in Table 4-2.

**Table 4-2. Aircraft Types and Categories in HITL Scenarios**

<b>B</b>	<b>C</b>	<b>D</b>	<b>E</b>
B772/W	B763	B737/8	CRJ2/7
A346		A319	
A332		A320	
B744/8		B752	

#### 4.3.4 Operational Chronology Summary

The following five series of non-simulated events were assumed to have occurred prior to the start of the scenarios:

1. For pairing compatibility and spacing goal computations, ground automation was made aware of the final approach speeds for each aircraft.
2. IM PA pairs were identified, and spacing goals were computed by automation.
3. An IM Spacing List was generated to represent the pairing and spacing goal information. Aircraft pairs were added and removed, along with their associated information, at the appropriate times.
4. The first part of the IM Clearance was provided in feeder airspace. The Assigned Spacing Goal, however, was withheld.
5. It was assumed that any flight crew “rejection” of the initial Partial IM Clearance message would happen in feeder airspace. If that occurred, the Feeder Controllers would remove those aircraft from the IM Spacing List and they would therefore not be presented as IM PA candidates on the IM Spacing List.

After the non-simulated events were completed, the following six events in the operational chronology were simulated and evaluated:

6. A list of proposed IM PA pairs and related information (via the IM Spacing List) was displayed to the Final Approach controllers<sup>10</sup>.
7. As the aircraft entered the final sectors and were established on their extended final approach courses, the Foster (28R) Controller consulted the IM Spacing List and provided the Assigned Spacing Goal to the IM Trail Aircraft. Altitude separation was then no longer required.
8. The IM Trail Aircraft flight crew accepted the Assigned Spacing Goal and entered it into their FIM Equipment. The controller assumed the operation then began; the IM Trail Aircraft started following its IM Speeds.
9. The Final Approach controllers cleared the aircraft for their approaches and instructed them to change to the Local controller frequency.

<sup>10</sup> Not every scenario included staffing the Final Controller position with a participant. See Section 4.5.6.

10. The IM Trail Aircraft followed the IM Speeds until reaching the FAF, at which point nominal termination occurred.
11. The Monitor controller(s) monitored the IM PA pairs until the IM Lead Aircraft crossed the runway threshold.

## 4.4 Controller Roles, Responsibilities, and Procedures

Controller participants had two primary tasks in the simulation: 1) initiate IM PA operations and 2) provide separation on final, including for IM PA and non-IM PA aircraft. The specific positions and tasks for each are detailed in the following sections. The simulation also used confederates as Local controllers; their responsibilities in the HITL are also described in this section.

### 4.4.1 IM PA Initiation and Final Approach Controller Tasking

As described in Section 4.3.4, before an arriving IM Trail Aircraft entered the Final controller's airspace, it will have been provided a Partial IM Clearance by the Feeder Controller to allow the flight crew to prepare the FIM Equipment for the operation. Therefore, the Final controller only needed to provide the Assigned Spacing Goal to clear the aircraft to begin the IM PA operation.

The 28R Final controller was the only position that could issue the Assigned Spacing Goal to complete the IM Clearance. Using the information provided via the IM Spacing List, the 28R Final controller completed the Partial IM Clearance after the IM Trail Aircraft entered their airspace. Upon receipt of the Assigned Spacing Goal, the IM Trail Aircraft was able to begin the procedure. Therefore, the Assigned Spacing Goal and clearance for the instrument approach had to be provided before the IM Trail Aircraft joined its glideslope. Participants were allowed to provide the Assigned Spacing Goal before, after, or as part of the final approach clearance.

As the IM PA operation begins as soon as the Assigned Spacing Goal is provided, the 28R Final controller also had to ensure that the IM Trail Aircraft remained behind its CSL until transfer to the Local controller. If the IM Trail Aircraft was forward of the CSL at the time of initiation, the Final Approach controller was instructed to cancel the IM Clearance and establish alternate separation. The suggested procedure was to put the 28R aircraft on a 280 heading and transfer it to TRACON Departure (SUTRO), but participants were told they had full discretion to resolve developing separation problems as they saw fit.

The tasking for Final Approach controllers varied based on the runway they were working. In the HITL, the 28L Final controller position was not staffed by a participant; the HITL automation managed the arrivals and frequency changes for arriving aircraft. Still, tasking for the 28L Final controller position needed to be identified.

The **28L Final controller** was responsible for the following tasks:

- Accept 28L handoffs from Feeder Controller.
- Provide 28L traffic with approach clearances.
- Issue 28L traffic frequency change to Local controller at approximately 15 to 20 NM.

The 28R Final controller had initiation and monitoring responsibilities related to the IM PA operation and had access to the following tools: IM Spacing List, Data Block Distances, and the CSL when PA is initiated.

The **28R Final controller** was responsible for the following tasks:

- Accept 28R handoffs from Feeder Controller.
- Provide 28R traffic with approach clearances.
- View IM Spacing List and provide 28R traffic with Assigned Spacing Goal at the appropriate time.
- Indicate proposed IM Clearance acceptance, rejection, or termination in the IM Spacing List.
- Ensure the IM Trail Aircraft remains behind the CSL from the time the Assigned Spacing Goal is issued to when the aircraft has transferred to the Local controller frequency.
- Issue frequency change to 28R traffic to Local controller at approximately 15 to 20 NM.

#### 4.4.2 Local Controller Position Tasking

Staffed by confederates in the HITL, Local (Tower) Controllers were necessary to provide landing, takeoff, and other clearances as necessary for SFO arrival and departure traffic. They provided a steady stream of communications that the controller participants, serving as Monitor controllers, could hear. Though the confederate Local controllers issued landing clearances, they were not responsible for aircraft separation along the final approaches.

IM PA monitoring in both combined and separate Local controller configurations was examined. The Combined Monitor configuration employed a single Local controller who issued landing clearances for both 28L and 28R runways. The Separate Monitor configuration involved separate Local controllers, one for each arrival runway, and had split responsibilities. The tasking for the confederate Local controllers for each configuration is described below.

**Combined Local controller** configuration:

- Provide landing clearances to arriving 28L/28R traffic.
- Provide takeoff clearances to aircraft on 1L/1R.
- Provide other clearances, such as runway crossings, as needed.

**Separate Local controller** configuration:

- 28L Local controller
  - Provide landing clearances to arriving 28L traffic.
- 28R Local controller
  - Provide landing clearances to arriving 28R traffic.
  - Provide takeoff clearances for aircraft on 1L/1R.
  - Provide other clearances, such as the 28L runway crossing, as needed.

#### 4.4.3 IM PA Monitoring and Monitor Controller Tasking

Although the Final Approach controller ensured that the IM PA operations began with the IM Trail Aircraft behind the CSL, the Monitor controller(s), assisted by IM PA display features and alert automation had separation responsibility for the majority of the approach. The general monitoring task and procedures for both longitudinal (along track) and lateral deviations is

described below, followed by specific Monitor controller responsibilities and procedures as conveyed to the participants.

#### 4.4.3.1 Longitudinal Monitoring Procedures

As described in Section 4.2.1, controllers were informed that an IM Trail Aircraft was safely separated while it remained within the safety limit(s). Controllers were alerted if an aircraft began to encroach on either of the safety limits. Depending on the alert, the procedures to resolve the situation and ensure separation are as described in Section 4.2.7. These consisted of:

- *Predictive (yellow) CSL or WSL Alert*: Monitor the situation, be prepared to take action. If desired, can optionally confirm IM PA equipment status with IM PA aircraft.
- *Caution (orange) CSL or WSL alert*: Break out the trail aircraft.

#### 4.4.3.2 Lateral Monitoring Procedures

As described in Section 4.2.8, Lateral Boundaries were implemented to help controllers determine whether observed flight path deviations were within design bounds for normal variability, or whether they constituted a situation beyond what the CSL and WSL were designed to accommodate.

Research with respect to lateral deviations during an IM PA operation is still in its early stages. Thus, in the design of the lateral deviation monitoring task and response procedures, the HITL made assumptions based on work done to date. An analysis of over 1.8 million recorded approach paths suggests that flight path deviations on approach are rare; 82 were found, for a rate of  $4.47 \times 10^{-5}$  (Eckstein, Massimini, McNeill, & Niles, 2012). Of those, 42 involved a deviation angle of 10 degrees or more. The remainder involved a deviation angle of less than 10 degrees. The impact on spacing, separation and wake turbulence avoidance of a potential protracted shallow angle deviation during a PA operation is not fully understood. However, the safety limits are designed using assumptions about the nature of TSE with respect to lateral course tracking (Williams & Wood, 2017). Flight path deviations in excess of the assumed TSE invalidate the protections that the CSL and WSL provide. It may therefore become necessary to break out one or both IM PA Aircraft in response to some flight path deviations, not just to terminate IM PA, but also to manage collision and wake turbulence risk within the IM PA pair. This may especially be the case for an inboard deviation by the IM Lead Aircraft.

The HITL simulation assumed that outboard deviations by either aircraft beyond what the CSL and WSL have been designed to accommodate result in the end of the IM PA operation and the need to establish an alternate form of separation. However, the safest course of action in these cases is probably for the non-deviating aircraft of the pair to continue on the approach. An inboard deviating IM Trail Aircraft, in either direction, should not be in a position to affect the IM Lead Aircraft.

Based on this, controllers were provided three procedures<sup>11</sup> two with respect to IM Lead Aircraft lateral deviations, and one with respect to an IM Trail Aircraft lateral deviation. They were not required to take action until the Lateral Boundary Exceedance Warning was triggered.

1. *IM Lead Inboard Deviation*: If the IM Lead Aircraft deviates to the right and crosses its inboard lateral boundary, advise the IM Trail Aircraft that the IM PA operation is over, issue a go-around procedure to the IM Trail Aircraft, and manage the IM Lead Aircraft per standard operating procedures.
2. *IM Lead Outboard Deviation*: If the IM Lead Aircraft deviates to the left and crosses its outboard lateral boundary, do not break out the IM Trail Aircraft. Terminate the IM PA operation, establish an alternate form of separation, and manage the resolution per standard operating procedures.
3. *IM Trail Deviation*: If the IM Trail Aircraft deviates laterally and crosses either boundary, inboard or outboard, the IM PA operation ends. The controller leaves the IM Lead Aircraft on the approach, advises the IM Trail Aircraft that the procedure has ended, and manages the deviating aircraft per standard operating procedures.

Controllers were given the following guidance for breakouts, but were told they had full discretion to resolve developing separation problems as they saw fit:

- For the left aircraft, the controller was to climb them to an altitude of their discretion, put them on a 260 heading, and transfer them to Departure (SUTRO).
- For the aircraft on the right, the controller was to climb them to an altitude of their discretion, put them on a 280 heading, and transfer them to Departure (SUTRO).

#### 4.4.3.3 Monitor Controller Position Tasking

As described earlier, this HITL examined IM PA monitoring with respect to both Combined and Separate Monitor configurations. The specific tasking for each configuration is outlined below.

**Combined Monitor** configuration:

- Monitor the Local controller's frequency.
- Issue speed instructions to aircraft as needed to provide required separation.
  - For an IM PA pair, any speed instructions should be given to the IM Lead Aircraft. Speed instructions given to the IM Trail Aircraft terminate the IM PA operation.
  - Break out any aircraft as needed to ensure separation.
  - If breaking out a Lead Aircraft, terminate IM PA operation with the trail aircraft.
- Use the display features to monitor the IM PA operation and provide separation.
  - Issue control instructions as needed to keep the IM Trail Aircraft from violating the WSL and CSL.
- Terminate IM PA operation in the event of a lateral deviation by either aircraft.

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<sup>11</sup> The controller procedures for managing aircraft deviations across any of the Lateral Boundaries were notional constructs developed specifically for the HITL simulation. Actual procedures accounting for the range of possible lateral deviation geometries require further development.

In this configuration, the Monitor controller had the following tools available: CSL, WSL, WSL-P, data block additions, Alerting, and Lateral Boundaries.

#### **Separate Monitor configuration:**

- *28L Monitor Controller:* Monitor the 28L Local controller's frequency. Provide separation between (not within) IM PA pairs by providing speed assignments to 28L aircraft, including the IM Lead Aircraft, if needed.
- *28R Monitor Controller:* Monitor the 28R Local controller's frequency. Provide separation within IM PA pairs by taking action if a safety limit is about to be exceeded.
- Both controllers had the following tasks:
  - Monitor aircraft positions with respect to the lateral boundaries.
  - Intervene as needed to ensure separation is maintained.
  - Apply (Wake RECAT) single runway separation to non-IM aircraft.

Both controllers had the following tools available: CSL, WSL, WSL-P, data block additions, Alerting, and Lateral Boundaries.

#### **4.4.4 IM PA Termination**

The Monitor and Local controllers were made aware that IM Speeds were only provided up to the IM PTP, which was co-located with the FAF. The Assigned Spacing Goal would have been calculated to ensure separation was maintained during compression between the FAF and runway. However, the Monitor controller(s) still had to monitor with respect to the safety limits until the IM Lead Aircraft crosses the threshold. WSL monitoring was no longer needed once the IM Lead Aircraft crossed its runway threshold. All IM PA monitoring tools, including alerting, were suppressed at this point. Under nominal IM PA operations, flight crews were not required to inform controllers that they were no longer following IM Speeds as they crossed the PTP/FAF.

#### **4.4.5 Simulation Phraseology**

The HITL assumed that Feeder Controllers informed the aircraft which approach to expect and provided the initial communication as part of a Partial IM Clearance. Therefore, the simulation phraseology was only applicable to the (28R) Final controller and Monitor position(s). Participants were provided the phraseology below to use during the experiment.

- Non-IM PA Aircraft Approach Clearance:  
*Final Controller: "Aircraft 123, maintain 6000 until established. Cleared RNAV 28R approach."*
- Partial IM Clearance Assigned Spacing Goal Message:  
*Final Controller: "Aircraft 123, spacing goal [x] seconds behind Aircraft 456."*
- IM Trail Aircraft Approach Clearance:  
*Final Controller: "Aircraft 123, cleared RNAV PAPA 28R approach."*
- IM PA Off-Nominal Termination, Flight Crew "Unable":  
*Aircraft 123: "ATC, unable interval spacing."*

ATC: “Aircraft 123, terminate interval spacing. [Instructions...]”

- IM PA Off-Nominal Termination, Controller Initiated:

ATC: “Aircraft 123, terminate interval spacing. [Instructions...]”

## 4.5 Experimental Design

This section describes how the HITL experiment was conducted, including detailed research objectives, participants, traffic files, scenario matrices, and the run order and data collection strategy.

### 4.5.1 Objectives

Based on the research questions and hypotheses described in Section 3.3, the experimental design addressed the following seven objectives:

1. Examine overall acceptability of monitoring nominal IM PA operations, in both Combined and Separate Monitor configurations.
2. Examine acceptability of the following IM PA Tools: IM Spacing List, Data Block IM Status, CSL/WSL Line Displays, Predictive and Caution Alerts, Lateral Boundaries and Exceedance Warning.
3. Examine usefulness of potentially optional IM PA tools: WSL-P and Data Block Distance to CSL/WSL display.
4. Examine the effect of decreasing the alert timing values: ATPA Timing, plus two additional Timings.
5. Examine the acceptability of the IM PA Tools with respect to two off-nominal conditions: Spacing Loss, IM Lead Aircraft Deviations.
6. Examine the impact of display type, monitor configuration, and Lateral Boundaries on the lateral monitoring task.
7. Examine feasibility and acceptability of using Partial IM Clearance procedures to initiate an IM PA operation.

The design strategy to collect data to evaluate these is described in the following sections.

### 4.5.2 Participants

Participant controllers were coordinated through the FAA and National Air Traffic Controllers Association (NATCA) using standard procedures. Controllers were compensated for their participation through standard FAA processes. Twelve certified and current terminal area controllers with at least three years of experience in parallel runway approach operations were requested. This included at least two from NCT per week, each with at least three years certification in Area B. The request also asked that no one with prior MITRE PA simulation experience should be included.

Twelve currently certified controllers participated in the simulation. Four of the controllers were from NCT and had experience in the area being simulated (Area B). Eight of the controllers were from other terminal facilities with parallel runway approach operations. Including those

from NCT, eight of the twelve participants were current TRACON Approach Controllers. Two of the participants were currently Tower controllers, but had TRACON experience. Due to a miscommunication related to the request, two participants only had Tower experience. These two controllers were provided extra training on the separation tasking and their results were usually pooled separately.

The TRACON controllers and Tower controllers with TRACON experience had an average age of 37.1 years and on average actively controlled traffic for 13.75 years (with a minimum of 9 years and a maximum of 26 years). The two Tower-only controllers had an average age of 33.5 years and had controlled traffic for 8.5 and 11 years.

There were four non-participant roles. Two pseudopilots controlled and responded as all aircraft. Two confederate controllers served as Local controllers.

### **4.5.3 Simulation Schedule, Procedures, and Controller Training**

The HITL was conducted over three weeks. Each week involved the four participant controllers participating in a 3-day simulation session. The schedule was based on a repeated-measures experimental design, intended to maximize experimental power by having every participant experience each experimental condition from each position.

Each weekly session consisted of three self-contained experiments. The first, which occurred over Days 1 and 2, examined normal operations with combined versus separate Monitor controllers. The IM PA tools were also varied to examine their relative usefulness. The first day began with a pre-simulation briefing, which covered the PA concept, the simulation environment (i.e., airspace, traffic, separation, and other procedures), controller roles and responsibilities (as described in Section 4.4), and the overall schedule and conduct of the simulation. After that, controllers were brought into the lab and given a practice scenario that allowed them to familiarize themselves with the workstation and simulation-specific procedures, including initiating, monitoring, and terminating IM PA. Controllers were also provided a summary sheet with key procedures (such as responses to off-nominal conditions) and communications frequencies. Following the training, controllers started the data collection scenarios.

Day 2 started with a shortened training briefing that summarized the IM PA concept information from Day 1 and introduced new procedures for the roles the participants would be assuming that day. Controllers were again provided a practice scenario that allowed them to familiarize themselves with the new procedures and tasks. As with Day 1, controllers began the data collection scenarios directly following the training.

The third day of each session consisted of two separate, self-contained evaluations. The first, in the morning, examined different longitudinal alert timing values. The second, in the afternoon, took an initial look at lateral monitoring and introduced IM Lead Aircraft and IM Trail Aircraft deviations that exceeded the Lateral Boundaries. Each evaluation was preceded by a short training briefing that described the new aspects of the scenarios they would be working and reviewed key procedures. For the Alert Timing scenarios, controllers were informed what the new alert values would consist of. For the lateral monitoring scenarios in the afternoon, controllers were reminded of the procedures to manage these off-nominal deviations. Training

scenarios were not provided for either as the traffic and controller position configurations were the same as they had already experienced in Days 1 and 2.

Each run for all three days was followed by a short questionnaire asking for controllers to rate their experience in that scenario across a variety of metrics. A final questionnaire was provided at the end of Day 1 asking about their experience across all the scenarios they experienced that day. A different final questionnaire was provided at the end of Day 2 and consisted of two parts. The first asked controllers to rate their experiences for only the scenarios they experienced on Day 2. A second part then asked controllers to rate their experiences across both Days 1 and 2. For Day 3, in addition to the post-run questionnaires, final questionnaires were provided at the end of each of the two evaluations (i.e., Alert Timing and Lateral Deviations) asking them to rate their experience across all the scenarios for that particular evaluation. A Day 3 final questionnaire was also provided at the end of Day 3 which asked controllers to rate their experiences across all the scenarios for all three days. After that, controllers were invited into a conference room for a discussion and debrief. Some questions were prepared to guide the discussion, but controllers were also invited to provide feedback on any topic or aspect of the simulation they wished.

As shown in the daily schedules in Figure 4-34, the four participants were divided into a Pair A and a Pair B for each of the three days. Each scenario involved only two participants at a time. Therefore, two participants filled out their post-run questionnaires while the other two ran the scenario.

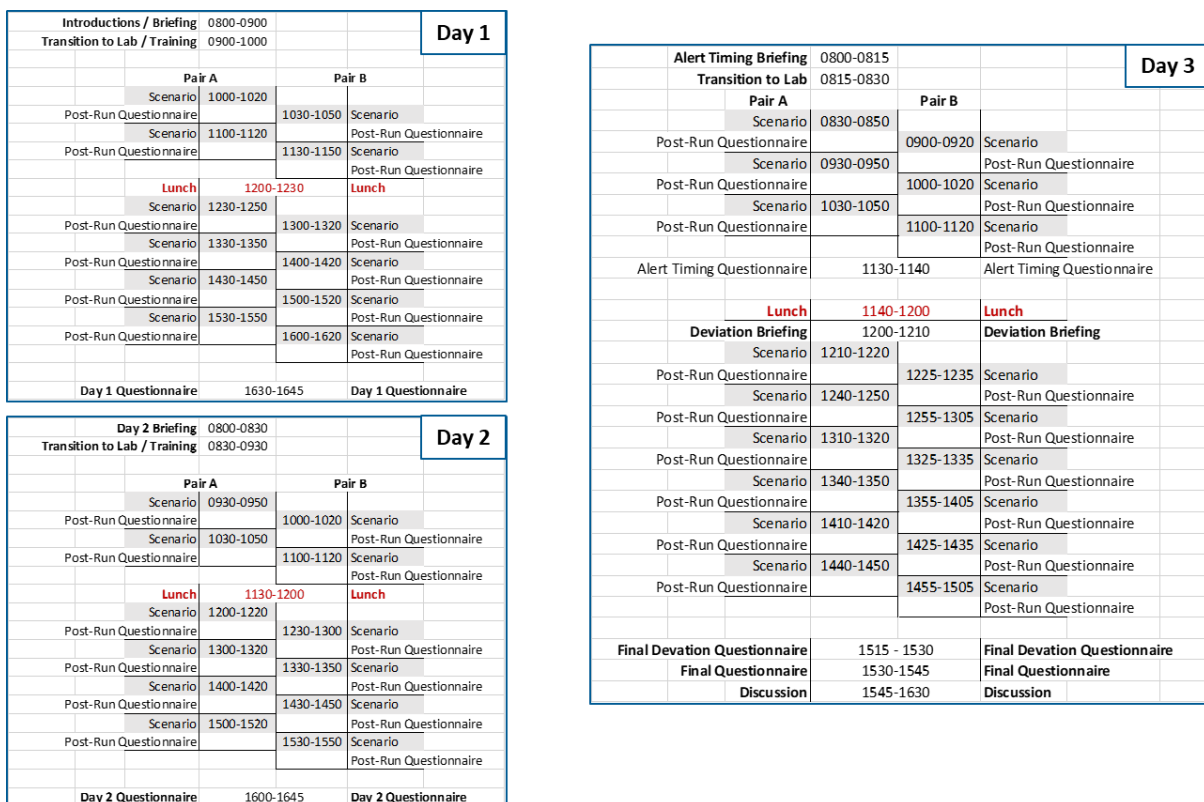


Figure 4-34. Daily Schedules

## 4.5.4 Independent Variables

Independent variables were chosen to test the hypotheses described in Section 3.3 and the more detailed research objectives listed in Section 4.5.1 including Number of Monitor controllers, selected PA Tools, alert timing values, and display type. The independent variables and associated levels of each are shown in Figure 4-35.

<ul style="list-style-type: none"> <li>▪ <b>Number of Monitor Controllers</b> <ul style="list-style-type: none"> <li>– (1) Combined Monitor</li> <li>– (2) Separate Monitors</li> </ul> </li> <li>▪ <b>WSL Preview Display</b> <ul style="list-style-type: none"> <li>– (1) On</li> <li>– (2) Off</li> </ul> </li> <li>▪ <b>Data Block CSL/WSL Distance Display</b> <ul style="list-style-type: none"> <li>– (1) On</li> <li>– (2) Off</li> </ul> </li> </ul>	<p><b>Days 1-2</b> <b>Nominal Operations with</b> <b>Longitudinal Monitoring</b></p>
<ul style="list-style-type: none"> <li>▪ <b>Alert Timing</b> <ul style="list-style-type: none"> <li>– (1) Timing Set X (sec) (ATPA Default 45 sec / 24 sec)</li> <li>– (2) Timing Set Y (sec) (35 sec / 20 sec)</li> <li>– (3) Timing Set Z (sec) (25 sec / 15 sec)</li> </ul> </li> </ul>	<p><b>Day 3</b> <b>Longitudinal Alert Timing</b></p>
<ul style="list-style-type: none"> <li>▪ <b>Number of Monitor Controllers</b> <ul style="list-style-type: none"> <li>– (1) Combined Monitor</li> <li>– (2) Separate Monitors</li> </ul> </li> <li>▪ <b>Display Type</b> <ul style="list-style-type: none"> <li>– (1) Normal STARS</li> <li>– (2) FMA 4:1 Aspect Ratio</li> </ul> </li> </ul>	<p><b>Day 3</b> <b>Lateral Monitoring and</b> <b>Deviations</b></p>

**Figure 4-35. HITL Independent Variables and Levels**

For both the Day 1 and Day 2 Nominal scenarios and the Day 3 Lateral Monitoring and Deviation scenarios, the Number of Monitor controllers was varied as an Independent Variable. Some scenarios involved a single, Combined Monitor controller assuring separation for traffic arriving to both 28L and 28R. Other scenarios involved Separate Monitor controllers managing the traffic only on their respective approach.

For the Day 1 and Day 2 Nominal scenarios, the WSL-Display and the Data Block CSL/WSL Distance Display were made to be Independent Variables and were either made available or removed from the display, depending on the scenario. This was intended to examine whether they were helpful or necessary for the controller IM PA monitoring task. The other IM PA tools such as the IM Spacing List, IM Status, CSL/WSL Lines, Alerts, and Lateral Boundaries features were fixed. These were always available to participants, for every scenario.

Day 3 for each session included a self-contained evaluation of the longitudinal alert timing values. As described in Section 4.2.7, the default Predictive / Caution alert timings were the same as those implemented for ATPA: 45 seconds and 24 seconds, respectively. However, reduced timings may ultimately be used to mitigate against nuisance alerts (which would occur more frequently with greater timings). Therefore, two additional alert timings were

investigated in the HITL to examine whether lower alert timings than those chosen for ATPA remain acceptable to controllers for the IM PA monitoring task. These were: 35 seconds / 20 seconds and 25 seconds / 15 seconds, for the Predictive and Caution Alerts, respectively. To create a more stressing condition, these scenarios only evaluated alert timing in the context of the Combined Monitor configuration. However, all of the IM PA-related tools described previously were available to the Combined Monitor controller for these scenarios.

Day 3 also took an initial look at lateral monitoring with deviations as a self-contained evaluation in the afternoon. This included determining to what degree will controllers want to detect developing deviations before a Lateral Boundary is crossed, whether a 4:1 aspect ratio FMA display is needed, especially with only an Exceedance Warning (no Lateral Predictive Alert) with a tighter Lateral Boundary size (ILS versus 500 ft), and how task acceptability was affected by Combined versus Separate Monitor positions. Therefore, the Independent Variables for this portion of the experiment included display type (STARS versus FMA) and the number of Monitor controllers (Combined versus Separate). All of the IM PA-related tools described previously were available to the Monitor controllers for these scenarios.

#### 4.5.5 Traffic File Attributes

Three general types of scenario traffic files were developed for the HITL, one for each type of scenario. These included: 1) Nominal scenarios, 2) Alert Timing scenarios, and 3) Lateral Deviation scenarios. Depending on what was being tested, these traffic files may have contained either of two types of off-nominal events: Spacing Loss and Lateral Deviation.

- A **Spacing Loss** occurred when an IM Trail Aircraft began to encroach on one of the safety limits, triggering an alert. When this occurred, the controller procedures varied depending on if it was a Predictive Alert or a Caution Alert.
- A **Lateral Deviation** occurred when during the IM PA operation, one aircraft sharply deviates from its approach path, either to the left or right, and keeps going; or, one aircraft starts a long, shallow deviation to the left or right. In this instance, the controller followed the procedures for lateral deviations discussed.

These only apply to aircraft in IM PA pairings, though loss-of-separation could occur between non-IM PA aircraft as well. None of these cases were intentionally introduced, however.

The traffic file attributes for each type of scenario are summarized in the following sections.

##### 4.5.5.1 Nominal Scenarios

Four nominal core traffic files approximately 20 minutes in length. Each had seven IM PA pairings, five with WSL and two without WSL. There were two non-paired SRS aircraft. There were two Spacing Loss events per scenario; one was an IM PA Predictive Alerts that was intended to resolve without controller intervention being required. The second was an IM PA Predictive Alert that led to a Caution Alert if the controller did not intervene. Given the scenario timeframe, these occurred at a higher frequency than would be experienced in actual operations to provide controllers with concentrated experience in dealing with them and to get feedback on the alerting.

These core traffic files were then cloned and varied in which aircraft experienced the Predictive and Caution Alerts, the location of SRS aircraft within the flow, with respect to the IM PA pairings, the order of the IM PA pairings, and the aircraft call signs.

#### 4.5.5.2 Alert Timing Scenarios

The Alert Timing scenarios were based on the nominal scenario and was approximately 20 minutes in duration, with six IM PA pairings. All pairs required a WSL and five of the six pairings were manipulated to show an alert related to Spacing Loss. The same traffic file was used for each run so participants could clearly isolate the effect of each alert timing set.

A CSL alert can be triggered either earlier in the approach, or later. A WSL alert can only be triggered late, when the WSL is active. The distribution of the alerts in the scenario is shown in Table 4-3.

**Table 4-3. Distribution of CSL and WSL Alerts in the Scenario**

Pair 1		Pair 2		Pair 3		Pair 4		Pair 5		Pair 6	
Early	Late	Early	Late	Early	Late	Early	Late	Early	Late	Early	Late
CSL			WSL		CSL				WSL	CSL	

#### 4.5.5.3 Lateral Deviation Scenarios

Each Lateral Deviation scenario lasted for approximately 10 minutes and included four IM PA pairings, two of which exhibited Lateral Deviations that required the controller to take action. There were three potential lateral deviation variables considered in the scenario design. First, the deviating aircraft could be either be the IM Lead or IM Trail Aircraft. Second, the deviation angle could be sharp or shallow. A sharp deviation occurs suddenly, with little warning. A shallow deviation evolves gradually, over a long portion of the approach. And third, the deviation could either be inboard (toward the other aircraft) or outboard (away from the other aircraft). Based on the lateral deviation variables, two deviation types were developed:

- *Deviation Type A:* Lead / Sharp (30 deg) / Inboard.
- *Deviation Type B:* Trail / Shallow (10 deg) / Outboard.

A lateral deviation could also occur earlier or later in the approach. Therefore, four traffic files were developed for the Lateral Deviation scenarios. Variations included deviation location (earlier versus later), deviation order (whether Type A occurred before Type B, or whether Type B occurred before Type A), and which of the four IM PA pairings experienced them. Table 4-4 shows the how the variations were implemented and distributed across each of the four traffic files (named L through O).

**Table 4-4. Distribution of Lateral Deviation Types**

Traffic File	Pair 1		Pair 2		Pair 3		Pair 4	
	10 NM	5 NM	10 NM	5 NM	10 NM	5 NM	10 NM	5 NM
L		A			B			
M			B			A		
N	A							B
O				B	A			

These lateral deviation events occurred at a far higher frequency than would be experienced in actual operations. This was intended to provide controllers with concentrated experience in dealing with them to get feedback on the lateral monitoring display features. It should also be noted that the scenario presented in the scenario that involved traffic file O was deliberately designed as an extreme case. The timing of this scenario was such that that the shallow-deviating Trail crossed its Lateral Boundary and triggered its Exceedance Warning shortly after the Lead Aircraft (of a different pair) triggered its Exceedance Warning. In effect, this appeared to controllers as a near-simultaneous lateral deviation of two aircraft. In real world operations, a near-simultaneous lateral deviation of multiple aircraft on CSPR is expected to occur rarely, if at all. An investigation of over 1.8 million approach paths did not detect any (Eckstein, Massimini, McNeill, & Niles, 2012), nor was there a record of any in an examination of 7790 go-arounds that were logged over multiple years by NCT (Stassen, Domino, Hefley, & Weitz, 2019). Though this has never been observed in real world operations, it was still included in the simulation to stress the display features and probe for a potential failure point with IM PA Tools or Monitoring configuration.

#### 4.5.6 Scenario Matrices and Run Orders

This section describes the scenario matrices across the three weeks of runs. Some changes were made after the Week 1 scenarios were run, so they are described separately from the Week 2-3 scenarios. The data reduction and analysis process accounted for those differences.

The Day 1-2 scenarios were considered “nominal operations.” Though some longitudinal Spacing Loss events were included, the alert timing values were fixed, and no deliberate Lateral Deviations were introduced. As noted in Section 4.5.3, two controllers participated per run while the other two filled out their post-run questionnaires. When the Combined Monitor configuration was evaluated, one participant controller served as the Monitor and the other served as the 28R Final controller. When the Separate Monitor configuration was run, one participant served as the 28L Monitor controller and the other served as the 28R Monitor controller. The 28R Final controller position was not staffed in these cases, and IM PA pairs were initiated via the simulation before they were turned over to the Local controller.

The scenario order for each day was counterbalanced across the three weeks. The monitor configurations were alternated by run week. The daily simulation topic by week is summarized in Table 4-5.

**Table 4-5. Daily Simulation Topic by Week**

	<b>Week 1 (ATC 1-4)</b>	<b>Week 2 (ATC 5-8)</b>	<b>Week 3 (ATC 9-12)</b>
<b>Day 1</b>	Combined Monitor / 28R Final	Separate Monitors	Separate Monitors
<b>Day 2</b>	Separate Monitors	Combined Monitor / 28R Final	Combined Monitor / 28R Final
<b>Day 3</b>	Alert Timing / Lateral Deviation	Alert Timing / Lateral Deviation	Alert Timing / Lateral Deviation

#### 4.5.6.1 Day 1 Scenario Matrix (Participants 1-4)

For Week 1, Day 1, Participant controllers (referred to as ATC 1-4) staffed the Combined 28L/R Monitor and the 28R Final controller positions. A confederate controller (Conf) served as the Combined 28L/R Local controller. Two unique traffic files were created and alternated across the scenarios. The traffic files were then cloned, and the call signs changed to create two alternate traffic files. For this day of runs: Traffic File A = Traffic File C (except for call signs) and Traffic File B = Traffic File D (except for call signs). Table 4-6 shows the scenario run order and IM PA Tool Independent Variable manipulations.

**Table 4-6. Week 1, Day 1 Scenario Run Order and IM PA Tool Variable Manipulations**

Scenario Name	Data Block (DB)		Combined Monitor 28L/R	Combined Local 28L/R	Final Approach	
	CSL/WSL	WSL-P			28L	28R
1A	On	On	ATC 1	Conf	-	ATC 2
1C	On	On	ATC 3	Conf	-	ATC 4
1B	On	On	ATC 2	Conf	-	ATC 1
1D	On	On	ATC 4	Conf	-	ATC 3
2A*	Off	On	ATC 4	Conf	-	ATC 3
2D	Off	On	ATC 3	Conf	-	ATC 4
2C	Off	On	ATC 2	Conf	-	ATC 1
2B*	Off	On	ATC 1	Conf	-	ATC 2
4A	Off	Off	ATC 2	Conf	-	ATC 1
4B	Off	Off	ATC 3	Conf	-	ATC 4
4C	Off	Off	ATC 4	Conf	-	ATC 3
4D	Off	Off	ATC 1	Conf	-	ATC 2

\* Due to a simulation issue, scenarios 2A and 2B were erroneously transposed in the run order.

#### 4.5.6.2 Day 1 Scenario Matrix (Participants 5-12)

For Day 1 in Weeks 2-3, participant controllers (ATC 5-12) staffed the Separate 28L/28R Monitor positions. The 28R Final controller position was not staffed and IM PA pairs were initiated via the simulation. Two confederate controllers (A and B) served as separate 28L and 28R Local controllers, and two other confederate controllers served as the pseudopilots.

Three unique traffic files were used. Two of these (A and E) were clones, except for call signs. The traffic file used in each scenario is reflected in its name code. The scenario matrices in Table 4-7 and Table 4-8 show the scenario run order counterbalancing and display Independent Variable manipulations for Week 2 and Week 3, respectively.

**Table 4-7. Week 2, Day 1 Scenario Run Order and IM PA Tool Variable Manipulations**

Scenario Name	DB		Monitor		Local	
	CSL/WSL	WSL-P	28L	28R	28L	28R
1E	On	On	ATC 5	ATC 6	Conf A	Conf B
4E	Off	Off	ATC 7	ATC 8	Conf A	Conf B
2F	Off	On	ATC 6	ATC 5	Conf B	Conf A
1F	On	On	ATC 8	ATC 7	Conf B	Conf A
2A	Off	On	ATC 5	ATC 6	Conf A	Conf B
1A	On	On	ATC 7	ATC 8	Conf A	Conf B
4E	Off	Off	ATC 6	ATC 5	Conf B	Conf A
2E	Off	On	ATC 8	ATC 7	Conf B	Conf A
4F	Off	Off	ATC 5	ATC 6	Conf B	Conf A
2F	Off	On	ATC 7	ATC 8	Conf B	Conf A
1A	On	On	ATC 6	ATC 5	Conf A	Conf B
4A	Off	Off	ATC 8	ATC 7	Conf A	Conf B

**Table 4-8. Week 3, Day 1 Scenario Run Order and IM PA Tool Variable Manipulations**

Scenario Name	DB		Monitor		Local	
	CSL/WSL	WSL-P	28L	28R	28L	28R
2A	Off	On	ATC 9	ATC 10	Conf A	Conf B
1A	On	On	ATC 11	ATC 12	Conf A	Conf B
4E	Off	Off	ATC 10	ATC 9	Conf B	Conf A
2E	Off	On	ATC 12	ATC 11	Conf B	Conf A
4F	Off	Off	ATC 9	ATC 10	Conf A	Conf B
2F	Off	On	ATC 11	ATC 12	Conf A	Conf B
1A	On	On	ATC 10	ATC 9	Conf B	Conf A
4A	Off	Off	ATC 12	ATC 11	Conf B	Conf A
1E	On	On	ATC 9	ATC 10	Conf B	Conf A
4E	Off	Off	ATC 11	ATC 12	Conf B	Conf A
2F	Off	On	ATC 10	ATC 9	Conf A	Conf B
1F	On	On	ATC 12	ATC 11	Conf A	Conf B

**4.5.6.3 Day 2 Scenario Matrix (Participants 1-4)**

For Week 1, Day 2, participant controllers (ATC 1-4) staffed the separate 28L and 28R Monitor controller positions. The 28R Final controller position was not staffed and IM PA pairs were initiated via the simulation. Two confederate controllers (A and B) served as separate 28L and 28R Local controllers and two other confederate controllers served as the pseudopilots.

Two unique traffic files were created and alternated across the scenarios. The traffic files were then cloned, and the call signs changed to create two alternate traffic files. For this day of runs Traffic File E = Traffic File G (except for call signs), and Traffic File F = Traffic File H (except for call signs). The traffic file used in each scenario is reflected in its name code. Table 4-9 shows the scenario run order and display Independent Variable manipulations.

**Table 4-9. Week 1, Day 2 Scenario Run Order and IM PA Tool Variable Manipulations**

Scenario Name	DB		Monitor		Local	
	CSL/WSL	WSL-P	28L	28R	28L	28R
1E	On	On	ATC 1	ATC 2	Conf A	Conf B
1G	On	On	ATC 3	ATC 4	Conf A	Conf B
1F	On	On	ATC 2	ATC 1	Conf B	Conf A
1H	On	On	ATC 4	ATC 3	Conf B	Conf A
3G	On	Off	ATC 1	ATC 2	Conf A	Conf B
3E	On	Off	ATC 3	ATC 4	Conf A	Conf B
3H	On	Off	ATC 2	ATC 1	Conf B	Conf A
3F	On	Off	ATC 4	ATC 3	Conf B	Conf A
4H	Off	Off	ATC 1	ATC 2	Conf B	Conf A
4F	Off	Off	ATC 3	ATC 4	Conf B	Conf A
4E	Off	Off	ATC 2	ATC 1	Conf A	Conf B
4G	Off	Off	ATC 4	ATC 3	Conf A	Conf B

**4.5.6.4 Day 2 Scenario Matrix (Participants 5-12)**

Participant controllers (ATC 5–12) staffed the Combined 28L/R Monitor and the 28R Final controller positions for Day 2 in Week 2 and Week 3. A confederate controller served as the Combined 28L/R Local controller. Three unique traffic files were used. Two of these (C and G) were clones, except for call signs. The traffic file used in each scenario is reflected in its name code. The scenario matrices in Table 4-10 and

Table 4-11 show the scenario run order and IM PA Tool Independent Variable manipulations.

**Table 4-10. Week 2, Day 2 Scenario Run Order and IM PA Tool Variable Manipulations**

Scenario Name	DB		Comb Mon 28L/R	Comb Local 28L/R	Final Approach	
	CSL/WSL	WSL-P			28L	28R
3B	On	Off	ATC 5	Conf	-	ATC 6
1B	On	On	ATC 7	Conf	-	ATC 8
4G	Off	Off	ATC 6	Conf	-	ATC 5
3G	On	Off	ATC 8	Conf	-	ATC 7
4C	Off	Off	ATC 5	Conf	-	ATC 6
3C	On	Off	ATC 7	Conf	-	ATC 8
1B	On	On	ATC 6	Conf	-	ATC 5
4B	Off	Off	ATC 8	Conf	-	ATC 7
1G	On	On	ATC 5	Conf	-	ATC 6
4G	Off	Off	ATC 7	Conf	-	ATC 8
3C	On	Off	ATC 6	Conf	-	ATC 5
1C	On	On	ATC 8	Conf	-	ATC 7

**Table 4-11. Week 3, Day 2 Scenario Run Order and IM PA Tool Variable Manipulations**

Scenario Name	Data Block		Comb Mon 28L/R	Comb Local 28L/R	Final Approach	
	CSL/WSL	WSL-P			28L	28R
1G	On	On	ATC 9	Conf	-	ATC 10
4G	Off	Off	ATC 11	Conf	-	ATC 12
3C	On	Off	ATC 10	Conf	-	ATC 9
1C	On	On	ATC 12	Conf	-	ATC 11
3B	On	Off	ATC 9	Conf	-	ATC 10
1B	On	On	ATC 11	Conf	-	ATC 12
4G	Off	Off	ATC 10	Conf	-	ATC 9
3G	On	Off	ATC 12	Conf	-	ATC 11
4C	Off	Off	ATC 9	Conf	-	ATC 10
3C	On	Off	ATC 11	Conf	-	ATC 12
1B	On	On	ATC 10	Conf	-	ATC 9
4B	Off	Off	ATC 12	Conf	-	ATC 11

#### 4.5.6.5 Day 3 Scenario Matrix: Alert Timing (Participants 1-12)

This portion of the study focused on differences to the Monitor controller with respect to alert timing. All IM PA Tools were On (i.e., Data Block [DB] CSL/WSL and the WSL-P) and only the alert timings were varied. In this case, only the 28R traffic experience a longitudinal alert. Therefore, these scenarios used a Combined Monitor configuration and two participants were run “side-by-side,” independent and in parallel (indicated by the shading in Table 4-12). Each scenario also involved a single, confederate Local controller and a pseudopilot. The same traffic file was used for each run so participants could clearly isolate the effect of each alert timing set. A scenario issue compromised the usability of the alert timing data for Week 1; therefore, only the Week 2-3 runs are summarized here and only Week 2-3 alert timing data is included in the results. The timing values used in the HITL and the counterbalance order is shown in the matrix in Table 4-12.

**Table 4-12. Week 2-3 Alert Timing Values and Counterbalance Order**

Comb Monitor	Week 2 Timing Order (sec)			Comb Monitor	Week 3 Timing Order (sec)	
	Predictive	Caution			Predictive	Caution
ATC 5	45	24		ATC 9	25	15
ATC 6	45	24		ATC 10	25	15
ATC 7	45	24		ATC 11	25	15
ATC 9	45	24		ATC 12	25	15
ATC 5	35	20		ATC 9	35	20
ATC 6	35	20		ATC 10	35	20
ATC 7	35	20		ATC 11	35	20
ATC 9	35	20		ATC 12	35	20
ATC 5	25	15		ATC 9	45	24
ATC 6	25	15		ATC 10	45	24
ATC 7	25	15		ATC 11	45	24
ATC 9	25	15		ATC 12	45	24

**4.5.6.6 Day 3 Scenario Matrix: Lateral Deviations (Participants 1-12)**

As described in Section 4.5.5.3, the Lateral Deviations portion of the study focused on differences to the Monitor controller with respect to IM Lead Aircraft and IM Trail Aircraft deviations against the Lateral Boundaries. Two variables were manipulated: Monitor configuration (Combined versus Separate) and Display Type (STARS versus FMA 4:1). Four separate traffic files (termed L, M, N, and O) were developed for the Lateral Deviation scenarios. They included variations on deviation location (earlier versus later), deviation order (whether Type 1 occurred before Type 2, or whether Type 2 occurred before Type 1), and which of the four IM PA pairings experienced them.

The Combined Monitor configuration scenarios were run in the same manner as the Alert Timing scenarios: two participants “side-by-side,” independent and in parallel (indicated by the shading in the following tables). The Separate Monitor configuration scenarios were run in the same manner as the Day 1-2 Nominal scenarios. Each scenario lasted approximately 10 minutes.

Table 4-13 shows the scenario run order and Independent Variable manipulations for Week 1. The traffic file used in each scenario is reflected in its name code. Due to time constraints, scenarios 1N, 4O, 1O, and 4N were not run for ATC 1-4 (indicated by the strikethroughs in Table 4-13).

**Table 4-13. Week 1 Lateral Deviation Run Order and Variable Manipulations**

Scenario Name	Traffic File	Monitor Config	Display Type	Monitor Position	
				28L (M)	28R (M)
1L	L	Combined	STARS	ATC 1	
2L	L	Combined	STARS	ATC 2	
3L	L	Combined	STARS	ATC 3	
4L	L	Combined	STARS	ATC 4	
1M	M	Combined	FMA 4:1	ATC 1	
2M	M	Combined	FMA 4:1	ATC 2	
3M	M	Combined	FMA 4:1	ATC 3	
4M	M	Combined	FMA 4:1	ATC 4	
<del>1N</del>	<del>N</del>	<del>Separate</del>	<del>STARS</del>	<del>ATC 1</del>	<del>ATC 2</del>
2O	O	Separate	STARS	ATC 2	ATC 1
3N	N	Separate	STARS	ATC 3	ATC 4
<del>4O</del>	<del>O</del>	<del>Separate</del>	<del>STARS</del>	<del>ATC 4</del>	<del>ATC 3</del>
<del>1O</del>	<del>O</del>	<del>Separate</del>	<del>FMA 4:1</del>	<del>ATC 1</del>	<del>ATC 2</del>
2N	N	Separate	FMA 4:1	ATC 2	ATC 1
3O	O	Separate	FMA 4:1	ATC 3	ATC 4
4N	N	Separate	FMA 4:1	ATC 4	ATC 3

Table 4-14 and Table 4-15 show the scenario run order and Independent Variable manipulations for the Week 2 and Week 3 participants, respectively. The traffic file used in each scenario is reflected in its name code.

**Table 4-14. Week 2 Lateral Deviation Run Order and Variable Manipulations**

Scenario Name	Monitor Config	Display Type	Monitor Position	
			28L (M)	28R (M)
1N	Separate	STARS	ATC 5	ATC 6
3N	Separate	STARS	ATC 7	ATC 8
2O	Separate	STARS	ATC 6	ATC 5
4O	Separate	STARS	ATC 8	ATC 7
1L	Combined	STARS	ATC 5	
2L	Combined	STARS	ATC 6	
3L	Combined	STARS	ATC 7	
4L	Combined	STARS	ATC 8	
1M	Combined	FMA 4:1	ATC 5	
2M	Combined	FMA 4:1	ATC 6	
3M	Combined	FMA 4:1	ATC 7	
4M	Combined	FMA 4:1	ATC 8	
1O	Separate	FMA 4:1	ATC 5	ATC 6
3O	Separate	FMA 4:1	ATC 7	ATC 8
2N	Separate	FMA 4:1	ATC 6	ATC 5
4N	Separate	FMA 4:1	ATC 8	ATC 7

**Table 4-15. Week 3 Lateral Deviation Run Order and Variable Manipulations**

Scenario Name	Monitor Config	Display Type	Monitor Position	
			28L (M)	28R (M)
1M	Combined	FMA 4:1	ATC 9	
2M	Combined	FMA 4:1	ATC 10	
3M	Combined	FMA 4:1	ATC 11	
4M	Combined	FMA 4:1	ATC 12	
1N	Separate	FMA 4:1	ATC 9	ATC 10
3N	Separate	FMA 4:1	ATC 11	ATC 12
2O	Separate	FMA 4:1	ATC 10	ATC 9
4O	Separate	FMA 4:1	ATC 12	ATC 11
1L	Combined	STARS	ATC 9	
2L	Combined	STARS	ATC 10	
3L	Combined	STARS	ATC 11	
4L	Combined	STARS	ATC 12	
1O	Separate	STARS	ATC 9	ATC 10
3O	Separate	STARS	ATC 11	ATC 12
2N	Separate	STARS	ATC 10	ATC 9
4N	Separate	STARS	ATC 12	ATC 11

## 4.5.7 Data Collection

Two main methods of data collection were used for this simulation. These were subjective data (i.e., participant questionnaires) and objective data (i.e., system recorded data). In addition, simulation observers made notes throughout the sessions and a final discussion/debrief was held at the end of each week.

### 4.5.7.1 Subjective Data Collection

As described in Section 4.5.3, the subjective data included questionnaires after each run, each day, and at the end of the simulation. The topics included: workload, acceptability of displays / individual IM PA Tools, communications and concepts, monitoring configuration, and ideas for improvements.

The individual questionnaires are included in the appendices and are as follows:

#### Day 1-2 Questionnaires

- Demographics (Appendix B)
- Combined Monitor Post-Run (Appendix C)
- 28R Final Approach Post-Run (Appendix C)
- 28R Monitor Post-Run (Appendix C)
- 28L Monitor Post-Run (Appendix C)
- Day 1 End (Appendix D)
- Day 2 End (Appendix D)

#### Day 3 Questionnaires

- Alert Timing Post-Run (Appendix E)
- Alert Timing Final (Appendix E)

- Lateral Deviation Post-Run (Appendix F)
- Lateral Deviation Final (Appendix F)
- Simulation Final (Day 3 End) (Appendix G)
- Debrief Questions (Appendix G)

#### 4.5.7.2 Objective Data Collection

Objective data was automatically collected and recorded by the simulation environment after each run. This data included:

- Aircraft state including position, altitude, heading, speed, etc.
- IM Clearances provided.
- IM Trail Aircraft tolerance within Assigned Spacing Goal and location relative to safety limits.
- Occurrences of Predictive and Caution Alerts.
- IM Speed changes, reversals, and increases.
- Time between IM Speed changes and distance to go.
- Aircraft broken out per longitudinal alert.
- Aircraft broken out relative to Lateral Bound proximity.
- Times and occurrences of Push-To-Talk (PTT) “clicks.”
- Controller screen video recordings.

This data was filtered and reduced to provide the summary data for analyzing the effect of the procedures and tools on controller response time to developing separation issues and any actual separation violations.

## 5 Results

This section summarizes the results from the questionnaire subjective data and objective data analyses. Section 5.1 first discusses the methods for data reduction, analysis and presentation used to convey the results of the subjective and objective data. Results are organized and presented by topic in Sections 5.2 through 5.7. Section 5.8 evaluates the hypotheses described in Section 3.3 in consideration of results across various related metrics. All of the major results are then listed in Section 5.9.

### 5.1 Data Analysis Methodology

#### 5.1.1 Subjective Data

The subjective data analysis methodology and presentation of the subjective (questionnaire) data are summarized in this section. To reduce the potential for family-wise error (i.e., erroneously finding a significant result due to excessive unplanned comparisons), statistical tests were only performed on subjective results that were specifically used to examine a hypothesis. Therefore, the subjective results reported in Sections 5.2 through 5.7 only include descriptive statistics and any trends that are inferred are based on the methodology described in Section 5.1.1.3. The statistical analysis results for subjective data are reported separately in the hypothesis evaluations in Section 5.8, though results are referenced in the individual questions in the prior sections.

##### 5.1.1.1 Sample Sizes

Despite having a total of 12 controllers participate in the experiment, not all 12 questionnaire responses were included in every question analysis. This results in different sample size ( $n$ ) values across the various questions. One of the main reasons was that the Nominal and Alert Timing scenarios were modified after Week 1. The Week 1 post-run results could therefore not be appropriately combined with Week 2-3 results. However, the experimenters felt that the Week 1 controller participants still received sufficient experience with the IM PA Tools and thus their responses were still typically included in the Day End and Final Questionnaires. No changes were made to the Lateral Deviation scenarios after Week 1; therefore, all controller responses were included in the analyses for these cases.

In addition, as noted in Section 4.5.2, two participants only had Tower experience; one participant in Week 1 and one participant in Week 3. The results from these participants were rarely pooled with the TRACON controller responses, unless the experimenters felt it was appropriate to do so. The Tower controller responses are thus usually reported separately.

Unless otherwise noted, the following rationales were used for the typically occurring n values used for each of the reported statistical calculations. If an individual result does not include a specific explanation for the n, it falls into one of the below cases.

- **n = 12:** All 12 participant controllers' responses were included in reported findings.
- **n = 10:** Includes responses for participant controllers with TRACON experience across all three run weeks. It does not include Tower-only responses.
- **n = 7:** Due to scenario changes made between Week 1 and Weeks 2-3, it was not always appropriate to include Week 1 TRACON controller responses in the data pool for the post-run questionnaires. Therefore, this case represents only the Week 2-3 TRACON controller responses.
- **n = 6, n = 4:** For questions where NCT responses may be of particular interest, the four NCT Controller responses were reported separately. This resulted in an n = 6 for non-NCT TRACON controller responses.
- **n = 2, n = 1:** Indicates the responses for controllers that only had Tower (i.e., no TRACON) experience.

Other n values were possible if questionnaire responses were left blank. These are noted on a case-by-case basis in the results. In many figures, additional responses such as NCT-specific values or Week 1 controller responses are represented with an open circle. These may or may not be included in the findings analysis and any of these special cases are noted alongside each result.

#### 5.1.1.2 Questionnaire Sources

As introduced in Section 4.5.3 and Section 4.5.7, the findings present results from across the eight Questionnaire Types (QT). These included:

- **QT1:** Day 1-2 Post-Run
- **QT2:** Day 1 End and Day 2, Part 1 End
- **QT3:** Day 2, Part 2 End
- **QT4:** Alert Timing Post-Run
- **QT5:** Alert Timing Final
- **QT6:** Lateral Deviation Post-Run
- **QT7:** Lateral Deviation Final
- **QT8:** Simulation Final (Day 3 End)

In some cases, similar questions were asked in the post-run and final questionnaires. Post-run results were usually reported when examining controller response to an independent variable. Final questionnaire results were reported when summarizing overall results, irrespective of a manipulated variable. Sometimes both are reported, sometimes only one. Therefore, the source questionnaire (e.g., QT1) is included with the results.

In summary, the major types of reported results came from the following questionnaire types:

- When the sample size was greater than seven (i.e.,  $n > 7$ ) for the TRACON controllers, the question(s) likely came from either the Day End or Final Questionnaires (QT2, QT3, QT5, QT8). This is because, as described earlier, Tower controller and some Week 1 responses were usually included in the final questionnaire results, but not in the post-run data summaries.
- When monitor configuration is compared (i.e., Combined versus Separate), these are comparisons from the Day 1 and Day 2 End Questionnaires (QT2, QT3).
- When IM PA Tools configuration is compared (i.e., IM PA Tools On versus IM PA Tools Off; Data Block Distances On / WSL-P Off versus Data Block Distances Off / WSL-P On), these are comparisons from the Day 1 and Day 2 Post-Run Questionnaires (QT1).
- When the specific alert timings are compared, these are from the Alert Timing Post-Run Questionnaires (QT4).
- For Lateral Deviation results, when display type and monitor configuration are compared, these are from the Lateral Deviation Post-Run and Final Questionnaires (QT6, QT7).

### 5.1.1.3 Question Analysis and Presentation

The majority of questions on each of the different questionnaire types consisted of statements with a scale containing 100 hash marks (without numeric labels). Participants were instructed to answer the questions by drawing a vertical line through the option on each of the scales at the point that matched their experience (i.e., how strongly they agreed with the statement). The scale was anchored on the left with the label “Strongly Disagree” and on the right with the label “Strongly Agree.” During data reduction, responses were rounded to the nearest single digit between 0 and 100. If it could not be determined which mark was closest to the participant rating, the response was rounded to the mark closer to the “Strongly Disagree” anchor.

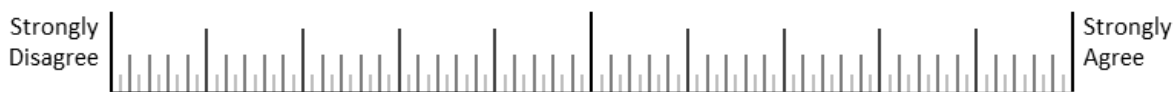
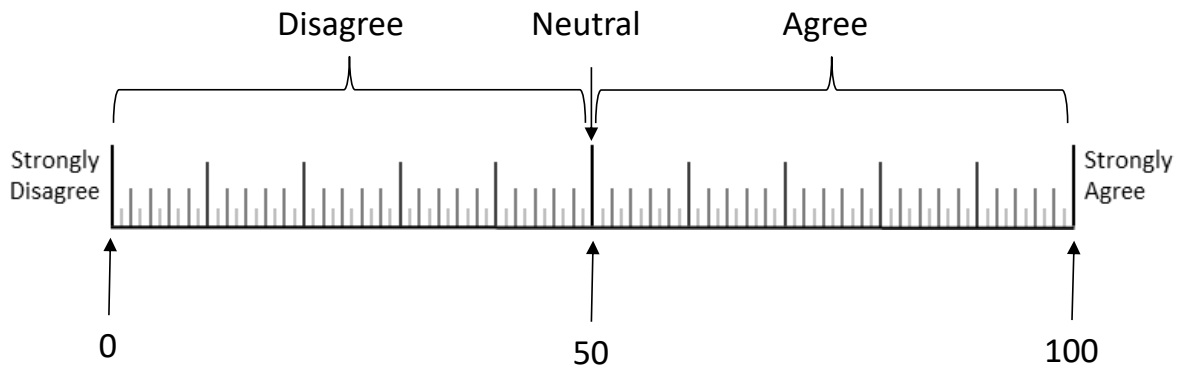


Figure 5-1. Questionnaire Scale and Anchors

The analysis methodology is similar to that used in Bone & Mendolia (2018). In their presentation of results shown in Figure 5-2, any individual response below the midpoint (i.e., lower than 50) on the scale was characterized to be on the “disagree” side, while any response above the midpoint (i.e., higher than 50) on the scale was considered to be on the “agree” side. Any response at the midpoint (i.e., equal to 50) was considered to be “neutral.”



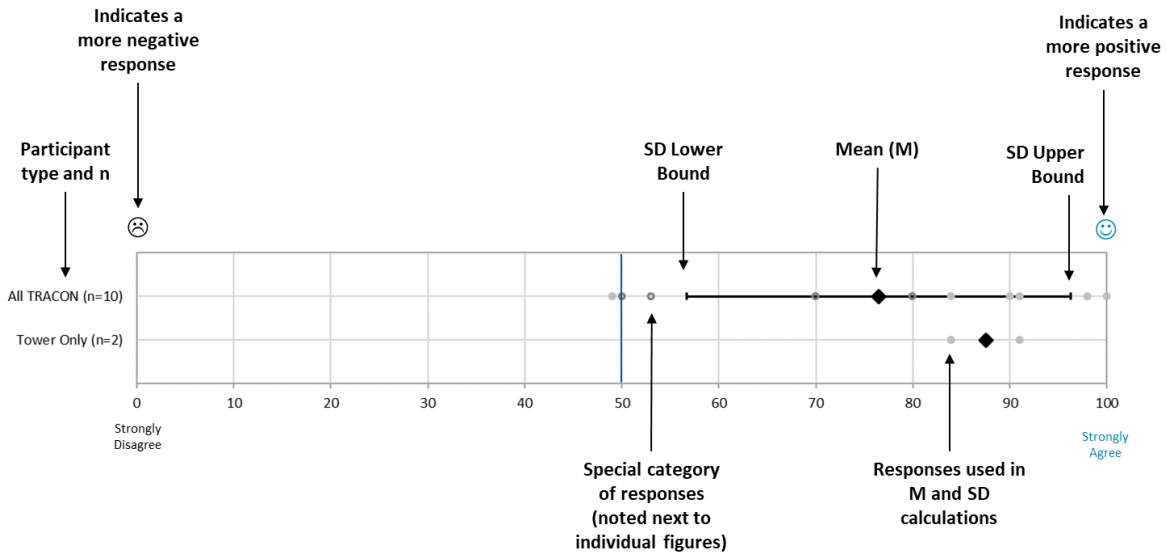
**Figure 5-2. 100-Point Agreement Scale Agreement Rating Breakdown from Bone & Mendolia (2018)**

When presenting results on the 100-point agreement scale in the post-simulation questionnaires, the following terminology / methodology was used to describe five possible levels of agreement based on the Mean (M) and Standard Deviation (SD) of the responses. It is modified slightly from that defined in Bone & Mendolia (2018).

1. All Controllers [agreed / disagreed].
  - All of the individual participant responses were on the agree or disagree side of the scale.
2. The majority (n; %) of Controllers [agreed / disagreed].
  - Low variability, e.g., SD was less than 25 (unless one value drove a SD slightly higher).
3. Controller responses were variable, but the majority (n; %) [agreed / disagreed].
  - Response SD was greater than 25 and distribution was skewed to either side of the scale.
4. Controllers neither agreed nor disagreed.
  - Response M was within one point of neutral (49-51), and no clear skew of the distribution to either side of the scale was observable.
5. Controller responses were variable.
  - Response SD was greater than 25 and no clear skew of the distribution to either side of the scale was observable.

Figure 5-3 provides an example of annotated description of the information presented in the figures depicting the reported statistical calculations. The figure includes the M, the SD of the responses as upper and lower bounds, and the individual responses included in the descriptive statistics. “Smiling” or “frowning” faces are shown on the scale where the replies to the statements have a subjectively positive or negative meaning. In most cases, TRACON and Tower controller responses are described separately and SDs are not shown for Tower controller results due to a typical n of only 1 or 2 responses. Tower controller results are included in the figures and tables for completeness; however, they are only discussed in the text when there is

a particular applicability to the question. Any additional presentation-specific information is indicated below the figures. Related questions are sometimes grouped together in the same figure.



**Figure 5-3. Explanation of Questionnaire Figures**

In addition to the subjective ratings, the Bedford Workload Rating Scale (Roscoe & Ellis, 1990) was used in the post-run questionnaires to measure subjective controller workload for each scenario. Also, some questions in the questionnaires were yes / no and participants were asked to circle their answer.

Almost all questions had space for participants to provide any open-ended comments. Comments that illuminate the reason for a response that varies from many of the other responses are included in explanation when available. Other selected comments are reproduced in the results to provide additional insights. Minor spelling and grammar edits were made for some comments to improve their readability.

#### 5.1.1.4 IM PA Tool Configurations

As described in the experimental design in Section 4.5.4, the Day 1-2 Nominal scenarios varied: 1) the display presentation of the Distances to the CSL/WSL in Line 3 of the Data Block (termed “DB CSL/WSL” or “DB Distances”), and 2) the display of the WSL-P.

- “IM PA Tools On” means that BOTH the DB Distances AND the WSL-P were displayed in that scenario.
- “IM PA Tools Off” means that NEITHER the DB Distances NOR the WSL-P were displayed in that scenario.
- All the other described IM PA features, such as the CSL/WSL Lines, Alerting, and Lateral Boundaries, were displayed for every scenario.

All controllers experienced the IM PA Tools On and IM PA Tools Off for each monitor configuration, allowing for direct comparisons. However, there was insufficient time for each controller to experience each IM PA Tool variation for each monitor configuration. Therefore, post-run scenario comparisons of Data Block Distances and the WSL-P were across different monitor configurations, which may have also affected the responses. Additionally, due to scenario changes between Week 1 and Weeks 2-3, post-run comparative responses for Week 1 were not included in the monitor configuration results. However, the Final Approach controller position was not affected by these changes. Therefore, Week 1 28R Final controller responses for IM PA Tools On and IM PA Tools Off are reported in the results. Table 5-1 summarizes the variations that were tested for each monitor configuration.

**Table 5-1. Monitor Configuration IM PA Tool Configurations**

<b>Monitor Configuration</b>	<b>Week 1 * (ATC 1-4)</b>	<b>Week 2 (ATC 5-8)</b>	<b>Week 3 (ATC 9-12)</b>
<b>Combined</b>	DB Distances Off WSL-P On	DB Distances On WSL-P Off	DB Distances On WSL-P Off
<b>Separate</b>	DB Distances On WSL-P Off	DB Distances Off WSL-P On	DB Distances Off WSL-P On

\* Due to scenario changes between Week 1 and Weeks 2-3, post-run comparative responses for Week 1 are usually not included in the monitor results. Exceptions are otherwise noted.

### 5.1.2 Objective Data

Three analyses were performed on the objective data that was described in Section 4.5.7.2. These were:

- Whether any losses of separation occurred and if so, if monitor configuration or IM PA Tool configuration had any effect. (Section 5.2.5.2)
- An evaluation of alternate longitudinal alert timings to examine whether lower alert timings than those chosen for ATPA affected controller response time to a Caution Alert. (Section 5.5.4.3)
- Whether Controller Monitor or Display configuration had an effect on controller response time to an aircraft crossing a Lateral Boundary. (Section 5.6.5)

The data reduction, assumptions, and statistical methods used for each analysis are described in their respective sections. However, it should be noted that the objective response-time analyses were based on PTT post-processing, which proved challenging. First, the simulation audio system PTT handset “click” data had to be manually aligned with scenario data after data collection was complete. This was a complicated process and though the experimenters have confidence that it was done correctly, it is still possible that the resulting combined data contains error. Secondly, the use of the PTT data in this way required an assumption that the click immediately following an event of interest (such as a Caution Alert) was the controller’s intent to resolve the situation. Therefore, the first click that was recorded after an event of interest was used as a proxy for the controller response time to resolve a situation. Though this

is likely to be a safe assumption generally, there may be an occasional case where it is not. Though these cases cannot be precisely identified from the data, some additional post-processing was done to increase confidence that the “correct” PTT value was being used. These methods are described further in the context of the specific analyses.

Finally, the audio system did not allow a true override capability for the Monitor controllers. If the Local controller or pseudopilot was talking on the frequency, the Monitor controllers could not break in. They were, however, told to still click their handsets when they wanted to speak. However, it is possible that some controllers did not “click” when blocked. In these cases, response times may therefore have been artificially inflated.

## 5.2 Results Topic 1: Overall Acceptability and Performance

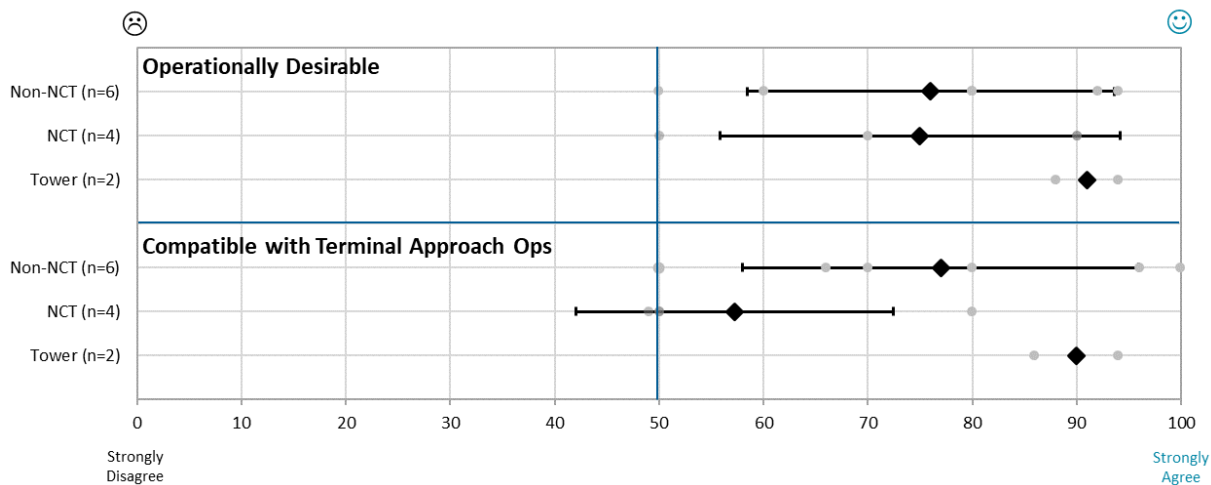
This section includes results related to the acceptability and performance of IM PA operations as examined. The metrics consisted of: Concept Desirability and Terminal Compatibility, Dual Safety Limit Acceptability, IM Speed Control, Traffic Situation Awareness, Separation Assessment, and Task Acceptability by Position. Participant responses to open-ended questions are also summarized, including what they liked about IM PA, what concerned them, and what aspects of the operation they felt could be improved.

### 5.2.1 Concept Desirability and Terminal Compatibility

At the end of Day 2 (QT3), after experiencing the nominal scenarios across all IM PA Tool and monitor configurations, controllers were asked if IM PA is **operationally desirable and compatible with terminal approach operations**. Given their specific experience in the areas being simulated, NCT responses are shown separately. Non-NCT and Tower responses are thus also shown as separate categories. Response Means and Standard Deviations are summarized in Table 5-2. Scale responses are shown in Figure 5-4.

**Table 5-2. Controller Responses to Concept Desirability and Terminal Compatibility**

	Participant Experience		
	Non-NCT	NCT	Tower
<b><i>IM PA is operationally desirable.</i></b>			
Sample Size (n)	6	4	2
Mean (M)	<b>76.0</b>	<b>75.0</b>	<b>91</b>
Standard Deviation (SD)	17.6	19.1	-
<b><i>IM PA is compatible with terminal approach operations.</i></b>			
Sample Size (n)	6	4	2
Mean (M)	<b>77.0</b>	<b>57.3</b>	<b>90.0</b>
Standard Deviation (SD)	19.0	15.2	-



**Figure 5-4. IM PA is operationally desirable and compatible with terminal approach operations.**

The majority (83%) of non-NCT (M=76.0; SD=17.6) and the majority (75%) of NCT (M=75.0; SD=19.1) controllers agreed IM PA is operationally desirable. Though not shown in Figure 5-4, 80% of all TRACON controllers agreed (n=10, M=75.6, SD=17.1) when averaged together.

Open-ended comments for this question included:

- (Non-NCT TRACON) Allows focus elsewhere and reduces workload.
- (Non-NCT TRACON) This operation could provide a benefit to airports with closely spaced parallels like SFO in IMC conditions, especially where there are a lot of heavy jets. Where there are less heavy jets and a tighter final (no need for departure gaps), this operation could be more challenging, and provide less operational gain.

When asked if IM PA is compatible with terminal approach operations, the majority (83%) of non-NCT (M=77.0; SD=6.0) controllers agreed. On average the NCT controllers also agreed (M=57.3; SD=15.2). However, this was driven by an “80” rating by one of the four NCT controllers. The other three controllers neither agreed nor disagreed. Though not shown in Figure 5-4, 60% of all TRACON controllers agreed (n=10, M=69.1, SD=19.5) when averaged together.

Open-ended comments for this question included:

- (NCT) I'm just not sure about the monitor position overriding local. I think it is totally doable in some form, though. Kinks would have to be worked out at facility level.

At the end of Day 3 (QT8) controllers were asked **which is the most appropriate position to monitor IM PA operations?** They were given the choices of Final Approach Monitor, Final Approach Control, Local controller, or Other. Some participants selected more than one and their responses and comments are provided in Table 5-3.

**Table 5-3. Controller Responses to Most Appropriate Position to Monitor IM PA Operations**

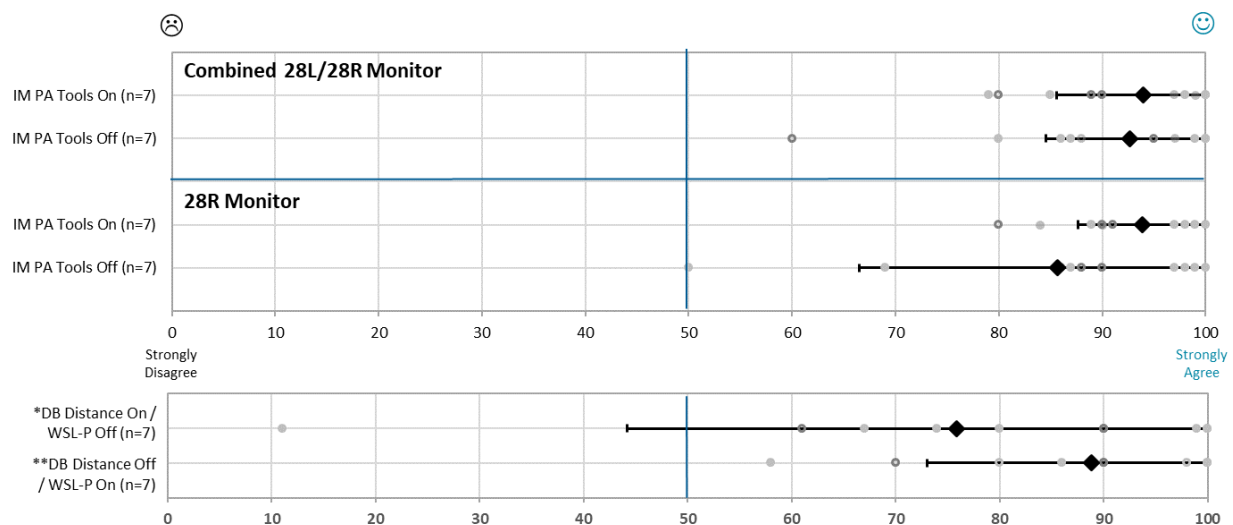
Position	Number of Selections	Comments
Final Approach Monitor	8	<ul style="list-style-type: none"> <li>• (NCT) Final Monitor needs to be able to solely focus on IM PA operations.</li> <li>• (non-NCT TRACON) Depends on the airport. At SFO it seems like monitor. At BOS, I feel like it would be a Local controller. Others it may be Final.</li> <li>• (NCT) I think it could work as a Final controller. However, the Monitor controller is the most appropriate due to workload.</li> <li>• (NCT) It's their only task. They can watch aircraft in the zone with no other distractions.</li> <li>• (non-NCT TRACON) They can concentrate on one task and act quickly to establish separation when it doesn't work correctly.</li> <li>• (non-NCT TRACON) A dedicated position w/ override capability is needed, as every other position would likely be too busy to safely provide this service.</li> <li>• (non-NCT TRACON) The available reaction time given the close proximity of aircraft pairs requires a dedicated controller to the monitor function.</li> </ul>
Final Approach Control	3	<ul style="list-style-type: none"> <li>• (Tower) Depends on facility. At [my facility], the Final &amp; Local controller would most likely do this.</li> </ul>
Local Controller	2	<ul style="list-style-type: none"> <li>• (Tower) At [my facility], 2000 and below should be monitored by local due to all the airport vectoring and situational awareness of terminal traffic.</li> </ul>
Other	1	<ul style="list-style-type: none"> <li>• It depends on how each individual operation is run.</li> </ul>

### 5.2.2 Dual Safety Limit Comfort

In the Day 1-2 Post-Run Questionnaires (QT1), controllers were asked: **given the IM PA-related tools provided in this scenario, I was comfortable monitoring IM PA operations when both a CSL and WSL were active at the same time.** Their responses were examined with respect to both the IM PA Tools and monitor configurations. Response Means and Standard Deviations are summarized in Table 5-4. Scale responses are shown in Figure 5-5. For the Separate Monitor configuration, only 28R Monitor responses are included because the safety limits did not apply to the 28L Monitor position.

**Table 5-4. Controller Responses to Dual Safety Limit Comfort**

	IM PA Tool Configuration			
	Tools On	Tools Off	DB On / WSL-P Off	DB Off / WSL-P On
<b>Combined 28L/28R Monitor</b>				
Sample Size (n)	7	7	7	0
Mean (M)	<b>94.0</b>	<b>92.7</b>	<b>75.9</b>	-
Standard Deviation (SD)	8.4	8.2	31.6	-
<b>28R Monitor</b>				
Sample Size (n)	7	7	0	7
Mean (M)	<b>93.9</b>	<b>85.7</b>	-	<b>88.9</b>
Standard Deviation (SD)	6.1	19.2	-	15.8



**Figure 5-5. Given the IM PA-related Tools provided in this scenario, I was comfortable monitoring IM PA operations when both a CSL and WSL were active at the same time.**

*\*Combined Monitor configuration / \*\*28R Monitor configuration*

*Note: o indicates Week 1 TRACON controller responses for reference. These are not included in the M and SD computations.*

For the Combined 28L/28R Monitor configuration, all Week 2-3 TRACON controllers agreed they were comfortable monitoring IM PA operations with both limits at the same time with IM PA Tools On (M=94.0; SD=8.4) and IM PA Tools Off (M=92.7; SD=8.2). For the Separate 28R Monitor configuration position, all Week 2-3 TRACON controllers agreed with IM PA Tools On (M=93.9; SD=6.1). With IM PA Tools Off, the majority (86%) of controllers agreed (M=85.7; SD=19.2). One controller neither agreed nor disagreed in this case. As described in Section

5.8.1, a two-tailed T-Test analysis did not find a significant difference in strength of controller agreement between the two IM PA Tool configurations.

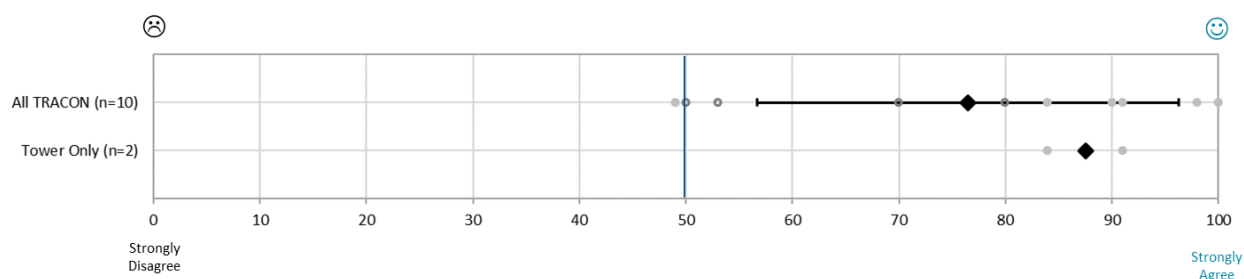
Responses were variable for the Data Block CSL Distance On / WSL-P Off configuration, but a majority (86%) of Week 2-3 TRACON controllers agreed (M=75.9; SD=31.6). One controller disagreed, however this same controller agreed to this question in both the IM PA Tools On and Off conditions. Therefore, this particular rating may not have been deliberate. All Week 2-3 TRACON controllers agreed with the Data Block CSL Distance Off / WSL-P On configuration (M=88.9; SD=15.8).

### 5.2.3 IM Speed Control

At the end of Day 2 (QT3), after experiencing the nominal scenarios across all IM PA Tool and monitor configurations, controllers were asked if **they were comfortable allowing an IM Trail Aircraft to manage its own speed to achieve the desired spacing goal at the FAF**. Responses are shown for all TRACON (NCT and non-NCT combined) and Tower Only. Response Means and Standard Deviations are summarized in Table 5-5. Scale responses are shown in Figure 5-6.

**Table 5-5. Controller Responses to Comfort in Allowing an IM Trail Aircraft to Manage its Own Speed**

	Participant Experience	
	TRACON	Tower
Sample Size (n)	10	2
<b>Mean (M)</b>	<b>76.5</b>	<b>87.5</b>
Standard Deviation (SD)	19.8	-



**Figure 5-6. I was comfortable allowing an IM Trail Aircraft to manage its own speed to achieve the desired spacing goal at the Final Approach Fix.**

Note: o indicates NCT controller responses.

The majority (80%) of TRACON controllers agreed (M=76.5; SD=19.8) that they were comfortable allowing an IM Trail Aircraft to manage its own speed to achieve the desired spacing goal at the FAF. Two controllers neither agreed nor disagreed.

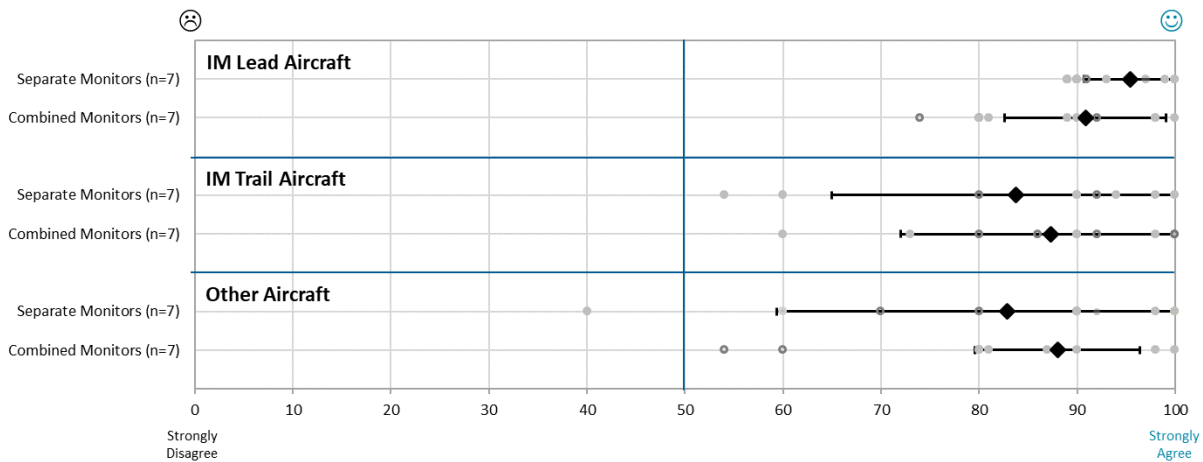
From the open-ended comments, at least three of the lower ratings appeared to be a result of controllers not being allowed to manually keep the IM Trail Aircraft between the limits when it became apparent that a Caution Alert was imminent.

## 5.2.4 Traffic Awareness

At the end of Day 1 and Day 2, controllers were asked about the **acceptability of their overall level of traffic awareness with respect to the IM Lead Aircraft, IM Trail Aircraft, and Other Aircraft**. Their responses were examined with respect to monitor configuration. Response Means and Standard Deviations are summarized in Table 5-6. Scale responses are shown in Figure 5-7. Only Week 2-3 TRACON controller responses were included in the analysis.

**Table 5-6. Controller Responses to Traffic Awareness Acceptability: Aircraft Type**

	Monitor Configuration	
	Separate	Combined
<b><i>IM Lead Aircraft</i></b>		
Sample Size (n)	7	7
<b>Mean (M)</b>	<b>95.4</b>	<b>90.9</b>
Standard Deviation (SD)	4.7	8.2
<b><i>IM Trail Aircraft</i></b>		
Sample Size (n)	7	7
<b>Mean (M)</b>	<b>83.7</b>	<b>87.3</b>
Standard Deviation (SD)	18.7	15.3
<b><i>Other Aircraft</i></b>		
Sample Size (n)	7	7
<b>Mean (M)</b>	<b>82.9</b>	<b>88.0</b>
Standard Deviation (SD)	23.5	8.4



**Figure 5-7. My overall level of traffic awareness today was acceptable with respect to [IM Lead Aircraft / IM Trail Aircraft / Other Aircraft].**

Note: o indicates Week 1 TRACON controller responses for reference. These are not included in the M and SD computations.

All Week 2-3 TRACON controllers agreed their overall level of traffic awareness was acceptable with respect to all aircraft types for both monitor configurations, except for Separate Monitors / Other Aircraft. In this case, the one participant that disagreed noted in the open-ended comments: “Difficult to determine distance between successive lead aircraft.” This participant has TRACON experience, though is currently assigned to a Tower position. This may help explain the lower rating.

The overall results do not suggest any apparent differences in acceptability by monitor configuration among aircraft types. However, Lead Aircraft response variability for the IM Lead Aircraft appeared to be lower for the Separate Monitor configuration than for all the other cases.

Other open-ended comments for this question included:

- (Non-NCT TRACON / Separate): Trails do not need to be monitored as closely because there is automation to ensure separation. Focus can be spent elsewhere.
- (Non-NCT TRACON / Combined): Definitely was more aware of the trail aircraft because of the new procedures. But spacing required more attention to the lead aircraft following other pairs.
- (Non-NCT TRACON / Combined): As the day went on, I focused more on distance between pairs as opposed to the aircraft in the PA. This was easy because of the alerts and warnings.

## 5.2.5 Separation

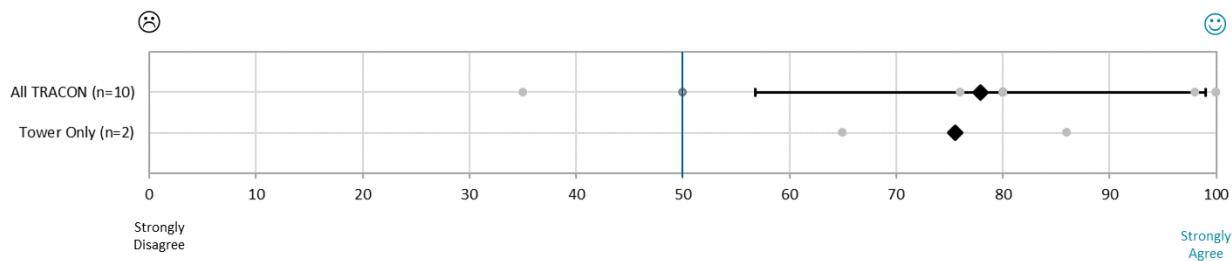
This section summarizes the subjective questionnaire data with respect to controller confidence of ensuring separation within the IM PA pairs. It also includes the objective data analysis with respect to observed separation violations within and between the IM PA pairs on the arrivals.

### 5.2.5.1 Subjective Data Assessment

At the end of Day 2 (QT3), after experiencing the nominal scenarios across all IM PA Tool and monitor configurations, controllers were asked: **overall, I was confident that I could assess whether the separation between the IM Trail Aircraft and their Lead Aircraft would be maintained.** Responses are shown for all TRACON (NCT and non-NCT combined) and Tower Only. Response Means and Standard Deviations are summarized in Table 5-7. Scale responses are shown in Figure 5-8.

**Table 5-7. Monitor Controller Responses to Confidence in Assessing Separation between IM Trail and their Lead Aircraft**

	Participant Experience	
	TRACON	Tower
Sample Size (n)	10	2
Mean (M)	77.9	75.5
Standard Deviation (SD)	21.1	-



**Figure 5-8. Overall, I was confident that I could assess whether the separation between the IM Trail Aircraft and their Lead Aircraft would be maintained.**

Note: *o* indicates NCT Controller responses.

When asked if they could assess whether the separation between the IM Trail Aircraft and their Lead Aircraft would be maintained, the majority (80%) of TRACON controllers agreed (M=77.9; SD=21.1). One TRACON controller disagreed and commented: “Need CSL & WSL sooner.” It is unclear why CSL was noted since it was present at the start of the IM PA operation. Though not shown, further analysis suggests the subjective separation assessment did not appear to be affected by varying the alert timing.

Another open-ended comment from a TRACON controller noted: “Relying on the automation. Without it, I could not at this proximity.”

### 5.2.5.2 Objective Data Assessment

As noted in Section 4.5.7.2, the simulation recorded aircraft state data and PTT click data for each scenario. This data was then post-processed to determine if any losses of separation

occurred and if so, whether monitor configuration or IM PA Tool configuration had any effect. This data only includes the Nominal and Alert Timing scenarios for Weeks 2-3 due to scenario changes after Week 1. The Day 3 Lateral Deviation scenarios were not included in the post-processing analysis due to their complexity. There was one controller in Week 3 who had considerable experience at a major tower, but no TRACON experience. This participant's separation data is not included and 21 runs (across seven controller participants) were evaluated for the Day 1-2 Nominal scenarios. The same number of runs, 21, were also evaluated for the Day 3 Alert Timing scenarios.

Separation was considered within and between IM PA pairs.

- **Within IM PA Pairs.** Here, separation was considered lost if a trail aircraft crossed a CSL or WSL boundary *before* a controller contacted it to provide breakout instructions. Contact was determined to have occurred if there was a PTT click between the time of a Caution Alert and the aircraft crossing either safety limit.
- **Between Pairs.** Here, separation was defined per the minima as described in Section 4.3.3. If the spacing between any non-IM PA combination of aircraft went below than the Wake Turbulence or MRS minima, it was considered a separation violation.

The post-processing involved an automated script that examined the traffic data and flagged instances where the above separation definitions were violated. Each resulting case was then verified manually against the controller display video capture videos and/or other MITRE visualization tools. MITRE controller subject matter expert (SME) input was used to make a final determination of the instances that should count as violations. Across all the scenarios, the number of separation violations that were observed is summarized in Table 5-8:

**Table 5-8. Number of Observed Separation Violations (Weeks 2-3)**

	Separation Violations	
	Within IM PA Pairs	Between Pairs
Day 1-2 Nominal	0	10
Day 3 Alert Timing	1	2

### Within IM PA Pair Separation Violations

For the seven TRACON Week 2-3 participants, there were zero IM PA separation violations observed for the 21 evaluated Day 1-2 Nominal scenarios.

For the 21 evaluated Week 2-3, Day 3 Alert Timing scenarios, 5 cases were observed in which an IM Trail Aircraft crossed a safety limit line while it was still being displayed. These may have been cases, however, where the controller prioritized communicating a break out instruction to the aircraft before terminating IM PA in the automation. A controller PTT click was observed between the time of the Caution Alert and the time of the crossing. As described in Section 5.1.2, due to the lack of override capability, it was also possible that the controller was blocked

and therefore the break out instruction could not be provided to the IM Trail Aircraft before IM PA was terminated and the safety limit line was crossed. These cases were therefore not counted as violations as the controller may have in effect terminated the operation before the line was crossed. Further analysis was performed to examine how soon the PTT click happened in these cases before the crossing occurred. The results are shown in Table 5-9.

**Table 5-9. Day 3 Alert Timing Safety Limit Exceedances with PTT Response (Weeks 2-3)**

Case	Alert Timing	Safety Limit Crossed	Time Between Preceding PTT click and Crossing
1	25/15	WSL	8 sec
2	25/15	CSL	11 sec
3	25/15	CSL	9 sec
4	25/15	CSL	17 sec
5	25/15	WSL	9 sec
<b>M</b>			<b>10.8 sec</b>
<b>SD</b>			<b>3.6 sec</b>

Only a single separation violation case was observed for the 21 evaluated Week 2-3, Day 3 Alert Timing scenarios, and it involved the 25/15 sec alert timing. In this scenario, an IM Trail Aircraft, AAL2435, was deliberately designed to maintain a faster-than-normal speed on the approach so that the IM PA alerts would be triggered relative to its CSL. Shortly after the Predictive Alert was displayed, the controller issued a 30 kt speed reduction to this aircraft. Per the instructions to the participants, the controller should then have terminated IM PA and broken the aircraft out. However, the controller elected to keep the IM PA active and watch the situation. The aircraft began to implement the 30 kt speed reduction but due to a simulation artifact, did not reduce further to its final approach speed after the FAF. A Caution Alert was triggered and the aircraft exceeded the CSL on a three-mile final. Exactly 15 seconds after the Caution Alert was displayed, the aircraft exceeded the CSL, as shown in Figure 5-9. The controller then terminated IM PA approximately two seconds later and issued the break out.



**Figure 5-9. IM PA Day 3 Alert Timing Scenario Separation Violation**

Although a situation like this was only observed to occur once across all of the evaluated scenarios, it supports comments and feedback from several controllers that they would like the ability to try to manually provide speed assignments to aircraft that were at risk of encroaching

on a safety limit. It is notable that every observed instance of a safety limit exceedance, whether or not it resulted in an IM PA separation violation, occurred with the shortest alert timing values. Therefore, if a PA separation standard would allow controllers to manually manage Trail Aircraft speeds, further alert timing research is recommended to examine values that would ensure interventions can be successfully implemented before a safety limit is exceeded.

### Between Pair Separation Violations

The Day 1-2 Nominal and Day 3 Alert Timing scenarios were also examined to determine if any separation violations occurred between aircraft that were being separated with MRS or RECAT minima. Twelve total instances were observed; the circumstances are shown in Table 5-10.

These instances had many similar or identical circumstances and so they were then categorized into five unique cases for analysis and discussion. In the table, Nom is short for Nominal, AT is short for Alert Timing, Comb is short for Combined, and Sep is short for Separate. An MRS value of 2.5 NM within 10 NM of the runway was used in the analysis as the participants were trained that they could allow that level of compression.

**Table 5-10. Between Pair Separation Violations (Weeks 2-3)**

Occurrence Number	Unique Case	Scenario Type	Controller Configuration	IM PA Tools / Alert Timing Configuration*	Leading Aircraft Type	Leading Aircraft Runway	Trailing Aircraft Type	Trailing Aircraft Runway	Separation Standard / Value (NM)	IM PA Alert concurrent with Violation?
1	A	Nom	Comb	4	B772	28L	A320	28R	RECAT / 5	Unk <sup>†</sup>
2		Nom	Comb	3	B772	28L	A320	28R	RECAT / 5	Yes
3		Nom	Comb	3	B772	28L	A320	28R	RECAT / 5	Yes
4		Nom	Comb	1	B772	28L	A320	28R	RECAT / 5	Yes
5		Nom	Comb	3	B772	28L	A320	28R	RECAT / 5	Yes
6		Nom	Comb	4	B772	28L	A320	28R	RECAT / 5	Yes
7		Nom	Comb	3	B772	28L	A320	28R	RECAT / 5	No
8	B	Nom	Comb	3	B772	28L	B763	28L	RECAT / 4	No
9	C	Nom	Comb	4	A320	28R	B763	28L	MRS / 2.5	No
10	D	Nom	Sep	2	B772	28L	B737	28L	RECAT / 5	Unk <sup>†</sup>
11	E	AT	Comb**	35/20	A320	28R	B763	28L	MRS / 2.5	No
12		AT	Comb**	25/15	A320	28R	B763	28L	MRS / 2.5	Yes

\* IM PA Tool Configurations: [1] All On; [2] DB Distance Off / WSL-P On; [3] DB Disc On / WSL-P Off; and [4] All Off.

\*\* All Alert Timing scenarios used All Tools On and a Combined Monitor Configuration.

<sup>†</sup> A simulation error in the recording of the controller display for this scenario precluded further assessment.

**Case A.** Of the ten Nominal scenario occurrences, seven involved the same aircraft pairing under nearly identical circumstances. As a B772 aircraft (Category B) on 28L (UAL905) approached the runway threshold, the A320 aircraft (Category D) behind it on the parallel runway (UAL136) continued to compress. Based on the Wake RECAT standards used in the HITL (Table 4-1), 5 NM was the required separation. However just before the B772 crossed the threshold, the spacing reduced to between 4.8 to 4.9 NM, which at SFO is considered a “compression error.” As shown in Figure 5-10, one controller used the STARS range tool to monitor this pair; however, still elected not to intervene.



**Figure 5-10. Case A: Example Separation Violation Between UPS905 and UAL136**

At the time this occurred, one to two other IM PA alerting events were happening simultaneously in the scenario. In at least four<sup>12</sup> cases, UAL136 was experiencing a Predictive Alert as shown in Figure 5-10. In those same four cases, plus at least two more, an aircraft that just joined the 28R approach experienced a Caution Alert as shown in Figure 5-27. It is possible, even likely, that the controller participants were aware of the compression error occurring between these two aircraft. However, they may have determined that the safest course of action was to prioritize their attention with the IM PA issues occurring at the same time and let the aircraft proceed to landing.

**Case B.** This situation occurred in one of the Case A scenarios and involved one of the same controllers. This time, however, the separation violation occurred between the leading B772 (UAL905) and the trailing B763 (UAL951) arriving to the same runway as shown in Figure 5-11. Based on the Wake RECAT standards used in the HITL (Table 4-1), 4 NM between these aircraft were required. The aircraft compressed to approximately 3.5 NM at the time UAL905 crossed the threshold, as shown in Figure 5-12. At the time of this violation, there was no Predictive Alert for UAL136 and no Caution Alert (yet) for the aircraft joining the 28R Approach forward of the CSL.

<sup>12</sup> Controller video capture was not available for one of the runs and so the other circumstances at the time of this violation were not able to be assessed.



Figure 5-11. Case B: Separation Violation Between UPS905 and UAL951 at the Time of Occurrence



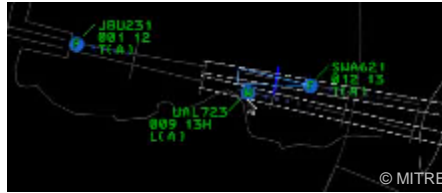
Figure 5-12. Case B: Minimum Observed Separation Between UPS905 and UAL951

**Case C.** This situation involved a B763 (UAL723, Category C) compressing to less than 2.5 NM behind an A320 (JBU231, Category D) arriving to the parallel runway. Due to the weight categories involved (C following D), 2.5 NM MRS was required. The situation at the time of the violation is shown in Figure 5-13. As this was an All Tools Off scenario, this particular controller found that placing a 1.5 NM ring around each Heavy IM Lead Aircraft helped keep track of pairings in which a WSL would eventually become active.



Figure 5-13. Case C: Separation Violation Between JBU231 and UAL723 at the Time of Occurrence

As shown in Figure 5-14, the two aircraft compressed to approximately 2.25 NM at the time UAL905 crossed the threshold. No other scenario alerts were observed to have occurred during this event.



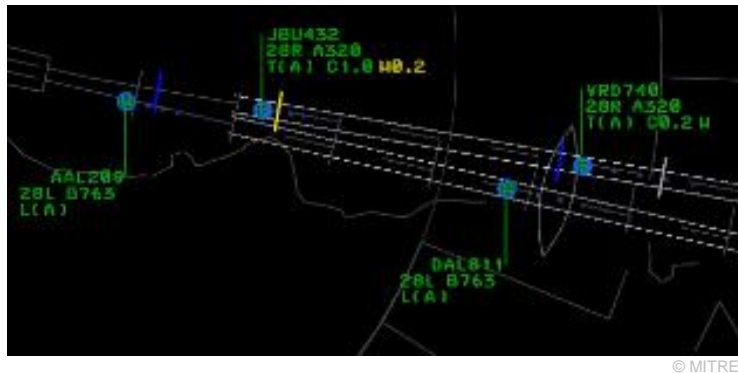
**Figure 5-14. Case C: Minimum Observed Separation Between JBU231 and UAL723**

**Case D.** This was the only case to involve the Separate Controller configuration. Here, a separation violation occurred between a leading B772 and a trailing B737 arriving to the same runway. Based on the Wake RECAT standards used in the HITL (Table 4-1), 5 NM were required between the two aircraft. From the aircraft state data, they compressed to 4.4 NM at their closest point. A simulation error in the recording of the controller display for this scenario precluded further assessment.

**Case E.** The two occurrences observed for the Alert Timing scenarios involved the same aircraft pairing under similar circumstances. A B763 (DAL811, Category C) compressed to less than 2.5 NM behind an A320 (JBU432, Category D) arriving to the parallel runway. Due to the weight categories involved (C following D), 2.5 NM MRS was required. The situation at the time of violation occurrence 11 (as listed in Table 5-10) is shown in Figure 5-15. The situation at the time of violation occurrence 12 is shown in Figure 5-16.



**Figure 5-15. Case E, Occurrence 11: Separation Violation Between JBU432 and DAL811 at the Time of Occurrence**



**Figure 5-16. Case E, Occurrence 12: Separation Violation Between JBU432 and DAL811 at the Time of Occurrence**

The only difference between the two Case E scenarios was the alert timing values and that a Predictive Alert was displayed for occurrence 12 as it had the smaller value. However, this may not have been a primary distraction as this violation was also observed in occurrence 11, where there was no Predictive Alert for this pairing at the time of the occurrence (though it came a few seconds later). The situation was further complicated as JBU432 then experienced a WSL Caution Alert. The alert happened 18 seconds after the separation violation for occurrence 11 (Figure 5-17), and 11 seconds after the separation violation for occurrence 12 (Figure 5-18). Controllers in both situations then terminated IM PA for JBU432. In both cases, the distance between the two aircraft at the time of the JBU432 Caution Alert was just over 2 NM.



**Figure 5-17. Case E, Occurrence 11: Separation Between JBU432 and DAL811 at the Time of the JBU432 Caution Alert**



**Figure 5-18. Case E, Occurrence 12: Separation Between JBU432 and DAL811 at the Time of the JBU432 Caution Alert**

In summary, twelve total separation violations were observed across the evaluated runs. They were distributed across the seven individual participants; every participant had at least one and no single controller was responsible for more than two. The separation violations occurred under varying circumstances. Ten of the 12 involved aircraft arriving to different runways, and 9 of the 12 involved a Category B aircraft in the lead. In at least half of the occurrences, an IM PA Predictive or Caution Alert was active on the display at the time of the separation violation, which may have served as either a distraction or was determined to be a higher priority. It should also be noted that ATPA functionality and data block weight category information (other than identifying Heavy aircraft) were not present. This made the between-pair separation task more difficult than what controllers were used to, as several noted in open-ended comments.

Eight of the 12 violations occurred with either just the WSL-P Off (IM PA Tool configuration 3 as shown in Table 5-10) or both the Data Block Distances and WSL-P Off (IM PA Tool configuration 4). When reviewing the individual occurrences, however, they either happened late in the approach when the WSL was already active or had other circumstances that made it challenging to see what effect a WSL-P might have for helping to avoid the occurrence. As these occurrences did not appear to be related to IM PA, at least directly, it seems unlikely that the presence or absence of the WSL-P may have been a contributing factor.

Across the 10 Nominal Scenario occurrences, 9 involved the Combined Monitor configuration. However, a review of the equivalent scenarios for cases A and B during the Separate Monitor configuration runs showed that the separation for these pairs only decreased below the RECAT minima once the leading B772 crossed the runway threshold. Observer notes for these scenarios did not indicate any controller interventions that would have precluded this compression error from occurring. Therefore, this occurrence of the violation in these cases was only present in the Combined Monitor Scenarios. It is likely more of an artifact of the slight timing variations between the scenarios and thus cannot be conclusively attributed to monitor configuration.

IM PA pair-wise separation assurance appeared to be a straightforward task for controllers as only a single violation was observed within an IM Trail Aircraft and IM Lead Aircraft pairing, despite the introduction of far more lateral and longitudinal deviations than would be expected in actual operations. This instance involved a controller appearing to attempt to manually assign a speed to keep an IM Trail Aircraft behind the CSL and allowing the IM PA operation to continue. The controller may have then expected the aircraft to reduce to its final approach speed; however it did not due to a simulation artifact. Still, the aircraft crossed the CSL before the controller commanded a break out. Though the controller should have terminated IM PA and commanded a break out sooner than what occurred, this instance was not a result of the controller failing to notice a developing situation.

The separation violation occurrences observed between the aircraft pairs not performing IM PA happened under varying circumstances, which makes it difficult to conclude that they were significantly influenced by the presence of IM PA operations in the environment or any of the independent variable manipulations. They may have been more related to controllers in the simulation not having current separation tools such as ATPA available to them. Although these violations occurred in the context of simulation events that were designed to stress test the concept and ground tools, their presence still suggests that tools and procedures need to be fully integrated to ensure that separation between aircraft pairs not performing IM PA can be maintained while IM PA operations are in progress. In addition, IM PA setup spacing requirements should ensure that between-pair separation can be sufficiently maintained during compression on final.

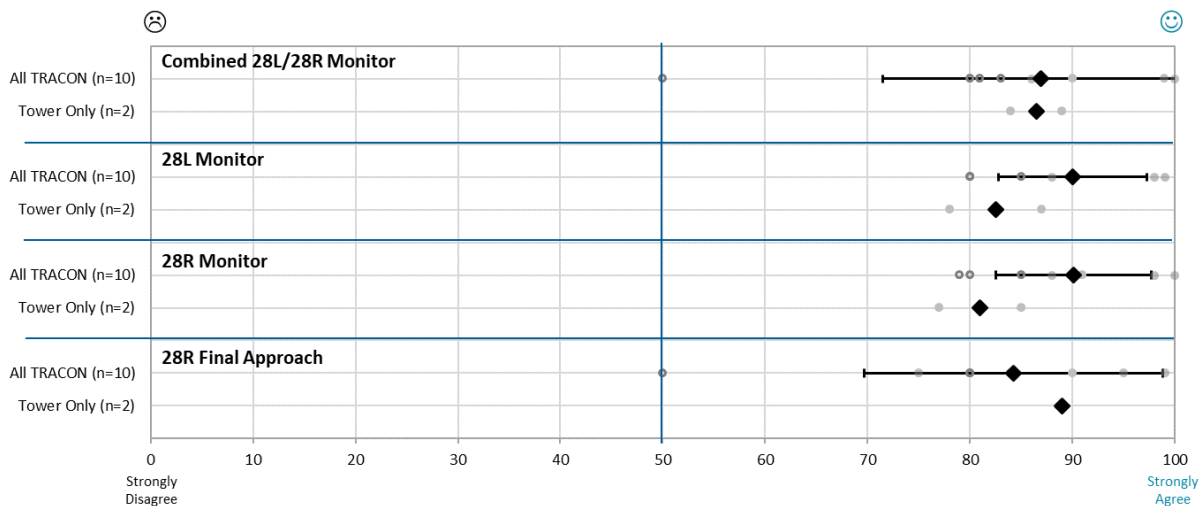
## 5.2.6 Task Acceptability by Position

At the end of Day 2 (QT3), after experiencing the nominal scenarios across all IM PA Tool and Role configurations, controllers were asked if **the tasks required of each simulation position**

were acceptable. Responses are shown for all TRACON (NCT and non-NCT combined) and Tower Only. Response Means and Standard Deviations are summarized in Table 5-11. Scale responses are shown in Figure 5-19.

**Table 5-11. Controller Responses to Task Acceptability by Position**

	Participant Experience	
	TRACON	Tower
<b><i>Combined Monitor</i></b>		
Sample Size (n)	10	2
<b>Mean (M)</b>	<b>86.9</b>	<b>86.5</b>
Standard Deviation (SD)	15.4	-
<b><i>28L Monitor</i></b>		
Sample Size (n)	10	2
<b>Mean (M)</b>	<b>90.0</b>	<b>82.5</b>
Standard Deviation (SD)	7.3	-
<b><i>28R Monitor</i></b>		
Sample Size (n)	10	2
<b>Mean (M)</b>	<b>90.1</b>	<b>81.0</b>
Standard Deviation (SD)	7.6	-
<b><i>28R Final Approach</i></b>		
Sample Size (n)	10	2
<b>Mean (M)</b>	<b>84.2</b>	<b>89.0</b>
Standard Deviation (SD)	14.6	-



**Figure 5-19. The tasks required of each simulation position were acceptable.**

*Note: o indicates NCT Controller responses.*

When asked if the tasks required of each simulation position were acceptable, all (100%) TRACON controllers agreed for the Separate 28L (M=90.0; SD=7.3) and 28R (M=90.1; SD=7.6) Monitor positions. In the Combined Monitor configuration, the majority (90%) of controllers agreed (M=86.9; SD=15.4). One controller neither agreed nor disagreed in this case. For the 28R Final Approach position, the majority (90%) of controllers agreed (M=84.2; SD=14.6). The same controller that neither agreed nor disagreed in the Combined Monitor configuration, also neither agreed nor disagreed in this case.

From the open-ended comments, one controller noted that the “final could be much more difficult than we saw today. Given point outs, traffic calls, Visual Flight Rules (VFRs), and other coordination, it may be difficult to clear and give spacing in the short window afforded.” This is an understandable comment, given that the Final Approach position in the simulation was intended to be a part task position to evaluate the Partial IM Clearance phraseology and communication of the Assigned Spacing Goal. Due to the setup assumptions detailed in Section 4.3.1, it did not involve vectoring to final.

Overall, the tasks required for the combined 28L/28R Monitor position, separate 28L and 28R Monitor positions, and 28R Final Approach position all appeared to be acceptable.

## 5.2.7 General Comments: Likes, Concerns, Improvements

The Day 2 Final Questionnaire (QT3) included questions relating to what controllers generally liked about IM PA, what concerned them, and what aspects of the operation could be improved. This section summarizes the controller responses. Given their specific experience in the areas being simulated, NCT responses are specifically identified. Non-NCT TRACON and Tower responses are thus also individually identified.

When asked if there were **any aspects of the IM PA operation that you especially liked**, controllers provided the following comments:

- (NCT) Extra [number] of planes potentially landing per hour.
- (NCT) I liked that heavies could be the lead or trailing aircraft.
- (Non-NCT TRACON) Ability to run more aircraft in with lower visibility/ceilings.
- (Non-NCT TRACON) The ability not to have to watch the spacing closely knowing an alert would occur if anything needed to be done.
- (Non-NCT TRACON) The CSL & WSL lines are useful.
- (Non-NCT TRACON) Simplicity of 28R final. There aren't really options, traffic just needs [to be] pulled out if spacing is lost. Makes that part idiot proof.
- (Non-NCT TRACON) Entire operation is very straight forward and easy to understand.

Controllers were also asked if they had **concerns with any aspect of the IM PA operation**. The majority of the responses were related to wanting more manual control when it became clear an aircraft was going to encroach upon a safety limit. Several controllers expressed frustration that they were unable to manually issue a speed to keep an IM Trail Aircraft within the limits when they observed a spacing situation start to develop.

Other comments included:

- (NCT) Shipping the aircraft to the tower so early clearly is not a practical application, I was transmitting way too much as the monitor, that would cause a real unsafe situation for the local controller having to split time with the monitor.
- (Non-NCT TRACON): WSL is my main concern. It shows up late and without a preview WSL, I focus too much on the area of final where WSL activates.
- (Non-NCT TRACON) When a pair appeared as though they were close to alerting, I focused on that pair (so as not to miss an alert) and lost some degree of focus on the other pairs.
- (Non-NCT TRACON) Judging spacing and separation between aircraft outside the pairs on adjacent approach courses.
- (Tower) The initial separation using IM before predictions are turned on.

Controllers were also asked **how the conduct of IM PA operations could be improved**. Related to the concern about not being able to intervene manually to keep an IM Trail Aircraft within the safety limits, several controllers, including those from NCT, suggested allowing controllers to issue speeds to the trailing aircraft to allow it to stay on the approach. Another NCT controller suggested that the Assigned Spacing Goal should be in data block and that if an aircraft starts to encroach on a safety limit, controllers should be able to cancel IM, resolve the issue, then re-initiate IM once the trailing aircraft is back within the limits. Another participant felt that the IM portion of the operation was not a requirement and noted that if IM was not available, but the CSL and WSL lines were, controllers could manually provide speeds to keep a trailing aircraft within the safety limits and save a go-around.

Some controllers also commented on the need for more predictive information, earlier. This included providing the WSL lines sooner and adding a “CSL Preview” line on the display to indicate where the IM Trail Aircraft was relative to the IM PA safety limits *before* controllers needed to provide the IM Clearance. This would enable a Tower controller’s request for the ability to adjust speeds prior to the start of IM PA to increase the probability of the trail aircraft achieving its spacing.

Comments were also made with respect to the feeder and final approach tasks. These included:

- (NCT) For this to provide the greatest benefit and efficiency, the vectoring to final by the feeders/final will be the most critical part. If that is done well, this offers much hope.
- (NCT) Figure out some phraseology, maybe high feeder can tell trail aircraft to expect to follow so final controller only has to say spacing interval & issue approach clearance.
- (Non-NCT TRACON) More airspace for final to finesse if feeder didn't achieve correct spacing. Spacing between 28R and following 28L traffic should be retained. Crossing restriction for 28R final so clearance can be issued early.
- (Non-NCT TRACON) For future implementation, a fix with an above crossing altitude would allow final to clear for the approach, then assign the spacing goal once established on final, which would make the timing less critical.
- (Non-NCT TRACON) Cancelling approach clearance should automatically terminate IM spacing.
- (Tower) The Monitor should have its own frequency, as opposed to being a Local override.

## 5.3 Results Topic 2: 28R Final Position

This section includes results related to the examination of the 28R Final controller IM PA initiation task. The metrics consisted of: workload, IM PA initiation acceptability and information requirements, IM Clearance communications, IM Speed control, and separation at handoff. It also summarizes participant responses to open-ended questions related to the 28R Final controller role and IM PA initiation.

The scenario changes that precluded the inclusion of Week 1 monitoring task data in the results did not affect the 28R Final controller position tasking. Therefore, the data in this section includes response data from all three weeks, unless otherwise indicated. Also, as with the Monitor positions, IM PA Tool configuration was also varied for the 28R Final controllers. Several of the metrics in this section were thus examined with respect to having IM PA Tools On and IM PA Tools Off.

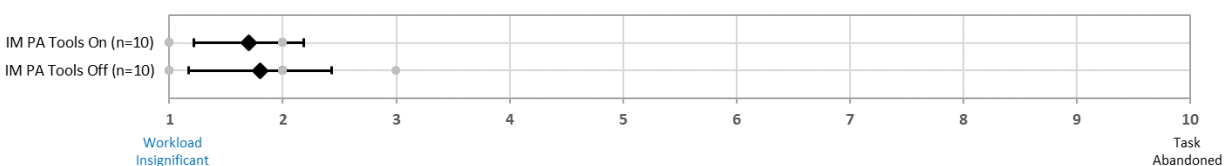
### 5.3.1 Workload

At the end of each run, controllers were asked to **rate their workload for the scenario they just experienced** (QT1) using the Bedford Workload Scale. Their responses were then examined with respect to IM PA Tool configuration. Response Means and Standard Deviations are

summarized in Table 5-12. Scale responses are shown in Figure 5-20. Only TRACON controller responses were included in the analysis.

**Table 5-12. Controller Average Workload Ratings for 28R Final Position**

	IM PA Tool Configuration	
	Tools On	Tools Off
Sample Size (n)	10	10
<b>Mean (M)</b>	<b>1.7</b>	<b>1.8</b>
Standard Deviation (SD)	0.5	0.6



**Figure 5-20. Controller Average Workload Ratings for 28R Final Position**

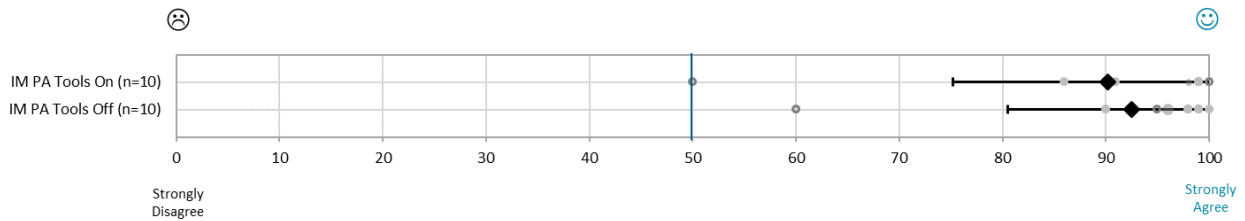
Note: *o* indicates NCT Controller responses.

On average, the TRACON controllers reported low workload in the 28R Final controller position for IM PA Tools On (M=1.7; SD=0.5) and IM PA Tools Off (M=1.8; SD=0.6). No practical difference was observed between the two IM PA Tool configurations.

At the end of each run (QT1), controllers were also asked **if their overall workload was acceptable for the scenario they just experienced**. Their responses were then examined with respect to IM PA Tool configuration. Response Means and Standard Deviations are summarized in Table 5-13. Scale responses are shown in Figure 5-21. Only TRACON controller responses were included in the analysis.

**Table 5-13. Controller Responses to Acceptability of Overall Workload for 28R Final Position**

	IM PA Tool Configuration	
	Tools On	Tools Off
Sample Size (n)	10	10
<b>Mean (M)</b>	<b>90.2</b>	<b>92.5</b>
Standard Deviation (SD)	15.0	12.0



**Figure 5-21. 28R Final Controller: My overall workload was acceptable for the scenario I just experienced.**

*Note: o indicates NCT Controller responses.*

On average, the TRACON controllers reported acceptable workload in the 28R Final controller position for IM PA Tools On (M=90.2; SD=15.0) and IM PA Tools Off (M=92.5; SD=12.0). No practical difference was observed between the two IM PA Tool configurations. Open-ended comments suggested that workload was low and that more tasks could have been handled.

### 5.3.2 IM PA Initiation Task

At the end of each run (QT1), controllers were asked questions regarding the IM PA initiation task. These were:

- **Given the appropriate training, and the IM PA-related tools I had available in this scenario, Final controllers can acceptably initiate the IM PA operation.**
- **Once the IM Trail Aircraft joined the final, I had sufficient time and airspace to initiate IM PA before transferring the aircraft to the Local controller.**
- **In this scenario, I had the necessary display elements to provide the appropriate IM Clearance information to the trail aircraft in an IM PA pair.**

Their responses were then examined with respect to IM PA Tool configuration. Response Means and Standard Deviations for each question are summarized in Table 5-14. Scale responses are shown in Figure 5-22. Only TRACON controller responses were included in the analysis.

Table 5-14. Controller Responses to IM PA Initiation Task

	IM PA Tool Configuration	
	Tools On	Tools Off
<b><i>Final controllers can acceptably initiate the IM PA operation</i></b>		
Sample Size (n)	10	10
<b>Mean (M)</b>	<b>81.2</b>	<b>73.6</b>
Standard Deviation (SD)	31.4	29.1
<b><i>Sufficient time and airspace to initiate IM PA</i></b>		
Sample Size (n)	10	10
<b>Mean (M)</b>	<b>76.5</b>	<b>74.5</b>
Standard Deviation (SD)	34.3	27.8
<b><i>Had the necessary display elements</i></b>		
Sample Size (n)	10	10
<b>Mean (M)</b>	<b>86.7</b>	<b>83.1</b>
Standard Deviation (SD)	20.3	18.8

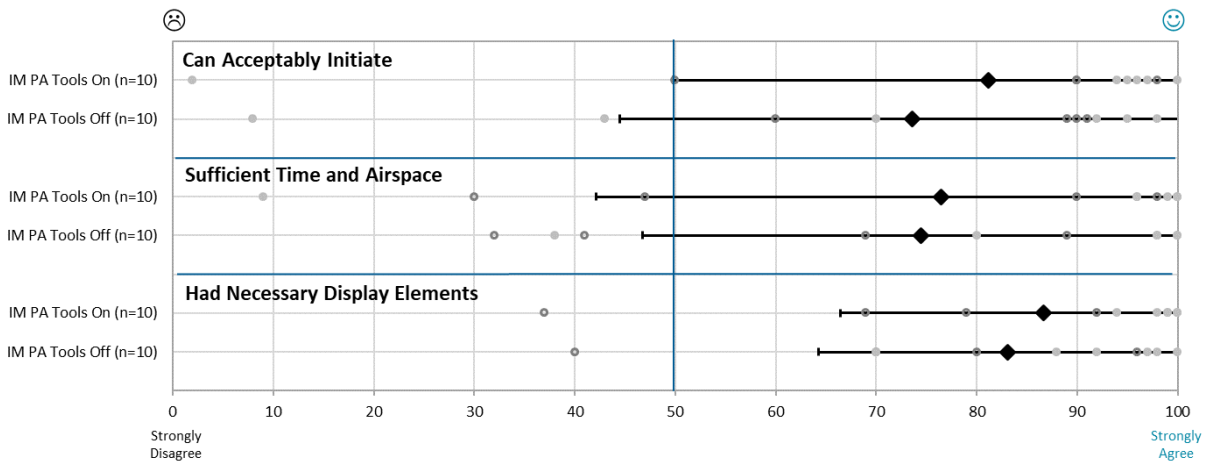


Figure 5-22. IM PA Initiation Task Responses

Note: o indicates NCT controller responses.

Controller responses were variable for the first question, but a majority (80%) agreed Final controllers can acceptably initiate the IM PA operation with IM PA Tools On (M=81.2; SD=31.4) and with IM PA Tools Off (M=73.6; SD=29.1). The high variability resulted from strong

disagreement by a non-NCT TRACON controller, who indicated in the open-ended comments that the WSL was needed “sooner.” In the IM PA Tools Off case, another non-NCT controller disagreed and explained this rating in a comment by saying the CSL and WSL are needed “sooner.” Despite this, no practical difference between the two IM PA Tool configurations was observed for this question.

Other open-ended comments for this question included:

- (non-NCT TRACON / Tools On) The [Spacing] list is very clear and easy to understand. I like having the list displayed in the order the radio transmissions are made.
- (non-NCT TRACON / Tools Off) There was an aircraft that is already ahead of CSL when clearance is issued... A/C needs to be immediately broken out. There should be a gray "preview" CSL available prior to initiation of IM Clearance to prevent this.
- (NCT) Spacing list should show all aircraft, not just who can play.

Controller responses were also variable for the second question, but a majority (70%) agreed once the IM Trail Aircraft joined the final, they had sufficient time and airspace to initiate IM PA before transferring the aircraft to the Local controller. This was for both IM PA Tools On (M=76.5; SD=34.3) and with IM PA Tools Off (M=74.5; SD=27.8). One NCT controller disagreed for both configurations and explained in a comment that more than 2-3 miles are needed when the aircraft turns on final. The controller noted further that 7-10 miles would help make sure aircraft are in a better position. However, two non-NCT controllers felt there was sufficient time and airspace to initiate IM PA. One commented that this was because the aircraft were already sequenced and vectored to join the final approach course. Another noted that a 20 mile final at 6000 ft is sufficient time and altitude. No practical difference between the two IM PA Tool configurations was observed for this question.

Controller responses were less variable for the third question. A majority (90%) agreed they had the necessary display elements to provide the appropriate IM Clearance information to the trail aircraft in an IM PA pair. This was for both IM PA Tools On (M=86.7; SD=20.3) and with IM PA Tools Off (M=83.1; SD=18.8). In explaining a disagree rating with IM PA Tools On, one NCT controller commented that the data block should include the Assigned Spacing Goal and that regular viewing of the Spacing List distracts from scanning the traffic. A different NCT controller with a disagree rating with IM PA Tools Off commented that the CSL should be available prior to initiating IM PA. No practical difference between the two IM PA Tool configurations was observed for this question.

Other open-ended comments for this question included:

- (Non-NCT TRACON / Tools On) Spacing list read easily from left to right.
- (NCT / Tools On) Yes but the box is annoying & I couldn't find an acceptable location to have it on my scope.
- (NCT / Tools Off) Would be nice if spacing list has indicator if it was a heavy next to aircraft call sign that aircraft are pairing with.

### 5.3.3 IM Clearance Communications

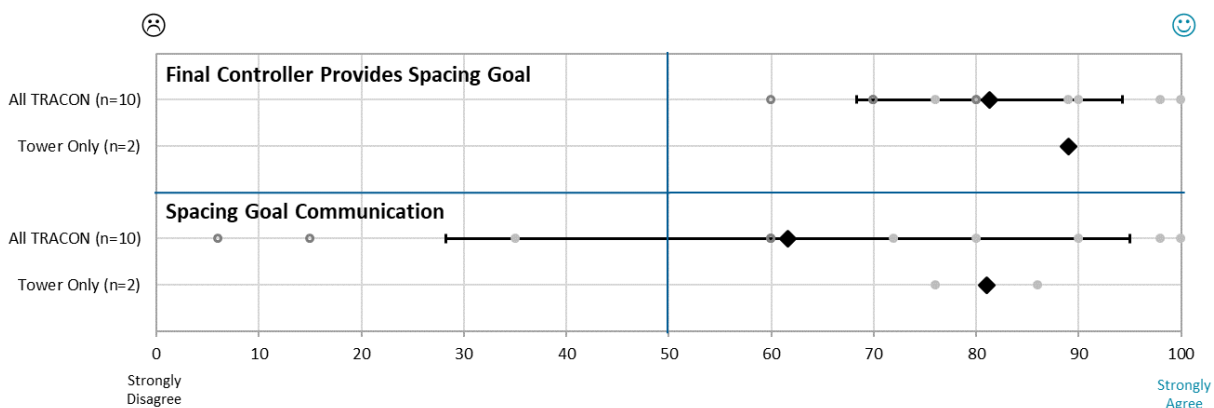
At the end of Day 2 (QT3), controllers were asked two questions regarding the acceptability of IM Clearance communications. These were:

- It is operationally acceptable for the Final controller to provide the IM PA spacing goal.
- The IM PA spacing goal communication was acceptable.

Responses are shown for all TRACON (NCT and non-NCT combined) and Tower Only. Response Means and Standard Deviations are summarized in Table 5-15. Scale responses are shown in Figure 5-23.

**Table 5-15. Controller Responses to IM Clearance Communications Acceptability**

	Participant Experience	
	TRACON	Tower
<b><i>Final Controller Provides Spacing Goal</i></b>		
Sample Size (n)	10	2
Mean (M)	<b>81.3</b>	<b>89.0</b>
Standard Deviation (SD)	12.9	-
<b><i>Spacing Goal Communication</i></b>		
Sample Size (n)	10	2
Mean (M)	<b>61.6</b>	<b>81.0</b>
Standard Deviation (SD)	33.4	-



**Figure 5-23. It is operationally acceptable for the Final controller to provide the IM PA spacing goal and the IM PA spacing goal communication was acceptable.**

Note: o indicates NCT controller responses.

For the first question, all (100%) TRACON controllers agreed it is operationally acceptable for the Final controller to provide the IM PA spacing goal (M=81.3; SD=12.9). One non-NCT TRACON controller commented that it takes the place of speed control so there was little impact on workload. Two other controllers noted that the phraseology could be consolidated and improved. One suggestion was that the word “Goal” should be replaced with “your interval spacing.”

Controller responses were variable for the second question, but a majority (70%) agreed the IM PA spacing goal communication was acceptable (M=61.6; SD=33.4). The controllers that disagreed provided comments that suggested they had concerns with the overall phraseology and that there were too many transmissions on the override frequency. Their disagreement did not appear to be specifically related to providing the Assigned Spacing Goal.

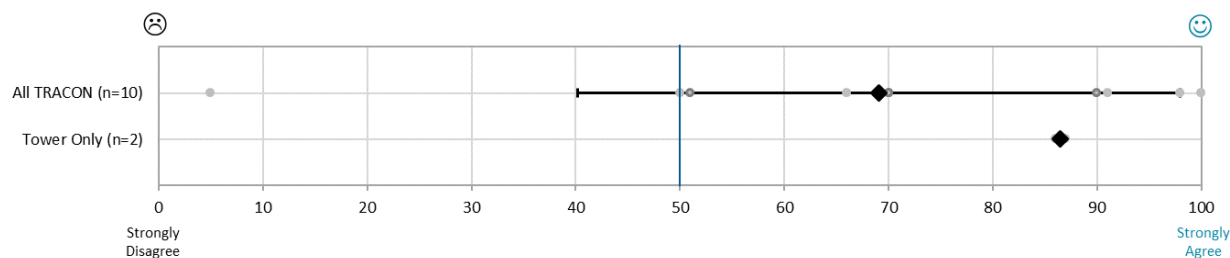
Another open-ended comment for this question included:

- (Non-NCT TRACON) Seconds is unfamiliar to controllers and somewhat cumbersome to say. I don't know what the alternative could be though.

Controllers were also asked at the end of Day 2 (QT3) whether **they were comfortable with the use of the Lead Aircraft call sign in the IM Clearance communication**. Responses are shown for all TRACON (NCT and non-NCT combined) and Tower Only. Response Means and Standard Deviations are summarized in Table 5-16. Scale responses are shown in Figure 5-24.

**Table 5-16. Controller Responses to Use of Lead Aircraft Call Sign in the IM Clearance**

	Participant Experience	
	TRACON	Tower
Sample Size (n)	10	2
Mean (M)	69.1	86.5
Standard Deviation (SD)	28.9	-



**Figure 5-24. I was comfortable with the use of the Lead Aircraft call sign in the IM Clearance communication.**

Note: **o** indicates NCT controller responses.

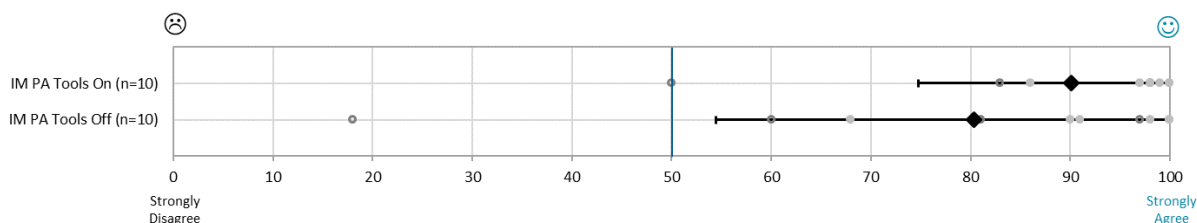
TRACON controller responses were variable, but the majority (80%) agreed they were comfortable with the use of the Lead Aircraft call sign in the IM Clearance communication (M=69.1; SD=28.9). One controller disagreed and another neither agreed nor disagreed.

### 5.3.4 IM Speed Control

At the end of each run (QT1), controllers were asked if they were **comfortable with the IM Trail Aircraft managing their speeds to achieve the spacing goal I assigned, while they were in my area**. Their responses were then examined with respect to IM PA Tool configuration. Response Means and Standard Deviations are summarized in Table 5-17. Scale responses are shown in Figure 5-25. Only TRACON controller responses were included in the analysis.

**Table 5-17. 28R Final Controller Speed Control Responses**

	IM PA Tool Configuration	
	Tools On	Tools Off
Sample Size (n)	10	10
<b>Mean (M)</b>	<b>90.1</b>	<b>80.3</b>
Standard Deviation (SD)	15.4	25.9



**Figure 5-25. 28R Final Controller: I was comfortable with the IM Trail Aircraft managing their speeds to achieve the spacing goal I assigned, while they were in my area.**

*Note: o indicates NCT controller responses.*

The majority (90%) of TRACON controllers agreed they were comfortable with the IM Trail Aircraft managing their speeds to achieve the spacing goal with IM PA Tools On (M=90.1; SD=15.4) and IM PA Tools Off (M=80.3; SD=25.9). With IM PA Tools On, one controller neither agreed nor disagreed. Though the response variability was lower with IM PA Tools On, no practical difference was observed between the IM PA Tool configurations for the 28R Monitor position.

### 5.3.5 Separation at Handoff

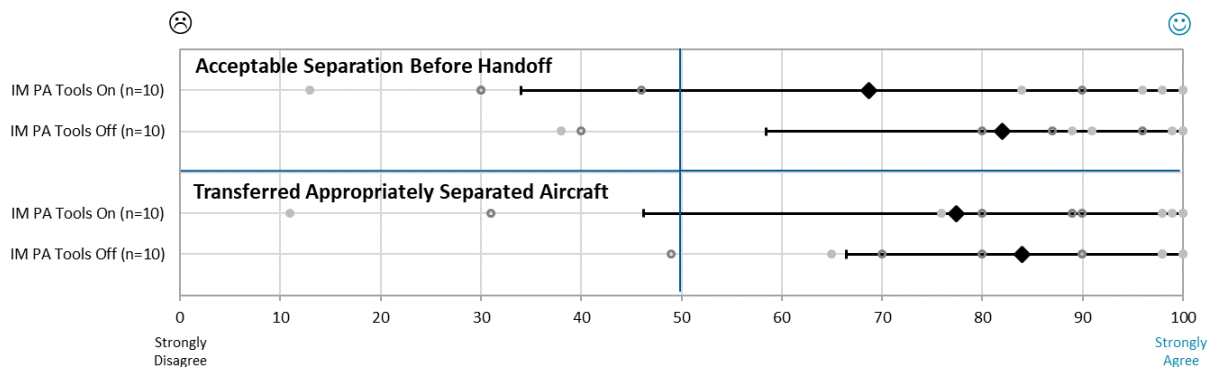
At the end of Day 2 (QT3), controllers were asked two questions regarding IM Trail Aircraft separation at the time of handoff to the Local controller. These were:

- Given the appropriate training, and the IM PA-related tools I had available in this scenario, Final controllers can acceptably ensure separation during IM PA operations before transferring aircraft to the Local controller.
- I was comfortable that I was transferring appropriately separated aircraft to the Local controller.

Their responses were examined with respect to both the IM PA Tools and monitor configurations. Response Means and Standard Deviations are summarized in Table 5-18. Scale responses are shown in Figure 5-26.

**Table 5-18. 28R Final Controller Responses to Separation at Handoff**

	IM PA Tool Configuration	
	Tools On	Tools Off
<b><i>Acceptable Separation Before Handoff</i></b>		
Sample Size (n)	10	10
<b>Mean (M)</b>	<b>68.7</b>	<b>82.0</b>
Standard Deviation (SD)	34.7	23.6
<b><i>Transferred Appropriately Separated Aircraft</i></b>		
Sample Size (n)	10	10
<b>Mean (M)</b>	<b>77.4</b>	<b>84.0</b>
Standard Deviation (SD)	31.2	17.6



**Figure 5-26. Final Controllers can acceptably ensure separation during IM PA operations before transferring aircraft to the Local controller and I was comfortable that I was transferring appropriately separated aircraft to the Local controller.**

Note: o indicates NCT controller responses.

Controller responses were variable for the first question, but a majority (60%) agreed Final controllers can acceptably ensure separation during IM PA operations, before transferring aircraft to the Local controller with IM PA Tools On (M=68.7; SD=34.7). A majority (80%) also agreed with IM PA Tools Off (M=82.0; SD=23.6). Though no practical difference was observed between IM PA Tool configurations, response variability was lower with IM PA Tools Off. It is unclear why.

The four controllers that disagreed when IM PA Tools were On provided the following comments:

- (NCT / Tools On) For Foster this statement is true, because no speeds are being assigned to the trail, but Woodside might have to hold onto the aircraft to ensure separation.
- (NCT / Tools On) We have to ship them too early. You are asking finals to ensure separation and then ship them far out right before most of the speed adjustments for in trail spacing are made.
- (NCT / Tools On) Need to have some sort of CSL or WSL line on so controller knows before they clear aircraft if they are within the zones.
- (Non-NCT TRACON / Tools On) Need to figure out when and where spacing can be lost before ship to tower, possibly re-design approaches to accommodate.

Controller responses were also variable for the second question, but a majority (80%) agreed they were comfortable that they were transferring appropriately separated aircraft to the Local controller with IM PA Tools On (M=77.4; SD=31.2). A majority (90%) also agreed with IM PA Tools Off (M=84.0; SD=17.6). Though no practical difference was observed between IM PA Tool configurations, response variability was lower with IM PA Tools Off. It is unclear why.

One NCT controller that disagreed when IM PA Tools were On provided the following comment:

- (NCT / Tools On) Again, for Foster it's no big deal, but for the Woodside controller spacing can change dramatically 15-2 miles and in.

### 5.3.6 Open-Ended Questions

The 28R Final controller Post-Run Questionnaires (QT1) included general questions relating to what controllers liked about IM PA and what concerned them. This section summarizes responses specific to 28R Final controller tasking. Given their experience in the areas being simulated, NCT responses are specifically identified. Non-NCT TRACON and Tower responses are thus also individually identified.

When asked if there was **any operational information not provided in this scenario that you would have found helpful**, numerous comments were made that related to adding predictive CSL and WSL lines. A representative comment by a TRACON controller was: "A preview of where the CSL will be would be useful before clearing for the approach. That way a clearance would not need to be cancelled immediately if the aircraft was ahead of it."

As shown in Figure 5-27, controllers experienced this situation in one of the nominal scenarios. In this case, VRD112 was inside of the allowable spacing with the IM Lead Aircraft, UAL857, at

the time of initiation. This was not apparent from the display, thus the 28R Final controller had to terminate IM PA for that pair just after providing the clearance. A preview CSL would have helped avoid this situation.

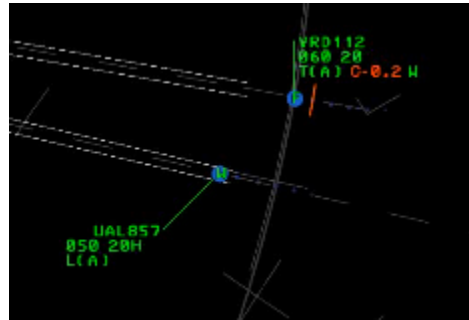


Figure 5-27. CSL Caution Alert at Time of Initiation

Controllers were also asked if they had **concerns with any aspect of the IM PA operation** while working as the 28R Monitor. Comments included:

- (NCT) Monitor breaking a guy out at a higher altitude. Prob not a concern in real life because programs would be in place to standardize.
- (NCT) (Aircraft in front of CSL) what if I needed to take aircraft off final to get them in the zone, no tools to show me how much I need, if I needed a short vector to set aircraft in zone.
- (NCT) Not enough space for final controller to make speed adjustments if needed.

## 5.4 Results Topic 3: Monitor Configurations

The analyses in this section examine the Combined and Separate Monitor configurations for the Day 1-2 Nominal scenarios. No lateral deviations were deliberately introduced; further monitor configuration results for these off-nominal conditions are described in Section 5.6.

As described in Table 4-5, monitor configuration for the Day 1-2 Nominal scenarios was divided by simulation day. That is, the same monitor configuration was used for the first day, then the other configuration was used for the second day. As the IM PA Tool configurations and scenarios were varied in the same way between the two days, monitor configuration was the primary difference. Therefore, differences between the days with respect to the various metrics should be primarily attributable to the difference in monitor configuration. These metrics include: Workload, Clarity of Roles and Responsibilities, Spacing Issue Detection, and Effectiveness and Acceptability.

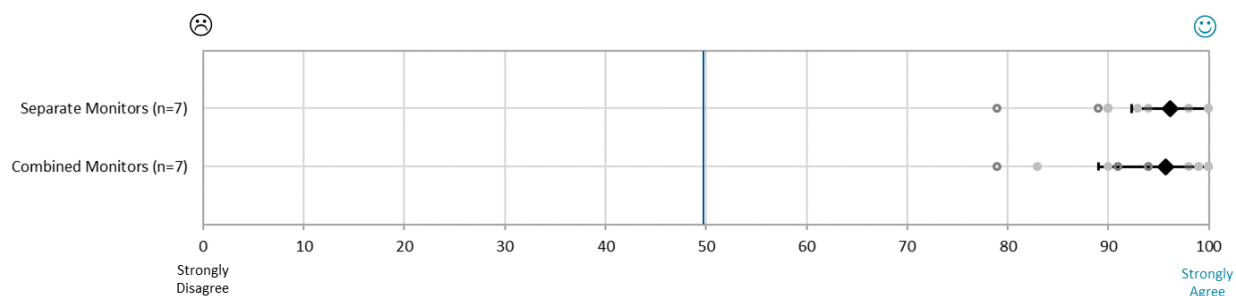
### 5.4.1 Workload Acceptability

At the end of Day 1 and Day 2 (QT2), controllers were asked **if their overall workload today was acceptable**. Their responses were then examined with respect to monitor configuration. Response Means and Standard Deviations are summarized in Table 5-19. Scale responses are

shown in Figure 5-28. Only Week 2-3 TRACON controller responses were included in the analysis.

**Table 5-19. Controller Responses to Acceptability of Overall Workload (Nominal Scenarios)**

	Monitor Configuration	
	Separate	Combined
Sample Size (n)	7	7
Mean (M)	96.1	95.7
Standard Deviation (SD)	3.8	6.7



**Figure 5-28. My overall workload today was acceptable.**

*Note: o indicates Week 1 TRACON controller responses for reference. These are not included in the M and SD computations.*

All Week 2-3 TRACON controllers agreed their overall workload was acceptable for both the Separate Monitor configuration (M=96.1; SD=3.8) and Combined Monitor configuration (M=95.7; SD=6.7). No practical difference was observed between the two monitor configurations.

With respect to workload by monitor configuration, open-ended comments included:

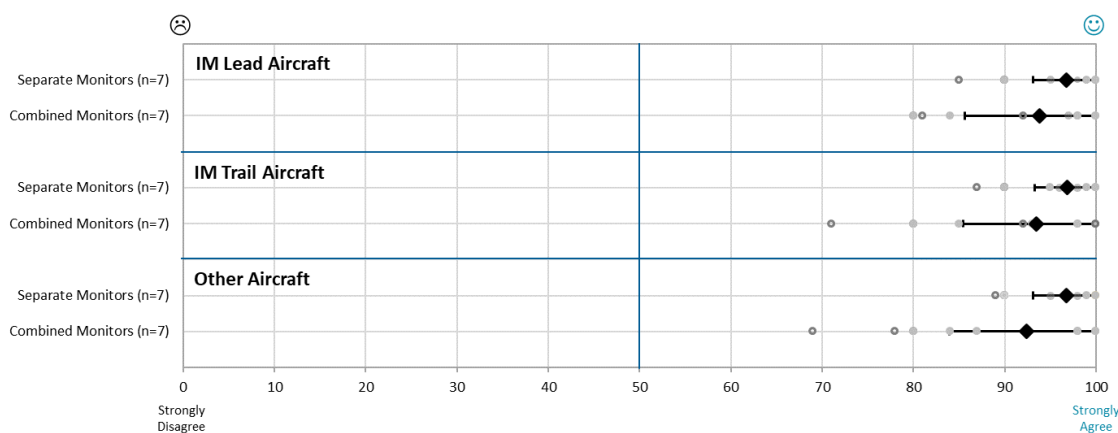
- (Non-NCT TRACON / Separate Monitor configuration) Busier than [Combined], due to required speed control. The IM PA was a very minimal part of the workload.
- (Non-NCT TRACON / Separate Monitor configuration) Workload this low could lull a controller into complacency.
- (Non-NCT TRACON / Separate Monitor configuration) Somewhat complex with spacing complexity between different runways and types. Not overworked, but not in drone zone.
- (Non-NCT TRACON / Combined Monitor configuration) I felt better about working both combined. The extra traffic helped me to stay focused.

## 5.4.2 Clarity of Roles and Responsibilities

At the end of Day 1 and Day 2 (QT2), controllers were asked if **when monitoring today, my roles and responsibilities with respect to the IM Lead Aircraft, IM Trail Aircraft, and Other Aircraft were clear**. Their responses were examined with respect to monitor configuration. Response Means and Standard Deviations are summarized in Table 5-20. Scale responses are shown in Figure 5-29. Only Week 2-3 TRACON controller responses were included in the analysis.

**Table 5-20. Controller Responses to Clarity of Roles and Responsibilities**

	Monitor Configuration	
	Separate	Combined
<b>IM Lead Aircraft</b>		
Sample Size (n)	7	7
Mean (M)	96.7	93.9
Standard Deviation (SD)	3.6	8.3
<b>IM Trail Aircraft</b>		
Sample Size (n)	7	7
Mean (M)	96.9	93.4
Standard Deviation (SD)	3.6	8.0
<b>Other Aircraft</b>		
Sample Size (n)	7	7
Mean (M)	96.7	92.4
Standard Deviation (SD)	3.6	8.5



**Figure 5-29. When monitoring today, my roles and responsibilities with respect to the IM Lead Aircraft, IM Trail Aircraft, and Other Aircraft were clear.**

Note: **o** indicates Week 1 TRACON controller responses for reference. These are not included in the M and SD computations.

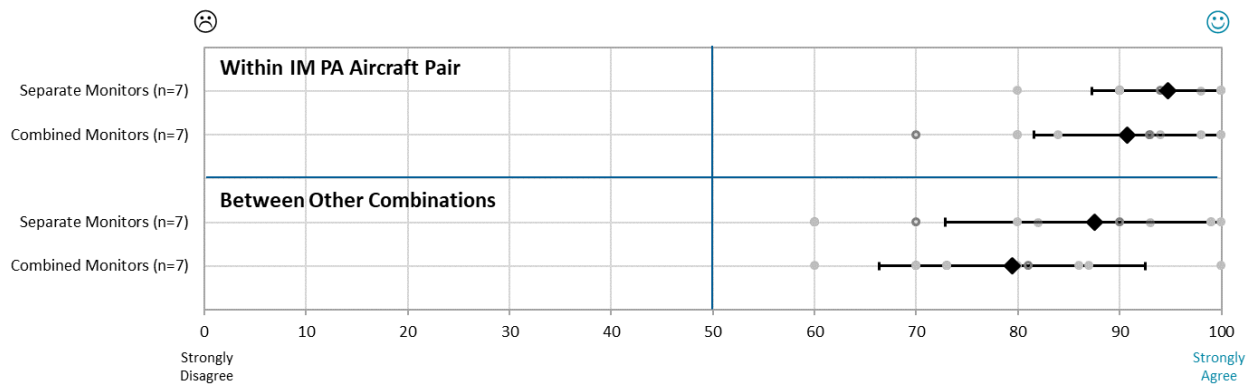
All Week 2-3 TRACON controllers agreed their roles and responsibilities were clear with respect to all aircraft for both monitor configurations. Though no practical differences were observed in the responses, the overall response variability was slightly greater for the Combined Monitor configuration.

### 5.4.3 Spacing Issue Detection

At the end of Day 1 and Day 2 (QT2), controllers were asked if they **were able to detect in a sufficient amount of time when spacing / separation issues were developing within an IM PA Aircraft Pair and Between Other Combinations**. Their responses were examined with respect to monitor configuration. Response Means and Standard Deviations are summarized in Table 5-21 . Scale responses are shown in Figure 5-30. Only Week 2-3 TRACON controller responses were included in the analysis.

**Table 5-21. Controller Responses to Detection of Developing Spacing / Separation Issues**

	Monitor Configuration	
	Separate	Combined
<b><i>Within an IM PA Aircraft Pair</i></b>		
Sample Size (n)	7	7
Mean (M)	<b>94.7</b>	<b>90.7</b>
Standard Deviation (SD)	7.5	9.2
<b><i>Between Other Combinations</i></b>		
Sample Size (n)	7	7
Mean (M)	<b>87.6</b>	<b>79.4</b>
Standard Deviation (SD)	14.7	13.1



**Figure 5-30. I was able to detect in a sufficient amount of time when spacing / separation issues were developing within an IM PA Aircraft Pair and Between Other Combinations.**

Note: o indicates Week 1 TRACON controller responses for reference. These are not included in the M and SD computations.

All Week 2-3 TRACON controllers agreed they were able to detect in a sufficient amount of time when spacing / separation issues were developing within an IM PA pair and Between Other Combinations for both monitor configurations. Though no practical differences were observed in the responses between the two monitor configurations, the means were slightly higher and overall response variability was slightly lower for IM PA pairs versus other aircraft pair combinations.

With respect to spacing issue detection, open-ended comments included:

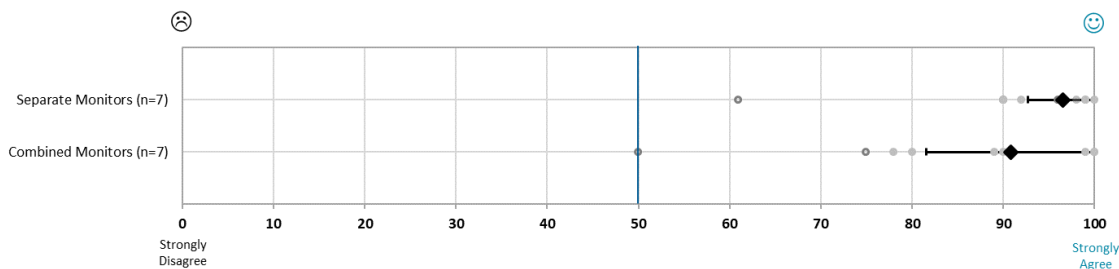
- (Non-NCT TRACON / Separate Monitor configuration) The pairs were easier to determine and required less focus.
- (Non-NCT TRACON / Combined Monitor configuration) The IM PA pair did not have to be watched nearly as closely which allowed focus on the other a/c spacing.
- (Non-NCT TRACON / Combined Monitor configuration) It is more difficult to determine distance between pairs than it is within pairs.

### 5.4.4 Effectiveness and Comfort

At the end of Day 1 and Day 2 (QT2), controllers were asked if **given the appropriate training and IM PA-related tools, IM PA operations can be effectively monitored by the number of positions I experienced today**. Their responses were then examined with respect to monitor configuration. Response Means and Standard Deviations are summarized in Table 5-22. Scale responses are shown in Figure 5-31. Only Week 2-3 TRACON controller responses were included in the analysis.

**Table 5-22. Controller Responses to Effective Monitoring**

	Monitor Configuration	
	Separate	Combined
Sample Size (n)	7	7
Mean (M)	96.6	90.9
Standard Deviation (SD)	3.9	9.3



**Figure 5-31. Given the appropriate training and IM PA-related tools, IM PA operations can be effectively monitored by the number of positions I experienced today.**

Note: o indicates Week 1 TRACON controller responses for reference. These are not included in the M and SD computations.

All Week 2-3 TRACON controllers agreed IM PA operations can be effectively monitored by both the Separate Monitor configuration (M=96.6; SD=3.9) and Combined Monitor configuration (M=90.9; SD=9.3). Though no practical differences were observed in the responses, the overall response variability was slightly greater for the Combined Monitor configuration.

With respect to monitoring effectiveness by configuration, open-ended comments included:

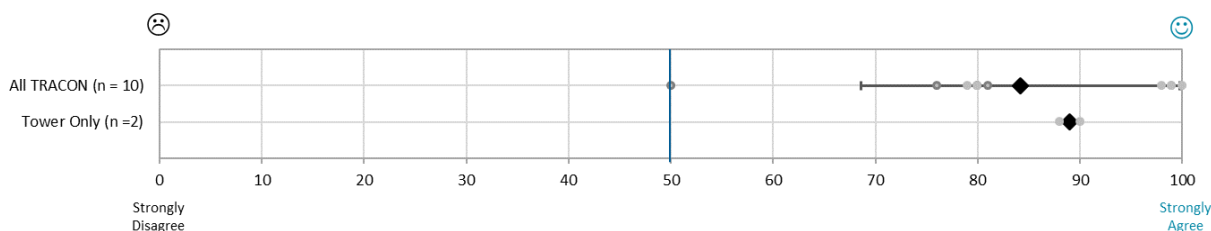
- (NCT / Separate Monitor configuration) Depends on traffic, but two monitors [controllers] seem better than one.
- (Non-NCT TRACON / Separate Monitor configuration) Maybe overly monitored, but definitely effective.
- (NCT / Separate Monitor configuration) I feel it could be done by final by itself.
- (Non-NCT TRACON / Combined Monitor configuration) Better today with one monitor.

-----

At the end of Day 2 (QT3), after experiencing the nominal scenarios across all IM PA Tool and monitor configurations, controllers were asked if **given the appropriate training and IM PA-related tools, a single (Combined) Monitor controller can effectively ensure separation across both approaches during IM PA operations**. Responses are shown for all TRACON (NCT and non-NCT combined) and Tower Only. Response Means and Standard Deviations are summarized in Table 5-23. Scale responses are shown in Figure 5-32.

**Table 5-23. Controller Responses to whether a Single (Combined) Monitor Controller can Effectively Ensure Separation Across Both Approaches**

	Participant Experience	
	TRACON	Tower
Sample Size (n)	10	2
Mean (M)	84.2	89.0
Standard Deviation (SD)	15.6	-



**Figure 5-32. Given the appropriate training and IM PA-related tools, a single (Combined) Monitor controller can effectively ensure separation across both approaches during IM PA operations.**

Note: o indicates NCT controller responses.

The majority (90%) of TRACON controllers agreed (M=84.2; SD=15.6) that a single Monitor controller can effectively ensure separation across both approaches during IM PA operations. One NCT controller neither agreed nor disagreed and noted that more runs as a single monitor would be helpful to evaluate this better.

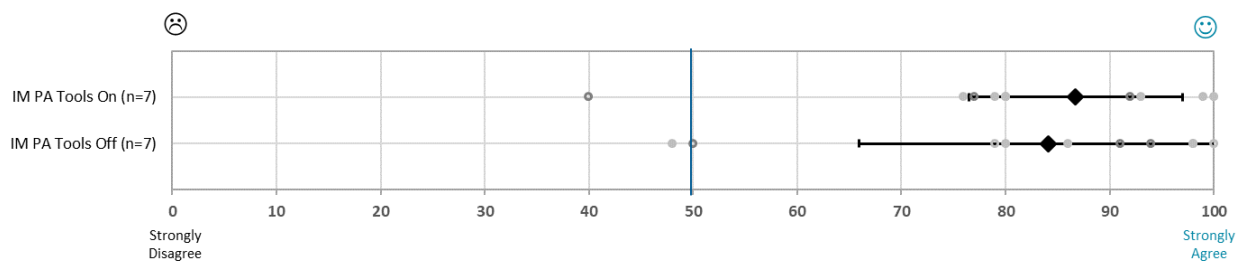
With respect to the effectiveness of a Combined Monitor position, open-ended comments included:

- (Non-NCT TRACON) I think it would be reasonable, especially when the final controller sets up a well-spaced final.
- (Non-NCT TRACON) Depends on airport, but KSFO seems to work better combined.
- (Non-NCT TRACON) If using STARS display, two monitors should be used. If using FMA, one monitor is okay.

To examine if the IM PA Tool configuration affected the effectiveness of the Combined Monitor configuration, controllers were asked the same question at the end of each run (QT1). Their responses were then examined with respect to IM PA Tool configuration. Response Means and Standard Deviations are summarized in Table 5-24. Scale responses are shown in Figure 5-33.

**Table 5-24. Controller Responses to whether a Single (Combined) Monitor Controller can Effectively Ensure Separation Across Both Approaches: IM PA Tool Configuration**

	IM PA Tool Configuration	
	Tools On	Tools Off
Sample Size (n)	7	7
Mean (M)	86.7	84.1
Standard Deviation (SD)	10.3	18.2



**Figure 5-33. Given the appropriate training and the IM PA-related tools, a single (Combined) Monitor Controller can effectively ensure separation across both approaches during IM PA operations.**

*Note: o indicates Week 1 TRACON controller responses for reference. These are not included in the M and SD computations.*

All Week 2-3 TRACON controllers agreed a single (Combined) Monitor controller can effectively ensure separation across both approaches during IM PA operations with IM PA Tools On

(M=86.7; SD=10.3) and IM PA Tools Off (M=84.1; SD=18.2). This is consistent with the prior results and no practical difference was observed between the two IM PA Tool configurations.

Selected open-ended comments for this question included:

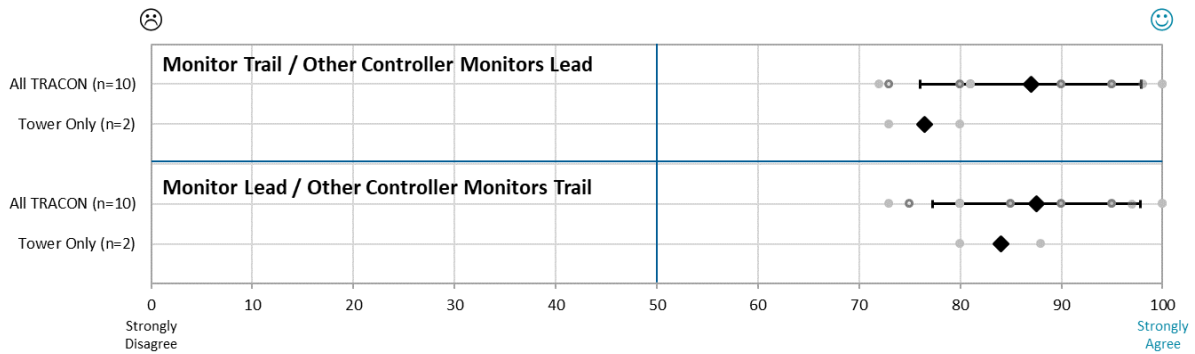
- (NCT / Tools On) Seems like a lot for one person with a busy final.
- (Non-NCT TRACON / Tools On) The IM PA allows much less need to monitor that spacing and more time to monitor spacing on same runway or between pairs.

-----

At the end of Day 2 (QT3), after experiencing the nominal scenarios across all IM PA Tool and monitor configurations, controllers were asked **if they were comfortable monitoring one aircraft in an IM PA pair, while another controller monitored the other**. Responses are shown for all TRACON (NCT and non-NCT combined) and Tower Only. Response Means and Standard Deviations are summarized in Table 5-25. Scale responses are shown in Figure 5-34.

**Table 5-25. Controller Responses to Separate Monitor Comfort**

	Participant Experience	
	TRACON	Tower
<b><i>Monitor Trail / Other Controller Monitors Lead</i></b>		
Sample Size (n)	10	2
<b>Mean (M)</b>	<b>87.0</b>	<b>76.5</b>
Standard Deviation (SD)	10.9	-
<b><i>Monitor Lead / Other Controller Monitors Trail</i></b>		
Sample Size (n)	10	2
<b>Mean (M)</b>	<b>87.5</b>	<b>84.0</b>
Standard Deviation (SD)	10.3	-



**Figure 5-34. I was comfortable monitoring one aircraft in an IM PA pair, while another controller monitored the other.**

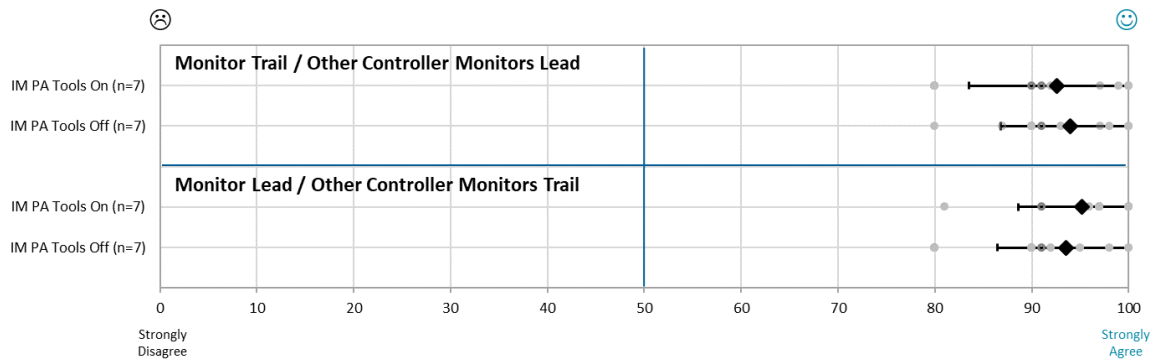
Note: o indicates NCT controller responses.

All (100%) TRACON controllers agreed they were comfortable monitoring the Trail Aircraft in an IM PA pair, while another controller monitored the Lead Aircraft (M=87.0; SD=10.9). All (100%) TRACON controllers also agreed they were comfortable monitoring the Lead Aircraft in an IM PA pair, while another controller monitored the Trail Aircraft (M=87.5; SD=10.3).

To examine if the IM PA Tool configuration affected the effectiveness of the Combined Monitor configuration, controllers were asked the same question at the end of each run (QT1). Their responses were then examined with respect to IM PA Tool configuration. Response Means and Standard Deviations are summarized in Table 5-26. Scale responses are shown in Figure 5-35.

**Table 5-26. Controller Responses to Separate Monitor Comfort: IM PA Tools**

	IM PA Tool Configuration	
	Tools On	Tools Off
<b><i>Monitor Trail / Other Controller Monitors Lead</i></b>		
Sample Size (n)	7	7
Mean (M)	92.6	94.0
Standard Deviation (SD)	9.0	7.2
<b><i>Monitor Lead / Other Controller Monitors Trail</i></b>		
Sample Size (n)	7	7
Mean (M)	95.1	93.6
Standard Deviation (SD)	6.5	7.1



**Figure 5-35. IM PA Tool Configuration: I was comfortable monitoring one aircraft in an IM PA pair, while another controller monitored the other.**

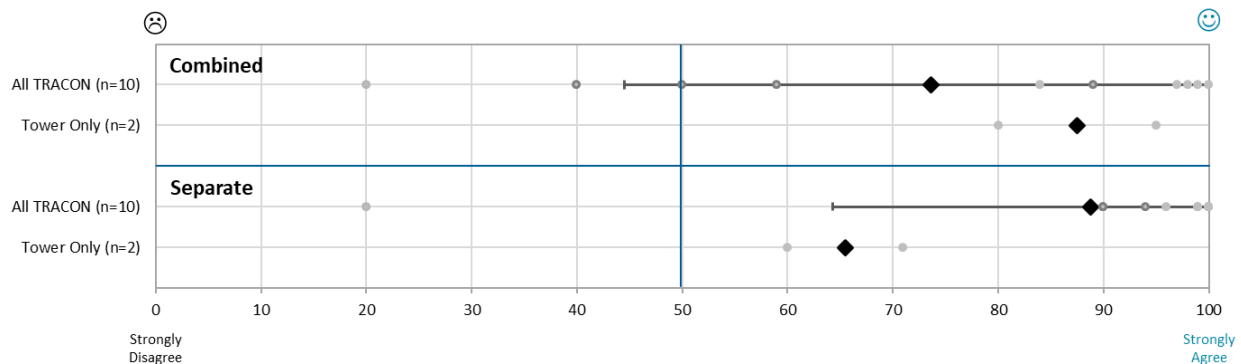
Note: o indicates Week 1 TRACON controller responses for reference. These are not included in the M and SD computations.

All Week 2-3 TRACON controllers agreed they were comfortable monitoring one aircraft in an IM PA pair, while another controller monitored the other aircraft. This is consistent with the prior results and no practical difference was observed between the two IM PA Tool configurations.

At the end of Day 3 after all scenarios were complete (QT8), controllers were asked if they **would expect to be able to effectively monitor any number of IM PA pairs, up to and including all aircraft pairs performing IM PA (100%)**. Their responses were then examined with respect to monitor configuration. Response Means and Standard Deviations are summarized in Table 5-27. Scale responses are shown in Figure 5-36. Only Week 2-3 TRACON controller responses were included in the analysis.

**Table 5-27. Controller Responses to Effective Monitoring Any Number if IM PA Pairs**

	Participant Experience	
	TRACON	Tower
<b><i>Combined Monitor Position for Both Approaches</i></b>		
Sample Size (n)	10	2
<b>Mean (M)</b>	<b>73.6</b>	<b>87.5</b>
Standard Deviation (SD)	29.1	-
<b><i>Separate Monitor for Each Approach</i></b>		
Sample Size (n)	10	2
<b>Mean (M)</b>	<b>88.8</b>	<b>65.5</b>
Standard Deviation (SD)	24.5	-



**Figure 5-36. I would expect to be able to effectively monitor any number of IM PA pairs, up to and including all aircraft pairs performing IM PA (100%).**

Note: **o** indicates NCT controller responses.

Responses were variable, but the majority (70%) of TRACON controllers agreed they would expect to be able to effectively monitor any number of IM PA pairs in a Combined Monitor position (M=73.6; SD=29.1). A majority (90%) also agreed for a Separate Monitor configuration for each approach (M=88.8; SD=24.5). The controller that disagreed for the Separate Monitor configuration also disagreed for the Combined Monitor configuration.

As described in Section 5.8.6, a paired-sample T-Test analysis found a significant difference in controller agreement with respect to the strength of agreement between the two configurations, with controllers appearing to expect to be able to more effectively monitor any number of IM PA pairs in a Separate Monitor configuration.

## 5.5 Results Topic 4: IM PA Tools

This section examines the general effects of varying the IM PA Tool configurations as well as focused evaluations of the individual features. The Lateral Boundaries and Exceedance Warning features, however, are examined in Section 5.6. Results in this section are usually from the Post-Run Questionnaires (QT1), unless otherwise indicated.

### 5.5.1 General Effects

This section examines differences between the IM PA Tool configurations with respect to Monitor controller workload (in the nominal scenarios), traffic awareness, IM Speed control, and separation assessment.

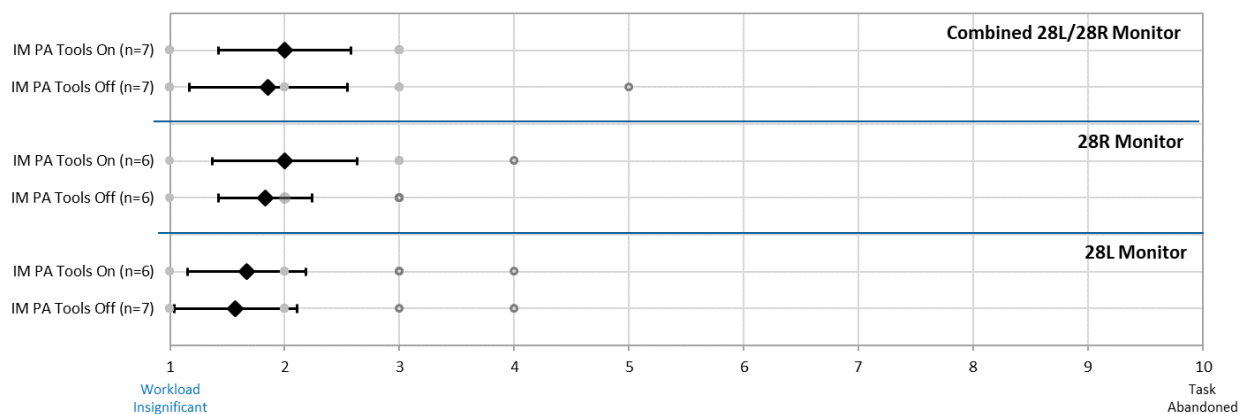
#### 5.5.1.1 Monitor Controller Workload (Nominal Scenarios)

At the end of each run, controllers were asked to **rate their workload for the scenario they just experienced** (QT1) using the Bedford Workload Scale. Their responses were then examined with respect to IM PA Tool configuration. Response Means and Standard Deviations are summarized in Table 5-28. Scale responses are shown in Figure 5-37. Only TRACON controller

responses were included in the analysis. Also, some rows indicate an n=6 because one of the participants did not include a rating in the questionnaire.

**Table 5-28. Monitor controller Workload Ratings: IM PA Tools On/Off**

	IM PA Tool Configuration	
	Tools On	Tools Off
<b>Combined 28L/28R Monitor</b>		
Sample Size (n)	7	7
<b>Mean (M)</b>	<b>2.0</b>	<b>1.9</b>
Standard Deviation (SD)	0.6	0.7
<b>28R Monitor</b>		
Sample Size (n)	6	6
<b>Mean (M)</b>	<b>2.0</b>	<b>1.8</b>
Standard Deviation (SD)	0.6	0.4
<b>28L Monitor</b>		
Sample Size (n)	6	7
<b>Mean (M)</b>	<b>1.7</b>	<b>1.6</b>
Standard Deviation (SD)	0.5	0.5



**Figure 5-37. Monitor Controller Workload Ratings: IM PA Tools On/Off**

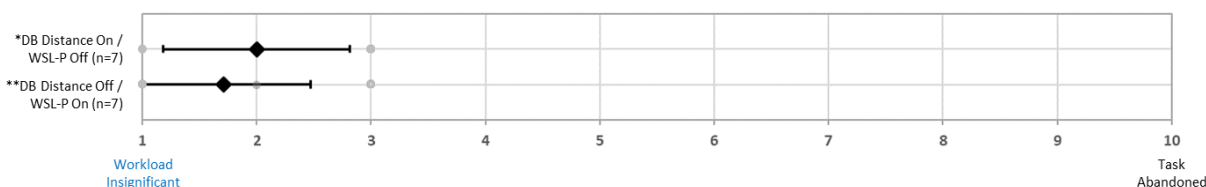
Note: o indicates Week 1 TRACON controller responses for reference. These are not included in the M and SD computations.

On average, the TRACON controllers reported low workload for all three Monitor positions and for both IM PA Tool configurations. No practical difference was observed between the two IM PA Tool configurations and among any of the positions.

Workload ratings were also collected for the other IM PA Tool configurations: Data Block Distance On / WSL-P Off and DB Distance Off / WSL-P On. However, due to simulation time limits, the former was only run for the Combined Monitor configuration and the latter was only run with the 28R (Separate) Monitor configuration. This data was still captured, however, to possibly illuminate any workload effects that could be attributed to having or not having one of the individual features available, when compared to the all IM PA Tools On or Off configurations for the Combined and 28R Monitor positions. Response Means and Standard Deviations are summarized in Table 5-29. Scale responses are shown in Figure 5-38. Only TRACON controller responses were included in the analysis.

**Table 5-29. Monitor Controller Workload Ratings: Other IM PA Tool Configurations**

	IM PA Tool Configuration	
	DB On / WSL-P Off	DB Off / WSL-P On
Sample Size (n)	7	7
<b>Mean (M)</b>	<b>2.0</b>	<b>1.7</b>
Standard Deviation (SD)	0.8	0.8



**Figure 5-38. Monitor Controller Workload Ratings: Other IM PA Tool Configurations**

*\*Combined Monitor configuration / \*\*28R Monitor configuration*

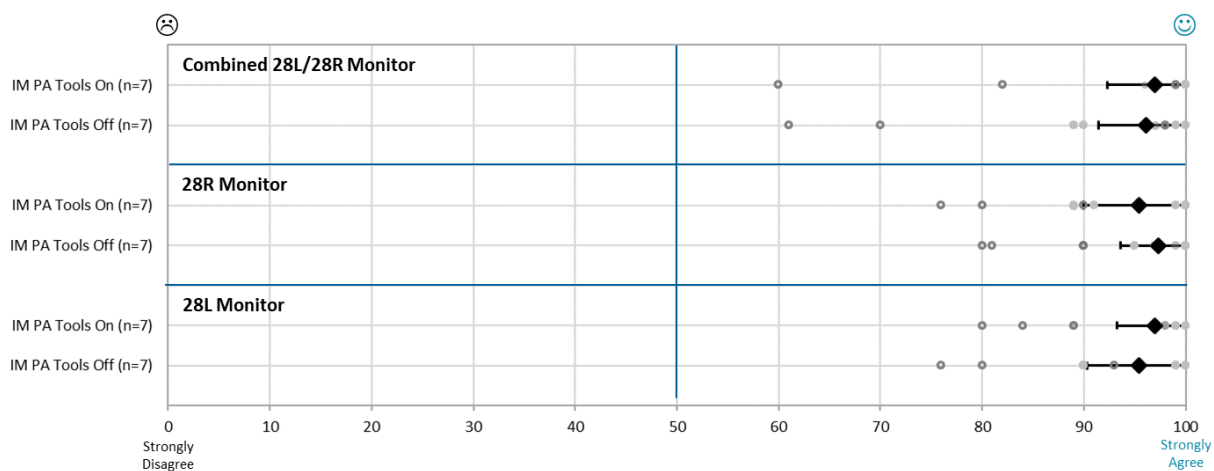
*Note: o indicates Week 1 TRACON controller responses for reference. These are not included in the M and SD computations.*

On average, the TRACON controllers also reported low workload for these additional IM PA Tools configurations and no practical difference was observed between them. When examined in context with the all IM PA Tools On or Off configurations, there did not appear to be any practical workload differences attributable to IM PA Tool or monitor configuration.

At the end of each run (QT1), controllers were also asked **if their overall workload was acceptable for the scenario they just experienced**. Their responses were then examined with respect to IM PA Tool configuration. Response Means and Standard Deviations are summarized in Table 5-30. Scale responses are shown in Figure 5-39. Only TRACON controller responses were included in the analysis.

**Table 5-30. Monitor Controller Workload Acceptability (Nominal Scenarios)**

	IM PA Tool Configuration	
	Tools On	Tools Off
<b>Combined 28L/28R Monitor</b>		
Sample Size (n)	7	7
<b>Mean (M)</b>	<b>97.0</b>	<b>96.1</b>
Standard Deviation (SD)	4.7	4.7
<b>28R Monitor</b>		
Sample Size (n)	7	7
<b>Mean (M)</b>	<b>95.4</b>	<b>97.3</b>
Standard Deviation (SD)	5.4	3.7
<b>28L Monitor</b>		
Sample Size (n)	7	7
<b>Mean (M)</b>	<b>97.0</b>	<b>95.4</b>
Standard Deviation (SD)	3.7	5.1



**Figure 5-39. Monitor Controllers: My overall workload was acceptable for the scenario I just experienced. (Nominal Scenarios)**

Note: o indicates Week 1 TRACON controller responses for reference. These are not included in the M and SD computations.

All Week 2-3 TRACON controllers agreed their overall workload was acceptable for all three Monitor positions and for both IM PA Tools configurations. No practical difference was observed between the two IM PA Tool configurations and among any of the positions. This is consistent with the Day 1 and Day 2 End Questionnaire results described in Section 5.4.1.

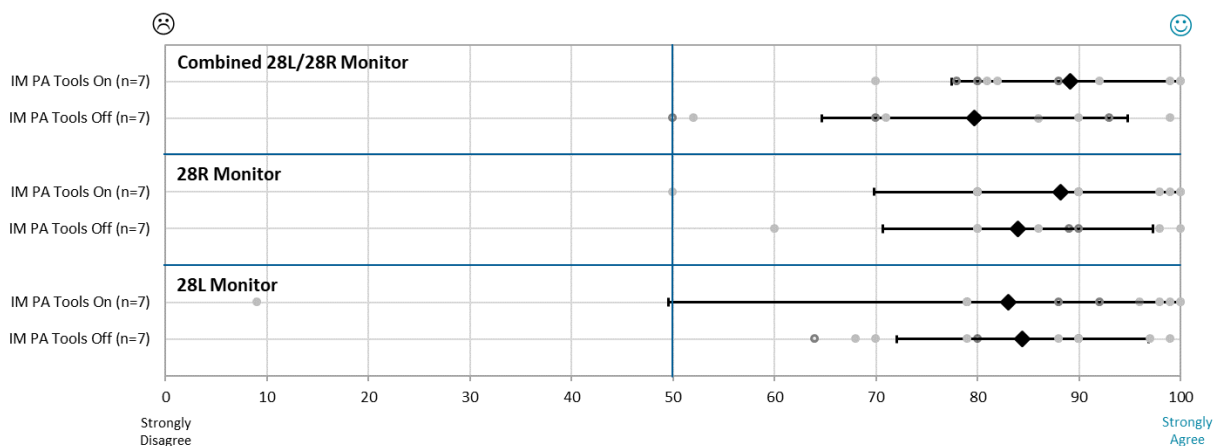
The Week 1 controllers had consistently lower workload acceptability ratings; however, the Week 2-3 scenarios were modified to resolve some scenario issues that the Week 1 controllers experienced.

### 5.5.1.2 Traffic Awareness

At the end of each run (QT1), controllers were asked **if given the IM PA-related tools they had in this scenario, they had sufficient overall traffic situation awareness**. Their responses were then examined with respect to IM PA Tool configuration. Response Means and Standard Deviations are summarized in Table 5-31. Scale responses are shown in Figure 5-40. Only TRACON controller responses were included in the analysis.

**Table 5-31. Controller Responses to Traffic Awareness: IM PA Tool Configuration**

	IM PA Tool Configuration	
	Tools On	Tools Off
<b>Combined 28L/28R Monitor</b>		
Sample Size (n)	7	7
<b>Mean (M)</b>	<b>89.1</b>	<b>79.7</b>
Standard Deviation (SD)	11.7	15.1
<b>28R Monitor</b>		
Sample Size (n)	7	7
<b>Mean (M)</b>	<b>88.1</b>	<b>84.0</b>
Standard Deviation (SD)	18.4	13.3
<b>28L Monitor</b>		
Sample Size (n)	7	7
<b>Mean (M)</b>	<b>83.0</b>	<b>84.4</b>
Standard Deviation (SD)	33.5	12.4



**Figure 5-40. Given the IM PA-related tools I had in this scenario, I had sufficient overall traffic situation awareness.**

Note: **o** indicates Week 1 TRACON controller responses for reference. These are not included in the M and SD computations.

On average, all Week 2-3 TRACON controllers agreed they had sufficient overall traffic situation awareness for the Combined Monitor configuration with IM PA Tools On (M=89.1; SD=11.7) and IM PA Tools Off (M=79.7; SD=15.1). They also all agreed for the 28R Monitor Position with IM PA Tools Off (M=84.0; SD=13.3) and the 28L Monitor Position with IM PA Tools Off (M=84.4; SD=12.4).

The majority (90%) all Week 2-3 TRACON controllers agreed for the 28R Monitor Position with IM PA Tools On (M=88.1; SD=18.4), with one controller neither agreeing nor disagreeing. This controller made the following comment with respect to this rating: "I would have preferred the grey wake line was visible farther out, on initial contact."

A majority (90%) also agreed for the 28L Monitor Position with IM PA Tools On (M=83.0; SD=33.5). The (NCT) controller that disagreed commented that "Would have been great to have [A]TPA on so you can see the miles between pairs." This rating therefore appears to be related to not having ATPA available versus the efficacy of the IM PA Tools.

Given the response variability, no apparent practical differences in acceptability between the IM PA Tool configurations were observed across the monitor configurations. However, Lead Aircraft response variability for the IM Lead Aircraft appeared to be lower for the Separate Monitor configuration than for all the other cases. Examination of the Data Block Distance and WSL-P Tool configurations in the post-run responses (not shown) also did not indicate a difference with respect to Traffic Awareness.

### 5.5.1.3 IM Speed Control

At the end of each run (QT1), controllers were asked if they were **comfortable with the IM Trail Aircraft managing their speeds to achieve the spacing goal assigned by the Final controller**. Their responses were then examined with respect to IM PA Tool configuration. Response Means and Standard Deviations are summarized in Table 5-32. Scale responses are shown in Figure 5-41. Only TRACON controller responses were included in the analysis.

Table 5-32. Controller Responses to IM PA Speed Control

	IM PA Tool Configuration			
	Tools On	Tools Off	DB On / WSL-P Off	DB Off / WSL-P On
<b>Combined 28L/28R Monitor</b>				
Sample Size (n)	7	7	7	0
Mean (M)	92.7	72.9	83.9	-
Standard Deviation (SD)	8.4	33.7	18.2	-
<b>28R Monitor</b>				
Sample Size (n)	7	7	0	7
Mean (M)	90.6	86.4	-	93.1
Standard Deviation (SD)	9.0	18.4	-	7.5
<b>28L Monitor</b>				
Sample Size (n)	7	7	0	0
Mean (M)	91.0	88.9	-	-
Standard Deviation (SD)	8.0	10.1	-	-

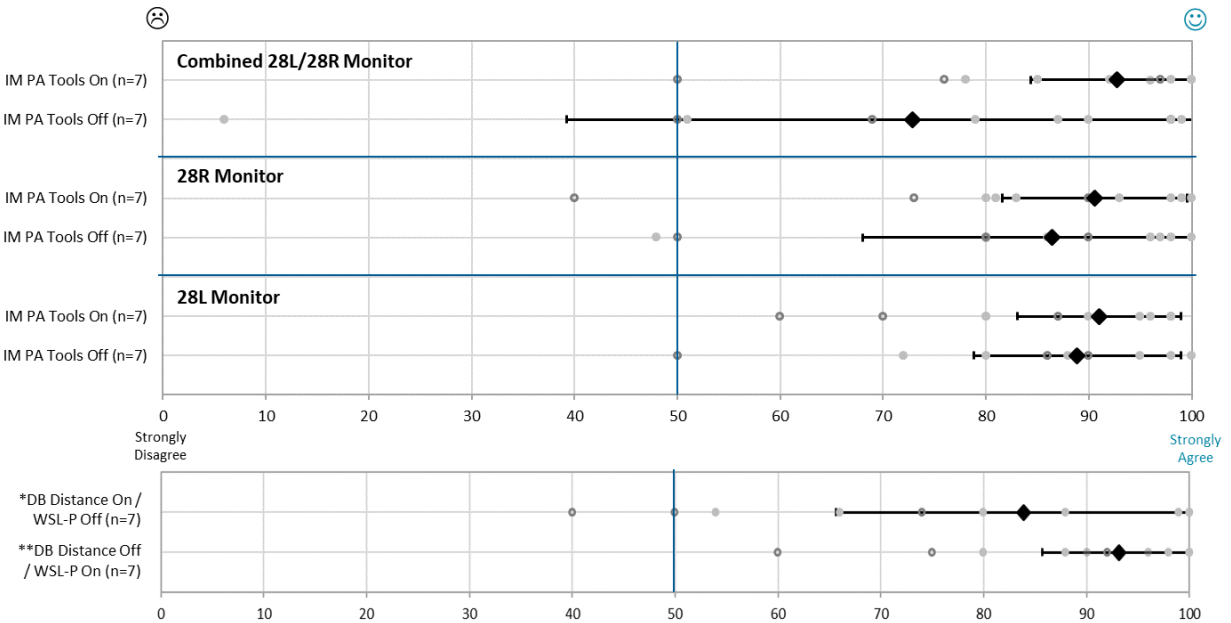


Figure 5-41. I was comfortable with the IM Trail Aircraft managing their speeds to achieve the spacing goal assigned by the Final controller.

\*Combined Monitor configuration / \*\*28R Monitor configuration

Note: o indicates Week 1 TRACON controller responses for reference. These are not included in the M and SD computations.

All Week 2-3 TRACON controllers agreed they were comfortable with the IM Trail Aircraft managing its speeds to achieve the spacing goal for the Combined Monitor position with the IM PA Tools On (M=92.7; SD=8.4). A majority (86%) of controllers agreed with the IM PA Tools Off (M=72.9; SD=33.7). One controller disagreed and suggested that it was because one of the aircraft failed to maintain a realistic speed. This response is therefore more due to a simulation artifact as that speed change was an intentional, off-nominal event implemented to trigger the longitudinal alerting. However, it occurred in the IM PA Tools On scenario as well and the controller did not appear to have as negative reaction to it then. Therefore, the increased variability for the IM PA Tools Off configuration suggests that at least for the Combined Monitor position, having the IM PA Tools available may increase controller comfort with IM Trail Aircraft managing their own speeds.

For the 28R Monitor position, all Week 2-3 TRACON controllers agreed with the IM PA Tools On (M=90.6; SD=9.0) and a majority (86%) of controllers agreed with the IM PA Tools Off (M=86.4; SD=18.4). Despite the higher variability with IM PA Tools Off, no practical difference was observed between the configurations.

For the 28L Monitor position, all Week 2-3 TRACON controllers agreed with the IM PA Tools On (M=91.0; SD=8.0) and IM PA Tools Off (M=88.9; SD=10.1). Despite the higher variability with IM PA Tools Off, no practical difference was observed between the configurations.

All Week 2-3 TRACON controllers agreed with the Data Block CSL Distance On / WSL-P Off (M=83.9; SD=18.2) and Data Block CSL Distance Off / WSL-P On (M=93.1; SD=7.5) configurations.

Overall, no practical differences between the Monitor and IM PA Tool configurations were observed. Selected open-ended comments for this question included:

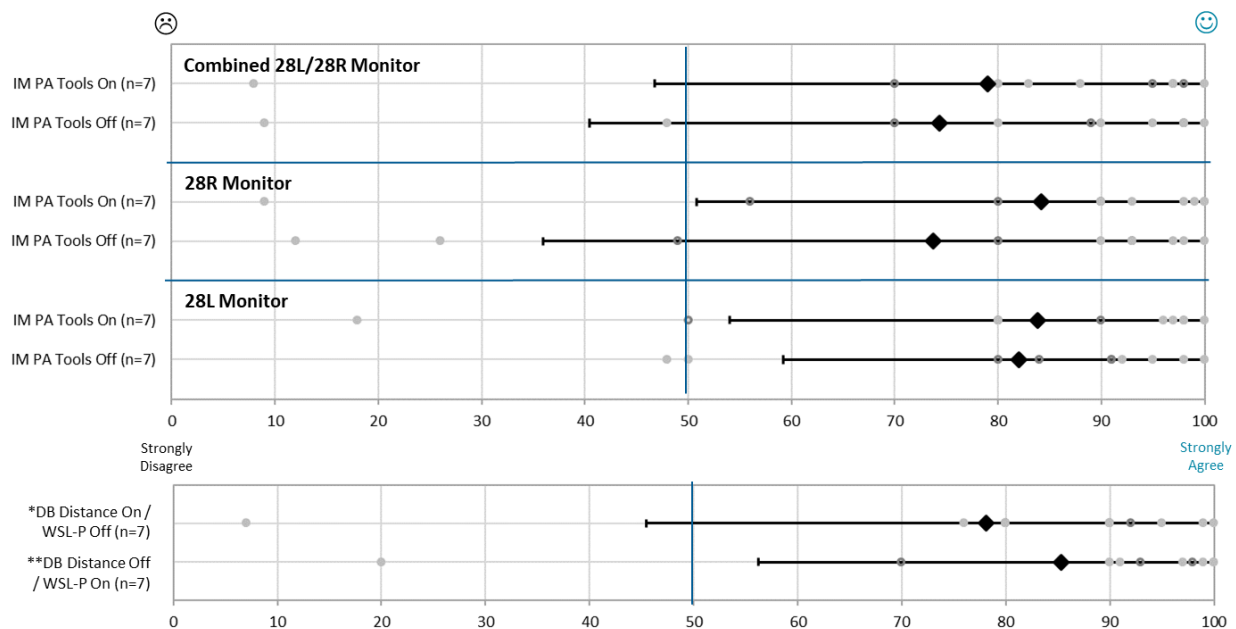
- (NCT Combined / Tools On) I didn't trust them at first but gradually became a little more comfortable.
- (NCT 28R / Tools Off) I would like to be able to override the IM PA and give a speed that I think would keep them in the window & try to prevent the go around.
- (Non-NCT TRACON 28R / Tools Off) It didn't always work out but gave fair warning.
- (Non-NCT TRACON 28L / Tools On) I trusted the equipment and did not pay much attention to the trail a/c IM spacing.

## 5.5.2 Separation Assessment

At the end of each run (QT1), controllers were asked **as the IM PA aircraft pairs became my responsibility, I had sufficient time to make a first assessment of their separation**. Their responses were then examined with respect to IM PA Tool configuration. Response Means and Standard Deviations are summarized in Table 5-33. Scale responses are shown in Figure 5-42. Only TRACON controller responses were included in the analysis.

**Table 5-33. Controller Responses for Sufficient Time for First Separation Assessment**

	IM PA Tool Configuration			
	Tools On	Tools Off	DB On / WSL-P Off	DB Off / WSL-P On
<b>Combined 28L/28R Monitor</b>				
Sample Size (n)	7	7	7	0
Mean (M)	<b>79.0</b>	<b>74.3</b>	<b>78.1</b>	-
Standard Deviation (SD)	32.2	33.9	32.7	-
<b>28R Monitor</b>				
Sample Size (n)	7	7	0	7
Mean (M)	<b>84.1</b>	<b>73.7</b>	-	<b>85.3</b>
Standard Deviation (SD)	33.4	37.7	-	29.1
<b>28L Monitor</b>				
Sample Size (n)	10	10	0	0
Mean (M)	<b>83.9</b>	<b>82.0</b>	-	-
Standard Deviation (SD)	29.8	22.8	-	-



**Figure 5-42. As the IM PA aircraft pairs became my responsibility, I had sufficient time to make a first assessment of their separation.**

\*Combined Monitor configuration / \*\*28R Monitor configuration

Note: o indicates Week 1 TRACON controller responses for reference. These are not included in the M and SD computations.

Responses were variable, but a majority (86%) of Week 2-3 TRACON controllers agreed they had sufficient time to make a first assessment of IM PA pair separation for the Combined Monitor position with the IM PA Tools On (M=79.0; SD=32.2). The controller that disagreed commented that the WSL should be displayed “sooner.” Responses were also variable for the majority (71%) of controllers that agreed with the IM PA Tools Off (M=74.3; SD=33.9). The two controllers that disagreed both commented that the WSL should be displayed “sooner” (one was the same controller in both cases). No practical differences were observed between the IM PA Tool configurations.

For the 28R Monitor position, responses were variable, but a majority (86%) of Week 2-3 TRACON controllers agreed they had sufficient time to make a first assessment of IM PA pair separation for the Combined Monitor position with the IM PA Tools On (M=84.1; SD=33.4). The controller that disagreed commented that the WSL should be displayed “sooner.” Responses were also variable for the majority (71%) of controllers that agreed with the IM PA Tools Off (M=73.7; SD=37.7). The two controllers that disagreed both commented that the WSL should be displayed “sooner.”

For the 28L Monitor position, responses were variable, but a majority (86%) of Week 2-3 TRACON controllers agreed they had sufficient time to make a first assessment of their separation for the Combined Monitor position with the IM PA Tools On (M=83.9; SD=29.8). The controller that disagreed commented that the WSL should be displayed “sooner.” A majority (71%) of controllers also agreed with the IM PA Tools Off (M=82.0; SD=22.8). One of the two controllers that disagreed commented that the WSL should be displayed “immediately.”

Responses were variable, but the majority (90%) of Week 2-3 TRACON controllers agreed with the Data Block CSL Distance On / WSL-P Off (M=78.1; SD=32.7) and Data Block CSL Distance Off / WSL-P On (M=85.3; SD=29.1) configurations. The same controller disagreed in both cases and commented that the WSL should be displayed “sooner.”

Due to the high variability in the responses no differences were observed between any of the IM PA Tool and monitor configurations.

Selected open-ended comments for this question included:

- (NCT Combined / Tools On) I watched prior to becoming my responsibility, so I was able to have an idea of what was happening.
- (Non-NCT TRACON / Tools On) It was quick and easy to see the CSL line and A/C target location with one quick glance.

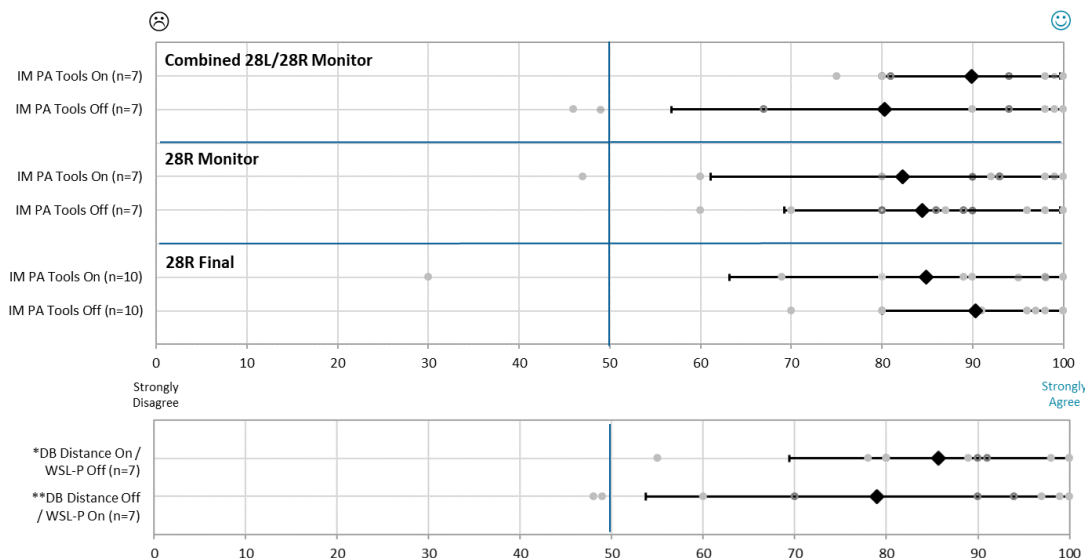
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At the end of each run (QT1), controllers were asked **with the IM PA-related tools provided in this scenario, I could easily assess the separation between the IM Trail Aircraft and its Lead, when they were my responsibility.** Their responses were then examined with respect to IM PA Tool configuration. Response Means and Standard Deviations are summarized in Table 5-34. Scale responses are shown in Figure 5-43. Only TRACON controller responses were included in the analysis. This question also only applied to controllers responsible for 28R, so the Separate 28L Monitor position results are not included. The 28R Final controller results are included as

they were responsible for assessing separation before they transferred the IM Trail Aircraft to the Local controller. In this case, results for all three weeks are included as the Final controller tasks were not affected by the scenario issues that affected the Monitor controller tasks.

**Table 5-34. Controller Responses for Ease of Separation Assessment**

	IM PA Tool Configuration			
	Tools On	Tools Off	DB On / WSL-P Off	DB Off / WSL-P On
<b>Combined 28L/28R Monitor</b>				
Sample Size (n)	7	7	7	0
Mean (M)	<b>89.9</b>	<b>80.3</b>	<b>85.7</b>	-
Standard Deviation (SD)	9.8	23.5	16.4	-
<b>28R Monitor</b>				
Sample Size (n)	7	7	0	7
Mean (M)	<b>82.3</b>	<b>84.4</b>	-	<b>79.0</b>
Standard Deviation (SD)	21.1	15.2	-	25.3
<b>28R Final</b>				
Sample Size (n)	10	10	0	0
Mean (M)	<b>84.9</b>	<b>90.3</b>	-	-
Standard Deviation (SD)	21.7	10.3	-	-



**Figure 5-43. With the IM PA-related tools provided in this scenario, I could easily assess the separation between the IM Trail Aircraft and its Lead, when they were my responsibility.**

\*Combined Monitor configuration / \*\*28R Monitor configuration

Note: o indicates Week 1 TRACON controller responses for reference. These are not included in the M and SD computations for the monitor configurations. However, they are included in the M and SD computations for the 28R Final controller position.

All Week 2-3 TRACON controllers agreed they could easily assess the separation between the IM Trail Aircraft and its Lead with the IM PA Tools On (M=89.9; SD=9.8) for the Combined Monitor configuration. A majority (71%) of controllers agreed with the IM PA Tools Off (M=80.3; SD=23.5). The increased variability for the IM PA Tools Off configuration suggests that at least for the Combined Monitor position, having the IM PA Tools available may help controllers more easily assess the separation between the IM Trail Aircraft and its Lead.

For the 28R Monitor position, a majority (86%) of Week 2-3 TRACON controllers agreed with the IM PA Tools On (M=82.3; SD=21.1). The controller that disagreed commented the WSL should be displayed “sooner.” All controllers agreed with the IM PA Tools Off (M=84.4; SD=15.2), though one commented that “A predictive WSL would be an improvement.” No practical difference was observed between the IM PA Tool configurations.

For the 28R Final controller position, a majority (90%) of TRACON controllers agreed with the IM PA Tools On (M=84.9; SD=21.7). The controller that disagreed commented the CSL and WSL should be displayed before the aircraft is cleared. All controllers agreed with the IM PA Tools Off (M=90.3; SD=10.3), though one commented that they would have liked to have seen the “automatic distance” displayed. Despite the higher variability in the responses with IM PA Tools On, no practical difference was observed between the two configurations.

All Week 2-3 TRACON controllers agreed with the Data Block CSL Distance On / WSL-P Off configuration (M=85.7; SD=16.4). A majority (71%) agreed with the Data Block CSL Distance Off / WSL-P On configuration (M=79.0; SD=25.3). No practical difference was observed between the two configurations.

Overall, no practical differences were observed between any of the IM PA Tool configurations and positions. However, for the Combined Monitor position, having the IM PA Tools available may help controllers more easily assess the separation between the IM Trail Aircraft and its Lead.

### 5.5.3 Safety Limit Depictions

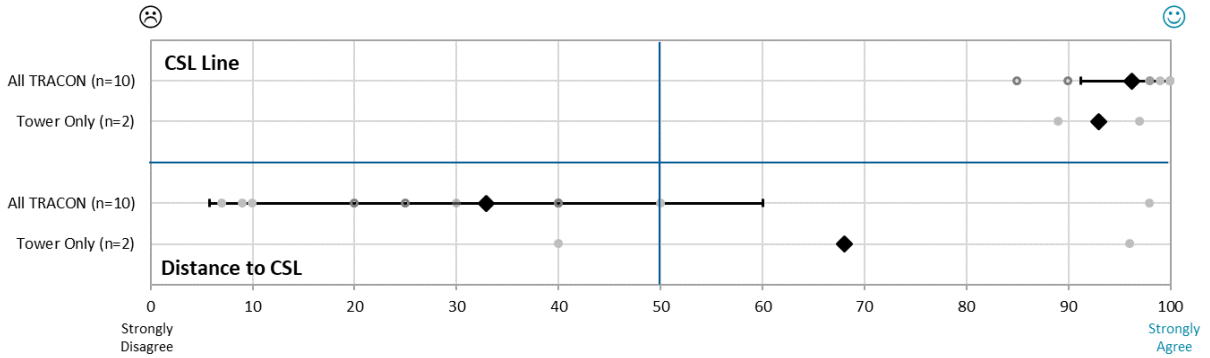
This section examines the acceptability, effectiveness, and usefulness of the CSL and WSL features as implemented.

#### 5.5.3.1 CSL Features

At the end of Day 2 (QT3), after experiencing the nominal scenarios across all IM PA Tool and monitor configurations, controllers were asked **if the CSL Line and Data Block Distance to CSL features were useful for the overall IM PA monitoring task**. Responses are shown for all TRACON (NCT and non-NCT combined) and Tower Only. Response Means and Standard Deviations are summarized in Table 5-35. Scale responses are shown in Figure 5-44.

**Table 5-35. Controller Responses to CSL Feature Usefulness**

	Participant Experience	
	TRACON	Tower
<b>CSL Line</b>		
Sample Size (n)	10	2
Mean (M)	96.2	93.0
Standard Deviation (SD)	5.0	-
<b>Data Block Distance to CSL</b>		
Sample Size (n)	10	2
Mean (M)	32.9	68.0
Standard Deviation (SD)	27.2	-



**Figure 5-44. The CSL Line and Data Block Distance to CSL features were useful for the overall IM PA monitoring task.**

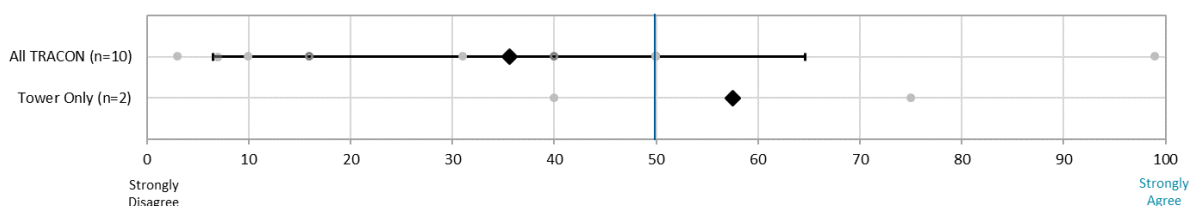
Note: o indicates NCT controller responses.

All (100%) TRACON controllers agreed the CSL Line was useful for the overall IM PA monitoring task (M=96.2; SD=5.0). However, only one TRACON controller agreed the Data Block Distance to the CSL was useful for the overall IM PA monitoring task (M=32.9; SD=27.2). Another controller neither agreed nor disagreed.

At the end of Day 2 (QT3), controllers were also asked to compare the two CSL features directly by rating their agreement with the statement: **If the CSL is shown as a graphic line, the numeric distance to it in the data block is also helpful.** Responses are shown for all TRACON (NCT and non-NCT combined) and Tower Only. Response Means and Standard Deviations are summarized in Table 5-36. Scale responses are shown in Figure 5-45.

**Table 5-36. Controller Responses to Helpfulness of CSL Numeric Distance, Given CSL Line**

	Participant Experience	
	TRACON	Tower
Sample Size (n)	10	2
Mean (M)	35.6	57.5
Standard Deviation (SD)	29.1	-



**Figure 5-45. If the CSL is shown as a graphic line, the numeric distance to it in the data block is also helpful.**

Note: *o* indicates NCT controller responses.

Responses were variable, but the majority (60%) of TRACON controllers disagreed the CSL Distance was helpful, if given the CSL Line (M=35.6; SD=29.1). Three controllers neither agreed nor disagreed. One controller agreed and was the same controller that agreed the Distance to CSL was useful in Figure 5-44. In a comment for a separate question, this controller noted that: “The numbers in the data block gave very good trend information as to what was happening to separation.”

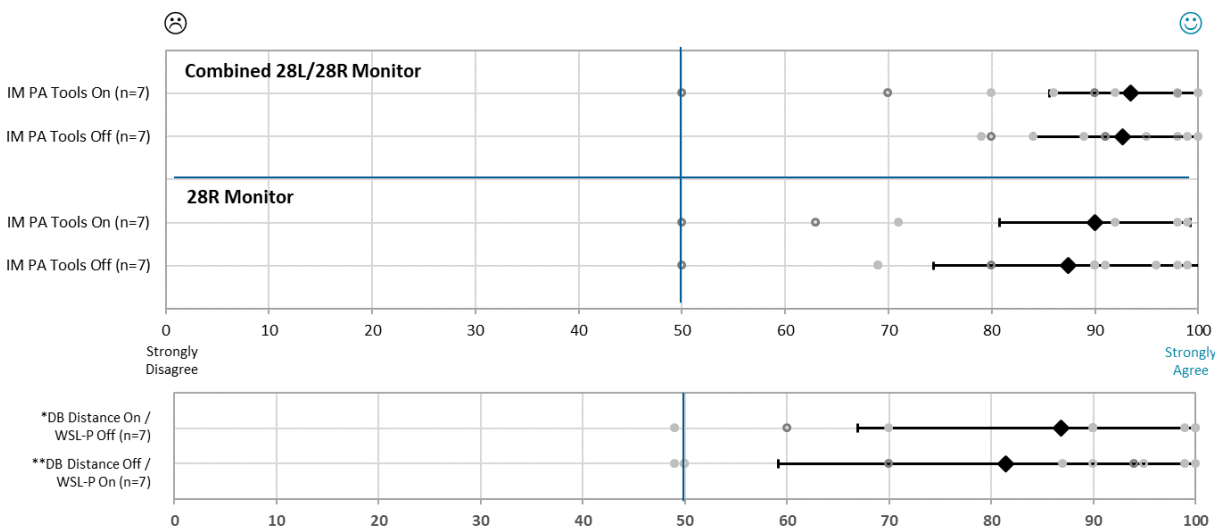
Open-ended comments for this question included:

- (Non-NCT TRACON) Not necessary. Visual indications are often more useful than numerical.
- (NCT) The line helps, but didn't look at distance in data block as I was looking at speeds to see if there was a difference.
- (Non-NCT TRACON) The distance can be misleading since sometimes 0.1 was still blue while 0.5 was yellow. Speed is the factor, not so much distance.

At the end of each run (QT1), controllers were asked if they **could easily assess whether the IM Trail Aircraft would remain behind the CSL during the approach**. Their responses were then examined with respect to IM PA Tool configuration. Response Means and Standard Deviations for the monitor configurations are summarized in Table 5-37. Scale responses are shown in Figure 5-46. Only TRACON controller responses were included in the analysis.

**Table 5-37. Monitor Controller Responses to CSL Assessment**

	IM PA Tool Configuration			
	Tools On	Tools Off	DB On / WSL-P Off	DB Off / WSL-P On
<b>Combined 28L/28R Monitor</b>				
Sample Size (n)	7	7	7	0
Mean (M)	93.4	92.7	86.9	-
Standard Deviation (SD)	7.8	8.7	20.0	-
<b>28R Monitor</b>				
Sample Size (n)	7	7	0	7
Mean (M)	90.0	87.4	-	81.4
Standard Deviation (SD)	9.2	13.0	-	22.3



**Figure 5-46. Monitor Controller: I could easily assess whether the IM Trail Aircraft would remain behind the CSL during the approach.**

\*Combined Monitor configuration / \*\*28R Monitor configuration

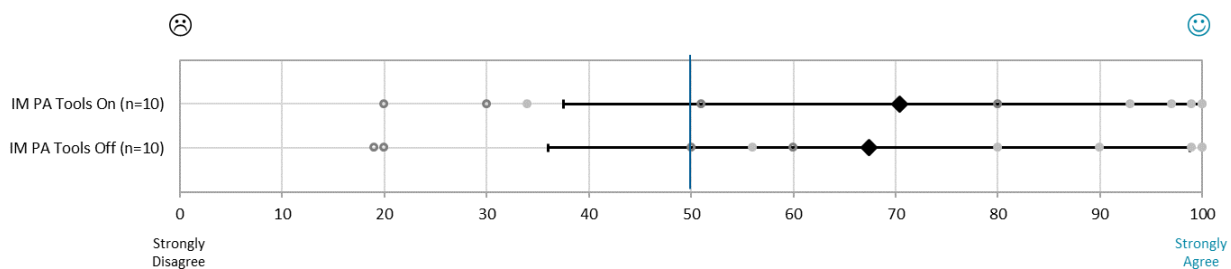
Note: o indicates Week 1 TRACON controller responses for reference. These are not included in the M and SD computations.

All (100%) Week 2-3 TRACON controllers agreed they could easily assess whether the IM Trail Aircraft would remain behind the CSL during the approach for both monitor configurations with IM PA Tools On and IM PA Tools Off. The majority of Week 2-3 TRACON controllers agreed with the Data Block CSL Distance On / WSL-P Off (86%) and with Data Block CSL Distance Off / WSL-P On (71%) configurations. Overall, no practical differences between the Monitor and IM PA Tool configurations were observed.

This same question, whether they **could easily assess whether the IM Trail Aircraft would remain behind the CSL during the approach**, was also examined for the 28R Final controllers at the end of each run (QT1). TRACON controller responses were also then examined with respect to IM PA Tool configuration. Response Means and Standard Deviations for the 28R Final controller position are summarized in Table 5-38. Scale responses are shown in Figure 5-47. Only TRACON controller responses were included in the analysis.

**Table 5-38. 28R Final Controller Responses to CSL Assessment**

	IM PA Tool Configuration	
	Tools On	Tools Off
Sample Size (n)	10	10
<b>Mean (M)</b>	<b>70.4</b>	<b>67.4</b>
Standard Deviation (SD)	32.9	31.4



**Figure 5-47. 28R Final Controller: I could easily assess whether the IM Trail Aircraft would remain behind the CSL during the approach.**

Note: **o** indicates NCT controller responses.

Responses were variable, but a majority (70%) of TRACON controllers agreed the 28R Final controller position could easily assess whether the IM Trail Aircraft would remain behind the CSL during the approach for both IM PA Tool configurations. Several comments from the controllers that disagreed suggested this was because there was no indication of where the CSL would be located before they cleared the IM Trail Aircraft for IM PA. Overall, no practical difference between the IM PA Tool configurations was observed.

Other open-ended comments for this question included:

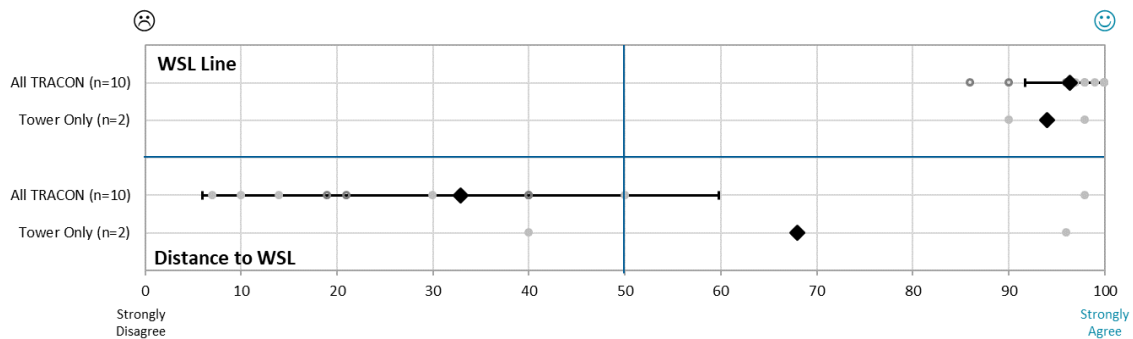
- (NCT / Tools On) Was not easy to determine, but wasn't a concern as I knew the Monitor controller could react next to the CSL warning if needed.
- (NCT / Tools On) I did not pay as close attention after I shipped them.

### 5.5.3.2 WSL and Pre-Activation Features

At the end of Day 2 (QT3), after experiencing the nominal scenarios across all IM PA Tool and monitor configurations, controllers were asked **if the WSL Line and Data Block Distance to WSL features were useful for the overall IM PA monitoring task**. Responses are shown for all TRACON (NCT and non-NCT combined) and Tower Only. Response Means and Standard Deviations are summarized in Table 5-39. Scale responses are shown in Figure 5-48.

**Table 5-39. Controller Responses to WSL Feature Usefulness**

	Participant Experience	
	TRACON	Tower
<b><i>WSL Line</i></b>		
Sample Size (n)	10	2
<b>Mean (M)</b>	<b>96.4</b>	<b>94.0</b>
Standard Deviation (SD)	4.7	-
<b><i>Data Block Distance to WSL</i></b>		
Sample Size (n)	10	2
<b>Mean (M)</b>	<b>32.9</b>	<b>68.0</b>
Standard Deviation (SD)	26.9	-



**Figure 5-48. The WSL Line and Data Block Distance to WSL features were useful for the overall IM PA monitoring task.**

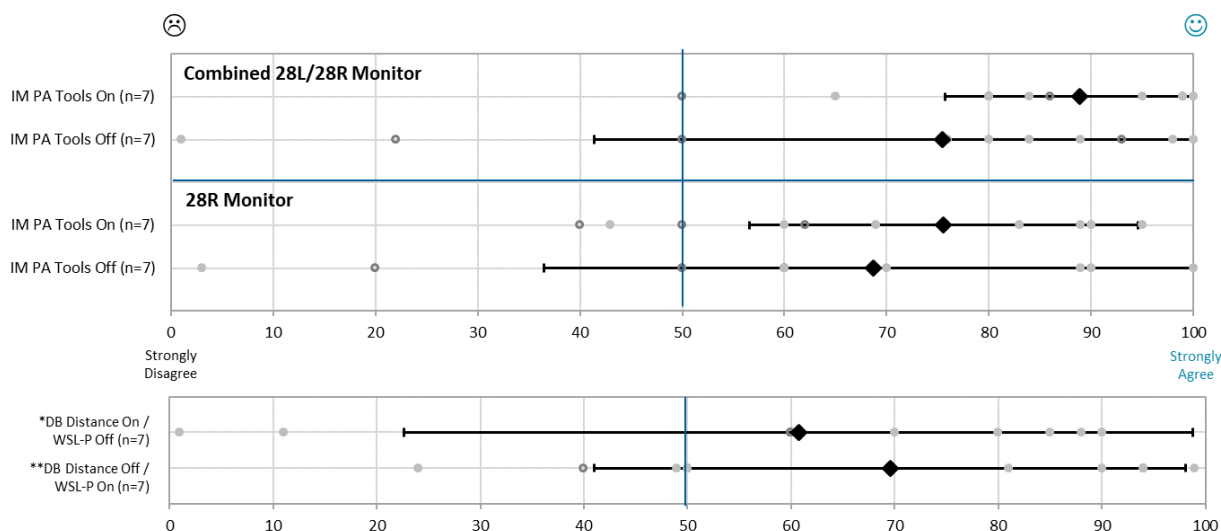
Note: *o* indicates NCT controller responses.

All (100%) TRACON controllers agreed the WSL Line was useful for the overall IM PA monitoring task (M=96.4; SD=4.7). However, only one TRACON controller agreed the Data Block Distance to the WSL was useful for the overall IM PA monitoring task (M=32.9; SD=27.2). This was the same controller in Section 5.5.3.1 that agreed the Distance to the CSL was useful. Another controller neither agreed nor disagreed.

At the end of each run (QT1), controllers were asked if they **could easily assess whether the IM Trail Aircraft would remain forward of the WSL during the approach, when applicable**. Their responses were then examined with respect to IM PA Tool configuration. Response Means and Standard Deviations for the monitor configurations are summarized in Table 5-40. Scale responses are shown in Figure 5-49. Only TRACON controller responses were included in the analysis.

**Table 5-40. Monitor Controller Responses to WSL Assessment**

	IM PA Tool Configuration			
	Tools On	Tools Off	DB On / WSL-P Off	DB Off / WSL-P On
<b>Combined 28L/28R Monitor</b>				
Sample Size (n)	7	7	7	0
Mean (M)	<b>88.9</b>	<b>75.4</b>	<b>60.7</b>	-
Standard Deviation (SD)	13.2	34.0	38.1	-
<b>28R Monitor</b>				
Sample Size (n)	7	7	0	7
Mean (M)	<b>75.6</b>	<b>68.7</b>	-	<b>69.6</b>
Standard Deviation (SD)	19.0	32.2	-	28.6



**Figure 5-49. I could easily assess whether the IM Trail Aircraft would remain forward of the WSL during the approach, when applicable.**

\*Combined Monitor configuration / \*\*28R Monitor configuration

Note: o indicates Week 1 TRACON controller responses for reference. These are not included in the M and SD computations.

All (100%) Week 2-3 TRACON controllers agreed they could easily assess whether the IM Trail Aircraft would remain forward of the WSL for the Combined Monitor position with IM PA Tools On (M=88.9; SD=13.2). Responses were variable, but a majority (86%) agreed for the Combined Monitor position with IM PA Tools Off (M=75.4; SD=34.0). This higher variability was due to one controller who strongly disagreed and noted that the WSL should appear sooner. Other controllers agreed in the comments that the WSL should appear sooner, though they still responded on the agree side of the scale.

Responses were variable for the other IM PA Tool configurations. However, the majority (71%) of Week 2-3 TRACON controllers agreed with the Data Block CSL Distance On / WSL-P Off (M=60.7; SD=38.1) and the majority (57%) agreed with Data Block CSL Distance Off / WSL-P On (M=69.6; SD=28.6).

As described in Section 5.8.2, a three-factor analysis of variance (ANOVA) test found that though all or most controllers agreed they could easily assess the IM Trail Aircraft with respect to both the CSL versus the WSL, they agreed more strongly for the CSL. No statistically significant differences were observed between Monitor and IM PA Tool configurations or any of the factor combinations.

Several controllers made open-ended comments across these scenarios that suggested the WSL appeared later than desired and that having the WSL-P would help. These included:

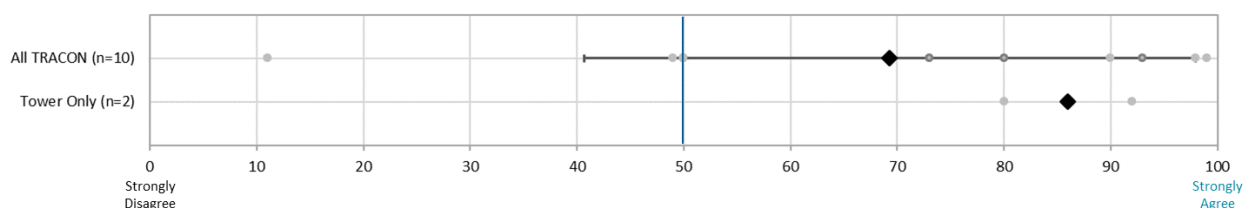
- (NCT / Tools On) I'm just not sure where the WSL will be until the preview pops up, once it does show up then I am more easily able to assess.
- (Non-NCT TRACON / Tools On) Once the line appeared, it was easy.
- (NCT / Tools On) The WSL should come on sooner so that if aircraft is lagging, we could use speed to get aircraft in front of WSL instead of sending around.
- (NCT / Tools Off) WSL is a little bit harder to notice and focus on when it pops up so late and without predictor.
- (NCT / Tools Off) I find myself staring when they get close to where the WSL activates and I'm spending too much time guessing where the AC will be in relation to active WSL. This is mitigated by preview WSL.
- (Non-NCT TRACON / DB Distance On/WSL-P Off) Not as much situational awareness as when the gray line is active, but still doable without difficulty.

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At the end of Day 2 (QT3), after experiencing the nominal scenarios across all IM PA Tool and monitor configurations, controllers were asked if **it was helpful to know whether an aircraft would eventually require an active WSL**. Responses are shown for all TRACON (NCT and non-NCT combined) and Tower Only. Response Means and Standard Deviations are summarized in Table 5-41. Scale responses are shown in Figure 5-50.

**Table 5-41. Controller Responses to Helpfulness of CSL Numeric Distance, Given CSL Line**

	Participant Experience	
	TRACON	Tower
Sample Size (n)	10	2
Mean (M)	69.3	86.0
Standard Deviation (SD)	28.6	-



**Figure 5-50. It was helpful to know whether an aircraft would eventually require an active WSL.**

Note: *o* indicates NCT controller responses.

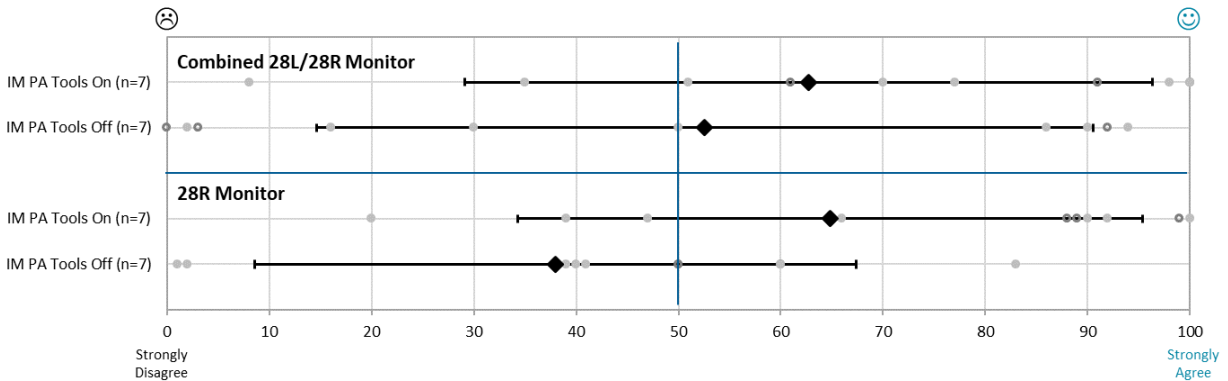
Responses were variable, but a majority (60%) of TRACON controllers agreed it was helpful to know whether an aircraft would eventually require an active WSL (M=69.3; SD=29.1). Two controllers that neither agreed nor disagreed commented aircraft type differences would indicate an active WSL to the controller.

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In the Day 1-2 Post-Run Questionnaires (QT1), controllers were asked if **given the IM PA-related tools provided in this scenario, I could easily tell when an aircraft would require a WSL later in the approach**. Their responses were examined with respect to both the IM PA Tools and monitor configurations. Response Means and Standard Deviations are summarized in Table 5-42. Scale responses are shown in Figure 5-51. For the Separate Monitor configuration, only 28R Monitor responses are included because the WSL and WSL-P did not apply to the 28L Monitor position.

**Table 5-42. Controller Responses to Ease of Predicting WSL**

	IM PA Tool Configuration	
	Tools On	Tools Off
<b>Combined 28L/28R Monitor</b>		
Sample Size (n)	7	7
<b>Mean (M)</b>	<b>62.7</b>	<b>52.6</b>
Standard Deviation (SD)	33.6	38.0
<b>28R Monitor</b>		
Sample Size (n)	7	7
<b>Mean (M)</b>	<b>64.9</b>	<b>38.0</b>
Standard Deviation (SD)	30.6	29.4



**Figure 5-51. Given the IM PA-related tools provided in this scenario, I could easily tell when an aircraft would require a WSL later in the approach.**

Note: o indicates Week 1 TRACON controller responses for reference. These are not included in the M and SD computations.

Responses were variable for all configurations. For the Combined 28L/28R Monitor configuration, a majority (71%) of Week 2-3 TRACON controllers agreed they could easily tell when an aircraft would require a WSL later in the approach with IM PA Tools On (M=62.7; SD=33.6). An equal number (43%) agreed and disagreed with IM PA Tools Off (M=52.6; SD=38.0) and one controller neither agreed nor disagreed.

For the Separate 28R Monitor configuration position, a majority (57%) of Week 2-3 TRACON controllers agreed with IM PA Tools On (M=64.9; SD=30.6). With IM PA Tools Off, a majority (71%) of controllers disagreed (M=38.0; SD=29.4).

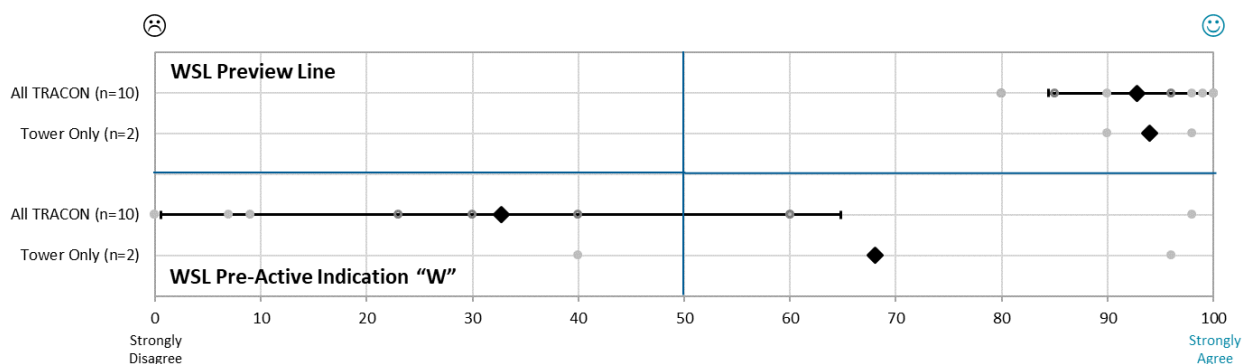
Due to the high variability observed with the IM PA Tools Off conditions, no practical difference was observed overall among the configurations. However, controllers may have found it somewhat easier to determine if a WSL would be required for the 28R Monitor position when

the IM PA Tools were available. Several controllers made open-ended comments that suggested aircraft type was sufficient to indicate whether a WSL would be required, though the Data Block W or WSL-P features would have made it easier.

At the end of Day 2 (QT3), after experiencing the nominal scenarios across all IM PA Tool and monitor configurations, controllers were asked **if the WSL-P and WSL Pre-Active Indication (“W”) features were useful for the overall IM PA monitoring task**. Responses are shown for all TRACON (NCT and non-NCT combined) and Tower Only. Response Means and Standard Deviations are summarized in Table 5-43. Scale responses are shown in Figure 5-52.

**Table 5-43. Controller Responses to WSL Pre-Activation Feature Usefulness**

	Participant Experience	
	TRACON	Tower
<b>WSL-P</b>		
Sample Size (n)	10	2
<b>Mean (M)</b>	<b>92.8</b>	<b>94.0</b>
Standard Deviation (SD)	8.4	-
<b>WSL Pre-Active Indication (“W”)</b>		
Sample Size (n)	10	2
<b>Mean (M)</b>	<b>32.7</b>	<b>68.0</b>
Standard Deviation (SD)	32.1	-



**Figure 5-52. The WSL-P and WSL Pre-Active Indication (“W”) features were useful for the overall IM PA monitoring task.**

Note: o indicates NCT controller responses.

All (100%) TRACON controllers agreed the WSL-P was useful for the overall IM PA monitoring task (M=92.8; SD=8.4). However, responses were variable for the WSL Pre-Active Indication

(“W”) and a majority (70%) of TRACON controllers disagreed it was useful (M=32.7; SD=32.1). As described in Section 5.8.3, a two-tailed, paired sample T-Test analysis found a significant difference in controller agreement for the usefulness of the two elements, with controllers appearing to prefer the WSL-P instead of the WSL Pre-Active Indication (“W”) in the data block.

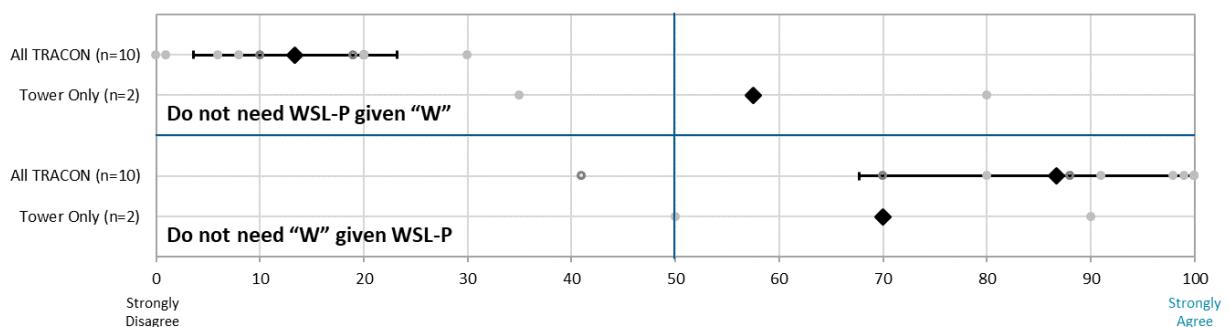
At the end of Day 2 (QT3), controllers were also asked to compare the two WSL Pre-Activation features directly by rating their agreement with these statements:

- **If provided the initial WSL “W” indicator in the data block, I do not also need the WSL Preview Line.**
- **If provided the WSL Preview Line, I do not also need the initial WSL “W” indicator in the data block.**

Responses are shown for all TRACON (NCT and non-NCT combined) and Tower Only. Response Means and Standard Deviations are summarized in Table 5-44. Scale responses are shown in Figure 5-53.

**Table 5-44. Controller Responses to WSL Pre-Activation Feature Comparison**

	Participant Experience	
	TRACON	Tower
<b>CSL Line</b>		
Sample Size (n)	10	2
Mean (M)	<b>13.4</b>	<b>57.5</b>
Standard Deviation (SD)	9.8	-
<b>Data Block Distance to CSL</b>		
Sample Size (n)	10	2
Mean (M)	<b>86.7</b>	<b>70</b>
Standard Deviation (SD)	19.0	-



**Figure 5-53. WSL Pre-Activation Feature Comparison**

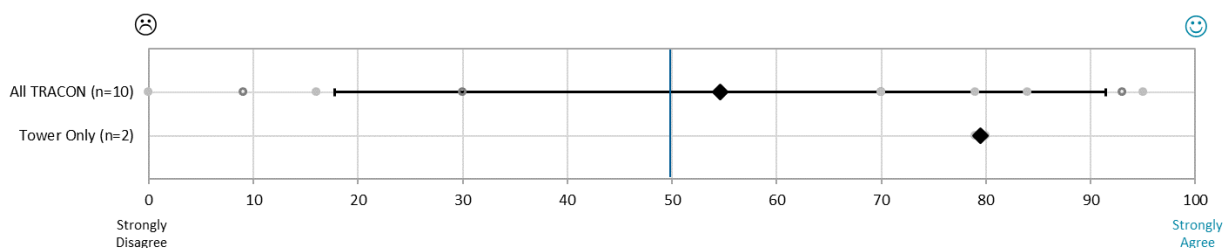
Note: o indicates NCT controller responses.

All (100%) TRACON controllers disagreed they did not need the WSL-P if they were provided with the Pre-Activation “W” in the data blocks (M=13.4; SD=9.8). Conversely, a majority (90%) of TRACON controllers agreed they did not need the Pre-Activation “W” in the data blocks if they were provided with the WSL-P. Consistent with prior results, TRACON controllers appeared to find the WSL-P to be more useful than the WSL “W” and several open-ended comments for this question suggested the WSL-P was far more useful than the “W.”

At the end of Day 2 (QT3), controllers were also asked **if the WSL-P first appeared with sufficient lead time<sup>13</sup> to be useful**. Responses are shown for all TRACON (NCT and non-NCT combined) and Tower Only. Response Means and Standard Deviations are summarized in Table 5-45. Scale responses are shown in Figure 5-54.

**Table 5-45. Controller Responses to WSL-P Activation Location**

	Participant Experience	
	TRACON	Tower
Sample Size (n)	10	2
<b>Mean (M)</b>	<b>54.6</b>	<b>79.5</b>
Standard Deviation (SD)	36.8	-



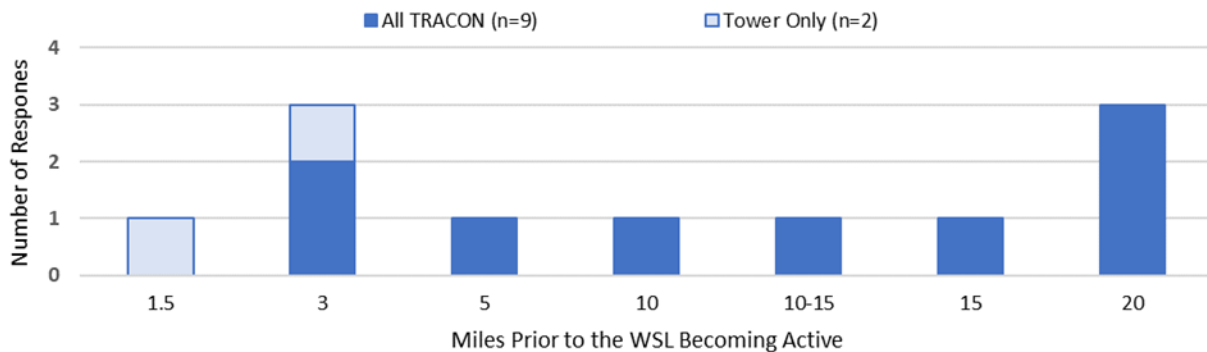
**Figure 5-54. The WSL-P first appeared with sufficient lead time to be useful.**

*Note: o indicates NCT controller responses.*

TRACON controller responses were variable, but a majority (60%) agreed the WSL-P first appeared with sufficient lead time to be useful (M=54.6; SD=36.8).

As a follow on, controllers at the end of Day 2 (QT3), were asked: **approximately how many miles prior to the Wake Safety Limit becoming active should the WSL Preview Line start to be displayed?** They were given an open field to enter any value they wished. Figure 5-55 shows participant responses for all TRACON (NCT and non-NCT combined) and Tower Only.

<sup>13</sup> As noted in Section 4.2.6, the WSL-P was first displayed in the HITL when the IM Trail Aircraft is approximately 7 NM from the runway threshold.



**Figure 5-55. Approximately how many miles prior to the Wake Safety Limit becoming active should the WSL Preview Line start to be displayed?**

Thought the responses were dispersed with regard to individual values, the groupings support prior results that controllers would like to have a preview become available sooner than what was implemented.

Selected open-ended comments for this question included:

- (NCT) It should start when the IM PA is activated, same time as CSL starts.
- (NCT) It should be on once cleared for approach. This tells controller if aircraft is behind and enough time to pick their speed up to get in front of zone.
- (Non-NCT TRACON) Wherever Monitor’s responsibility starts for separation, that’s where it needs to begin.
- (Non-NCT TRACON) The more times I worked monitor, I got better at predicting where the line would show up. Earlier would be better though.
- (Non-NCT TRACON) It was fine the way it was, but more time is beneficial. The more time I have to fix a potential problem, the better.

## 5.5.4 Longitudinal Alerting

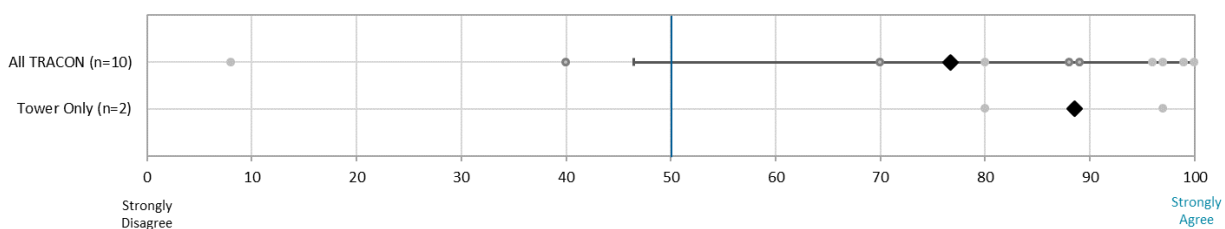
The Predictive and Caution Alerts described in Section 4.2.7 were examined in terms of their usefulness, timing values, display implementations in the HITL, and response procedures.

### 5.5.4.1 Usefulness

At the end of Day 3 after all scenarios were complete (QT8), controllers were asked if they: **want to be able to see a longitudinal CSL or WSL exceedance problem developing, vs. only being provided an alert when I have to take an action.** Responses are shown for all TRACON (NCT and non-NCT combined) and Tower Only. Response Means and Standard Deviations are summarized in Table 5-46 . Scale responses are shown in Figure 5-56.

**Table 5-46. Controller Responses to Wanting to See a Developing CSL or WSL Exceedance**

	Participant Experience	
	TRACON	Tower
Sample Size (n)	10	2
Mean (M)	<b>76.7</b>	<b>88.5</b>
Standard Deviation (SD)	30.2	-



**Figure 5-56. I want to be able to see a longitudinal CSL or WSL exceedance problem developing, vs. only being provided an alert when I have to take an action.**

Note: **o** indicates NCT Controller responses.

TRACON controller responses were variable, but a majority (80%) agreed they wanted to be able to see a situation developing versus only being provided an alert when they had to take action (M=76.7; SD=30.2).

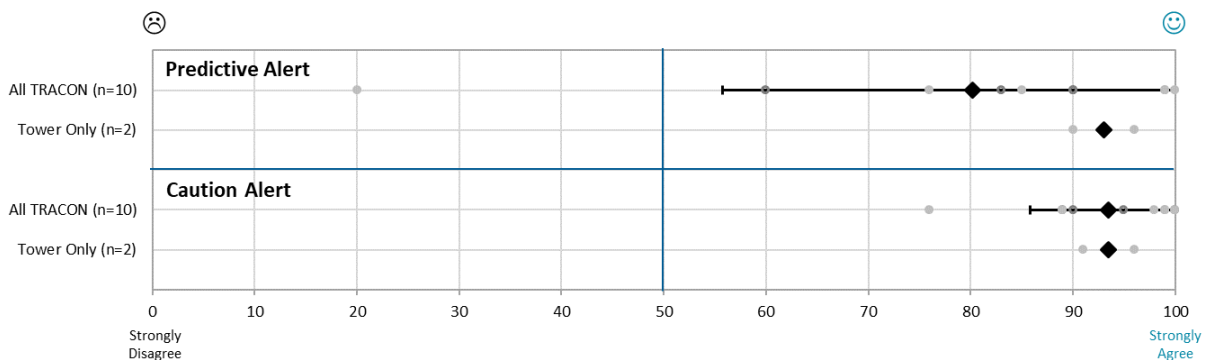
Two controllers disagreed and made the following comments in response to this question:

- (NCT) I don't mind it. However, just being alerted to take action is preferable.
- (Non-NCT TRACON) If I see it developing, I have very few options for keeping aircraft within limits, so I probably won't take action anyway until required.

At the end of Day 2 (QT3), after experiencing the nominal scenarios across all IM PA Tool and monitor configurations, controllers were asked **if the IM PA Predictive Alert and IM PA Caution Alert features were useful for the overall IM PA monitoring task**. Responses are shown for all TRACON (NCT and non-NCT combined) and Tower Only. Response Means and Standard Deviations are summarized in Table 5-47. Scale responses are shown in Figure 5-57.

**Table 5-47. Controller Responses to IM PA Alert Usefulness**

	Participant Experience	
	TRACON	Tower
<b><i>Predictive Alert</i></b>		
Sample Size (n)	10	2
Mean (M)	<b>80.2</b>	<b>93.0</b>
Standard Deviation (SD)	24.4	-
<b><i>Caution Alert</i></b>		
Sample Size (n)	10	2
Mean (M)	<b>93.5</b>	<b>93.5</b>
Standard Deviation (SD)	7.6	-



**Figure 5-57. The IM PA Predictive Alert and IM PA Caution Alert were useful for the overall IM PA monitoring task.**

Note: *o* indicates NCT controller responses.

The majority (90%) of TRACON controllers agreed the IM PA Predictive Alert was useful for the overall IM PA monitoring task (M=80.2; SD=24.4). One controller disagreed and was the same controller that noted in the previous question that they probably wouldn't take action until required. All (100%) TRACON controllers agreed the IM PA Caution Alert was useful for the overall IM PA monitoring task (M=93.5; SD=7.6).

As described in Section 5.8.4, a one-tailed, paired sample T-Test found a significant difference in controller agreement with respect to the usefulness of the two elements. Though both were found useful, stronger agreement was observed with the Caution Alert

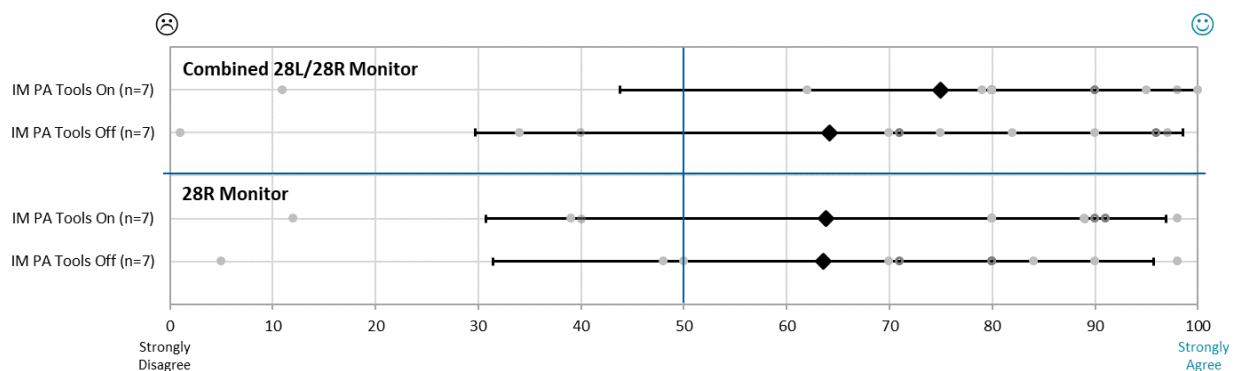
The higher average and lower variability of the Caution Alert suggests that controllers seem to have found it more useful than the Predictive Alert.

### 5.5.4.2 Timeliness Assessment

At the end of each run (QT1), controllers were asked if the IM PA-related tools provided in this scenario allowed for a timely detection of any impending exceedance of the WSL or CSL. Their responses were then examined with respect to IM PA Tool configuration. Response Means and Standard Deviations are summarized in Table 5-48. Scale responses are shown in Figure 5-58. Only Week 2-3 TRACON controller responses were included in the analysis. This question only applied to controllers responsible for 28R, so the Separate 28L Monitor position results are not included.

**Table 5-48. IM PA Tool Notification Timeliness**

	IM PA Tool Configuration	
	Tools On	Tools Off
<b>Combined 28L/28R Monitor</b>		
Sample Size (n)	7	7
Mean (M)	75.0	64.1
Standard Deviation (SD)	31.3	34.4
<b>28R Monitor</b>		
Sample Size (n)	7	7
Mean (M)	63.9	63.6
Standard Deviation (SD)	33.1	32.1



**Figure 5-58. The IM PA-related tools provided in this scenario allowed for a timely detection of any impending exceedance of the WSL or CSL.**

Note: o indicates Week 1 TRACON controller responses for reference. These are not included in the M and SD computations.

Week 2-3 TRACON controller responses were variable for each IM PA Tools and monitor configuration. However, the majority (86%) of TRACON controllers in the Combined Monitor configuration agreed the IM PA Tools allowed for a timely detection of an impending

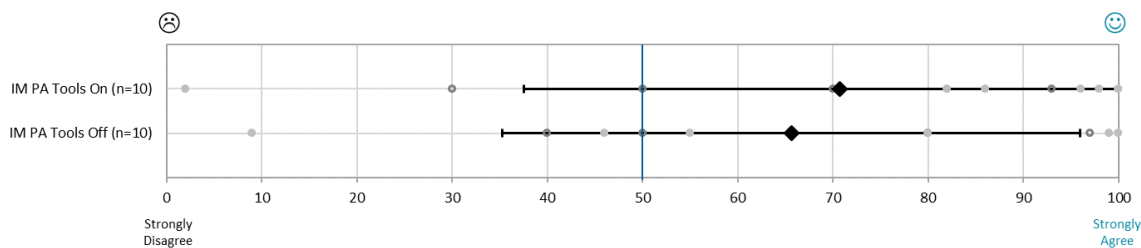
exceedance when On (M=75.0; SD=31.3). A majority (71%) also agreed when Off (M=64.1; SD=34.4). For the Separate 28R Monitor position, a majority (57%) agreed when On (M=33.1; SD=33.1) and Off (M=63.6; SD=32.1).

Though the mean was higher, and the variability was lower for the IM PA Tools On in the Combined 28L/28R Monitor configuration, the high variability across all of the conditions suggest none were actually more or less effective to the Week 2-3 TRACON controllers than any of the others.

A similar question was asked at the end of each run (QT1) to participants working as the 28R Final controller: **The IM PA-related tools provided in this scenario allowed for a timely detection of any spacing or separation issues.** TRACON controller responses were also then examined with respect to IM PA Tool configuration. Response Means and Standard Deviations for the 28R Final controller position are summarized in Table 5-49. Scale responses are shown in Figure 5-59. Only TRACON controller responses were included in the analysis.

**Table 5-49. 28R Final Controller: IM PA Tools Allowed for Timely Issue Detection**

	IM PA Tool Configuration	
	Tools On	Tools Off
Sample Size (n)	10	10
Mean (M)	70.7	65.6
Standard Deviation (SD)	33.2	30.4



**Figure 5-59. 28R Final Controller: The IM PA-related tools provided in this scenario allowed for a timely detection of any spacing or separation issues.**

Note: o indicates NCT controller responses.

TRACON controller responses were variable, but the majority (70%) agreed with IM PA Tools On (M=70.7; SD=33.2) and the majority (60%) agreed with IM PA Tools Off (M=65.6; SD=30.4). Comments from controllers who disagreed were related to not having prior knowledge of the safety limit proximity before issuing the clearance and not knowing the WSL “sooner.” No practical difference was observed between the two IM PA Tool configurations.

As described in Sections 4.5.4 and 4.5.6.5, a portion of the evaluation on Day 3 involved manipulating the Timing values for the Predictive and Caution Alerts to determine if reducing the alerting time would be more or less acceptable in the separation monitoring task. The timing values used in the HITL are shown in Table 4-12. Due to a Week 1 Alert Timing scenario issue, only the Week 2-3 TRACON controller responses are included in the analysis.

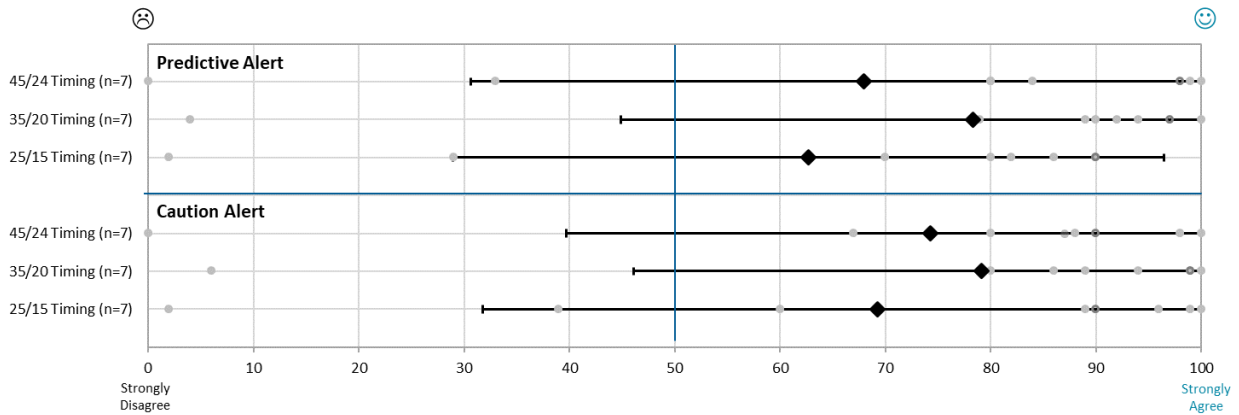
In the Alert Timing Post-Run Questionnaires (QT4), controllers were asked if:

- **The Predictive (yellow) alert provided sufficient advance notice of an impending Caution Alert.**
- **The Caution (orange) alert provided sufficient advance notice of an impending loss of separation.**

Responses are shown for all TRACON (NCT and non-NCT combined) for each Alert Timing value. Response Means and Standard Deviations are summarized in Table 5-50. Scale responses are shown in Figure 5-60.

**Table 5-50. Controller Responses to Sufficiently of Alert Timing Advance Notice**

	Alert Timing (Predictive / Caution)		
	45 / 24 sec	35 / 20 sec	25 / 15 sec
<b><i>Predictive Alert</i></b>			
Sample Size (n)	7	7	7
<b>Mean (M)</b>	<b>68.0</b>	<b>78.3</b>	<b>62.7</b>
Standard Deviation (SD)	37.4	33.4	33.7
<b><i>Caution Alert</i></b>			
Sample Size (n)	7	7	7
<b>Mean (M)</b>	<b>74.3</b>	<b>79.1</b>	<b>69.3</b>
Standard Deviation (SD)	34.6	33.0	37.5



**Figure 5-60. The IM PA [Predictive / Caution] Alert provided sufficient advance notice of an impending [Caution Alert / loss of separation].**

Note: o indicates Week 2-3 Tower controller responses for reference. These are not included in the M and SD computations.

Week 2-3 TRACON controller responses were variable for each type of alert and timing value. The majority (71%) of TRACON controllers agreed for the Predictive Alert with the 45/24 and 25/15 values. The majority (86%) of TRACON controllers agreed for 35/20 value. For the Caution Alert, the majority (86%) agreed for the 45/24 and 35/20 values and the majority (71%) agreed for the 25/15 value.

Though the means were relatively higher for the 35/20 value for both alert types, the high variability across all of the Alert Timing scenarios suggests that none of the timings were actually more or less acceptable to the Week 2-3 TRACON controllers than any of the others.

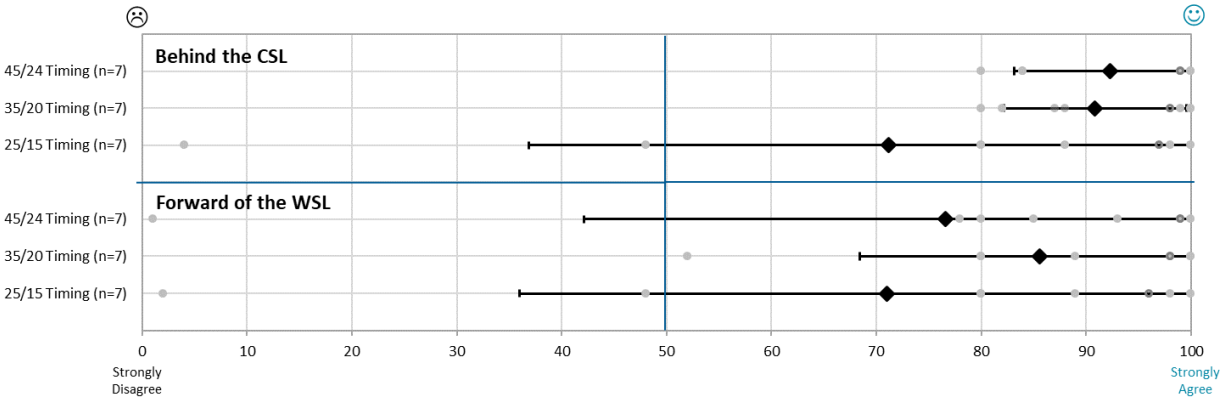
In the Alert Timing Post-Run Questionnaires (QT4), controllers were also asked if:

- **I could easily assess whether the IM Trail aircraft would remain behind the CSL during the approach.**
- **I could easily assess whether the IM Trail aircraft would remain forward of the WSL during the approach (when applicable).**

Responses are shown for all TRACON (NCT and non-NCT combined) for each alert timing value. Response Means and Standard Deviations are summarized in Table 5-51. Scale responses are shown in Figure 5-61.

**Table 5-51. Controller Responses to Safety Limit Assessment**

	Alert Timing (Predictive / Caution)		
	45 / 24 sec	35 / 20 sec	25 / 15 sec
<b>Behind the CSL</b>			
Sample Size (n)	7	7	7
Mean (M)	<b>92.3</b>	<b>90.9</b>	<b>71.1</b>
Standard Deviation (SD)	9.1	8.7	34.3
<b>Forward of the WSL</b>			
Sample Size (n)	7	7	7
Mean (M)	<b>76.6</b>	<b>85.6</b>	<b>71.0</b>
Standard Deviation (SD)	34.4	17.2	35.0



**Figure 5-61. I could easily assess whether the IM PA trail aircraft would remain [behind the CSL / forward of the WSL] during the approach.**

Note: **o** indicates Week 2-3 Tower controller responses for reference. These are not included in the M and SD computations.

All Week 2-3 TRACON controllers agreed they could easily assess whether the IM PA Trail Aircraft would remain behind the CSL during the approach for the 45/24 value (M=92.3; SD=9.1) and the 35/20 value (M=90.9; SD=8.7). All also agreed they could easily assess whether the IM PA Trail Aircraft would remain forward of the WSL during the approach for the 35/20 value (M=85.6; SD=17.2).

Week 2-3 TRACON controller responses were variable for the 25/15 alert timing values for each safety limit, but a majority (71%) agreed for the CSL (M=71.1; SD=34.3) and WSL (M=71.0; SD=35.0). Responses were also variable for the 45/24 value for the WSL, but a majority (86%) also agreed (M=76.6; SD=34.4).

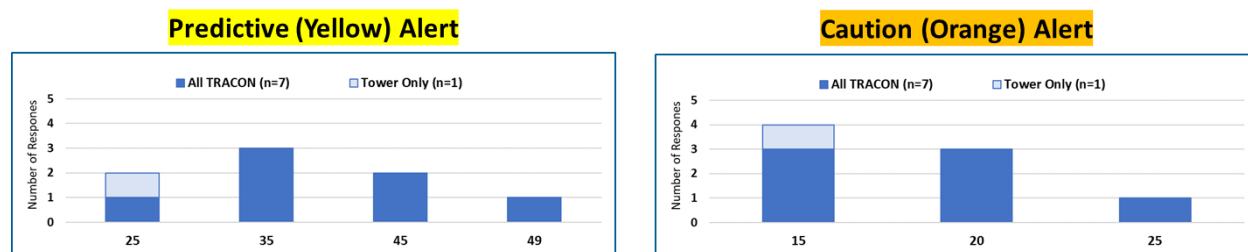
The means were relatively higher, and the variability lower, for the 45/24 and 35/20 values for the CSL than the other conditions. This suggests greater controller agreement on the effectiveness of these alert timing values for the CSL than the 25/15 value. For the WSL, the relatively higher mean and lower variability for the 35/20 value suggests greater controller agreement on the effectiveness of this value than the other two.

Selected open-ended comments for this question included:

- (Non-NCT TRACON / 45/24) Not easily, but definitely could guess with confidence when a deviation on the CSL would occur.
- (Non-NCT TRACON / 25/15) The more I watch scenarios, the better I become at predicting if the a/c will or will not stay behind the CSL. The automation helps in addition to this (i.e., warning and caution).
- (NCT / 45/24) Definitely works better w/ preview line, so I don't have to narrow my focus to the area where the WSL pops up.
- (Non-NCT TRACON / 25/15) [WSL is] more difficult than CSL assessment because WSL is effective so late on final. The warning helped.

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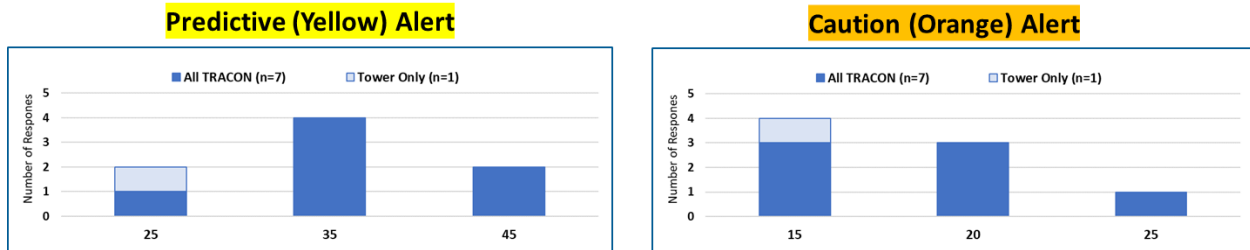
After all the Alert Timing scenarios were run (QT5), controllers were asked: **how many seconds before the IM Trail Aircraft crosses the CSL would you like to see the Predictive and Caution Alerts.** Participants were allowed to enter any value they liked. Responses are shown in Figure 5-62 for Week 2-3 TRACON (NCT and non-NCT combined) and Tower Only.



**Figure 5-62. How many seconds before the IM Trail Aircraft crosses the CSL would you like to see the Predictive and Caution Alerts?**

With respect to the CSL, the majority of Week 2-3 TRACON controllers responded with 35 seconds for the Predictive Alert. Controllers tied between 15 and 20 seconds for the Caution Alert.

After all the Alert Timing scenarios were run (QT5), controllers were also asked: **how many seconds before the IM Trail Aircraft crosses the WSL would you like to see the Predictive and Caution Alerts.** Participants were allowed to enter any value they liked. Responses are shown in Figure 5-63 for Week 2-3 TRACON (NCT and non-NCT combined) and Tower Only.



**Figure 5-63. How many seconds before the IM Trail Aircraft crosses the WSL would you like to see the Predictive and Caution Alerts?**

With respect to the WSL, the majority of Week 2-3 TRACON controllers responded with 35 seconds for the Predictive Alert. TRACON controllers tied between 15 and 20 seconds for the Caution Alert. In the comments, one participant noted for the Caution Alert: “Timing depends on type of position responsible for the aircraft pairs at the time. With a monitor, no less than 15 seconds. With a local or final, 24 seconds seems reasonable.”

### 5.5.4.3 Alert Response Times

As described in Section 4.5.4, Day 3 for each week included a self-contained evaluation of alternate longitudinal alert timings. The analysis in this section examined whether lower alert timings than those chosen for ATPA affected controller response time to a Caution Alert, as reduced timings may ultimately be used to mitigate against nuisance alerts (which would occur more frequently with greater timings). Three sets of alert timing values were investigated in the HITL as levels of the Alert Timing Independent Variable and are shown in Table 5-52.

**Table 5-52. Alert Timing Independent Variable Levels**

	Predictive Alert Time (sec)	Caution Alert Time (sec)
<b>Set X</b>	45	24
<b>Set Y</b>	35	20
<b>Set Z</b>	25	15

The different alert timings were only examined in the context of the Combined Monitor configuration. All of the IM PA-related tools described previously were available to the Combined Monitor controller. The counterbalancing of the timing values used in the HITL is shown in Table 4-12.

As noted in Section 4.5.7.2, objective data was collected with respect to controller PTT times, aircraft state, and longitudinal alerting. The PTT data caveats described in Section 5.1.2 apply here. In sum, if the Local controller or pseudopilot was talking on the frequency, participants could not break in to override. They were, however, told to still click their handsets when they wanted to speak. The first “click” that was recorded after an event of interest was used as a proxy for the controller response time to resolve a situation. It was generally assumed that the

first click that was recorded after an event of interest represented the controller response time to resolve a situation.

Though this is likely to be a safe assumption generally, there were five cases in which unusually long delays (> 11 sec) were observed between the Caution Alert and the next PTT click. The lowest of these values were eight or more times higher than the other average responses and more than twice the average controller response times to the NTZ Warnings reported in Cox, Yates, & Savage (2011). These cases were further examined and it was found that there was also a very short time difference between the *preceding* PTT click and the Caution Alert. These likely represented instances in which the controller felt confident that the aircraft would receive a Caution Alert and therefore intervened just before the alert actually occurred. These five instances were removed from the data, resulting in different “n” values per condition, and are further discussed later in this section.

PTT response time Means and Standard Deviations are summarized in Table 5-53. Responses are shown for all TRACON (NCT and non-NCT combined) for each alert timing value. Due to a technical issue in Week 1 that affected the Alert Timing scenarios, only the Week 2-3 TRACON controller responses are included in the analysis.

**Table 5-53. Average Controller PTT Response Time (sec) After Caution Alert**

	Alert Timing (Predictive / Caution)		
	45 / 24 sec	35 / 20 sec	25 / 15 sec
<b>CSL Caution Alert</b>			
Sample Size (n)	16	16	15
<b>Mean (M)</b>	<b>1.8 sec</b>	<b>1.1 sec</b>	<b>1.5 sec</b>
Standard Deviation (SD)	2.7	1.6	1.9
<b>WSL Caution Alert</b>			
Sample Size (n)	9	10	10
<b>Mean (M)</b>	<b>1.0 sec</b>	<b>0.9 sec</b>	<b>1.4 sec</b>
Standard Deviation (SD)	1.0	1.2	1.8
<b>Total</b>			
Sample Size (n)	25	26	25
<b>Mean (M)</b>	<b>1.5 sec</b>	<b>1.0 sec</b>	<b>1.5 sec</b>
Standard Deviation (SD)	2.2	1.4	1.8

The HITL data shows that on average, controllers responded (via a PTT click) to Caution Alerts within approximately 1-2 seconds. Note this does not suggest controllers first *noticed* the Caution Alert 1-2 seconds after it occurred; these values only represent the time between the Caution Alert display and the next PTT “click” of the participant’s handset.

To examine whether alert timing had an effect on PTT Response times, a single-factor ANOVA test was performed. Due to the three levels of the Alert Timing Independent Variable, the Bonferroni correction was used to control for the potential for familywise error. The probability of finding an effect when there was none, alpha ( $\alpha$ ), was set to 0.05. The results are shown in Table 5-54.

**Table 5-54. Controller PTT Response Time After Caution Alert: Single Factor ANOVA Results**

	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>p-value</i>	<i>Significant?</i>
<b>Between Groups</b>	4.30	2	2.15	0.64	0.53	no
<b>Within Groups</b>	246.48	73	3.38			
Total	250.78	75	3.34			

The statistical analysis results from the simulation suggest there was no significant difference between average controller response times for any of the three alert timings ( $p = 0.53$ ).

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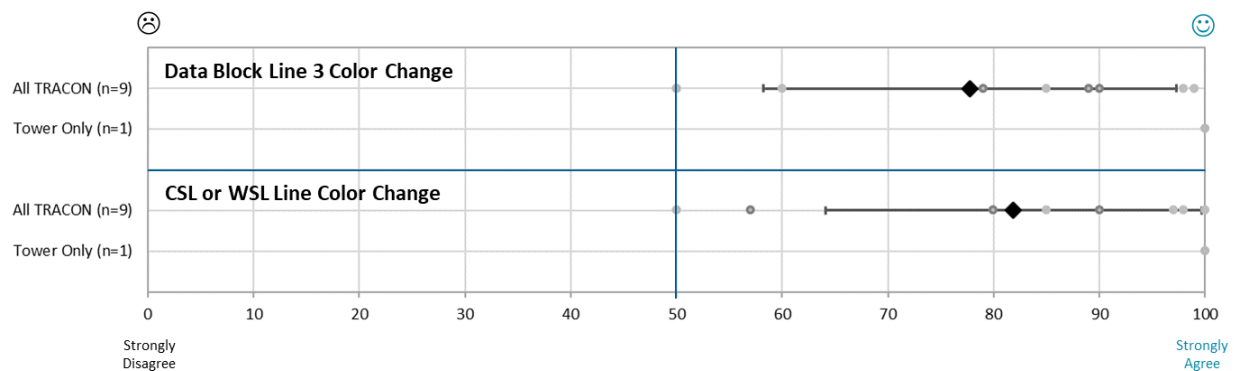
As noted earlier, five out of 82 (6%) cases were observed in which controllers appeared to have intervened with an aircraft *before* it triggered a Caution Alert. Three of these were with the 45/24 timing and three were with the 35/20 timing. Four of the five cases were related to a WSL alert and one was related to a CSL alert. Overall there were too few occurrences to suggest any trends.

#### 5.5.4.4 Display Implementation

As described in Section 4.2.7, an alert was indicated by both the respective safety limit line and data block numeric indicator changing color. To determine if controllers might exhibit a display preference for the Predictive Alert, they were asked after all the Alert Timing scenarios were run (QT5) if **it was helpful to indicate the Predictive Alert via the [Data Block Line 3 / CSL or WSL line] color change**. Responses are shown for all TRACON (NCT and non-NCT combined) and Tower Only. Response Means and Standard Deviations are summarized in Table 5-55. Scale responses are shown in Figure 5-64. One NCT and one Tower participant did not respond to this question, therefore  $n=9$  for the TRACON controller responses and  $n=1$  for the Tower responses.

**Table 5-55. Controller Responses for Predictive Alert Display Implementation Helpfulness**

	Participant Experience	
	TRACON	Tower
<b>Data Block Value Color Change</b>		
Sample Size (n)	9	1
Mean (M)	<b>77.8</b>	<b>100</b>
Standard Deviation (SD)	19.5	-
<b>CSL or WSL Line Color Change</b>		
Sample Size (n)	9	1
Mean (M)	<b>81.9</b>	<b>100</b>
Standard Deviation (SD)	17.8	-



**Figure 5-64. It was helpful to indicate the Predictive Alert via the [Data Block Line 3 / CSL or WSL line] color change.**

*Note: o indicates NCT controller responses. Rows indicate an n=9 and N=1 because one TRACON and one Tower participant did not include a rating in their questionnaires.*

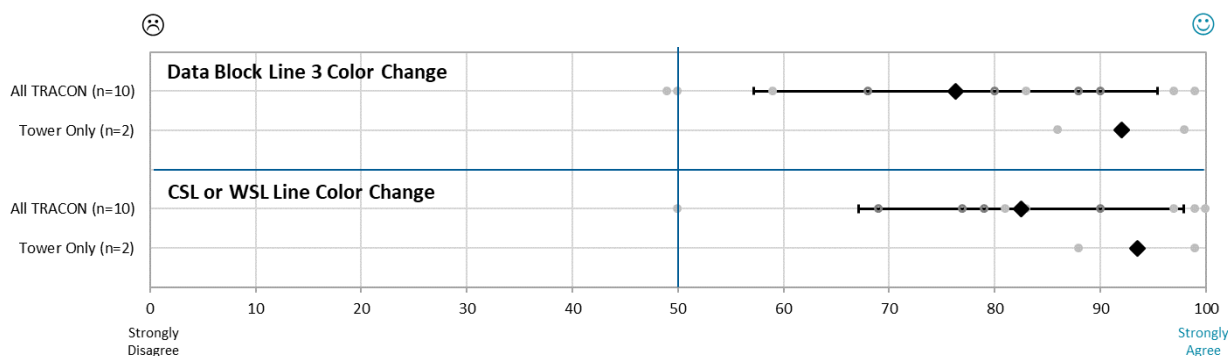
The majority (78%) of TRACON controllers agreed it was helpful to indicate the Predictive Alert via the data block line 3 color change (M=77.8; SD=19.5). The majority (89%) of TRACON controllers agreed it was helpful to indicate the Predictive Alert via the CSL or WSL line color change (M=81.9; SD=17.8). No practical difference was observed between displaying the Predictive Alert via a safety limit line color change versus the Data Block CSL/WSL value color change.

To determine if controllers might exhibit a display preference for the Caution Alert, they were asked after all the Alert Timing scenarios were run (QT5) if **it was helpful to indicate the Caution Alert via the [Data Block Line 3 / CSL or WSL line] color change**. Responses are shown

for all TRACON (NCT and non-NCT combined) and Tower Only. Response Means and Standard Deviations are summarized in Table 5-56. Scale responses are shown in Figure 5-65.

**Table 5-56. Controller Responses for Caution Alert Display Implementation Helpfulness**

	Participant Experience	
	TRACON	Tower
<b>Data Block Value Color Change</b>		
Sample Size (n)	10	2
Mean (M)	76.3	92.0
Standard Deviation (SD)	19.1	-
<b>CSL or WSL Line Color Change</b>		
Sample Size (n)	10	2
Mean (M)	82.5	93.5
Standard Deviation (SD)	15.4	-



**Figure 5-65. It was helpful to indicate the Caution Alert via the [Data Block Line 3 / CSL or WSL line] color change.**

Note: **o** indicates NCT controller responses.

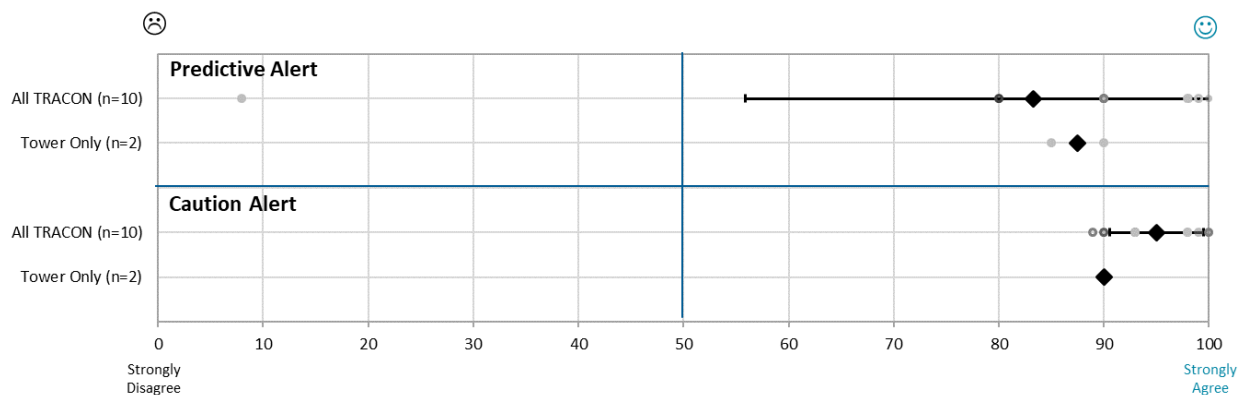
The majority (80%) of TRACON controllers agreed it was helpful to indicate the Caution Alert via the data block line 3 color change (M=76.3; SD=19.1). The majority (90%) of TRACON controllers agreed it was helpful to indicate the Caution Alert via the CSL or WSL line color change (M=82.5; SD=15.4). No practical difference was observed between displaying the Caution Alert via a safety limit line color change versus the Data Block CSL/WSL value color change. However, one TRACON controller commented for both Alert Types: “The color change is necessary, but not enough. The color change alone is not enough to grab my attention if I am focused on another part of the radar scope.”

### 5.5.4.5 Response Procedures

At the end of Day 2 (QT3), after experiencing the nominal scenarios across all IM PA Tool and monitor configurations, controllers were asked if **my responsibilities with respect to a Predictive Alert and Caution Alert were clear**. Responses are shown for all TRACON (NCT and non-NCT combined) and Tower Only. Response Means and Standard Deviations are summarized in Table 5-57. Scale responses are shown in Figure 5-66.

**Table 5-57. Controller Responses to Clarity of Responsibilities**

	Participant Experience	
	TRACON	Tower
<b>Predictive Alert</b>		
Sample Size (n)	10	2
Mean (M)	<b>83.3</b>	<b>87.5</b>
Standard Deviation (SD)	27.5	-
<b>Caution Alert</b>		
Sample Size (n)	10	2
Mean (M)	<b>95.0</b>	<b>90.0</b>
Standard Deviation (SD)	4.4	-



**Figure 5-66. My responsibilities with respect to a Predictive Alert and Caution Alert were clear.**

Note: o indicates NCT controller responses.

Responses were variable, but the majority (90%) of TRACON controllers agreed their responsibilities with respect to an IM PA Predictive Alert were clear (M=83.3; SD=27.5). One NCT controller commented: “Maybe develop some phraseology so I can make pilot aware they are messing up and need to take quick action to prevent a go around.”

All (100%) TRACON controllers agreed their responsibilities with respect to an IM PA Caution Alert were clear (M=95.0; SD=4.4). The higher average and lower variability of the Caution Alert suggests controllers found its response procedures more clear than those for the Predictive Alert.

### 5.5.5 IM Spacing List and IM Aircraft Status

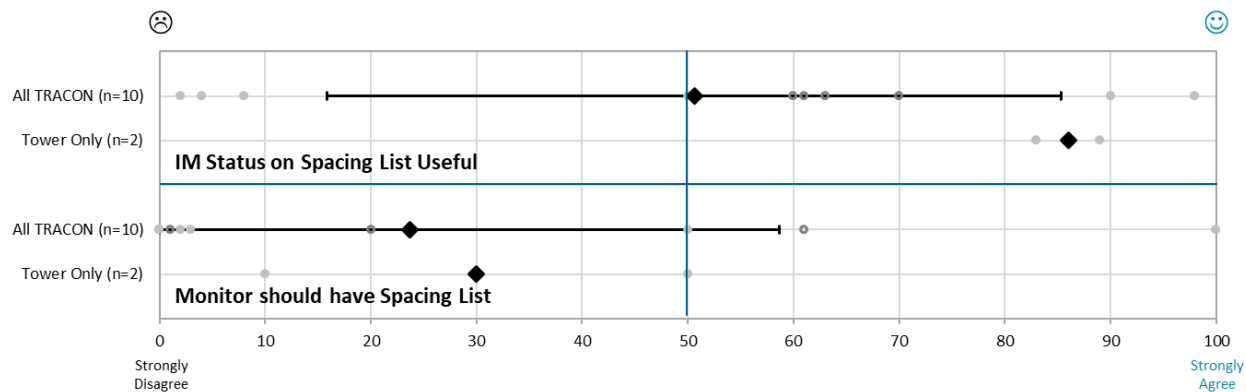
At the end of Day 2 (QT3), after experiencing the nominal scenarios across all IM PA Tool and monitor configurations, controllers were asked if:

- **The IM Spacing List IM Status Information was useful for the overall IM PA monitoring task.**
- **The Monitor controller should be provided an IM Spacing List.**

Responses are shown for all TRACON (NCT and non-NCT combined) and Tower Only. Response Means and Standard Deviations are summarized in Table 5-58. Scale responses are shown in Figure 5-67.

**Table 5-58. Controller Responses to IM Spacing List Usefulness**

	Participant Experience	
	TRACON	Tower
<b><i>IM Status on Spacing List Useful</i></b>		
Sample Size (n)	10	2
<b>Mean (M)</b>	<b>50.6</b>	<b>86.0</b>
Standard Deviation (SD)	34.8	-
<b><i>Monitor should have Spacing List</i></b>		
Sample Size (n)	10	2
<b>Mean (M)</b>	<b>23.7</b>	<b>30.0</b>
Standard Deviation (SD)	35.0	-



**Figure 5-67. IM Spacing List for Monitoring Task**

Note: o indicates NCT controller responses.

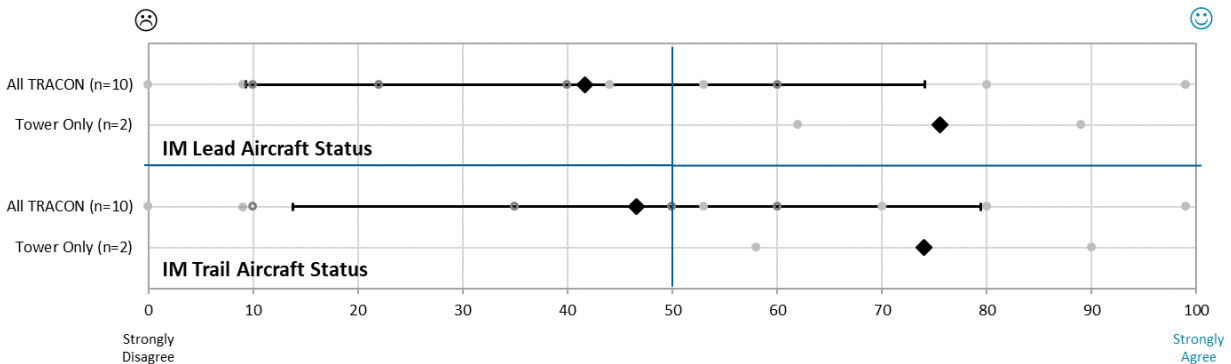
Responses were variable, but the majority (60%) of TRACON controllers agreed the IM Spacing List IM Status Information was useful for the overall IM PA monitoring task. However, on average, controllers neither agreed nor disagreed (M=50.6; SD=34.8).

Responses were variable, but a majority (70%) of TRACON controllers disagreed the Monitor controller should be provided an IM Spacing List (M=23.7; SD=35.0). One controller commented that it should be "...customizable. Personally, I would not want it but it should be an option if others do."

At the end of Day 2 (QT3), after experiencing the nominal scenarios across all IM PA Tool and monitor configurations, controllers were asked if **the IM Lead Aircraft and IM Trail Aircraft Status [in the data block] was useful for the overall IM PA monitoring task**. Responses are shown for all TRACON (NCT and non-NCT combined) and Tower Only. Response Means and Standard Deviations are summarized in Table 5-59. Scale responses are shown in Figure 5-68.

**Table 5-59. Controller Responses to IM Lead / Trail Aircraft Status Usefulness**

	Participant Experience	
	TRACON	Tower
<b><i>IM Lead Aircraft Status Useful</i></b>		
Sample Size (n)	10	2
Mean (M)	<b>41.7</b>	<b>75.5</b>
Standard Deviation (SD)	32.4	-
<b><i>IM Trail Aircraft Status Useful</i></b>		
Sample Size (n)	10	2
Mean (M)	<b>46.6</b>	<b>74.0</b>
Standard Deviation (SD)	32.8	-



**Figure 5-68. The IM Lead Aircraft and IM Trail Aircraft Status [in the data block] was useful for the overall IM PA monitoring task**

Note: o indicates NCT controller responses.

Responses were variable, but a majority (60%) of TRACON controllers disagreed the IM Lead Aircraft Status [in the data block] was useful for the overall IM PA monitoring task ( $M=41.7$ ;  $SD=32.4$ ). Responses were also variable for the IM Trail Aircraft, but only half (50%) of TRACON controllers agreed it was useful. On average, however, they disagreed ( $M=46.6$ ;  $SD=32.8$ ).

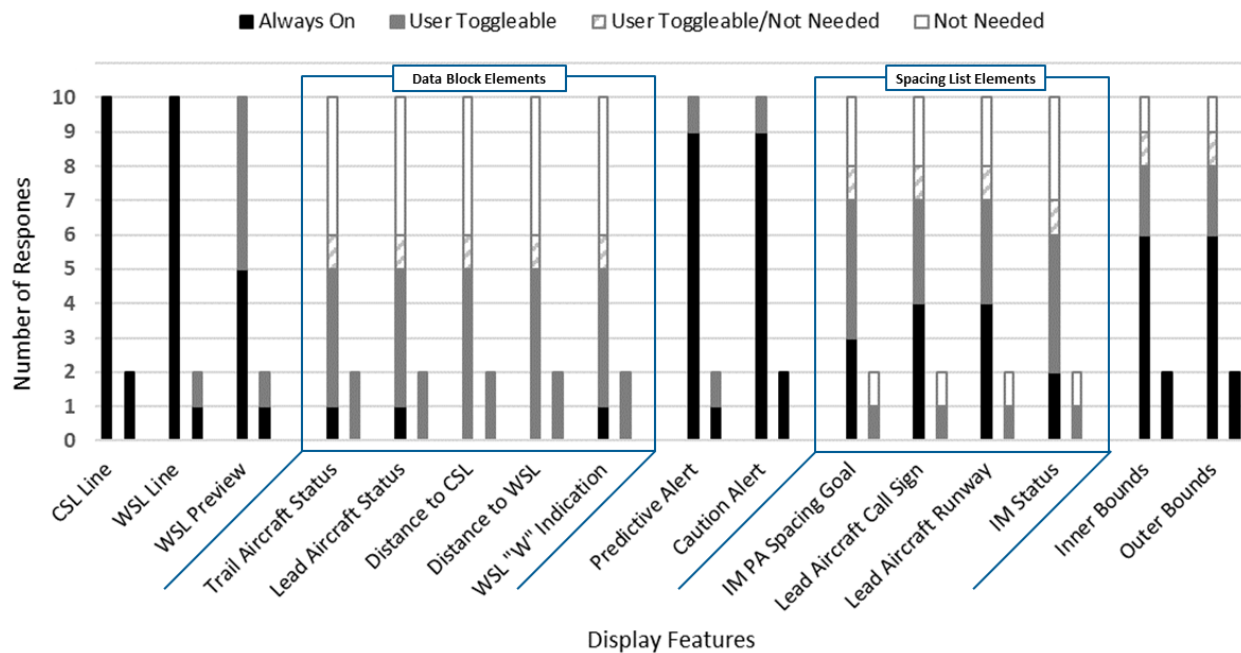
## 5.5.6 Display Feature Recommendations

This section presents the participant's recommendations for the various IM PA tool and display features. The Lateral Deviation results are discussed in Section 5.6. However, controller recommendations regarding the individual Lateral Monitoring display features are still summarized here.

### 5.5.6.1 Monitoring

At the end of Day 2 (QT3), after experiencing the nominal scenarios across all IM PA Tool and monitor configurations, controllers were asked: **what combination of tools would you recommend for the IM PA Monitor controller?** Participants selected [Always On / User Toggleable / Not Needed] for each element.

Figure 5-69 shows the number of participant responses for each type of recommendation for each IM PA Tool and display feature for the IM PA Monitor controller. The left column for each element consists of TRACON controller responses and the right column is the Tower controller responses. One participant selected both User Toggleable and Not Needed for several elements; this is therefore shown as a separate category.



**Figure 5-69. Monitoring Tool Recommendations**

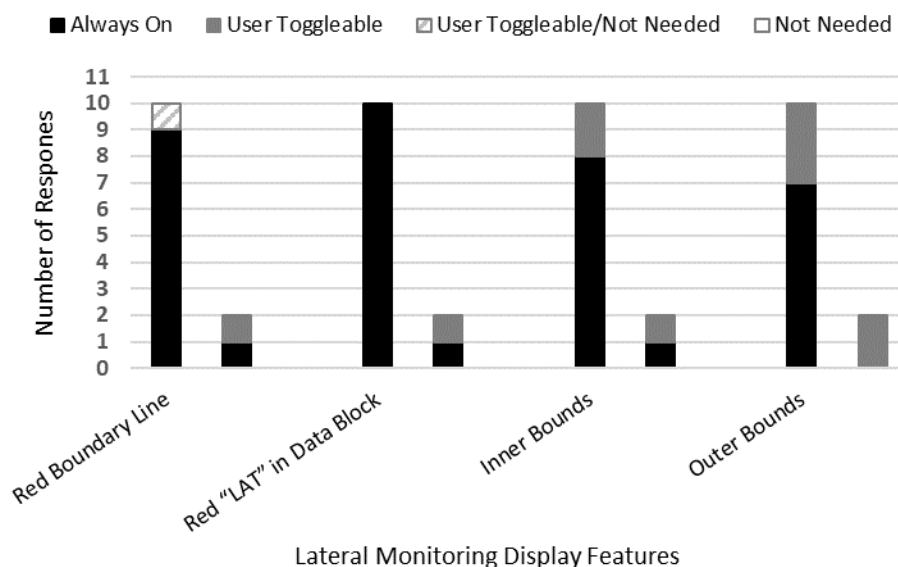
All (100%) TRACON controller participants responded that the CSL and WSL Lines should always be on. A majority (90%) responded that the Predictive and Caution Alerts should also always be on. Half (50%) felt the WSL-P should always be on and half felt that it should be user toggleable. Only half (50%) responded that the various data block IM PA features should either always be on or user toggleable. Responses were more variable for the necessity of the other elements. As described in Section 5.5.5, the majority of controllers disagreed the Monitor controller should be provided an IM Spacing List, though it was suggested in Section 5.2.7 that some information in the list, such as the Assigned Spacing Goal, could be provided in the IM Trail Aircraft’s data block.

At the end of Day 2 (QT3), a majority (80%) of TRACON controller responses suggested that the Inner and Outer Lateral Bounds should either be should either always be on or be user toggleable. These ratings were made before the participants experienced the Day 3 Lateral Deviation scenarios. Therefore, after the Lateral Deviation scenarios were complete (QT7), controllers were asked: **In terms of handling lateral deviations, what combination of tools would you recommend for the IM PA Monitor controller?** Participants selected [Always On / User Toggleable / Not Needed] for the following four features:

- Exceedance Warning: Boundary Line Color Line Change to Red
- Exceedance Warning: Red “LAT” in the data block
- Inner Bounds
- Outer Bounds

Figure 5-70 shows the number of participant responses for each type of recommendation for each Lateral Monitoring display feature for the IM PA Monitor controller. The left column for

each element consists of TRACON controller responses and the right column is the Tower controller responses. One participant selected both User Toggleable and Not Needed for several elements; this is therefore shown as a separate category.



**Figure 5-70. Lateral Monitoring Tool Recommendations**

After experiencing the Lateral Deviation scenarios, the number of TRACON controllers that felt the Lateral Boundaries should always be displayed increased by 10-20%. The majority of controllers felt the Inner Boundary should always be displayed (80%) and the Outer Boundary should always be displayed (70%). The rest felt the boundaries should be user toggleable. There were no instances of “Not Needed.”

For the two features related to the Exceedance Warning, all (100%) TRACON controllers thought the red “LAT” in the data block should always be displayed. A majority (90%) thought the Boundary Line Color Change to Red should always occur; however, one controller thought that it was not needed/should be user toggleable.

In the comments, two controllers recommended that for an Exceedance Warning, the entire data block of the deviating aircraft should turn red. Controllers also made the following comments with respect to the Lateral Boundaries:

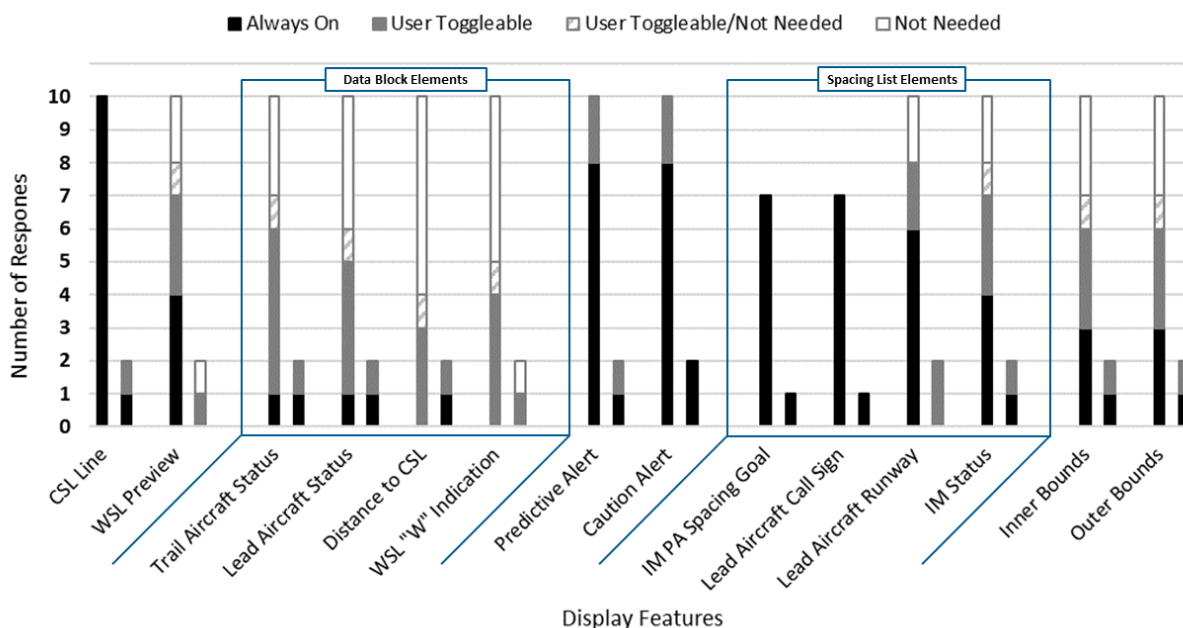
- (NCT) Lateral bounds not needed when monitoring from standard scope display since they are so hard to see inside them.
- (Non-NCT TRACON) Lateral bounds work great on 4:1 aspect ratio, but clutter final when on regular aspect.

### 5.5.6.2 IM Clearance Completion

At the end of Day 2 (QT3), after experiencing all nominal scenarios, controllers were asked a similar question: **what combination of tools would you recommend to help the Final**

**controller complete the IM Clearance?** Participants selected [Always On / User Toggleable / Not Needed] for each element.

Figure 5-71 shows the number of participant responses for each type of recommendation for each IM PA Tool and display feature for the IM PA Final controller. The left column for each element consists of TRACON controller responses and the right column is the Tower controller responses. One participant selected both User Toggleable and Not Needed for several elements; this is therefore shown as a separate category. The WSL Line was not included as it never applied in Final controller airspace.



**Figure 5-71. IM Clearance Completion Tool Recommendations**

*Note: The Week 1 controller questionnaires inadvertently omitted the IM PA Spacing Goal and Lead Aircraft Call Sign features. Therefore, only eight responses are shown for these features instead of twelve.*

All (100%) TRACON controller participants responded that the CSL Line should always be on. A majority (70%) of responses suggested that the WSL-P should either always be on or be user toggleable. A majority (80%) responded that the Predictive and Caution Alerts should always be on and the others responded that it should be user toggleable.

All (100%) TRACON controllers responded that the IM PA Spacing Goal and Lead Aircraft Call Sign should always be on. A majority (80%) responded that the Lead Aircraft Runway should either always be on or be user toggleable. A majority (70%) responded that IM Status (in the Spacing List) should either always be on or be user toggleable. This was higher than the responses to the IM Lead and IM Trail Aircraft Status indicators in the data blocks. Only a minority of controllers responded that the Distance to the CSL (30%) and WSL "W" (40%) should be user toggleable. The rest responded that they were not needed.

A majority (60%) of responses suggested that the Inner and Outer Lateral Bounds should either always be on or be user toggleable. These features are discussed further in Section 5.6. Responses were more variable regarding the necessity of the other elements.

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At the end of Day 2 (QT3), controllers were also asked if **the usefulness of any of the tools depend on whether there was single monitor for both approaches, or separate monitors for each approach?** All participants (n=12) answered “No.”

### 5.5.7 Other IM PA Tool Comments

The following is a collection of other selected comments made by the controller participants with respect to the IM PA Tools. Given their specific experience in the areas being simulated, NCT responses are specifically identified. Non-NCT TRACON and Tower responses are thus also individually identified.

- (NCT) I relied on the IM PA automation and trusted it, but could not verify because the aircraft were already much closer than standard separation.
- (Non-NCT TRACON) I think the best experience was with all tools available turned on. With select tools off, the scenarios were still easily workable, but the extra tools provide good trend data and overall improved awareness.
- (Non-NCT TRACON) The WSL did advise when I need to terminate an approach but did not provide a good advance notice.
- (Non-NCT TRACON) Situational awareness may be increased even more if the gray line [WSL-P] was there the whole time.
- (Non-NCT TRACON) Third line and wake preview lines are better than without. Not having the gray wake line hinders overall awareness. [WSL-P Only] I think I still had enough awareness but the numbers not being in the data block takes away a measure of awareness.
- (Non-NCT TRACON) Distance processing on CSL and WSL in data block not necessary for trailing aircraft unless it goes into alert status.
- (NCT) The CSL data turning color really caught my attention better than the line turning color. Don't care to have either on but they should pop up when it goes into an alert status.
- (NCT) The CSL line isn't that helpful but the data block changing color is more helpful and noticeable.
- (TRACON/NCT) Spacing list should show all aircraft not just who can play, put (non-pair with aircraft on 28R final) this will allow controller to know right away instead of searching for aircraft pair that they don't have.

## 5.6 Results Topic 5: Lateral Deviations

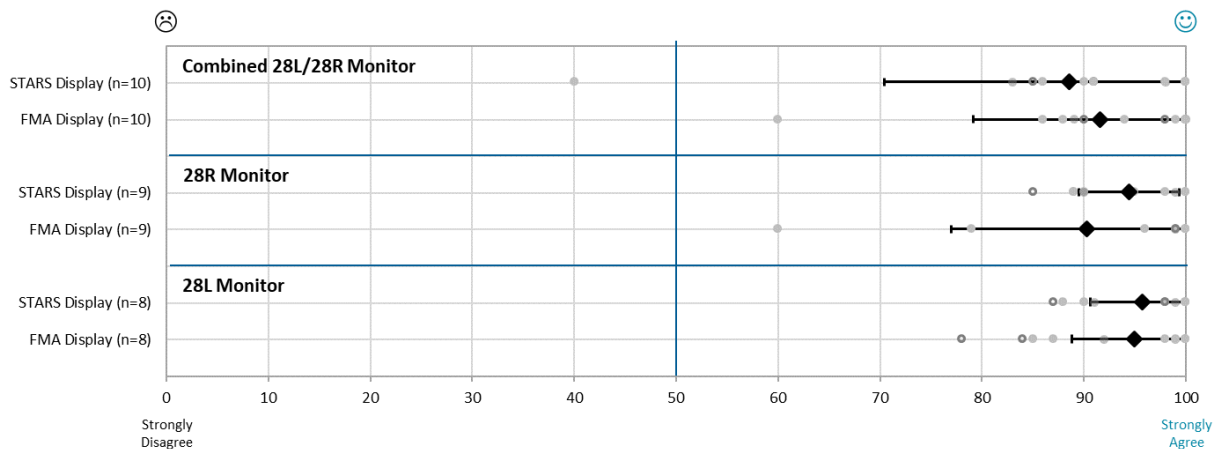
As described in Sections 4.5.4 and 4.5.6.6, a portion of the evaluation on Day 3 involved introducing lateral deviations to examine the acceptability of the monitoring configurations and effectiveness of the IM PA Tools in these rare, off-nominal conditions. This included determining to what degree will controllers want to detect developing deviations before a Lateral Boundary is crossed, whether a 4:1 aspect ratio display is needed, especially with only an Exceedance Warning (no Lateral Predictive Alert) with a tighter Lateral Boundary size (ILS versus 500 ft). All of the IM PA-related tools described previously were available to the Monitor controllers for these scenarios. The Final controller position was not evaluated for these conditions and unless otherwise noted, the results in this section are in response to the Lateral Deviation scenarios only.

### 5.6.1 Workload Acceptability

At the end of each Lateral Deviation scenario (QT6), controllers were asked if **their workload was acceptable** in the scenario they just experienced. Their responses were examined with respect to monitor configuration and display type. Response Means and Standard Deviations are summarized in Table 5-60. Scale responses are shown in Figure 5-72. Some rows indicate n=9 and n=8 because not all Week 1 controllers experienced all scenarios (see Section 4.5.6.6).

**Table 5-60. Controller Responses to Acceptability of Overall Workload (Lateral Deviation Scenarios)**

	Display Type	
	STARS	FMA
<b><i>Combined 28L/28R Monitor</i></b>		
Sample Size (n)	10	10
<b>Mean (M)</b>	<b>88.6</b>	<b>91.6</b>
Standard Deviation (SD)	18.2	12.4
<b><i>28R Monitor</i></b>		
Sample Size (n)	9	9
<b>Mean (M)</b>	<b>94.4</b>	<b>90.3</b>
Standard Deviation (SD)	4.9	13.3
<b><i>28L Monitor</i></b>		
Sample Size (n)	8	8
<b>Mean (M)</b>	<b>95.8</b>	<b>95.0</b>
Standard Deviation (SD)	5.1	6.1



**Figure 5-72. My overall workload was acceptable for the scenario I just experienced. (Lateral Deviation Scenarios)**

Note: o indicates the Tower controller responses for reference. These are not included in the M and SD computations. Some rows indicate n=9 and n=8 because not all Week 1 controllers experienced all of the Lateral Deviation scenarios.

All (100%) TRACON controllers agreed their workload was acceptable across all display types and monitor configurations, except for one. This controller disagreed for the Combined Monitor configuration with the STARS display and commented “Breaking out a 28L aircraft blundering right requires two simultaneous transmissions.” Despite this, no practical difference in workload acceptability was observed among any of the display type and monitor configurations.

Other selected open-ended comments for this question included:

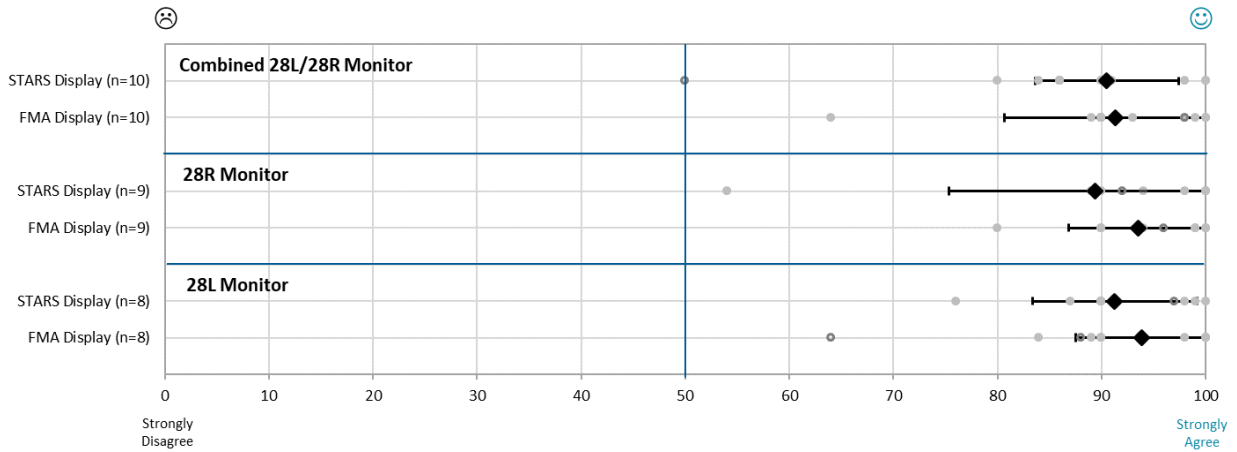
- (NCT / 28R/FMA) Two blundering at once was work intensive.
- (Non-NCT TRACON / 28R/FMA) Multiple alerts simultaneously make it impossible to talk to all involved aircraft in a timely manner.

## 5.6.2 Separation Assessment

At the end of each Lateral Deviation scenario (QT6), controllers were asked if they were **confident that I could assess whether separation would be maintained between the IM Trail Aircraft and their Lead aircraft** in the scenario they just experienced. Their responses were examined with respect to monitor configuration and display type. Response Means and Standard Deviations are summarized in Table 5-61. Scale responses are shown in Figure 5-73. Some rows indicate n=9 and n=8 because not all Week 1 controllers experienced all scenarios (see Section 4.5.6.6).

**Table 5-61. Controller Responses to Separation Assessment (Lateral Deviation Scenarios)**

	Display Type	
	STARS	FMA
<b>Combined 28L/28R Monitor</b>		
Sample Size (n)	10	10
<b>Mean (M)</b>	<b>90.5</b>	<b>91.3</b>
Standard Deviation (SD)	6.9	10.6
<b>28R Monitor</b>		
Sample Size (n)	9	9
<b>Mean (M)</b>	<b>89.3</b>	<b>93.6</b>
Standard Deviation (SD)	14.0	6.7
<b>28L Monitor</b>		
Sample Size (n)	8	8
<b>Mean (M)</b>	<b>91.3</b>	<b>93.9</b>
Standard Deviation (SD)	7.9	6.3



**Figure 5-73. I was confident that I could assess whether separation would be maintained between the IM Trail Aircraft and their Lead aircraft. (Lateral Deviation Scenarios)**

Note: o indicates the Tower controller responses for reference. These are not included in the M and SD computations. Some rows indicate n=9 and n=8 because not all Week 1 controllers experienced all of the Lateral Deviation scenarios.

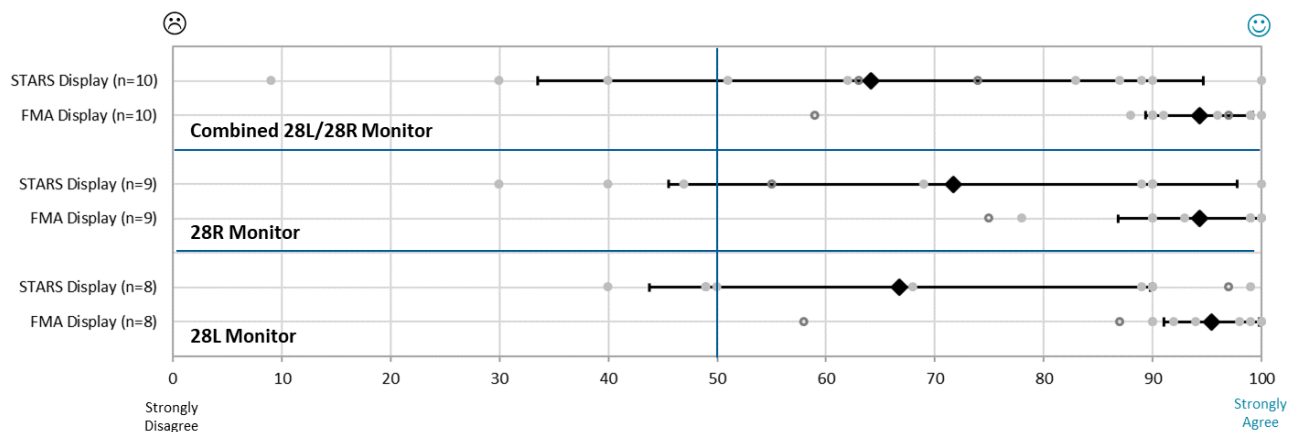
All (100%) TRACON controllers agreed they were confident they could assess whether separation would be maintained between the IM Trail Aircraft and their Lead aircraft for all display type and monitor configurations. No practical difference in workload acceptability was observed.

### 5.6.3 Lateral Boundaries Display Implementation

At the end of each Lateral Deviation scenario (QT6), controllers were asked if they **could easily assess whether aircraft involved in a PA operation were operating within their Lateral Boundaries** in the scenario they just experienced. Their responses were examined with respect to monitor configuration and display type. Response Means and Standard Deviations are summarized in Table 5-62. Scale responses are shown in Figure 5-74. Some rows indicate n=9 and n=8 because not all Week 1 controllers experienced all scenarios (see Section 4.5.6.6).

**Table 5-62. Controller Responses to Lateral Boundary Assessment**

	Display Type	
	STARS	FMA
<b>Combined 28L/28R Monitor</b>		
Sample Size (n)	10	10
<b>Mean (M)</b>	<b>64.1</b>	<b>94.3</b>
Standard Deviation (SD)	30.6	4.9
<b>28R Monitor</b>		
Sample Size (n)	9	9
<b>Mean (M)</b>	<b>71.7</b>	<b>94.3</b>
Standard Deviation (SD)	26.1	7.5
<b>28L Monitor</b>		
Sample Size (n)	8	8
<b>Mean (M)</b>	<b>66.8</b>	<b>95.4</b>
Standard Deviation (SD)	23.0	4.4



**Figure 5-74. In this scenario, I could easily assess whether aircraft involved in a PA operation were operating within their Lateral Boundaries.**

Note: **o** indicates the Tower controller responses for reference. These are not included in the M and SD computations. Some rows indicate n=9 and n=8 because not all Week 1 controllers experienced all of the Lateral Deviation scenarios.

All (100%) TRACON controllers agreed they could easily assess whether aircraft involved in a PA operation were operating within their Lateral Boundaries for every monitor configuration with the FMA display. With the STARS display, however, a majority agreed for the Combined Monitor (70%), 28R Monitor (67%), and 28L Monitor (50%). Though responses suggest the lateral monitoring task is possible with both display types across all configurations, means were higher and variability was lower for the FMA display.

As described in Section 5.8.5, a two-factor, repeated measures ANOVA test on this data found a significant difference with respect to display type. No difference was observed with respect to monitor configuration, nor were there any interaction effects. This suggests controllers found that the FMA display aided in their Lateral Boundaries Assessment, but that the assessment was not affected by the monitor configuration.

Selected open-ended comments for this question included:

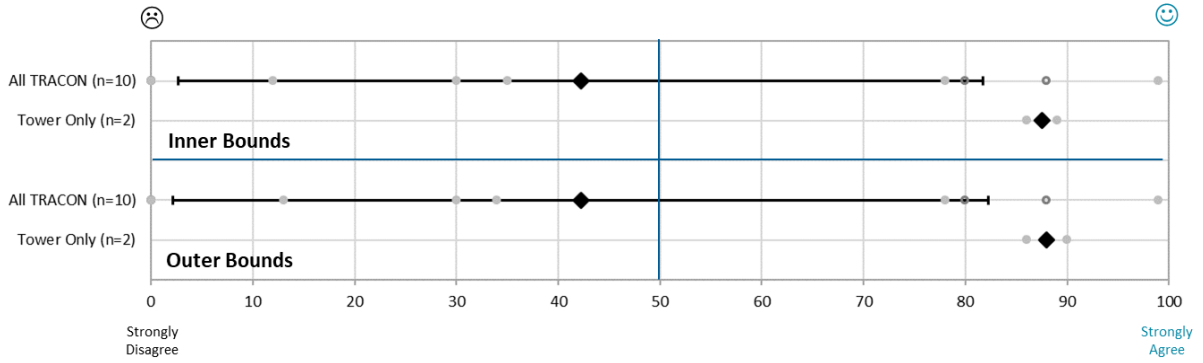
- (NCT / Combined/FMA) In comparison to STARS, 4:1 was more effective at displaying movement in the lateral confines.
- (NCT / 28R/STARS) It's difficult to observe movement within the lateral confines of the course windows. It's easier to determine movement on the 4:1 scope.
- (NCT / 28L/STARS) I wouldn't say easily, but you can see.
- (Non-NCT TRACON / 28L/FMA) Was more evident with this aspect ratio. I even noticed an aircraft off course on the other final before it alerted.
- (Non-NCT TRACON / Combined/FMA) 4:1 ratio was much better, you could see aircraft start to come off center and could correct if allowed.
- (Non-NCT TRACON / Combined/STARS) Both sides of 28L primary target are outside of lateral bounds. Extremely difficult to tell if they are starting to deviate until alert goes off.
- (Non-NCT TRACON / Combined/STARS) The lateral bounds are very narrow and the width of the target fills the entire bounds. Very difficult to spot impending deviation. 4:1 aspect ratio made it much easier to see.

-----

At the end of Day 2 (QT3), after experiencing the nominal scenarios across all IM PA Tool and monitor configurations, controllers were asked **if the Inner and Outer (Lateral) Bounds were useful for the overall IM PA monitoring task**. Responses are shown for all TRACON (NCT and non-NCT combined) and Tower Only. Response Means and Standard Deviations are summarized in Table 5-63. Scale responses are shown in Figure 5-75.

**Table 5-63. Controller Responses to Lateral Boundary Usefulness**

	Participant Experience	
	TRACON	Tower
<b>Inner Bounds</b>		
Sample Size (n)	10	2
Mean (M)	42.2	87.5
Standard Deviation (SD)	39.5	-
<b>Outer Bounds</b>		
Sample Size (n)	10	2
Mean (M)	42.2	88
Standard Deviation (SD)	40.1	-



**Figure 5-75. The Inner and Outer (Lateral) Bounds were useful for the overall IM PA monitoring task.**

Note: o indicates NCT controller responses.

Responses were variable, but a majority (60%) of TRACON controllers disagreed the Inner (M=42.2; SD=39.5) and Outer (M=42.2; SD=40.1) Lateral Bounds were useful for the overall IM PA monitoring task. These ratings were provided before the Day 3 Lateral Deviation scenarios. However, at the end of Day 3 controllers were asked: **Does anything you’ve experienced today change any of your previous positions with respect to minimum IM PA information for monitoring?** Only one controller answered yes, but the associated comment was unrelated to the Lateral Boundaries.

### 5.6.4 Lateral Boundary Exceedance Warning

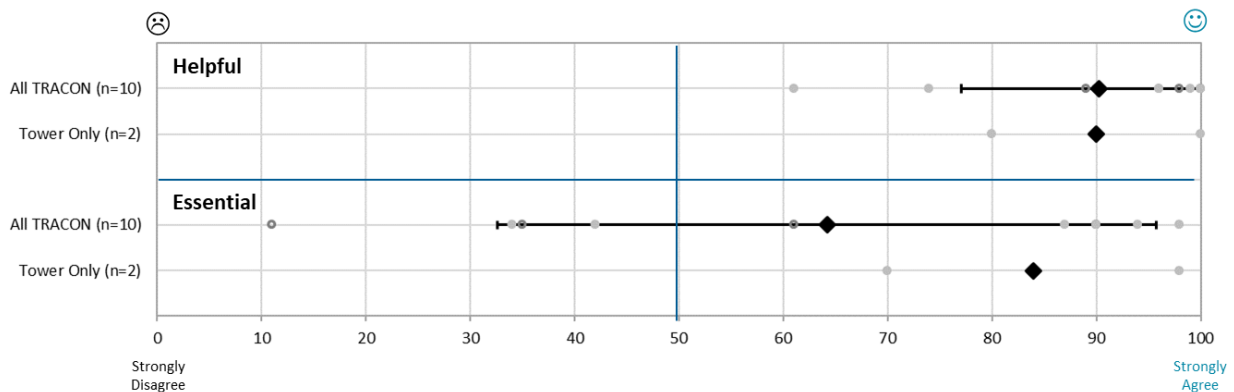
Unlike in the longitudinal case, a lateral deviation alert only occurred once an aircraft actually crossed a Lateral Boundary. There was no predictive-type alert to provide advance notice that an aircraft was likely to cross a boundary. Therefore, after the Lateral Deviation scenarios were complete (QT7), controllers were asked if:

- Advance notice of an impending exceedance of the lateral bounds would have been **helpful**.
- Advance notice of an impending exceedance of the lateral bounds would have been **essential**.

Responses are shown for all TRACON (NCT and non-NCT combined) and Tower Only. Response Means and Standard Deviations are summarized in Table 5-64. Scale responses are shown in Figure 5-76.

**Table 5-64. Controller Responses to Helpfulness of Lateral Boundary Crossing Advance Notice**

	Participant Experience	
	TRACON	Tower
<b>Helpful</b>		
Sample Size (n)	10	2
Mean (M)	90.3	90.0
Standard Deviation (SD)	13.3	-
<b>Essential</b>		
Sample Size (n)	10	2
Mean (M)	64.2	84.0
Standard Deviation (SD)	31.6	-



**Figure 5-76. Advance notice of an impending exceedance of the lateral bounds would have been [helpful / essential].**

Note: o indicates NCT controller responses.

All (100%) TRACON controllers agreed advance notice of an impending exceedance of the Lateral Boundaries would have been helpful (M=90.3; SD=13.3). A majority (60%) agreed it would have been essential (M=64.2; SD=31.6).

As described in Section 5.8.5, a paired-sample T-Test analysis found a significant difference in controller agreement response. Though controllers agreed for both, stronger agreement was observed for a predictive-type alert for lateral deviations being only helpful.

Open-ended comments for this question included:

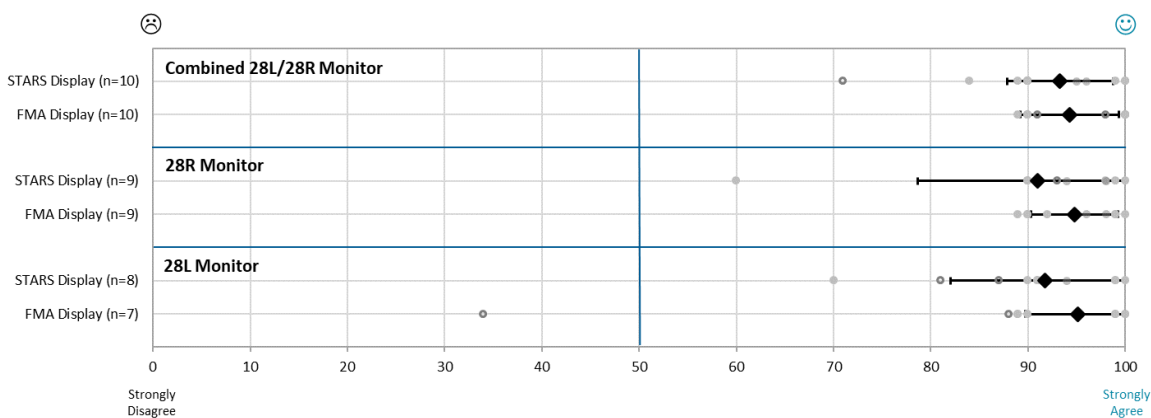
- (Non-NCT TRACON) Maybe. Too much info can sometimes divert our attention away from something that may take more precedence.
- (NCT) Absolutely, it would also give a chance for the controller to advise the pilot to correct.
- (Non-NCT TRACON) 4:1 aspect ratio did allow time for me to notice impending deviation and I found this very useful. On regular STARS display this was not possible and led to no advance warning of a deviation.
- (NCT) With 4:1 ratio it's easy to see them start to blunder, without 4:1 its harder.
- (Non-NCT TRACON) I think that due to the proximity of the final approach courses, some sort of advance notice of an impending deviation would be essential to ensure a safe operation.
- (Non-NCT TRACON) If I see it developing, I have very few options for keeping aircraft within limits, so I probably won't take action anyway until required.

-----

At the end of each Lateral Deviation scenario (QT6), controllers were asked if **the warning (red) alert was noticeable enough such that I became aware of it without undue delay** in the scenario they just experienced. Their responses were examined with respect to monitor configuration and display type. Response Means and Standard Deviations are summarized in Table 5-65. Scale responses are shown in Figure 5-77. Some rows indicate n=9 and n=8 because not all Week 1 controllers experienced all scenarios (see Section 4.5.6.6). The 28L Monitor FMA display has n=7 because one of the controllers left the question blank.

**Table 5-65. Controller Responses to Salience of Exceedance Warning**

	Display Type	
	STARS	FMA
<b>Combined 28L/28R Monitor</b>		
Sample Size (n)	10	10
<b>Mean (M)</b>	<b>93.3</b>	<b>94.3</b>
Standard Deviation (SD)	5.5	5.1
<b>28R Monitor</b>		
Sample Size (n)	9	9
<b>Mean (M)</b>	<b>91.0</b>	<b>94.8</b>
Standard Deviation (SD)	12.3	4.5
<b>28L Monitor</b>		
Sample Size (n)	8	7
<b>Mean (M)</b>	<b>91.8</b>	<b>95.1</b>
Standard Deviation (SD)	9.7	5.5



**Figure 5-77. The warning (red) alert was noticeable enough such that I became aware of it without undue delay.**

Note: o indicates the Tower controller responses for reference. These are not included in the M and SD computations. Some rows indicate n=9 and n=8 because not all Week 1 controllers experienced all of the Lateral Deviation scenarios.

All (100%) TRACON controllers agreed the warning (red) alert was noticeable enough such that they became aware of it without undue delay for all display type and monitor configurations. No practical difference in workload acceptability was observed. Selected open-ended comments for this question included:

- (Non-NCT TRACON / 28L/STARS) The alert was noticeable, but which aircraft it applied to was less obvious. Maybe the entire call sign changes to red? [Note: Several controllers suggested that the blundering aircraft's entire data block should turn red.]

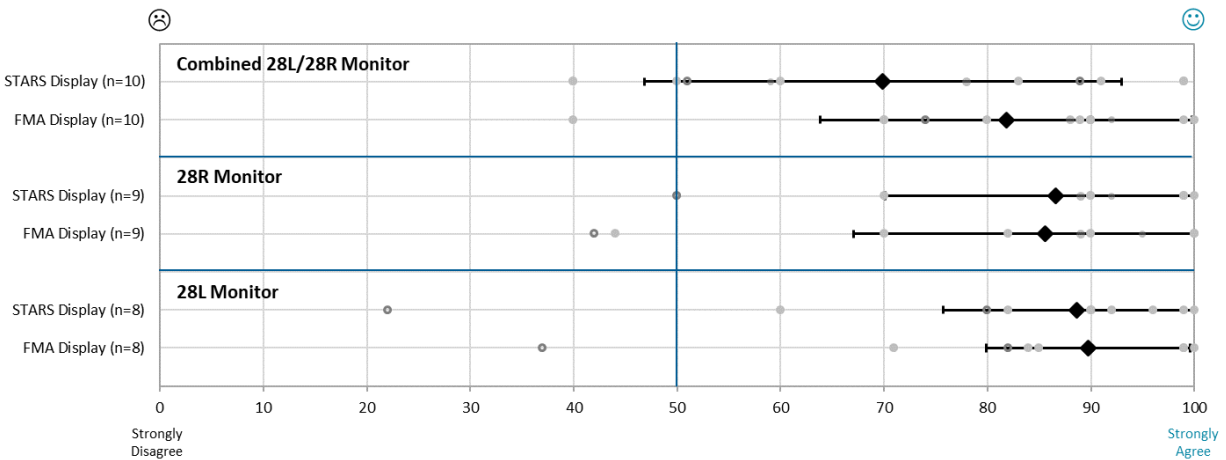
- (NCT / Combined/STARS) Would be nice if aircraft that blundered the whole data block turned red not just "LAT" in line zero with up to 4 aircraft on that runway it would stand out that much faster.
- (NCT / 28R/STARS) When the line was already red for the first blunder, it took me an extra second to notice another guy was blundering.
- (Tower / Combined/STARS) The first violator that was short final took me more time to locate because the red vertical guidance line was more distracting than helpful.
- (Non-NCT TRACON / 28L/FMA) Very noticeable. When two alert simultaneously, it took slightly more time to discern who was blundering and who to talk to first.
- (Tower / 28L/FMA) The ILS line lit was obvious, identifying the involved aircraft was less so.

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At the end of each Lateral Deviation scenario (QT6), controllers were asked if they **had sufficient time and situational awareness to choose and execute appropriate corrective action once the warning (red) alert occurred** in the scenario they just experienced. Their responses were examined with respect to monitor configuration and display type. Response Means and Standard Deviations are summarized in Table 5-66. Scale responses are shown in Figure 5-78. Some rows indicate n=9 and n=8 because not all Week 1 controllers experienced all scenarios (see Section 4.5.6.6).

**Table 5-66. Controller Responses to Timeliness of Exceedance Warning**

	Display Type	
	STARS	FMA
<b><i>Combined 28L/28R Monitor</i></b>		
Sample Size (n)	10	10
<b>Mean (M)</b>	<b>69.9</b>	<b>81.8</b>
Standard Deviation (SD)	23.0	18.0
<b><i>28R Monitor</i></b>		
Sample Size (n)	9	9
<b>Mean (M)</b>	<b>86.6</b>	<b>85.6</b>
Standard Deviation (SD)	16.4	18.5
<b><i>28L Monitor</i></b>		
Sample Size (n)	8	8
<b>Mean (M)</b>	<b>88.6</b>	<b>89.8</b>
Standard Deviation (SD)	12.9	9.9



**Figure 5-78. In this scenario, I felt I had sufficient time and situational awareness to choose and execute appropriate corrective action once the warning (red) alert occurred.**

Note: o indicates the Tower controller responses for reference. These are not included in the M and SD computations. Some rows indicate n=9 and n=8 because not all Week 1 controllers experienced all of the Lateral Deviation scenarios.

All (100%) TRACON controllers agreed they had sufficient time and situational awareness to choose and execute appropriate corrective action once the warning (red) alert occurred for both display types in the 28L position. A majority (89%) of TRACON controllers agreed for both display types in the 28R position. For the Combined Monitor configuration, a majority (70%) agreed for the STARS display and a majority (90%) also agreed for the FMA display.

Overall, no practical differences in exceedance warning timeliness were observed for all display type and monitor configurations, though the lower mean and higher response variability of the Combined Monitor position with the STARS display may have been a more challenging condition than the others.

Selected open-ended comments for this question included:

- (Tower / Combined/FMA) Not much time when the 28L guy blunders right. My situational awareness was ok, but no time to make appropriate transmissions & get readbacks. I see this problem being alleviated w/ split monitors.
- (Non-NCT TRACON / 28L/STARS) I pre-planned with the other monitor in case of a blunder situation into his final and I was able to see the a/c action and react properly, along with concurrent coordination.
- (Non-NCT TRACON / 28R/STARS) STARS display of lateral bounds is too small to notice any impending breach of boundary. 4:1 aspect ratio would improve this.

### 5.6.5 Lateral Deviation Response Times

As noted in Section 4.5.7.2, the objective data that was collected included controller PTT times, aircraft state, and Lateral Boundary exceedance. This data was used in the analysis of the

Lateral Deviation scenarios to examine whether controller monitor configuration or display type had an effect on controller response time to an aircraft crossing a Lateral Boundary.

The PTT data caveats described in Section 5.1.2 apply here. In sum, if the Local controller or pseudopilot was talking on the frequency, participants could not break in to override. They were, however, told to still click their handsets when they wanted to speak. The first “click” that was recorded after an event of interest was used as a proxy for the controller response time to resolve a situation. Though in the majority of cases clicks were observed shortly after a lateral deviation, there were three observed occasions of longer reaction times (i.e., 11-16 sec versus typically < 5 sec) after a Lateral Boundary crossing. Unfortunately, the limitations in the audio system make it impossible to conclusively determine if these longer times reflected controller situation awareness or frequency congestion. As these instances could not conclusively be determined to be a result of this simulation limitation, they were not removed from the analysis data.

A summary of the average Lateral Boundary crossing PTT response time data is shown in Table 5-67. The response time was defined as the time between an aircraft crossing the lateral boundary (triggering the Exceedance Warning) and the next PTT click. The data combines the two types of deviations (Type A Lead/Sharp versus Type B Trail/Shallow – see Section 4.5.5.3). During data collection, some controllers were observed to have intervened with deviating aircraft *before* they crossed the lateral boundary and triggered the Exceedance Warning. These cases were not included in the response time data in Table 5-67, but are examined separately later in this section. These cases were the primary reason for the different “n” values; however, data collection issues also resulted in some response times not being recorded for some scenarios.

**Table 5-67. Average Controller PTT Response Time (sec) After Lateral Boundary Crossings**

	Display Type	
	STARS	FMA
<b><i>Combined Monitor</i></b>		
Sample Size (n)	14	13
<b>Mean (M)</b>	<b>2.4 sec</b>	<b>3.1 sec</b>
Standard Deviation (SD)	1.2	5.5
<b><i>Separate Monitors</i></b>		
Sample Size (n)	14	12
<b>Mean (M)</b>	<b>2.1 sec</b>	<b>2.3 sec</b>
Standard Deviation (SD)	1.3	3.0

The HITL data shows that on average, controllers responded (via a PTT click) to Lateral Boundary crossings within approximately 2-3 seconds. Note this does not suggest controllers first *noticed* the boundary crossing 2-3 seconds after it occurred; these values only represent

the time between the Exceedance Warning display and the next PTT “click” of the participant’s handset.

To examine whether monitor configuration or display type had an effect on Lateral Boundary crossing response times, a two-factor, repeated measures ANOVA test was performed. Due to the unbalanced sample sizes, the ANOVA was performed via a regression analysis with the probability of finding an effect when there was none, alpha ( $\alpha$ ), set to 0.05. The results are shown in Table 5-68.

**Table 5-68. Controller PTT Response Time After Lateral Boundary Crossings: ANOVA Results**

	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>p-value</i>	<i>Significant?</i>
<b>Monitor Configuration</b>	3.58	1	3.58	0.35	0.56	no
<b>Display Type</b>	2.26	1	2.26	0.22	0.64	no
<b>Interactions</b>	1.24	1	1.24	0.12	0.73	no
Within	506.10	49	10.33			
Total	513.13	52	9.87			

The statistical analysis results from the simulation suggest controller response time to lateral deviations was not different as an effect of monitor configuration ( $p = 0.56$ ) or display type ( $p = 0.64$ ), nor were there any interaction effects ( $p = 0.73$ ).

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As noted earlier, some controllers were observed to have intervened with deviating aircraft *before* they crossed the lateral boundary and triggered the Exceedance Warning. Controllers usually did not have enough time to watch a Type A (sharp) deviation develop and the Exceedance Warning was often their first indication of the deviation. However, controllers had more time to see a Type B (shallow) deviation developing. The frequency of interventions before the Exceedance Warning is shown in Table 5-69. In this case, the PTT response time was defined as the difference in time between when the aircraft first started its lateral deviation to the time of the next controller PTT click. Due to the differences in time available to controllers to respond, the results are shown separately for Type A and Type B deviations.

**Table 5-69. Average Controller PTT Response Time (sec) for Interventions Before Lateral Boundary Exceedance Warning**

	Display Type / Deviation Type			
	Type A (Sharp) Deviation		Type B (Shallow) Deviation	
	STARS	FMA	STARS	FMA
<b>Combined Monitor</b>				
Sample Size (n)	0	1	1	0
Mean (M)	-	4.0 sec	3.0 sec	-
Standard Deviation (SD)	-	-	-	-
<b>Separate Monitors</b>				
Sample Size (n)	0	1	4	7
Mean (M)	-	5.0 sec	35.8 sec	28.3 sec
Standard Deviation (SD)	-	-	1.0	11.0

The small number of occurrences in which a controller intervened with a deviating aircraft *before* the Exceedance Warning was displayed precludes a statistical analysis. However, it is notable that the majority (11/14) of occurrences were with the Separate Controller configuration with Type B (shallow) deviations. A closer examination of the underlying data showed that the majority (10/14) of these overall cases occurred with the same traffic file (O). In this traffic file, the shallow deviation of a Trail Aircraft began shortly before the sharp deviation of the Lead Aircraft in a different pair. However, the Exceedance Warning of the (shallow) Trail occurred *after* the Exceedance Warning of the (sharp) Lead. It seems likely that some controllers noticed the (shallow) deviating Trail Aircraft but waited to take action. However, once the Exceedance Warning was displayed for the Lead, some controllers in this scenario may have then also decided to then intervene with the slowly-deviating Trail instead of waiting for it to cross the Lateral Boundary.

It is also notable that these cases occurred more often in the Separate Monitor configuration (12/14) versus Combined (2/14). This is likely due to the difference in the timing of the communications between the configurations, especially with the scenarios involving traffic file O, which comprised ten of these 14 cases. The timing of these O scenarios was such that that the shallow-deviating Trail crossed its Lateral Boundary and triggered its Exceedance Warning shortly after the Lead Aircraft (of a different pair) triggered its Exceedance Warning. In the Combined Monitor configuration, the controller typically contacted the sharply-deviating Lead Aircraft first to turn it back, then contacted its Trail Aircraft to instruct its breakout. This was given higher priority than the shallow-deviating Trail, and so it then crossed its Lateral Boundary and triggered the Exceedance Alert before the controller could contact it. In the Separate Monitor configuration, however, the 28R controller was not required to contact the deviating Lead Aircraft. Therefore, there was more time for the 28R controller to break out the Trail from

the deviating lead and then break out the shallow-deviating Trail before it actually crossed its Lateral Boundary.

As noted in Section 4.5.5.3, the O scenario was deliberately designed as an extreme case. In real world operations, a near-simultaneous lateral deviation of multiple aircraft on CSPR is expected to occur rarely, if at all. An investigation of over 1.8 million approach paths did not detect any (Eckstein, Massimini, McNeill, & Niles, 2012), nor was there a record of any in an examination of 7790 go-arounds that were logged over multiple years by NCT (Stassen, Domino, Hefley, & Weitz, 2019). Still, this was included in the simulation to stress the display features and probe for a potential failure point. The findings here, though not conclusive, may suggest controller behavioral differences with respect to intervening with aircraft deviating laterally may only be apparent in the most extreme situations. When this occurs, however, the findings are consistent with a general expectation that controllers may be able to take action more quickly when only having responsibility for one arrival.

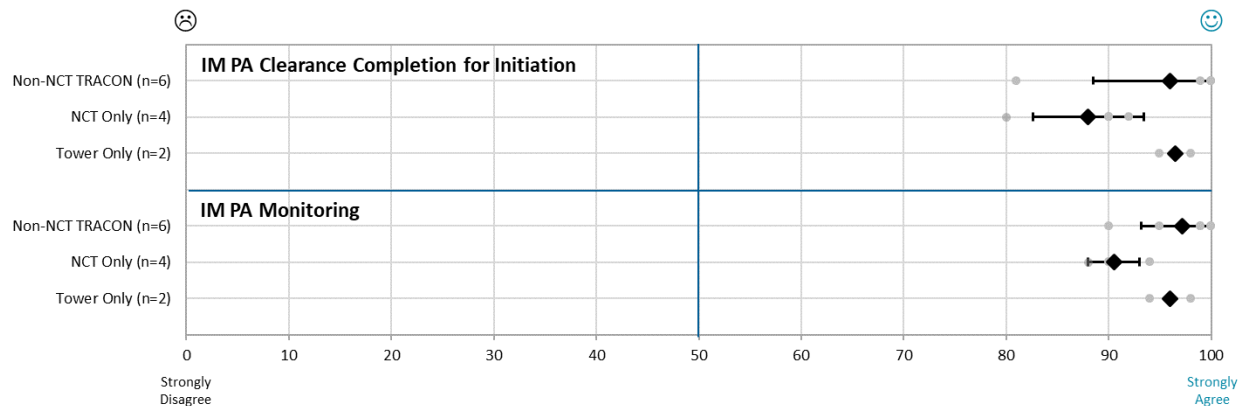
## 5.7 Simulation Evaluation

At the end of Day 3 (QT8) controllers were asked about their overall experience in the simulation and its effectiveness in evaluating IM PA. This section summarizes their responses.

Controllers were first asked if **the training I received was adequate for the IM Clearance Completion and IM PA monitoring tasks**. Given their specific experience in the areas being simulated, NCT responses are shown separately. Non-NCT and Tower responses are thus also shown as separate categories. Response Means and Standard Deviations are summarized in Table 5-70. Scale responses are shown in Figure 5-79.

**Table 5-70. Controller Responses to Adequacy of Simulation Training by Task**

	Participant Experience		
	Non-NCT	NCT	Tower
<b><i>IM Clearance Completion</i></b>			
Sample Size (n)	6	4	2
<b>Mean (M)</b>	<b>96.0</b>	<b>88.0</b>	<b>96.5</b>
Standard Deviation (SD)	7.5	5.4	-
<b><i>IM PA Monitoring</i></b>			
Sample Size (n)	6	4	2
<b>Mean (M)</b>	<b>97.2</b>	<b>90.5</b>	<b>96.0</b>
Standard Deviation (SD)	4.0	2.5	-



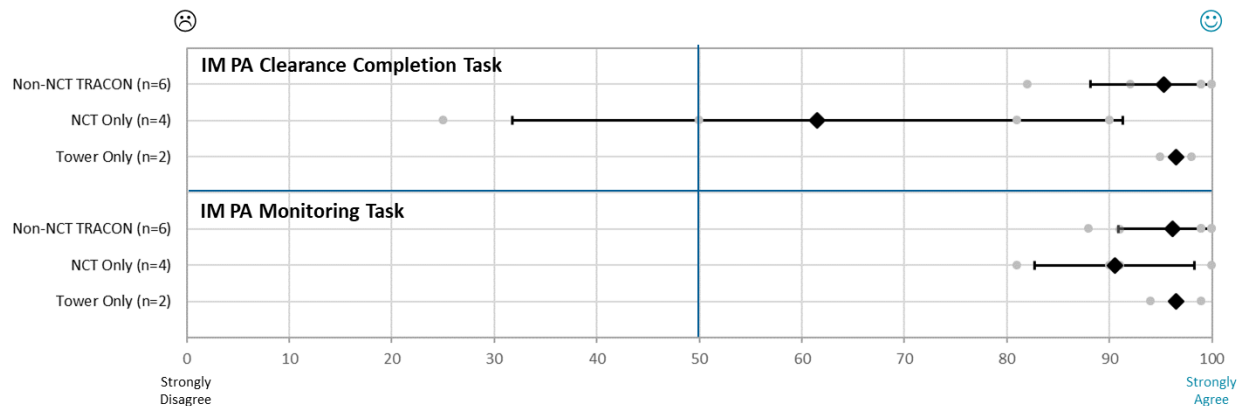
**Figure 5-79. The training I received was adequate.**

All controllers responded that the training they received was adequate for both tasks.

Controller participants were also asked whether **the overall activity was effective as a context for evaluating the IM Clearance Completion task and IM PA monitoring task**. Given their specific experience in the areas being simulated, NCT responses are shown separately. Non-NCT and Tower responses are thus also shown as separate categories. Response Means and Standard Deviations are summarized in Table 5-71. Scale responses are shown in Figure 5-80.

**Table 5-71. Controller Responses to Simulation Effectiveness by Task**

	Participant Experience		
	Non-NCT	NCT	Tower
<b><i>IM Clearance Completion</i></b>			
Sample Size (n)	6	4	2
Mean (M)	<b>95.3</b>	<b>61.5</b>	<b>96.5</b>
Standard Deviation (SD)	7.2	29.8	-
<b><i>IM PA Monitoring</i></b>			
Sample Size (n)	6	4	2
Mean (M)	<b>96.2</b>	<b>90.5</b>	<b>96.5</b>
Standard Deviation (SD)	5.3	7.8	-



**Figure 5-80. The overall activity was effective as a context for evaluating the IM Clearance completion task and the IM PA monitoring task.**

All controllers agreed the overall activity was effective as a context for evaluating the IM PA monitoring task. The majority (83%) agreed the simulation was effective for the IM Clearance completion task. One NCT controller neither agreed nor disagreed and commented that “Issuing the clearance did not seem realistic.” Another NCT controller disagreed and commented: “IM PA initiation did not take into account how much workload the final controller is doing prior to issuing the instructions.”

Finally, at the end of Day 3, controllers were asked **if there was anything about the simulation that artificially affected using it as a context for evaluating IM PA operations.** Four (4) controllers answered “Yes,” seven (7) answered “No,” and one (1) did not provide a response. Selected comments included:

- One “Yes” comment: (NCT) Lack of practical scenarios in which vectoring and other events are taking place.
- One “Yes” comment: (TRACON) At first, too much speed control required to maintain separation between pairs that took focus off IM PA functionality. It did bring to light how easy/noticeable the alerts were while focused on other tasks.
  - Note: this was a Week 1 controller response. Scenarios were modified between Week 1 and Weeks 2-3 to reduce the need for this speed control.
- One “Yes” comment: (TRACON) No instant override makes some blunders and overtakes look even worse because of the delay in implementing controllers instructions.
- One “Yes” comment: (TRACON) I didn't feel like the aircraft speeds throughout the final approach were necessarily realistic.

## 5.8 Hypothesis Evaluations

As discussed in Section 3.3, six research questions and seven hypotheses were defined prior to HITL data collection. This section consolidates and summarizes the findings relevant for each hypothesis. As needed, statistical tests were performed on the subjective questionnaire data to inform the hypothesis evaluation.

### 5.8.1 H1(RQ1): **Given an appropriate tool set, controllers will find it acceptable and feasible to monitor IM PA operations with respect to both minimum and maximum separation limits.**

This hypothesis was measured via responses to three questions related to monitoring comfort, separation assessment, and task acceptability. The first part of the hypothesis, acceptability, was measured by controller responses to the following Day 1-2 post-run (QT1) question: **Given the IM PA-related tools provided in this scenario, I was comfortable monitoring IM PA operations when both a CSL and WSL were active at the same time.** As described in Section 5.2.2, nearly all Week 2-3 TRACON controllers agreed they were comfortable monitoring IM PA operations with both limits at the same time for both the monitor configurations and IM PA Tools configurations. Only one controller neither agreed nor disagreed, and this was for the Separate 28R Monitor with IM PA Tools Off configuration.

To determine if this resulted in a statistically significant difference between controller responses for the On versus Off IM PA Tool configurations for the Separate 28R Monitor controller, a paired-sample T-Test analysis was run on the Week 2-3 TRACON controller agreement ratings for this question. The descriptive statistics (n, M, and SD) are shown in Table 5-4. The probability of finding an effect when there was none, alpha ( $\alpha$ ), was set to 0.05. The results of a two-tailed T-Test analysis failed to find statistical significance ( $p = 0.22$ ). This suggests no significant difference in strength of controller agreement between the two IM PA Tool configurations with respect to monitoring IM PA operations when both a CSL and WSL were active at the same time.

Acceptability was also measured by controller responses to the following Day 2 end (QT3) question: **The tasks required of each simulation position were acceptable.** As described in Section 5.2.5.2, nearly all TRACON controllers agreed for the positions that required IM Trail Aircraft Monitoring (Combined and Separate 28R). One controller neither agreed nor disagreed (for the Combined Monitor configuration).

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The second part of the hypothesis, feasibility, was measured by controller responses to the following Day 2 end (QT3) question: **Overall, I was confident that I could assess whether the separation between the IM Trail Aircraft and their Lead Aircraft would be maintained.** As described in Section 5.2.5, the majority (80%) of TRACON controllers agreed. This self-assessment was supported by the objective separation analysis in Section 5.2.5.2, which found only a single instance of a within-pair IM PA separation violation.

*Conclusion:* This hypothesis is supported by the simulation results. Overall, controllers found it acceptable and feasible to monitor IM PA operations with respect to both minimum and maximum separation limits. This did not appear to be affected by monitor configuration or IM PA Tools configuration.

### 5.8.2 H2(RQ2): Given an appropriate tool set, controllers will find it acceptable and feasible to provide PA separation with respect to separation values that change over the course of an approach.

Though not asked this question directly, controllers in every scenario experienced a CSL that changed in value over the course of an approach and a WSL that initially did not apply for certain aircraft (see Figure 4-6). Several questions were then related to their ability to provide separation with respect to these limits.

The first part of the hypothesis, acceptability, was measured by controller responses to the following Day 1-2 post-run (QT1) question: **I could easily assess whether the IM Trail Aircraft would remain behind the CSL during the approach.** As described in Section 5.5.3.1, All Week 2-3 TRACON controllers agreed for both monitor configurations and for All IM PA Tools On and All IM PA Tools Off.

The same question was asked with respect to the WSL: **I could easily assess whether the IM Trail Aircraft would remain forward of the WSL during the approach, when applicable.** Although, as described in Section 5.5.3.2, all Week 2-3 TRACON controllers agreed for the Combined Monitor position with IM PA Tools On, a majority (86%) agreed for the Combined Monitor position with IM PA Tools Off.

To examine whether there was a statistically significant difference between the CSL and WSL responses for this question, a three-factor ANOVA test was performed on the Week 2-3 TRACON controller post-run data with respect to safety limit (CSL versus WSL), Monitor configuration (Combined versus Separate [28R]), and IM PA Tool configuration (On versus Off). The probability of finding an effect when there was none, alpha ( $\alpha$ ), was set to 0.05. The descriptive statistics (n, M, and variance) for the three main factors are shown in Table 5-72. The ANOVA results are shown in Table 5-73.

**Table 5-72. Controller Responses to WSL versus CSL Assessment: Factor Summary**

Factor	Level	n	M	Variance
Safety Limit	CSL	28	90.9	92.7
	WSL	28	77.1	662.0
Monitor Configuration	28R	28	80.4	446.1
	Combined	28	87.6	379.9
IM PA Tool Configuration	Tools Off	28	81.1	635.7
	Tools On	28	87.0	199.0

**Table 5-73. Controller Responses to WSL versus CSL Assessment: Three-Factor ANOVA Results**

	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>p-value</i>	<i>Significant?</i>
<b>Safety Limit (A)</b>	2646.88	1	2646.88	6.79	0.01	yes
<b>Monitor Configuration (B)</b>	721.45	1	721.45	1.85	0.18	no
<b>IM PA Tool Configuration (C)</b>	486.16	1	486.16	1.25	0.27	no
<b>A x B</b>	111.45	1	111.45	0.29	0.60	no
<b>A x C</b>	252.88	1	252.88	0.65	0.42	no
<b>B x C</b>	19.45	1	19.45	0.05	0.82	no
<b>A x B x C</b>	62.16	1	62.16	0.16	0.69	no
Within	18722.57	48	390.05			
Total	23022.98	55	418.60			

The statistical analysis results from the simulation suggest all or most controllers agreed they could easily assess the IM Trail Aircraft with respect to both the CSL versus the WSL, they agreed more strongly for the CSL ( $p = 0.01$ ). No statistically significant differences were observed between Monitor and IM PA Tool configurations or any of the factor combinations.

The unanimous agreement for the CSL suggests controller participants did not have an issue with it changing over the course of the approach. However, the WSL did appear to increase the difficulty of the monitoring task. Given that no significant difference was found in IM PA Tool configuration, the challenge was likely due to the CSL being displayed from the start of the operation versus the WSL only becoming active late in the operation. Therefore, a Pre-Activation feature that starts sooner than that implemented in the HITL would provide controllers more information about what to expect and therefore likely reduce the challenge of monitoring with respect to the WSL. This is consistent with participant comments as reported in Section 5.5.3.2.

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The second part of the hypothesis, feasibility, was measured by controller responses to the following Day 2 end (QT3) question: **Overall, I was confident that I could assess whether the separation between the IM Trail Aircraft and their Lead Aircraft would be maintained.** As described in Section 5.2.5, the majority (80%) of TRACON controllers agreed. This self-assessment was supported by the objective separation analysis in Section 5.2.5.2, which found only a single instance of a within-pair IM PA separation violation.

*Conclusion:* This hypothesis is supported by the simulation results. Overall, controllers found it acceptable and feasible to provide PA separation with respect to separation values that change over the course of an approach, given an appropriate tool set. This did not appear to be affected by monitor configuration.

### 5.8.3 H3(RQ3): Controllers will find a WSL Pre-Activation indication and distances to the CSL and WSL useful, but not minimum requirements.

The first part of this hypothesis was measured via responses to questions related to usefulness of the WSL-P and WSL Data Block “W” features. At the end of Day 2 (QT3) controllers were asked **if the WSL-P was useful for the overall IM PA monitoring task**. As described in Section 5.5.3.2, all (100%) TRACON controllers agreed. In the same questionnaire, half (50%) felt the WSL-P should **always be on** and half felt that it should be **user toggleable** (Figure 5-69) for the IM PA monitoring task. Two controllers indicated in comments that aircraft type differences would indicate an active WSL to the controller, which suggests that though helpful, the WSL-P may be an optional feature.

When asked in the same questionnaire **if the WSL Pre-Active Indication (“W”) features were useful for the overall IM PA monitoring task**, TRACON controller responses were variable and a majority (70%) of TRACON controllers disagreed it was useful, as described in Section 5.5.3.2.

To determine if there was a statistically significant difference between controller responses to the two display elements, a paired-sample T-Test analysis was run on the TRACON controller agreement ratings for the following two questions:

- **The WSL-P was useful for the overall IM PA monitoring task.**
- **The WSL Pre-Active Indication (“W”) features were useful for the overall IM PA monitoring task.**

The descriptive statistics (n, M, and SD) for each question are shown in Table 5-43. The probability of finding an effect when there was none, alpha ( $\alpha$ ), was set to 0.05. The results of the two-tailed, paired sample T-Test analysis resulted in a statistically significant  $p = 0.0002$ . This suggests a significant difference in controller agreement for the usefulness of the two elements, with controllers appearing to prefer the WSL-P instead of the WSL Pre-Active Indication (“W”) feature in the data block.

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The second part of this hypothesis was measured via responses to questions related to usefulness of the CSL and WSL Data Block Distance feature. At the end of Day 2 (QT3) controllers were asked **if the Data Block Distance to CSL was useful for the overall IM PA monitoring task**. As described in Section 5.5.3.1, all but two controllers disagreed. In the same questionnaire, four of ten controllers rated it as **not needed** and the others suggested it should be **user toggleable** (Figure 5-69) for the IM PA monitoring task.

The same question was asked with respect to the WSL Data Block Distance feature: **if the Data Block Distance to WSL was useful for the overall IM PA monitoring task**. As described in Section 5.5.3.2, all but two controllers disagreed. In the same questionnaire, four of ten controllers rated it as **not needed** and the others suggested it should be **user toggleable** (Figure 5-69) for the IM PA monitoring task.

*Conclusion:* This hypothesis is partially supported by the simulation results. Controllers did appear to find the WSL-P useful, but not a minimum requirement. However, controllers did not

appear to find the Data Block “W” Indication useful. Almost all controllers also rated the Data Block Distances to the CSL and WSL as not useful, at least to them.

#### **5.8.4 H4(RQ3): A representation of the safety limits and an alert when the IM Trail Aircraft begins to encroach on the limits will be useful to Monitor controllers.**

The first part of this hypothesis was measured via responses to questions related to the usefulness of the safety limit features. As described in Section 5.5.3.1, at the end of Day 2 (QT3) all (100%) TRACON controllers found the **CSL Line useful for the overall IM PA monitoring task**. In the same questionnaire, all controllers recommended that **the CSL Line always be on** (Figure 5-69) for the monitoring task. The results were the same for the **WSL Line**, as described in Section 5.5.3.2 and Figure 5-69.

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The second part of this hypothesis was measured via responses to questions related to usefulness of the longitudinal alerting features. Results were examined with respect to the two levels of longitudinal alert presented in the HITL experiment: the Predictive Alert and the Caution Alert. As described in Section 4.2.7, controllers were only required to take action in response to the Caution Alert.

At the end of Day 2 (QT3) controllers were asked if **the IM PA Predictive Alert and IM PA Caution Alert features were useful for the overall IM PA monitoring task**. As described in Section 5.5.4.1, all (100%) TRACON controllers agreed for the Caution Alert and a majority (90%) agreed for the Predictive Alert. In the same questionnaire, a majority of TRACON controllers (90%) responded that **the Predictive and Caution Alerts should always be on** (Figure 5-69) for the IM PA monitoring task. The other controller suggested it should be user-toggable.

To determine if there was a statistically significant difference between controller responses to the two types of alerts, a paired-sample T-Test analysis was run on the TRACON controller agreement ratings for the following two questions:

- **The IM PA Predictive Alert was useful for the overall IM PA monitoring task.**
- **The IM PA Caution Alert was useful for the overall IM PA monitoring task.**

The descriptive statistics (n, M, and SD) for each question are shown in Table 5-47. The probability of finding an effect when there was none, alpha ( $\alpha$ ), was set to 0.05. A one-tailed, paired sample T-Test was used in this case as it was expected that if a difference would be observed, it would only be in one direction (i.e., based on their respective required response procedures, the Predictive Alert would not be expected to be more useful than the Caution Alert). The results of the one-tailed T-Test analysis resulted in a statistically significant  $p = 0.04$ . This suggests a significant difference in controller agreement with respect to the usefulness of the two elements. Though both were found useful, stronger agreement was observed with the Caution Alert.

*Conclusion:* This hypothesis is supported by the simulation results. On average, controllers found the CSL and WSL lines useful for the IM PA monitoring task and recommended that they

always be displayed. They also recommended that the Predictive and Caution Alerts were useful and should also always be active for the monitoring task, though responses were more variable for the Predictive Alert than the Caution Alert.

### 5.8.5 H5(RQ4): Controllers will find features such as Lateral Boundaries and an Exceedance Warning useful to alert them to IM Lead Aircraft and IM Trail Aircraft lateral path deviations.

The first part of this hypothesis was measured via responses to questions related to usefulness of the Lateral Boundary feature. As described in Section 5.6.3, at the end of Day 2 (QT3), a majority (60%) of TRACON controllers disagreed the Inner and Outer Lateral Bounds were useful for the overall IM PA monitoring task. As described in Section 5.5.6.1, however, the majority of TRACON controllers thought that the **Inner Boundary should always be displayed** (80%) and the **Outer Boundary should always be displayed** (70%) for the IM PA monitoring task after experiencing the Lateral Deviation scenarios (Figure 5-70). The rest felt the boundaries should be user toggleable.

Also as described in Section 5.6.3, at the end of each Lateral Deviation scenario (QT6), controllers were asked if they **could easily assess whether aircraft involved in a PA operation were operating within their lateral bounds** in the scenario they just experienced. All (100%) TRACON controllers agreed for every monitor configuration with the FMA display. With the STARS display, however, a majority agreed for the Combined Monitor (70%), 28R Monitor (67%), and 28L Monitor (50%).

To further examine if monitor configuration or display type had an effect on controller agreement to this question, a two-factor, repeated measures ANOVA test was performed on the data summarized in Table 5-62. Due to the unbalanced sample sizes, the ANOVA was performed via a regression analysis with the probability of finding an effect when there was none, alpha ( $\alpha$ ), set to 0.05. The results are shown in Table 5-74.

**Table 5-74. Controller Post-Run Lateral Boundary Assessment: ANOVA Results**

	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>p-value</i>	<i>Significant?</i>
<b>Monitor Configuration</b>	136.8	2	68.42	0.18	0.84	no
<b>Display Type</b>	9879.0	1	9879.01	25.79	0.00001	yes
<b>Interactions</b>	145.6	2	72.80	0.19	0.83	no
Within	18384.4	48	383.01			
Total	28671.0	53	540.96			

The statistical analysis results from the simulation suggest there was a significant difference with respect to display Type ( $p < 0.01$ ) for controller response for whether they could assess if aircraft involved in an IM PA operation were operating within their Lateral Boundaries. No difference was observed with respect to monitor configuration ( $p = 0.84$ ), nor were there any interaction effects ( $p = 0.83$ ). The results suggest controllers found that the FMA display aided

in their Lateral Boundary assessment, but that the assessment was not affected by the monitor configuration.

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The second part of this hypothesis was measured via responses to questions related to the usefulness of the Exceedance Warning feature. As described in Section 5.5.6.1, participants appeared to find the Exceedance Warning useful. As shown in Figure 5-70, all (100%) TRACON controllers felt the red “LAT” in the data block should always be displayed. A majority (90%) thought the Boundary Line color change to red should always occur.

As described in Section 5.6.4, at the end of each Lateral Deviation scenario (QT6), controllers were asked if they **had sufficient time and situational awareness to choose and execute appropriate corrective action once the warning (red) alert occurred** in the scenario they just experienced. All (100%) TRACON controllers agreed for both display types in the 28L position. A majority (89%) of TRACON controllers agreed for both display types in the 28R position. For the Combined Monitor configuration, a majority (70%) agreed for the STARS display and a majority (90%) also agreed for the FMA display.

Of interest as well was whether a predictive-type alert would have been helpful or essential for giving controllers advance notice of a potential Lateral Boundary exceedance. To determine if there was a statistically significant difference between controller responses, a paired-sample T-Test analysis was run on the TRACON controller agreement ratings for two separate questions asking if **advance notice of an impending exceedance of the lateral bounds would have been helpful or essential**. The descriptive statistics (n, M, and SD) for each question are shown in Table 5-64. The probability of finding an effect when there was none, alpha ( $\alpha$ ), was set to 0.05. A one-tailed, paired-samples T-Test was used in this case as it was expected that if a difference would be observed, it would only be in one direction (i.e., it was unlikely that if such a predictive-type alert would be found essential but not helpful). The one-tailed T-Test analysis resulted in a statistically significant  $p = 0.008$ . This suggests a significant difference in controller agreement response. Though controllers agreed for both, stronger agreement was observed for a predictive-type alert for lateral deviations being only helpful.

*Conclusion:* This hypothesis is supported by the simulation results. Overall, controllers appeared to find the Lateral Boundaries useful, especially with the FMA display. They also found the Exceedance Warning useful and provided sufficient time and situational awareness to choose and execute appropriate corrective action when needed. A predictive-type Exceedance Warning is likely to be more helpful than essential.

### **5.8.6 H6(RQ5): Though the workload may be increased, a single, combined Monitor controller can effectively and acceptably provide separation for CSPR finals involving IM PA operations, including separation between successive PA pairs.**

The first part of this hypothesis was measured via responses to questions pertaining to workload between the two monitor configurations. As described in Section 5.5.1.1, the Week 2-3 TRACON controllers reported **low workload for all three Monitor controller positions**. No

practical workload difference was observed between the Combined and Separate Monitor configurations. As described in Section 5.4.1, after experiencing the Nominal scenarios, all Week 2-3 TRACON controllers agreed their **overall workload was acceptable** for both the Combined and Separate Monitor configurations. A similar result was observed after the Lateral Deviation scenarios as the majority (90%) of TRACON controllers agreed their workload was acceptable across all display types and monitor configurations (Section 5.6.1). Despite this, some workload concerns were raised in the comments regarding a Combined Monitor's ability to intervene with two aircraft that deviate nearly simultaneously. Overall, however, controller responses did not suggest an appreciable difference in workload between the two monitor configurations.

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The second part of this hypothesis was measured via responses to several questions regarding the controllers' ability to provide separation with respect to aircraft type and monitor configuration. First, as described in Section 5.2.6, all (100%) TRACON controllers agreed the **tasks required of the Separate 28R and 28L Monitor positions were acceptable**. In the Combined Monitor configuration, the majority (90%) of TRACON controllers agreed.

As described in Section 5.4.3, all Week 2-3 TRACON controllers agreed they were **able to detect in a sufficient amount of time when spacing / separation issues were developing Within an IM PA Aircraft Pair and Between Other Combinations** for both monitor configurations. Though no practical differences were observed in the responses between the two monitor configurations, the means were slightly higher and overall response variability was slightly lower for IM PA pairs versus other aircraft pair combinations. This was likely due to not having ATPA functionality available in the HITL to assess separation between the non-IM PA pairs.

This self-assessment for IM PA was supported by the **objective separation analysis** in Section 5.2.5.2, which found only a single instance of a within-pair IM PA separation violation. With respect to between-pair separation, it should first be noted ATPA functionality and data block weight category information (other than identifying Heavy aircraft) were not present in the simulation environment. This made the between-pair separation task more difficult than what controllers were used to, as several noted in open-ended comments. Across ten Nominal scenario occurrences involving between-pair separation assessments, nine involved the Combined Monitor configuration. However, the occurrence of the violation in these cases is likely more of an artifact of the slight timing variations between the scenarios and cannot be conclusively attributed to monitor configuration.

As described in Section 5.4.4, controllers were asked after each Day 1-2 Nominal scenario if **IM PA operations can be effectively monitored by the number of positions they just experienced**. All Week 2-3 TRACON controllers agreed for both configurations, though overall response variability was slightly greater for the Combined Monitor configuration. In the same questionnaire, and as described in the same section, controllers were asked directly if **given the appropriate training and IM PA-related tools, a single (Combined) Monitor controller can effectively ensure separation across both approaches during IM PA operations**. The majority (90%) of TRACON controllers agreed.

At the end of Day 3, after experiencing all scenarios including Lateral Deviations, controllers were asked if **they would expect to be able to effectively monitor any number of IM PA pairs, up to and including all aircraft pairs performing IM PA (100%)**. Though majorities of TRACON controllers agreed for both monitor configurations, higher response variability was observed for the Combined Monitor. To determine if there was a statistically significant difference between controller responses for each configuration, a paired-sample T-Test analysis was run on the TRACON controller agreement ratings for this question. The descriptive statistics (n, M, and SD) are shown in Table 5-27. The probability of finding an effect when there was none, alpha ( $\alpha$ ), was set to 0.05. The results of the two-tailed T-Test analysis resulted in a statistically significant  $p = 0.049$ . This suggests a significant difference in controller agreement with respect to the strength of agreement between the two configurations, with controllers appearing to expect to be able to more effectively monitor any number of IM PA pairs in a Separate Monitor configuration.

*Conclusion:* This hypothesis is partially supported by the simulation results. First, despite some workload concerns raised in the comments regarding a Combined Monitor's ability to intervene with two aircraft that deviate nearly simultaneously, controller responses did not suggest an appreciable difference in workload rating and acceptability between the two monitor configurations under nominal conditions. Second, numerous questions were related to the effectiveness and acceptability of a Combined Monitor controller ensuring separation across both approaches during IM PA operations. Across these questions, the TRACON controllers almost always agreed the Combined Monitor position was effective and acceptable. When compared to responses to the Separate Monitor configuration, however, the response variability tended to be higher. When analyzing separation violations between and within IM PA pairs, no differences could be concluded with respect to monitor configuration. In addition, after the Lateral Deviation scenarios, controllers more strongly agreed they would expect to be able to effectively monitor any number of IM PA pairs, up to and including all aircraft pairs performing IM PA (100%), when working in a Separate Monitor configuration.

### **5.8.7 H7(RQ6): Final controllers will find the IM PA initiation task, including the use of the Partial IM Clearance, acceptable.**

This hypothesis was first measured via responses to questions pertaining to 28R Final controller workload. As described in Section 5.3.1, the TRACON controllers reported **low workload for all three Monitor controller positions**. The majority (90%) of TRACON controllers then described their **workload as acceptable**, and in the comments some indicated that more tasks could have been handled.

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The second part of this hypothesis was measured via responses to questions regarding the IM initiation task. As described in Section 5.2.5.2, the majority (90%) agreed **the tasks required of the 28R Final controller position** were acceptable. Also, as described in Section 5.3.2, the majority (80%) of TRACON controllers on average agreed **given the appropriate training, and IM PA-related tools, Final controllers can acceptably initiate the IM PA operation**, though

responses were variable. The majority (90%) of TRACON controllers also agreed, that on average, that **they had the necessary display elements to provide the appropriate IM Clearance information to the trail aircraft in an IM PA pair**. No practical difference between the two IM PA Tool configurations were observed for these questions. However, many controllers indicated in open-ended comments to several questions, including those in Section 5.3.6, that providing “preview” CSL and WSL lines *before* the IM Clearance needs to be sent would improve the IM initiation task.

The acceptability of the Partial IM Clearance procedure was measured via responses to two questions regarding the acceptability of the communications, as described in Section 5.3.3. First, all (100%) TRACON controllers agreed **it is operationally acceptable for the Final controller to provide the IM PA spacing goal**, though some had suggestions regarding the specific phraseology used. Second, controller responses were variable, but a majority (70%) agreed **the IM PA spacing goal communication was acceptable**. The controllers that disagreed provided comments that suggested their disagreement had more to do with the phraseology and number of override transmissions than providing the Assigned Spacing Goal.

Controller concerns regarding the IM PA initiation task had more to do with the available time and airspace to perform the task, as simulated in the HITL, versus the particular steps required to initiate IM PA. As described in Section 5.3.2, responses were variable to the question of **once the IM Trail Aircraft joined the final, I had sufficient time and airspace to initiate IM PA before transferring the aircraft to the Local controller**, though a majority (70%) agreed. This response variability also extended to the questions of: **given the appropriate training, and the IM PA-related tools I had available in this scenario, Final controllers can acceptably ensure separation during IM PA operations before transferring aircraft to the Local controller**. And, **I was comfortable that I was transferring appropriately separated aircraft to the Local controller**. Though majorities of controllers agreed to both questions, several concerns and suggestions were raised here, and in the open-ended comments in Section 5.3.6, regarding the initiation task integration into the scenario airspace.

*Conclusion:* This hypothesis is supported by the simulation results. Overall, controllers found the IM PA initiation task, including the use of the Partial IM Clearance, acceptable. However, concerns were raised regarding the phraseology, available CSL and WSL information at the time of initiation, and the available time and airspace to perform the task as simulated.

## 5.9 Results Summary

This section lists and summarizes the overall findings from the HITL subjective questionnaire data and objective analyses. It does not include inputs from the post-simulation debriefs held at the end of Day 3. These are included as appropriate in the Section 6 discussion.

## 5.9.1 Overall Acceptability and Performance

On average, all or a majority of TRACON controller participants agreed:

- IM PA is operationally desirable. (Section 5.2.1)
- IM PA is compatible with terminal approach operations. (Section 5.2.1)
- A Final Monitor controller is the most appropriate position to monitor IM PA operations, though this may depend on facility. (Section 5.2.1)
- They were comfortable monitoring IM PA operations when both a CSL and WSL were active at the same time. (Section 5.2.2 and Section 5.8.1)
- They were comfortable allowing an IM Trail Aircraft to manage its own speed to achieve the desired spacing goal at the FAF. (Section 5.2.3)
- Their overall level of traffic awareness was acceptable with respect to all aircraft types (IM Lead, IM Trail, and Other Aircraft). (Section 5.2.4)
- They were confident they could assess whether the separation between the IM Trail Aircraft and Lead Aircraft would be maintained. (Section 5.2.5)
- The tasks required of each simulation position (Monitor and Final) were acceptable. (Section 5.2.5.2)

An analysis of separation violations in Section 5.2.5.2 found:

- Only a single occurrence within the IM PA pairings, which happened when a controller appeared to try to manually assign a speed to keep an IM Trail Aircraft behind the CSL and that was ultimately not effective.
- Every observed instance of a safety limit crossing, whether or not it resulted in an IM PA separation violation, occurred with the shortest alert timing values (25/15 sec).
- Five cases were observed in which an IM Trail Aircraft crossed a safety limit; however, a controller PTT click was observed between the time of the Caution Alert and the time of exceedance. Average controller PTT response before each exceedance was 10.8 seconds (SD = 3.6).
- Twelve total separation violations were observed between IM PA pairs across 42 total runs. Ten of the 12 involved aircraft arriving to different runways, and nine of the 12 involved a Category B aircraft in the lead. In at least half of the occurrences, an IM PA Predictive or Caution Alert was active on the display at the time of the separation violation, which may have served as either a distraction or was determined to be a higher priority. The separation violation occurrences did not appear to be significantly influenced by the IM PA Tools or monitor configuration independent variable manipulations.

## 5.9.2 28R Final Position

### 5.9.2.1 IM PA Initiation Task

In the 28R Final controller position, all or a majority of TRACON controller participants agreed on average that:

- Workload was low and acceptable. (Section 5.3.1)
- Final controllers can acceptably initiate the IM PA operation. (Section 5.3.2 and Section 5.8.7)
- Once the IM Trail Aircraft joined the final, they had sufficient time and airspace to initiate IM PA before transferring the aircraft to the Local controller. (Section 5.3.2)
- They had the necessary display elements to provide the appropriate IM Clearance information to the Trail Aircraft in an IM PA pair. (Section 5.3.2)
- It is operationally acceptable for the Final controller to provide the IM PA spacing goal. (Section 5.3.3)
- The IM PA spacing goal communication was acceptable. (Section 5.3.3)
- They were comfortable with the use of the Lead Aircraft call sign in the IM Clearance communication. (Section 5.3.3)

As described in Section 5.5.6.2, on average, the TRACON participants recommended the following tools to always be on to help the Final controller complete the IM Clearance:

- CSL Line
- Predictive Alert and Caution Alert
- IM PA Spacing Goal
- Lead Aircraft Call Sign
- Lead Aircraft Runway

On average, the TRACON participants recommended the following tools either always be on or user toggleable to help the Final controller complete the IM Clearance:

- WSL-P
- Trail Aircraft Status
- IM Status
- Inner and Outer Lateral Boundaries

### 5.9.2.2 28R Final IM PA Monitoring Task

In the 28R Final controller position, all or a majority of TRACON controller participants agreed on average that:

- They were comfortable with the IM Trail Aircraft managing their speeds to achieve the spacing goal while in their area. (Section 5.3.4)

- Given the appropriate training and tools, Final controllers can acceptably ensure separation during IM PA operations before transferring aircraft to the Local controller. (Section 5.3.5)
- They were comfortable that they were transferring appropriately separated aircraft to the Local controller. (Section 5.3.5)

### 5.9.3 Monitor Configurations

On average, across *both* monitor configurations, all or a majority of TRACON controller participants agreed:

- Overall workload was low (Section 5.5.1.1) and acceptable. (Section 5.4.1)
- Roles and responsibilities were clear with respect to all aircraft in the simulation. (Section 5.4.2)
- They were able to detect in a sufficient amount of time when spacing / separation issues were developing within IM PA and other aircraft pairs. (Section 5.4.3)
- Given the appropriate training and IM PA-related tools, IM PA operations can be effectively monitored by either configuration. (Section 5.4.4)
- Given the appropriate training and IM PA-related tools, a single (Combined) Monitor controller can effectively ensure separation across both approaches during IM PA operations. (Section 5.4.4)
- They were comfortable monitoring one aircraft in an IM PA pair, while another controller monitored the other aircraft. (Section 5.4.4)
- They would expect to be able to effectively monitor any number of IM PA pairs, up to and including all aircraft pairs performing IM PA. (Section 5.4.4)

### 5.9.4 Lateral Deviation Monitoring

With respect to the Lateral Deviation scenarios, all or a majority of TRACON controller participants, on average, agreed:

- Their workload was acceptable across all display types and monitor configurations. (Section 5.6.1)
- They were confident they could assess whether separation would be maintained between the IM Trail Aircraft and their Lead aircraft. (Section 5.6.2)
- They could easily assess whether aircraft involved in an IM PA operation were operating within their Lateral Boundaries. (Section 5.6.3). Controllers appeared to find the FMA display (versus STARS) aided in their Lateral Boundary assessment. (Section 5.8.5)
- Advance notice of an impending exceedance of the Lateral Boundaries would have been more helpful than essential. (Section 5.6.4 and Section 5.8.5)
- The lateral Exceedance Warning was noticeable enough such that they became aware of it without undue delay. (Section 5.6.4)

- They had sufficient time and situational awareness to choose and execute appropriate corrective action once the Exceedance Warning occurred. (Section 5.6.4)
- Controllers responded (via a PTT click) to Lateral Boundary crossings within approximately 2-3 seconds, which did not appear to be affected by monitor configuration or display type. (Section 5.6.5)

## 5.9.5 IM PA Tools

### 5.9.5.1 General Effects

On average, a majority of TRACON controller participants did not agree:

- The Monitor controller should be provided an IM Spacing List. (Section 5.5.5)

On average for the Day 1-2 Nominal scenarios, TRACON controller responses suggested there was no apparent difference between IM PA Tool configurations (On versus Off) with respect to:

- Workload level and acceptability. (Section 5.5.1.1)
- Traffic awareness. (Section 5.5.1.2)
- Having sufficient time to make a first assessment of separation as the IM PA pairs became their responsibility. (Section 5.5.2)
- Comfort in monitoring IM PA operations when both a CSL and WSL were active at the same time. (Section 5.2.2 and Section 5.8.1)
- Ability of a single (Combined) Monitor controller to effectively ensure separation across both approaches during IM PA operations. (Section 5.4.4)
- Comfort in monitoring one aircraft while another controller monitored the other. (Section 5.4.4)
- Timely detection of any impending exceedance of the WSL or CSL. (Section 5.5.4.2)
- Timely detection of any spacing or separation issues. (Section 5.5.4.2)
- 28R Final controller Workload (Section 5.3.1) and IM PA initiation tasks. (Section 5.3.2)

On average for the Day 1-2 Nominal scenarios, TRACON controller responses suggested there may have been a difference between IM PA Tool configurations (On versus Off) with respect to:

- IM Speed Control. As described in Section 5.5.1.3, the increased variability for the IM PA Tools Off configuration suggests that at least for the Combined Monitor position, having the IM PA Tools available may increase controller comfort with IM Trail Aircraft managing their own speeds.
- Separation assessment between the IM Trail Aircraft and its Lead. As described in Section 5.5.2, the increased variability for the IM PA Tools Off configuration suggests that at least for the Combined Monitor position, having the IM PA Tools available may help controllers more easily assess the separation between the IM Trail Aircraft and its Lead.

- 28R Final controller ensuring appropriately separated aircraft at handoff to the Local controller. As described in Section 5.3.5, controller responses were variable, though response variability was lower with IM PA Tools Off. It is unclear why.
- Being able to easily tell when an aircraft would require a WSL later in the approach. As described in Section 5.5.3.2, for the Separate 28R Monitor configuration position, a majority (57%) of Week 2-3 TRACON controllers agreed they could easily tell with the IM PA Tools On. With IM PA Tools Off, a majority (71%) of controllers disagreed. This difference was not observed for the Combined Monitor configuration.

### 5.9.5.2 Safety Limit Depictions and WSL Pre-Active Notification Features

On average, all or a majority of TRACON controller participants agreed:

- The CSL Line was useful for the overall IM PA monitoring task. (Section 5.5.3.1)
- They could easily assess whether the IM Trail Aircraft would remain behind the CSL during the approach. (Section 5.5.3.1)
- The WSL Line was useful for the overall IM PA monitoring task. (Section 5.5.3.2)
- They could easily assess whether the IM Trail Aircraft would remain forward of the WSL. (Section 5.5.3.2)
- It was helpful to know whether an aircraft would eventually require an active WSL. (Section 5.5.3.2)
- The WSL-P was useful for the overall IM PA monitoring task. (Section 5.5.3.2)
- If provided the WSL-P, the WSL “W” indicator in the data block is not also needed. (Section 5.5.3.2)
- The WSL-P was more useful for the overall IM PA monitoring task than the WSL Pre-Active Indication (“W”) feature in the data block. (Section 5.8.3)
- The WSL-P first appeared with sufficient lead time to be useful. (Section 5.5.3.2)
- A WSL-P should become available sooner than the 7 NM implemented in the simulation. (Section 5.5.3.2)

On average, all or a majority of TRACON controller participants did not agree that:

- The Data Block Distance to the CSL was useful for the overall IM PA monitoring task. (Section 5.5.3.1)
- The Data Block Distance to the WSL was useful for the overall IM PA monitoring task. (Section 5.5.3.2)
- The WSL Pre-Active Indication “W” feature was useful for the overall IM PA monitoring task. (Section 5.5.3.2)
- If provided the initial WSL “W” indicator in the data block, the WSL-P is not needed. (Section 5.5.3.2)

### 5.9.5.3 Longitudinal Alerting

On average, all or a majority of TRACON controller participants agreed:

- They want to be able to see a situation developing versus only being provided an alert when they had to take action. (Section 5.5.4.1)
- The IM PA Predictive Alert and IM PA Caution Alert features were useful for the overall IM PA monitoring task. (Section 5.5.4.1)
- Controllers felt more strongly that the IM PA Caution Alert was useful for the overall IM PA monitoring task than the IM PA Predictive Alert. (Section 5.8.4)
- The IM PA-related tools allowed for a timely detection of any impending exceedance of the WSL or CSL. (Section 5.5.4.2)
- The IM PA-related tools allowed for a timely detection of any spacing or separation issues. (Section 5.5.4.2)
- It was helpful to indicate the Predictive Alert and Caution Alert via the data block line 3 color change. (Section 5.5.4.4)
- It was helpful to indicate the Predictive Alert and Caution Alert via the CSL or WSL line color change. (Section 5.5.4.4)
- Their responsibilities with respect to a Predictive Alert and Caution Alert were clear. (Section 5.5.4.5)

When different alert timing values were tested:

- The majority of Week 2-3 TRACON controllers agreed the Predictive (yellow) alert provided sufficient advance notice of an impending Caution Alert at any of the tested alert timing values. (Section 5.5.4.2)
- The majority of Week 2-3 TRACON controllers agreed the Caution (orange) alert provided sufficient advance notice of an impending loss of separation at any of the tested alert timing values. (Section 5.5.4.2)
- The Week 2-3 TRACON controllers appeared to agree that they could more easily assess whether the IM PA trail aircraft would remain behind the CSL during the approach for the 45/24 and 35/20 values, as opposed to the 25/15 value. (Section 5.5.4.2)
- The Week 2-3 TRACON controllers appeared to agree that they could more easily assess whether the IM PA Trail Aircraft would forward of the WSL during the approach for the 35/20 value, as opposed to the 45/24 and 25/15 values. (Section 5.5.4.2)
- The majority of Week 2-3 TRACON controllers reported preferring a value of 35 sec for the Predictive Alert with respect to both safety limits, and a 15 or 20 sec value for the Caution Alert. (Section 5.5.4.2)
- No significant difference was observed between average Week 2-3 TRACON controller response times for any of the three evaluated alert timings. (Section 5.5.4.3)

#### **5.9.5.4 Display Recommendations**

Table 5-75 summarizes the HITL findings associated with the various IM PA Tools provided to the controllers. For each feature, it repeats the usefulness for monitoring IM PA operations as summarized in prior sections, the display recommendation for that tool (e.g., Always On, User Toggleable, Not Needed) as summarized in Figure 5-69 and Figure 5-70, and notes any related findings.

**Table 5-75. Individual Feature Display Recommendations**

Feature	Useful for Monitoring	Display Recommendation	Related Findings
<b>Safety Limits</b>			
CSL Line	Agree	Always On	Controllers agreed they could easily assess whether the IM Trail Aircraft would remain behind the CSL during the approach.
WSL Line	Agree	Always On	Controllers agreed they could easily assess whether the IM Trail Aircraft would remain forward of the WSL during the approach.
WSL-P Line	Agree	Always On / User Toggleable	Controllers agreed it was helpful to know whether an aircraft would eventually require an active WSL, and that the WSL-P was more useful than the WSL (“W”) in the data block.
Lateral Boundaries	Agree	Always On / User Toggleable	Controller increased their display recommendation for the Boundaries after experiencing the Lateral Deviation scenarios.
<b>Data Block Elements</b>			
IM Trail Aircraft Status	Neutral	User Toggleable / Not Needed	
Lead Aircraft Status	Disagree	User Toggleable / Not Needed	
Distance to CSL	Disagree	User Toggleable / Not Needed	Controllers disagreed that If the CSL is shown as a graphic line, the numeric distance to it in the data block is also helpful.
Distance to WSL	Disagree	User Toggleable / Not Needed	
WSL Pre-Active Indication (“W”)	Disagree	User Toggleable / Not Needed	Controllers agreed the WSL-P was more useful for the overall IM PA monitoring task than the WSL (“W”) in the data block.
<b>Alerts</b>			
IM PA Predictive Alert	Agree	Always On	Controllers agreed they want to be able to see a CSL or WSL exceedance problem developing, versus only being provided an alert when they have to take an action.
IM PA Caution Alert	Agree	Always On	Controllers felt more strongly that the IM PA Caution Alert was useful for the overall IM PA monitoring task than the IM PA Predictive Alert.
Exceedance Warning: Red Boundary Line	<i>Not directly asked<sup>1</sup></i>	Always On	Controller comments suggested that the line color change was effective in indicating a boundary crossing; however, it did not clearly identify the deviating aircraft.
Exceedance Warning: “LAT”	<i>Not directly asked<sup>1</sup></i>	Always On	Controllers suggested that the entire data block should turn red during an exceedance, not just the “LAT” indication.
<b>IM Spacing List</b>			
Status: Eligible, Active, Terminated	Neutral	Varied	Controllers did not agree that the Monitor controller should be given an IM Spacing List.

<sup>1</sup>Was not included as a separate element in the questionnaire.

## 5.9.6 Simulation Evaluation

On average, all or a majority of TRACON controller participants agreed:

- The training they received was adequate, for both the IM Clearance completion and IM PA monitoring tasks. (Section 5.7)
- The overall activity was effective as a context for evaluating the IM PA monitoring task. (Section 5.7)
- The overall activity was effective as a context for evaluating the IM Clearance completion task. (Section 5.7)

## 6 Discussion

This HITL experiment was the first to examine an update to the IM PA concept that involved controllers monitoring the operation relative to a separation standard. This requires controllers to be able to assess separation within an IM PA pair and take effective action before separation is lost. Due to IM PA's safety limits that change over time, and the close inter-aircraft pair distances, it was expected that controllers would likely require new ground tools to detect and act on potential exceedances of the safety limits. It was also expected these tools would be required to allow controllers to provide a timely response to a lateral deviation by either the Lead or Trail Aircraft.

The primary goal of this HITL experiment therefore was to examine the updated IM PA concept with a focus on the new controller monitoring functions. This included an evaluation of the terminal controller monitoring task for IM PA aircraft pairs established on final approach, especially with respect to both minimum and maximum separation values that change over the course of the approach, and lateral deviations. Additionally, an objective was to determine the acceptability of a single Monitor controller to manage Lead and Trail Aircraft, or whether separate monitors should be required. The experiment also included an evaluation of prototype display features to facilitate this monitoring task. A secondary goal was to examine acceptability and information requirements for IM PA initiation.

This section discusses the findings from the HITL reported in Section 5 in context with the Research Questions and hypotheses discussed in Section 3.3 and evaluated in Section 5.8. As needed, it includes experimenter observations, participants comments, and outcomes of the post-simulation debriefs held at the end of Day 3.

### 6.1 IM PA Monitoring Task and Tools

The primary objective of the HITL was to evaluate the feasibility of the IM PA ATC monitoring task. The HITL assumed an operation in which a Final Approach controller would initiate the IM PA operation and one or two Monitor controllers would provide within-pair and between-pair separation. The feasibility and acceptability for Monitor controllers to do this was examined with respect to multiple metrics.

**General Effects.** From the results, IM PA Monitoring in general appeared to be feasible and acceptable, which is consistent with the monitoring results reported in Domino, Tuomey, Stassen, & Mundra (2014). After monitoring IM PA operations in the scenarios with the two Monitor and two IM PA Tool configurations, controllers on average reported: low and acceptable workload; acceptable tasks in each of the monitoring positions; acceptable levels of traffic awareness for all types of aircraft; comfort in allowing the IM Trail Aircraft to manage their own speeds; and confidence that they could assess whether the separation between the IM Trail Aircraft and their Lead Aircraft would be maintained. They also agreed IM PA is operationally desirable and compatible with terminal approach operations, though real-world facility and airspace integration may be challenging. Consistent with the findings of Mendolia, et al. (2016), most controllers reported that a Final Approach Monitor controller is the most

appropriate position to provide separation for IM PA operations. However, real-world implementations may ultimately depend on what is most practical for individual facilities.

Separation assurance within IM PA pairs appeared to be a straightforward task for controllers as only a single violation was observed to occur between an IM Trail Aircraft and IM Lead Aircraft, despite the introduction of far more off-nominal deviations than would be expected in actual operations. This instance involved a controller appearing to attempt to manually assign a speed to keep an IM Trail Aircraft behind the CSL and allowing the IM PA operation to continue. The controller may have then expected the aircraft to reduce to its final approach speed; however it did not due to a simulation artifact. Still, the aircraft crossed the CSL before the controller commanded a break out. Though the controller should have terminated IM PA and commanded a break out sooner than what occurred, this instance was not a result of the controller failing to notice a developing situation.

Separation was also examined between other aircraft combinations (e.g. between the trail aircraft of a leading pair and the lead aircraft of a following pair). Twelve total separation violations were observed between aircraft pair combinations not performing IM PA. In at least half of the occurrences, an IM PA Predictive or Caution Alert was active on the display at the time of the separation violation, which may either have served as a distraction or been deemed a higher priority. The observed separation violations that occurred between the IM PA pairs happened under varying circumstances, which makes it difficult to conclude that they were significantly influenced by any of the independent variable manipulations. It should be noted that ATPA functionality and data block weight category information (other than identifying Heavy aircraft) were not present in the simulation environment. This made the between-pair separation task more difficult than what controllers were used to, as several noted in open-ended comments. It was therefore unclear if these violations were due to the presence of IM PA in the operational environment or were more related to controllers in the simulation not having certain current separation tools available to them. Although these violations occurred in the context of simulation events that were designed to stress test the concept and ground tools, their presence still suggests that tools and procedures need to be fully integrated to ensure that separation between aircraft pairs not performing IM PA can be maintained while IM PA operations are in progress. In addition, IM PA setup spacing requirements should ensure that between-pair separation can be sufficiently maintained during compression on final.

**Number of Monitor Controllers.** IM PA is intended for operations in IMC and does not depend on visual separation during the final portion of the approach. Implementing separate L/R Monitor controllers, as would be required by current 7110.65 rules, may not be practical or feasible at certain facilities as that would then require separate Local controllers and frequencies. However, facilities with dependent parallel runway operations typically employ separate L/R Final Approach controllers due to the workload involved in vectoring aircraft to final and other intensive tasks. As it cannot be easily determined whether separate Monitor controller positions for IM PA would be practical for all facilities, it was necessary to examine whether a single, combined Monitor controller can effectively provide separation for CSPR finals involving IM PA operations.

Today's Monitor controller workload can be relatively low as they are only required to take action if an aircraft penetrates the NTZ. Workload for the IM PA concept as tested in the HITL may be higher, as the Monitor controllers must provide separation for all aircraft on the approach, including within and between IM PA pairs, and must monitor for lateral deviations. However, IM PA will likely involve alerting to tell controllers when to take action for an impending loss of IM PA separation. Therefore, if vectoring to final (or managing aircraft on RNAV paths that connect to the final) remains the responsibility of Final Approach controllers, it was hypothesized that a single Monitor controller can effectively and acceptably provide separation for IM PA and non-IM PA aircraft over the course of a long final approach segment.

This hypothesis was partially supported by the simulation results. First, controller responses on average did not suggest an appreciable difference in workload rating and acceptability between the two monitor configurations. Across both, they also agreed on average that: their tasks were acceptable and roles and responsibilities were clear; they were able to detect in a sufficient amount of time when spacing / separation issues were developing within IM PA and other aircraft pairs; and that given the appropriate training and IM PA-related tools, IM PA operations can be effectively monitored by either configuration.

However, when compared to responses for the Separate Monitor configuration, the response variability for the Combined Monitor configuration tended to be higher. This suggests controllers may not have agreed as strongly with the various measures in the Combined position versus when they were working as separate Monitors. Various open-ended comments suggest that as well. Still, at least after the nominal scenarios, controllers appeared to subjectively agree they could effectively provide separation when working in a Combined Monitor position.

The Lateral Deviation scenarios illuminated a further challenge of combining the monitor positions. After experiencing these scenarios, controllers more strongly agreed they would expect to be able to effectively monitor any number of IM PA pairs when working in a Separate Monitor configuration (versus Combined), up to and including all aircraft pairs performing IM PA (100%).

Furthermore, although average controller response time to lateral deviations did not appear to be different between monitor configurations, a small number of occurrences were observed in which a controller intervened with a deviating aircraft *before* the Exceedance Warning was displayed. Most of these occurred in the Separate Monitor configuration in the context of a particular scenario that was deliberately designed as an extreme case to stress the display features and probe for a potential failure point.

This scenario involved a shallow deviation of a Trail Aircraft beginning shortly before the sharp deviation of the Lead Aircraft in a different pair. However, the Exceedance Warning of the (shallow) Trail occurred shortly *after* the Exceedance Warning of the (sharp) Lead. In effect, this resulted in two separate, near-simultaneous lateral deviations. In the Combined Monitor configuration, the controller typically contacted the sharply-deviating Lead Aircraft first to turn it back, then contacted its Trail Aircraft to instruct it to break out. This was given higher priority than the shallow-deviating Trail, and so it then crossed its Lateral Boundary and triggered the

Exceedance Alert before the controller could contact it. In the Separate Monitor configuration, however, the 28R controller was not required to contact the deviating Lead Aircraft. Therefore, there was more time for the 28R controller to break out the Trail from the deviating Lead and then break out the shallow-deviating Trail before it actually crossed its Lateral Boundary.

The findings here, though not conclusive, are consistent with a general expectation that controllers may be able to take action more quickly when only having responsibility for one arrival flow. This is supported by the open-ended comments, which raised concerns regarding a Combined Monitor's workload and ability to communicate in a timely manner with two aircraft that deviate nearly simultaneously. This scenario is unlikely to occur in actual operations, however. An investigation of over 1.8 million approach paths did not detect any simultaneous flight path deviations (Eckstein, Massimini, McNeill, & Niles, 2012), nor was there a record of any in an examination of 7790 go-arounds that were logged over multiple years by NCT (Stassen, Domino, Hefley, & Weitz, 2019).

Under most conditions, results suggest a Combined Monitor controller is likely to be able to effectively and acceptably provide separation for IM PA and non-IM PA aircraft over the course of a long final approach segment. However, further study may be needed to examine whether separate monitors may ultimately be required for safety to manage extreme off-nominal lateral deviation situations.

**Longitudinal Safety Limit Monitoring.** The PA separation standard assumed for the HITL was defined by the minimum (CSL) and maximum (WSL) safety limits. The IM PA monitoring task was therefore evaluated with respect to the acceptability of having two limits active at the same time and that changed over the course of the approach.

The IM PA controller monitoring task includes separation assurance within IM PA pairs and between pairs of arrivals. In these situations, controllers today must ensure that a given aircraft maintains appropriate spacing from an aircraft ahead as well as an aircraft behind. And, given that controllers today have experience with separation minima that can change for a given pair of aircraft depending on the situation, they are already used to managing some degree of complexity in applying the appropriate separation standards to pairs of aircraft.

The IM PA Tools designed for, and evaluated in, the HITL experiment were intended to provide a clear picture of the PA separation limits applicable to a given IM PA pair at a given moment in time. This information was provided in two ways: graphically and numerically. First, the CSL and WSL values were indicated via cyan lines on the IM Trail Aircraft's path that moved with the IM Lead Aircraft's progression along its path. These were always available on the display, in every scenario. Second, the data block was able to display the IM Trail Aircraft's distances to the CSL and WSL, which provided controllers with a numeric indication of how much separation was available to the IM Trail Aircraft with respect to each safety limit. This Data Block Distance availability was varied as a level of an independent variable.

Though IM PA introduces a minimum and maximum separation limit with respect to a single leading aircraft, the task of keeping an aircraft within a forward and aft boundary was expected to be a simple extension of this basic controller task. It was therefore hypothesized that controllers would find IM PA safety limit monitoring both feasible and acceptable. It was further

hypothesized that changing PA separation limits should also be manageable as long as the required separation distance minimum is clear at any given time and the trend is generally predictable. These hypotheses were supported by the simulation results as controllers agreed they were comfortable monitoring IM PA when both the CSL and WSL were active at the same time. Controllers agreed they could easily assess whether the IM Trail Aircraft would remain behind the CSL and forward of the WSL during the approach and that they were confident that they could assess whether the separation between the IM Trail Aircraft and their Lead Aircraft would be maintained. The strength of agreement did not appear to be affected by monitor configuration or IM PA Tools configuration, though results suggest the IM PA separation assessment was easier for the CSL than the WSL. This hypothesis was further supported by the separation violation analysis, in which only a single aircraft was observed to exceed one of the safety limits.

**WSL Monitoring and Preview.** Though a CSL always applies and is displayed from the start of the operation through landing, the WSL requirement may depend on facility and approach geometry, wake class pairings, and prevailing crosswinds. Even in conditions where a WSL is required, it may not apply until the last portion of the approach. This can complicate IM PA Monitoring as it reduces controller certainty with respect to: when a WSL is required for an IM PA Pair, where it will start to apply, and the IM Trail Aircraft's proximity to it at the time it becomes active. Therefore, there is the potential for controllers to be surprised by a WSL suddenly "popping up" on the display.

Two WSL Pre-Activation display features designed to reduce this uncertainty were evaluated. First, a WSL-P was implemented to provide an advance indication of where the WSL will appear when it becomes active. It was represented by a grey line at the location where the WSL would eventually appear and was first displayed when the IM Trail Aircraft was approximately 7 NM from the runway threshold. Second, Line 3 in the data block displayed a "W" with no corresponding numeric value in cases where a WSL would eventually apply, but was not yet active. The availability of these two features was varied as levels of an independent variable.

It was hypothesized that one feature would be required by controllers, but not both. However, the underlying WSL may become predictable over time and this additional display feature could possibly be considered display "clutter" by controllers. It was therefore hypothesized that one or both of these features may be useful, but not a minimum requirement.

Controller uncertainty regarding WSL separation was reflected in various results. Though they usually agreed the overall separation task was acceptable with respect to both limits, they appeared to agree more strongly with respect to the CSL than the WSL, regardless of which IM PA Tools were available. Across their various responses and consistent with the hypothesis, controllers reported that the WSL-P was helpful for the overall IM PA monitoring task, but that the Data Block "W" Indication was not. Given the increased variability in the WSL monitoring responses, a WSL-P feature that starts sooner than that implemented in the HITL may reduce the challenge of monitoring with respect to the WSL. The desire for an earlier WSL-P display was reflected in several question responses and controller comments.

When deciding whether to display the WSL-P earlier in the operation, it should be considered that at greater groundspeed differentials between the IM Trail Aircraft and IM Lead Aircraft, the WSL-P can first appear in front of the IM Trail Aircraft's current position. Then, as the IM Trail Aircraft catches up, it crosses over the WSL-P. It is possible that this may prove confusing and undesirable to controllers. This case was included in the scenarios and no participant controllers noted any concerns in the responses, comments, or debrief discussion. However, the earlier a WSL-P is displayed, the further behind it an IM Trail Aircraft may appear. This could eventually become confusing and counterproductive to the monitoring task. This is an area that would benefit from further evaluation.

**Longitudinal Alerting.** As IM PA intra-pair spacing will be smaller than what controllers are used to today, and because the controller will be required to take action before an IM PA Aircraft longitudinally encroaches on either the WSL or CSL, it is expected that alerting will be helpful to controllers to indicate when an intervention is required. Therefore, the IM PA alerts indicated to the controller when: 1) an IM Trail Aircraft was potentially at risk of encroaching on either of the safety limits (IM PA Predictive Alert), and 2) when the controller must take an action (e.g., aircraft breakout) to maintain separation (IM PA Caution Alert). The two alert types shared the same logic; only the timing values were different. Based on the fielded ATPA Phase 1 alert implementation, it was hypothesized that a similar IM PA two-level alerting scheme would be acceptable to controllers.

This hypothesis is supported by the simulation results. Controllers generally found that the Predictive and Caution Alerts were useful for the overall IM PA monitoring task and suggested they should always be active. Responses were stronger for the Caution Alert than the Predictive Alert. On average the controllers agreed: they wanted to be able to see a situation developing versus only being provided an alert when they had to take action; the IM PA-related tools allowed for a timely detection of any impending exceedance of the WSL or CSL or spacing or separation issues; and their responsibilities with respect to a both alert types were clear. With respect to display implementation, they appeared to find both the data block line 3 and CSL/WSL Line color changes helpful.

The default Predictive / Caution alert timings were the same as those implemented for ATPA: 45 seconds and 24 seconds, respectively. However, reduced timings may ultimately be used to mitigate against nuisance alerts (which would occur more frequently with greater timings). Therefore, two additional alert timings were investigated in the HITL to examine whether smaller values than those chosen for ATPA remain acceptable to controllers for the IM PA monitoring task. These were: 35 seconds / 20 seconds and 25 seconds / 15 seconds, for the Predictive and Caution Alerts, respectively.

The controllers found both alert types to be effective in providing sufficient advance notice across all of the evaluated alert timing values and no significant difference was observed between average controller response times for any of the timings. The majority of Week 2-3 TRACON controllers reported preferring a 35 second value for the Predictive Alert with respect to both safety limits, and a 15 or 20 second value for the Caution Alert. This suggests that the default ATPA alert timing value of 45/24 sec could possibly be acceptably decreased; however,

responses also suggested that the 25/15 sec alert timing value was the most difficult for controllers to assess whether the IM PA Trail Aircraft would remain behind the CSL and forward of the WSL. Further research is recommended in this area to optimize the balance between nuisance alerts and the time available to take action once an alert is triggered.

Participant discussions suggested a potentially confusing consequence from how the alerts were designed to be time-based and dependent upon ground speed matching. Depending on the speed differences, an alert may not be displayed even if an aircraft was a very short distance to the limit. Then, if there was a sudden change in the ground speed differential between an IM Lead and Trail Aircraft, a Caution Alert could be triggered without a preceding Predictive Alert. Though this behavior was explained to the participants, it still appeared to require some experience with the operations and alerts to understand why an aircraft could be physically very close to a limit without a corresponding alert, or to have a Caution Alert suddenly appear. Strategies for minimizing the potential for confusion or sudden state changes should be considered in the further design of the IM PA alerting.

**Longitudinal Alert Response Procedures.** Further discussion and open-ended comments suggested that controllers desired more manual control to resolve a situation when it became clear via speed differences or a Predictive Alert that an aircraft was going to encroach upon a safety limit. Several controllers expressed frustration that they were unable to manually issue a speed to keep an IM Trail Aircraft within the limits. This was because issuing a speed to an IM Trail Aircraft terminates the FIM Equipment-generated speeds, and the HITL procedure when that happened was to issue a go-around to the trail. Although it is assumed that the PA separation standard will be designed to not require IM and FIM Equipment-generated IM Speeds, this HITL procedure was implemented because it seemed unlikely that controllers would be willing to manually issue speeds to keep the aircraft within limits due to their workload and other tasking.

Several controllers, however, expressed a strong desire to manually provide speeds to the IM Trail Aircraft when they observed a spacing situation start to develop. It was acceptable to them to keep the aircraft within the safety limits for the remainder of the approach and save a go-around. One instance was observed in which a controller attempted to do this, but was unsuccessful. This, and five observed instances of safety limit crossings that were not counted as violations due to a PTT click before the aircraft passed the line, occurred with the shortest alert timing values (25/15 sec). The average controller PTT response before each crossing was 10.8 seconds (SD = 3.6). If a future PA separation standard would allow controllers to manually manage Trail Aircraft speeds, further alert timing research is recommended to examine values that would ensure interventions can be successfully implemented before a safety limit is exceeded.

Though not part of their training, controllers were also observed attempting to assist a deteriorating IM PA operation by modifying the speed of the IM Lead Aircraft to help keep the IM Trail Aircraft within the safety limits. This was at times successful and was observed in both monitor configurations. When acting as Separate 28L / 28R Monitors, participants were observed to coordinate to make this happen.

Further discussion during the debrief suggested that the ability for controllers to manually provide speeds to assist the IM PA operation may ultimately depend on which position is responsible for providing separation. A dedicated Monitor controller or a Final Approach controller could be responsible for IM PA, depending on the facility configuration. This controller would likely have enough spare capacity to manually issue speeds to keep the IM Trail Aircraft within the safety limits. However, with a Monitor controller / Local controller override configuration such as that tested in the HITL, significant concerns were raised with the number of communications that could be required to manage deteriorating IM PA operations. A Tower controller especially noted that it would be highly undesirable or even dangerous for Monitor controllers to override the Local controller at even a moderate level. Even if the IM PA and the FIM Equipment proves to be highly reliable in keeping the IM Trail Aircraft within the safety limits, the Monitor controllers will still need frequency time to manage between-pair spacing.

Manual PA speed control may not be possible, however, if a Final controller position is responsible for providing IM PA separation. Depending on the task loading and communications bandwidth, a Final controller may simply not have enough spare capacity to issue speeds to resolve a deteriorating IM PA operation. There may only be time to break out an IM Trail Aircraft once a Caution Alert is triggered. In this case, the usefulness of a Predictive Alert may be reduced and so only a Caution Alert would be required. This suggests the need for at least some of the features may be dependent upon the specifics of how a facility may choose to integrate IM PA into their operation and which controller position would be responsible for providing separation. Though controllers overall suggested they would be able and willing to provide speeds to keep the aircraft within the safety limits, the practical considerations with respect to managing the required communications may make this highly challenging to implement.

Finally, upon receiving a Predictive Alert, controllers were often observed to contact the IM Trail Aircraft to confirm the status of the operation. Though allowed to do this, participants were not given specific guidance as to what to say. Controllers usually asked for verification their FIM Equipment was functioning. They also sometimes advised that the Trail Aircraft had a speed overtake on the Lead Aircraft. No matter the query, the pseudopilots were instructed to communicate to the controller that their equipment appeared to be functioning properly and that the operation seemed fine to them. Though appropriate for the HITL, these responses did not appear to be helpful to the controllers as they did not indicate the reason for the Predictive Alert nor indicate whether it would transition to a Caution Alert.

This controller finding was considered in a companion IM PA HITL that examined the current operation from the flight deck perspective (Lewis, Bone, Mendolia, & Nguyen, 2019). The study noted that the FIM Equipment does not provide pilots a way to determine whether they are in an overtake situation or whether they are close to the CSL or WSL. Pilot participants disagreed they would be able to verify a speed overtake on the lead if queried by ATC, with most citing the lack of ground speed as the reason. In response, the authors recommend that flight crew display features continue to be developed to give relevant information to the crew about the progress of the IM PA operation such that they can answer ATC queries. As this may or may not

prove sufficient depending on the nature of the controller query, further consideration is recommended for controller and pilot coordination actions and information transfer when the IM PA operation appears likely to require a breakout.

**Lateral Monitoring and Alerting.** The CSL and WSL were designed to accommodate some amount of normal aircraft crosstrack error from the approach path centerline. If either aircraft exceeded that amount in either direction (left or right), then it was assumed PA separation would no longer be valid. To indicate to controllers when deviations exceeded the CSL and WSL assumptions, Lateral Boundaries, and an associated Exceedance Warning based on current-day NTZ alerting, were implemented and evaluated as display features.

With respect to the Lateral Deviation scenarios, on average controller participants agreed their workload was acceptable across all display types and monitor configurations and that they were confident they could assess whether separation would be maintained between the IM Trail Aircraft and their Lead aircraft. They also on average agreed they could easily assess whether aircraft involved in a PA operation were operating within their Lateral Boundaries and the FMA display (versus STARS) appeared to aid in their Lateral Boundary assessment. Controllers on average suggested that advance notice of an impending exceedance of the lateral bounds would have been more helpful than essential, but noted during the discussion that a lateral predictive-type alert may only be practical on an FMA display. Current STARS display features such as PTL lines and separation “bats” (cones) appeared to provide an immediate and salient visual cue when aircraft ground tracks began to diverge from the approach course.

With respect to the lateral Exceedance Warning (red “LAT” in data block line 0 and Lateral Boundary Line color change), controllers agreed on average that it was noticeable enough such that they became aware of it without undue delay. They also agreed on average that they had sufficient time and situational awareness to choose and execute appropriate corrective action once the Exceedance Warning occurred. Controllers responded (via a PTT click) to Lateral Boundary crossings on average within 2.4 sec (SD=1.2) when working as a Combined Monitor, and within approximately 2.1 seconds (SD=1.3) when working as Separate Monitors. These response times did not appear to be affected by monitor configuration or display type. The averages observed in the current HITL are less than the average 4.3 sec (SD=2.7) for qualified controller response times observed in Cox, Yates, & Savage (2011). It is unclear from the report, however, the degree to which the experimental conditions were similar.

In comments and the debrief discussion, some controllers recommended that the Exceedance Warning should be more salient in identifying the deviating aircraft than what was simulated. Several controllers suggested changing the color of the entire data block instead of only displaying the red “LAT” indicator in line 0. Controller comments also suggested that the line color change was effective in indicating a boundary crossing; however, it did not clearly identify the deviating aircraft. During the debrief discussions, a suggestion was made to consider changing the color only of a line segment in proximity to the deviating aircraft.

Overall, it appeared that given the appropriate tools and training, the IM PA lateral separation monitoring task appeared feasible and acceptable to controllers. Though the FMA display was

found to significantly aid in the Lateral Boundary assessment, responses did not appear to suggest it should be a minimum requirement. And, as discussed earlier in this section, controller responses indicated that a Combined Monitor position may preclude timely communications with aircraft in the (highly unlikely) event of a simultaneous deviation of two or more aircraft. Further study is recommended to examine whether separate monitors may ultimately be required to safely manage extreme off-nominal lateral deviation situations.

## 6.2 IM PA Initiation Task and Tools

The second major HITL objective was to evaluate the IM PA initiation task, especially with respect to Partial IM Clearance procedures. The initial positioning of the aircraft in the arrival stream was therefore assumed to have been accomplished at the start of each scenario, before the aircraft arrived in the participant controllers' airspace. The HITL used RNAV routes to ensure that aircraft were delivered to the final approach courses in a consistent, reproducible manner. These procedures were developed for the HITL and are not currently in place at SFO. However, they may approximate procedures for a future metering environment.

Aircraft were handed off to the final controller when they were on a modified base leg, approximately 25 NM from the runway, with the desired initial spacing, and separated in altitude by 1000 ft. The HITL assumed that a Feeder Controller had first informed the candidate IM Trail Aircraft of the planned IM PA operation, providing the IM Clearance Type (IM PA) and IM Lead Aircraft Flight Identification. Using the IM Spacing List and IM information in the candidate Trail Aircraft's data block, the Final Approach controller provided the IM Trail Aircraft its Assigned Spacing Goal once it and its lead were established on the final approach course. This initiated the IM PA operation and the Final Approach controllers then cleared the aircraft for their approaches and instructed the aircraft to change to the Local controller frequency. Final Approach controllers were responsible for providing IM PA separation for the short duration of time between IM PA initiation and the aircraft change to the Local controller frequency. Monitor controllers then monitored separation with respect to the CSL and WSL (if applicable) until the IM Lead Aircraft crossed its runway threshold.

Previous research such as Mendolia, et al. (2016) examined the use of an "expect" message to provide IM Clearance information before the operation was intended to begin. Controller results suggested that clearance formulation in this manner was acceptable and during further concept development, was modified to the use of a Partial IM Clearance. The feasibility and acceptability for Final Approach controllers to do this was examined with respect to multiple metrics. As the intent was the same and the sequence of communications and information transfers was similar to prior work involving "expect," it was hypothesized that Final controllers would find the IM initiation task, including the use of Partial IM Clearance procedures, acceptable.

In the 28R Final controller position, controller participants on average agreed: Final controllers can acceptably initiate the IM PA operation and that their workload was low and acceptable. They also agreed on average that they were comfortable with the IM Trail Aircraft managing their speeds to achieve the spacing goal while in their area, and that given the appropriate

training and tools, Final controllers can acceptably ensure separation during IM PA operations before transferring aircraft to the Local controller. However, concerns were raised regarding the phraseology, available CSL and WSL information at the time of initiation, and the available time and airspace to perform the initiation task as simulated. Each of these concerns is discussed next.

**Communications.** On average, controllers agreed it is operationally acceptable for the Final controller to provide the IM PA spacing goal and that the IM PA spacing goal communication was acceptable. This suggests that the Partial IM Clearance procedures were acceptable to the Final controllers, though further research is recommended to examine Feeder controller acceptability to provide the first part of the clearance. In a companion IM PA flight deck features evaluation performed recently, pilots found these Partial IM Clearance procedures acceptable (Lewis, Bone, Mendolia, & Nguyen, 2019). However, less than half of the pilots agreed it was necessary to split the clearance information into two messages.

Domino, Tuomey, Stassen, & Mundra (2014) found IM PA initiation communications acceptable, including the use of Expect to convey PA-related information early. In that HITL simulation, however, the IM Clearance was conveyed with the IM PA 28R approach clearance and did not require a separate communication. Controllers were required to provide the Lead Aircraft's PFAS to the Trail Aircraft, which was not part of the IM PA initiation procedure for the evaluation being reported on in this document.

In the current simulation, the IM PA operation was initiated via a separate clearance and findings were consistent with the similar procedure used in Mendolia, et al. (2016). Though the IM initiation procedure was generally acceptable, several comments in both evaluations noted the IM Clearance phraseology and procedures could be improved and streamlined, and some specific suggestions were made. In the current evaluation, one suggestion was the word "Goal" should be replaced with "your interval spacing." Another suggestion was the Final controller should not have to repeat the IM Lead Aircraft's flight ID when providing the Assigned Spacing Goal. Some controllers were observed to combine the Assigned Spacing Goal transmission with the approach clearance. The main concern about the communications appeared to be related to the number of required transmissions on the override frequency. This would be an important consideration for IM PA implementation at a facility, as discussed in Section 6.1. Finally, controllers in both HITLs on average agreed they were comfortable with the use of the Lead Aircraft flight ID in the IM Clearance communication.

**IM PA Initiation Information.** On average controllers agreed they had the necessary display elements to provide the appropriate IM Clearance information to the trail aircraft in an IM PA pair. However, many controllers commented on the need for more predictive information, earlier. The simulation procedure required the Final controller to first issue the IM Clearance and then receive acknowledgement from the IM Trail Aircraft *before* accepting the proposed clearance in the IM Spacing List and activating the IM PA display features. This was designed to reduce the potential for controllers to accept the clearance in the automation, but potentially get distracted and fail to follow up and actually issue the IM Clearance to the Trail Aircraft. This would result in a situation where the automation is displaying an IM PA operation was being

performed, when in reality the candidate IM Trail Aircraft is not following IM Speeds to manage its spacing.

In the simulation, however, controllers expressed concerns this procedure did not allow them to know the IM Trail Aircraft's proximity to the safety limits before issuing the IM Clearance. This was exemplified by a scenario event in which a candidate IM Trail Aircraft was ahead of its CSL at the time of initiation. This was not displayed to the Final controllers, so they received a Caution Alert as soon as they accepted the IM Clearance in the IM Spacing List and then immediately had to terminate. To avoid this, controllers suggested adding a "CSL Preview" line on the display to indicate where the IM Trail Aircraft was relative to the CSL *before* controllers needed to provide the IM Clearance. This would enable a Tower controller's request for the ability to adjust speeds prior to the start of IM PA to increase the probability of the Trail Aircraft achieving its spacing. The suggestion was also made for a WSL-P to be displayed before initiation; however, this may prove confusing and counterproductive as discussed in Section 6.1.

**Initiation Time.** On average controllers agreed once the IM Trail Aircraft joined the final, they had sufficient time and airspace to initiate IM PA before transferring the aircraft to the Local controller. However, comments and discussion suggested this portion of the operation could be improved over what was implemented in the simulation. One controller suggested a Final controller should have more airspace to adjust the initial spacing if needed. This controller agreed with another controller who suggested a fix with an above crossing altitude. This would allow the Final controller to clear for the approach, then assign the spacing goal once established on final. The participant suggested this would make the timing less critical. Another comment suggested they could better ensure they were transferring appropriately separated aircraft to the Local controller if the IM Trail was in their area for a longer period following initiation.

## 7 Conclusions and Recommendations

### 7.1 Summary of Conclusions

The FAA, NASA, MITRE CAASD, and others have been conducting research on various aspects of PA for over two decades. In 2016, RTCA SC-186 WG 4 decided to make PA an IM application and include it in the updated FIM Equipment requirements. Through this process, stakeholders determined controllers must be able to monitor the operation relative to a separation standard. This requires controllers to be able to assess separation within an IM PA pair and take effective action before separation is lost. Therefore, the IM PA concept was changed to move the safety limit monitoring function from being a flight crew responsibility and FIM Equipment capability to a ground capability.

Sponsored by the FAA's SBS Program Office, MITRE CAASD developed and executed a HITL experiment to validate IM PA concept changes, address open controller acceptability and feasibility questions, provide input to air and ground system requirements, and mitigate technical risks associated with the revised PA concept. The primary goal of this HITL simulation was to examine new controller monitoring functions. This included an evaluation of the terminal controller monitoring task for IM PA aircraft pairs established on final approach, especially with respect to both minimum and maximum separation values that change over the course of the approach, and lateral deviations. Additionally, it examined the acceptability of a single monitor controller to manage Lead and Trail Aircraft, or whether separate monitors should be required. The experiment also included an evaluation of prototype display features to facilitate this monitoring task. A secondary goal was to examine acceptability and information requirements for IM PA initiation.

After initiating and monitoring IM PA operations with varying supporting IM PA (display) Tool configurations, monitor configurations, and off-nominal deviations, results suggest given the appropriate tools and training, the IM PA longitudinal and lateral separation monitoring task should be feasible and acceptable to controllers. IM PA pair-wise separation assurance appeared to be a straightforward task for controllers as only a single violation was observed within an IM Trail Aircraft and IM Lead Aircraft pairing, despite the introduction of far more off-nominal deviations than would be expected in actual operations. This instance involved a controller appearing to attempt to manually assign a speed to keep an IM Trail Aircraft behind the CSL and allowing the IM PA operation to continue. It was not a result of the controller failing to notice a developing situation.

Separation was also examined between other aircraft combinations (e.g. between the trail aircraft of a leading pair and the lead aircraft of a following pair). Twelve total instances of separation violations were observed between aircraft pairs not performing IM PA. It was unclear if this was due to the presence of IM PA in the operational environment or was related to controllers in the simulation not having current separation tools such as ATPA available to them. Although these violations occurred in the context of simulation events that were designed to stress test the concept and ground tools, their presence still suggests that tools and procedures need to be fully integrated to ensure that separation between aircraft pairs not

performing IM PA can be maintained while IM PA operations are in progress. In addition, IM PA setup spacing requirements should ensure that between-pair separation can be sufficiently maintained during compression on final.

Controller participants on average reported: low and acceptable workload; acceptable tasks in each of the monitoring positions; acceptable levels of traffic awareness for all types of aircraft; comfort in allowing the IM Trail Aircraft to manage their own speeds; and confidence they could assess whether the separation between the IM Trail Aircraft and Lead Aircraft would be maintained. They also agreed IM PA is operationally desirable and compatible with terminal approach operations, though real-world facility and airspace integration may be challenging. Controller participants appeared to be comfortable monitoring IM PA when safety limits that changed over the course of an approach were both active at the same time.

Facilities with dependent parallel runway operations typically employ separate L/R Final Approach controllers due to the workload involved in vectoring aircraft to final and other intensive tasks. Implementing separate L/R Monitor controllers, as would be required by current 7110.65X rules, may not be practical or feasible at SFO since that would also require separate Local controllers and frequencies, one for each arrival runway. It was therefore of interest to examine whether a single, combined Monitor controller can effectively provide separation for CSPR finals involving IM PA operations. Results suggest under nominal conditions, a single, Combined Monitor controller is likely to be able to effectively and acceptably provide separation within and between IM PA pairs. However, further study is recommended to examine whether separate monitors may ultimately be required for safety to manage extreme off-nominal lateral deviation situations.

With respect to the IM PA-related display features and tools introduced for the simulation, the graphic depictions of the CSL and WSL were found useful for the overall monitoring task and controllers recommended they always be displayed. As the WSL only became active late in the approach, controllers found the WSL-P tool helpful in indicating whether an aircraft would eventually require a WSL and the IM Trail Aircraft's current proximity to it. Half of the TRACON controller participants felt the WSL-P should always be on and half felt it should be user toggleable. Controllers also suggested the WSL-P should be displayed earlier than what was implemented in the HITL. Controllers on average agreed the IM PA Predictive and Caution Alerts were both useful, though they agreed more strongly for the Caution Alert. They also suggested the alert timing could be reduced from what was implemented for ATPA. The data block line 3 features, including the current numeric distance to each safety limit, along with a "W" indicating a future WSL, were not found to be useful.

The lateral monitoring task appeared feasible and acceptable to controllers, given the appropriate tools and training. Current STARS display features such as PTLs and separation "bats" (cones) appeared to provide an immediate and salient visual cue when aircraft ground tracks began to diverge from the approach course. Controllers appeared to find the Lateral Boundaries useful, especially with the FMA display. Though the FMA display was found to significantly aid in the Lateral Boundary assessment, responses did not appear to suggest it should be a minimum requirement. Controllers also found the Exceedance Warning useful and

provided sufficient time and situational awareness to choose and execute appropriate corrective action when needed. It could, however, possibly be made more salient by changing the color of the entire data block of the deviating aircraft, plus changing the color of only a boundary line segment near to the deviation instead of changing the color of the entire line. On average controllers also suggested a predictive-type Exceedance Warning may be helpful, but not essential.

Most controllers reported a Final Monitor controller is the most appropriate position to monitor IM PA operations, though this may ultimately depend on the facility. They also expressed a strong desire to manually provide speeds to the IM Trail Aircraft when they observed a spacing situation start to develop. The ability for controllers to manually provide speeds to assist the IM PA operation may ultimately depend on which position is responsible for providing separation. A dedicated Monitor controller or a Final Approach controller could be responsible for IM PA, depending on the facility configuration. This controller would likely have enough spare capacity to manually issue speeds to keep the IM Trail aircraft within the safety limits. However, with a Monitor controller / Local controller override configuration such as that tested in the simulation, significant concerns were raised with the number of communications that could be required to manage deteriorating IM PA operations. Even if the IM PA and the FIM Equipment proves to be highly reliable in keeping the IM Trail Aircraft within the safety limits, the Monitor controllers will still need frequency time to manage between-pair spacing.

Manual PA speed control may not be possible, however, if a Final Approach controller position is responsible for providing IM PA separation. Depending on the task loading and communications bandwidth, a Final controller may simply not have enough spare capacity to issue speeds to resolve a deteriorating IM PA operation. There may only be time to break out an IM Trail Aircraft once a Caution Alert is triggered. In this case, the usefulness of a Predictive Alert may be reduced and so only a Caution Alert would be required. This suggests the need for at least some of the features may be dependent upon the specifics of how a facility may choose to integrate IM PA into their operation and which controller position would be responsible for providing separation. Though controllers overall suggested they would be able and willing to provide speeds to keep the aircraft within the safety limits, the practical considerations with respect to managing the required communications may make this highly challenging to implement.

The second major HITL objective was to evaluate the IM PA initiation task, especially with respect to Partial IM Clearance procedures. Controller participants on average agreed Final controllers can acceptably initiate the IM PA operation and given the appropriate training and tools, can acceptably ensure separation during IM PA operations before transferring aircraft to the Local controller. They also agreed they were comfortable with the IM Trail Aircraft managing their speeds to achieve the spacing goal while in their area. The information contained in the IM Spacing List appeared useful for the IM PA initiation task.

Concerns were raised regarding the phraseology, available CSL and WSL information at the time of initiation, and the available time and airspace to perform the initiation task as simulated. On average, controllers agreed it is operationally acceptable for the Final controller to provide the

IM PA spacing goal and the IM PA spacing goal communication was acceptable. This suggests the Partial IM Clearance procedures were acceptable to the Final controllers, though further research is recommended to examine Feeder controller acceptability to provide the first part of the clearance. It was recommended, however, the IM Clearance phraseology and procedures could be improved over what was used. Controllers also suggested adding a “CSL Preview” line on the display to indicate where the IM Trail Aircraft was relative to the CSL *before* controllers needed to provide the IM Clearance. This would avoid IM PA initiations with aircraft not in the correct positions. Finally, although controllers had sufficient time and airspace to initiate IM PA before transferring the aircraft to the Local controller, they suggested more airspace would have been desirable to adjust the initial spacing if needed and reduce the criticality of the timing.

Overall results suggest given the appropriate tools and training, the IM PA longitudinal and lateral separation monitoring and initiation tasks should be acceptable to controllers. In a related IM PA flight deck features evaluation performed in 2018, pilots also found IM PA to be generally acceptable, even after experiencing significant lateral deviations by the Lead Aircraft. The current IM PA concept appears feasible and MITRE CAASD recommends the FAA continue its development.

This study provided initial findings on the initiation of and monitoring of an IM PA operation based on its current ConOps (FAA, 2017b). The results are intended to provide concept validation for the avionics standard development activities and A-IM ConOps, as well as specific recommendations for the FAA IM Initial Program Requirements document with respect to controller information needs and supporting ground tools. These results and recommendations should be considered by RTCA SC-186, FAA SBS Program Office, FAA Aircraft Certification, and FAA Flight Standards as IM PA proceeds through concept development.

## 7.2 Summary of Recommendations

Based on the results of the HITL experiment, the following 13 recommendations should be considered in the further development of the IM PA concept and air and ground requirements:

1. Concept development should continue based on results suggesting the IM PA longitudinal and lateral separation monitoring and initiation tasks should be feasible and acceptable to controllers given the appropriate tools and training.
2. Final Approach controllers should have an indication of how close the IM Trail Aircraft is to the safety limits before they initiate the IM PA operation. This could be in the form of a preview CSL Line. Further study is recommended as to what may be helpful for wake protection information.
3. IM PA setup spacing requirements should ensure that between-pair separation can be sufficiently maintained during compression on final.
4. A single Final Monitor controller is likely to be able to monitor across both approaches under nominal operations. However, further study is needed to examine whether

separate Monitor controllers will be required for safety to manage extreme off-nominal situations.

5. Graphic depictions of the CSL and WSL lines should be considered, as opposed to numeric distances in the data blocks.
6. A WSL-P for relevant aircraft should be considered, appearing as early as possible. Further study is recommended to determine at what point this may prove confusing and counterproductive.
7. An alert should be provided for longitudinal monitoring task to indicate when a controller must take action to stop an aircraft from exceeding a safety limit. The need for a situation awareness alert that does not require action may depend on the facility implementation and what controllers are able to do in response. Further study is recommended to optimize the balance between the potential for nuisance alerts and the time available to take action once an alert is triggered. Strategies for minimizing the potential for sudden state changes should also be considered.
8. For the lateral monitoring task, controllers should be provided an indication for where an aircraft's crosstrack error may result in the CSL and WSL no longer providing the required protection from collision or wake risk. The use of a 4:1 FMA display should be considered to aid in the controller's lateral deviation assessment.
9. Further examination of the monitoring task and response procedures is recommended for lateral deviations close to the runway (i.e. past the Lateral Bounds).
10. Controllers should be provided with an alert or warning for when PA separation may no longer apply due to a lateral deviation by the IM Lead or Trail Aircraft. Its saliency may be improved by changing the color of the entire data block of the deviating aircraft and changing the color of a boundary line segment near to the deviation instead of changing the color of the entire line.
11. Ground tools and procedures need to be fully integrated to ensure that separation between aircraft pairs not performing IM PA can be maintained while IM PA operations are in progress.
12. A Final Approach controller or a Monitor controller could be responsible for IM PA, depending on the facility configuration and further research is recommended with respect to allowing controllers to manually provide speeds to keep an IM Trail Aircraft within the safety limits if the FIM Equipment fails. This must be balanced with the potential for undesirable frequency overrides and workload.
13. Further consideration is recommended for controller and pilot coordination actions and information transfer when the IM PA operation appears likely to require an aircraft break out.

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## Appendix A Abbreviations and Acronyms

<b>Term</b>	<b>Definition</b>
<b>A/C or a/c</b>	Aircraft
<b>AAL</b>	American Airlines
<b>ABP</b>	Achieve-By Point
<b>ADS-B</b>	Automatic Dependent Surveillance-Broadcast
<b>AFS</b>	Flight Standards Service
<b>AFS-450</b>	Flight Standards Services, Flight Technologies Division, Flight Systems Lab
<b>AIAA</b>	American Institute of Aeronautics and Astronautics
<b>A-IM</b>	Advanced Interval Management
<b>AJM</b>	(FAA) Surveillance Services Directorate
<b>AJV-7</b>	(FAA) Mission Support Services
<b>ANG-C</b>	(FAA) Next Generation Air Transportation System Portfolio Management & Technology Development Office
<b>ANOVA</b>	Analysis of Variance
<b>ASG</b>	Assigned Spacing Goal
<b>ASPA-FIM</b>	Airborne Spacing – Flight Deck Interval Management
<b>ATC</b>	Air Traffic Control
<b>ATPA</b>	Automated Terminal Proximity Alert
<b>BOS</b>	Boston Logan International Airport
<b>CAASD</b>	Center for Advanced Aviation System Development
<b>CAT</b>	Category
<b>CLE</b>	Cleveland Hopkins International Airport
<b>Conf</b>	Confederate
<b>ConOps</b>	Concept of Operations
<b>CPDLC</b>	Controller Pilot Data Link Communications
<b>CRJ</b>	Canadair Regional Jet
<b>CSL</b>	Collision Safety Limit
<b>CSPO</b>	Closely Spaced Parallel Operations

<b>Term</b>	<b>Definition</b>
<b>CSPR</b>	Closely Spaced Parallel Runways
<b>DAL</b>	Delta Air Lines
<b>DASC</b>	Digital Avionics Systems Conference
<b>DB</b>	Data Block
<b>df</b>	Degrees of Freedom
<b>DSA</b>	Dependent Staggered Approaches
<b>e.g.</b>	for example
<b>EWR</b>	Newark Liberty International Airport
<b>EZ</b>	Early Zone
<b>F</b>	Fisher statistic
<b>FAA</b>	Federal Aviation Administration
<b>FAF</b>	Final Approach Fix
<b>FIM</b>	Flight deck-based Interval Management
<b>FMA</b>	Final Monitor Aid
<b>ft</b>	feet
<b>HITL</b>	Human-in-the-loop
<b>i.e.</b>	that is
<b>IDEA</b>	Integration Demonstration and Experimentation for Aeronautics
<b>IEEE</b>	Institute of Electrical and Electronics Engineers
<b>ILS</b>	Instrument Landing System
<b>ILZ</b>	Imbedded Late Zone
<b>IM</b>	Interval Management
<b>IMC</b>	Instrument Meteorological Conditions
<b>JBU</b>	JetBlue Airlines
<b>KSFO</b>	San Francisco International Airport
<b>kt</b>	Knots
<b>L</b>	Left
<b>L(A)</b>	Lead Active
<b>L/R</b>	Left/Right

<b>Term</b>	<b>Definition</b>
<b>LAT</b>	Lateral
<b>LZ</b>	Late Zone
<b>M</b>	Mean
<b>MEM</b>	Memphis International Airport
<b>MMC</b>	Marginal Meteorological Conditions
<b>MOPS</b>	Minimum Operational Performance Standards
<b>MRS</b>	Minimum Radar Separation
<b>MS</b>	Mean Squares
<b>MVA</b>	Minimum Vectoring Altitude
<b>N/A</b>	Not Applicable
<b>NAS</b>	National Airspace System
<b>NASA</b>	National Aeronautics and Space Administration
<b>NATCA</b>	National Air Traffic Controllers Association
<b>NCT</b>	Northern California TRACON
<b>NM</b>	Nautical Mile
<b>NNZ</b>	Non-Normal Zone
<b>NTZ</b>	No-Transgression Zone
<b>OAK</b>	Oakland International Airport
<b>PA</b>	Paired Approach
<b>PFAS</b>	Planned Final Approach Speed
<b>PHL</b>	Philadelphia International Airport
<b>PIRAT</b>	Tailored Oceanic Arrivals
<b>PRM</b>	Precision Runway Monitor
<b>PTL</b>	Predicted Track Line
<b>PTP</b>	Planned Termination Point
<b>PTT</b>	Push-To-Talk
<b>QT</b>	Questionnaire Type
<b>R</b>	Right
<b>RECAT</b>	Recategorization

<b>Term</b>	<b>Definition</b>
<b>RNAV</b>	Area Navigation
<b>RNP</b>	Required Navigation Performance
<b>RQ</b>	Research Question
<b>RWY</b>	Runway
<b>SBS</b>	Surveillance Broadcast Services
<b>SC</b>	Special Committee
<b>SD</b>	Standard Deviation
<b>SEA</b>	Seattle-Tacoma International Airport
<b>SEWG</b>	Systems Engineering Working Group
<b>SFO</b>	San Francisco International Airport
<b>SJC</b>	San Jose International Airport
<b>SME</b>	Subject Matter Expert
<b>SOIA</b>	Simultaneous Offset Instrument Approach
<b>SPR</b>	Safety and Performance Requirements
<b>SRS</b>	Single Runway Spacing
<b>SS</b>	Sum of Squares
<b>STARS</b>	Standard Terminal Automation Replacement System
<b>STL</b>	St. Louis Lambert International Airport
<b>T(A)</b>	Trail Active
<b>T(E)</b>	Trail Eligible
<b>TBFM</b>	Time-Based Flow Management
<b>TBO</b>	Trajectory Based Operations
<b>TERPS</b>	Terminal Instrument Procedures
<b>TMC</b>	Traffic Management Coordinator
<b>TRACON</b>	Terminal Radar Approach Control
<b>TSAS</b>	Terminal Sequencing and Spacing
<b>TSE</b>	Total System Error
<b>UAL</b>	United
<b>UPS</b>	United Parcel Service

<b>Term</b>	<b>Definition</b>
<b>VFR</b>	Visual Flight Rules
<b>VMC</b>	Visual Meteorological Conditions
<b>VRD</b>	Virgin America Airlines
<b>WG</b>	Working Group
<b>WSL</b>	Wake Safety Limit
<b>WSL-P</b>	Wake Safety Limit Preview

## Appendix B Demographics

### IM PAIRED APPROACH HITL ATC DEMOGRAPHICS QUESTIONNAIRE

Please complete the following background questionnaire. Your identity will be kept confidential and will not be included in any of the material that will be produced as a result of this study.

1. How many years of experience do you have actively controlling air traffic? \_\_\_\_\_ Years
2. How many months out of the past 12 have you actively controlled air traffic? \_\_\_\_\_ Months
3. Age: \_\_\_\_\_ Years
4. At which facility do you now (or did you last) work? \_\_\_\_\_
5. What is your current (or most recent) position? \_\_\_\_\_
6. Have you ever worked at a final approach monitor position? (circle one) **YES**      **NO**  
If yes, approximately how many months / years? \_\_\_\_\_  
If yes, which facility / facilities? \_\_\_\_\_  
If yes, did you monitor parallel runway arrivals? **YES**      **NO**  
If yes, were they dependent, independent, or both?    **DEPENDENT**    **INDEPENDENT**    **BOTH**
7. Have you ever worked at a final approach control position? (circle one) **YES**      **NO**  
If yes, approximately how many months / years? \_\_\_\_\_  
If yes, which facility? \_\_\_\_\_  
If yes, did you control during parallel runway arrivals?    **YES**      **NO**  
If yes, were they dependent, independent, or both?    **DEPENDENT**    **INDEPENDENT**    **BOTH**
8. What other positions have you held within the FAA (e.g., TMC, airspace operations, etc.)?  
\_\_\_\_\_  
\_\_\_\_\_

**(see next page)**

9. Have you ever been a controller at Northern California TRACON (NCT)? (circle one) **YES NO**

If yes, which sectors and approximately how many months / years in each:

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10. Have you ever been a controller at the San Francisco International Airport (SFO) air traffic control tower? (circle one) **YES NO**

If yes, which position(s) and approximately how many months / years: \_\_\_\_\_

11. Have you ever worked at a facility that conducted closely spaced parallel approaches? (circle one)

**YES NO**

If yes, which facility and position(s): \_\_\_\_\_

12. Do you have any experience (such as demos or simulations) with concepts like Interval Management and/or Paired Approach? (circle one) **YES NO**

If yes, please describe your previous experience:

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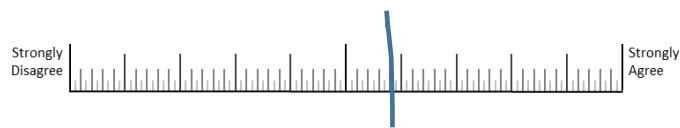
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## Appendix C Day 1-2 Post-Run Questionnaires

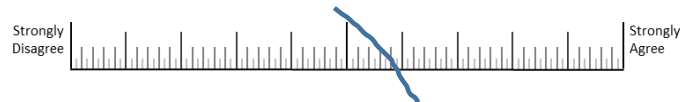
### IM PA HITL POST-RUN QUESTIONNAIRE – COMBINED MONITOR

**Instructions:** Please answer the questions by drawing a vertical line through the option on each of the scales at the point which matched your experience (as shown below) or circling an option (e.g., yes / no).

Please draw your line like this:



NOT like this:

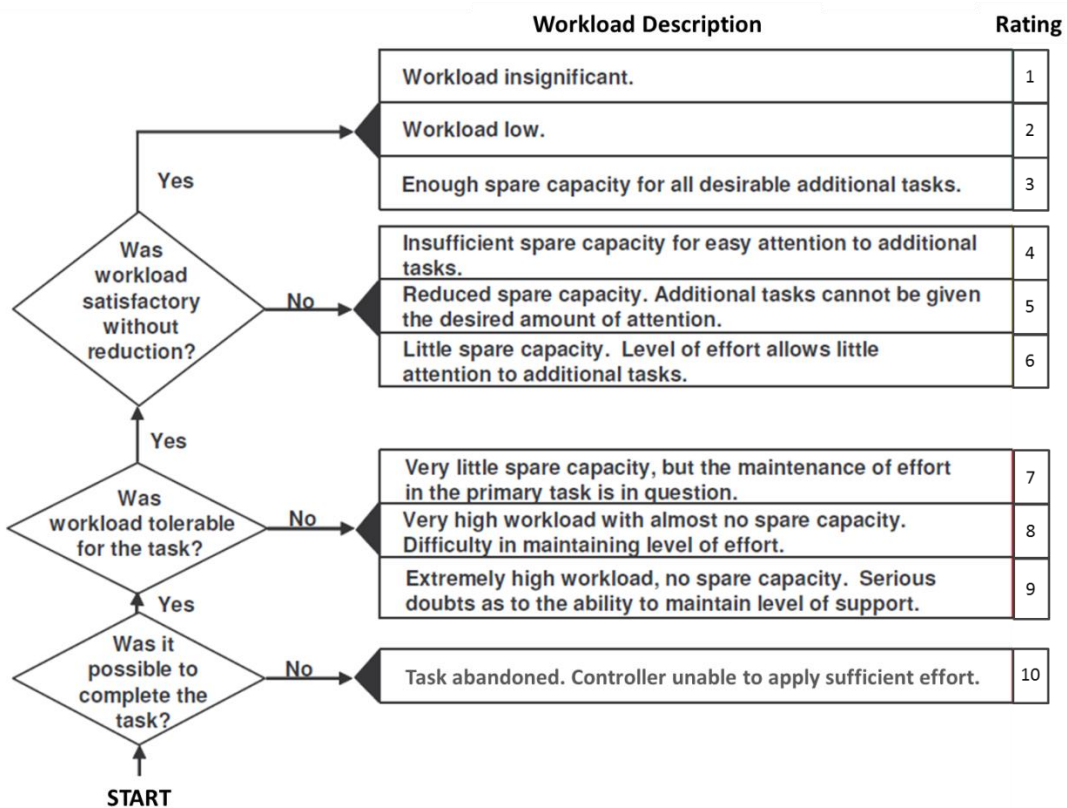


When choosing an option, keep in mind that the general monitoring task for an IM PA operation is the primary area of interest. Although the simulation used certain elements of the SFO airspace, **your answer should be more of a general consideration of the PA monitoring task**, instead of how it might specifically be applied to the SFO environment.

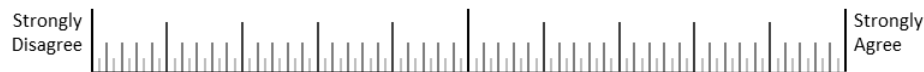
**Please consider only the current scenario when answering.** If you have any questions, please ask the experimenter.

**Workload**

1. Using the chart below, how would you rate your *average* level of workload in this scenario?
  - (a) Working up from the bottom left corner, answer each yes/no question and follow the path.
  - (b) Circle the numerical rating that best reflects your experience.



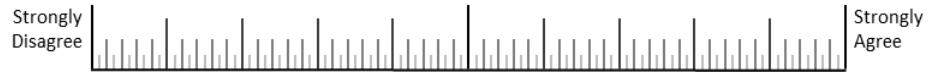
2. My workload in this scenario was acceptable. (draw a line on the scale)



Comments: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

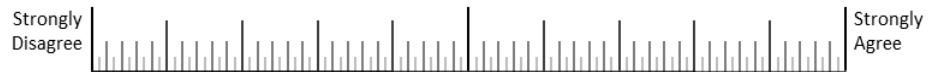
**Operations**

3. As the IM PA aircraft pairs became my responsibility, I had sufficient time to make a first assessment of their separation. (draw a line on the scale)



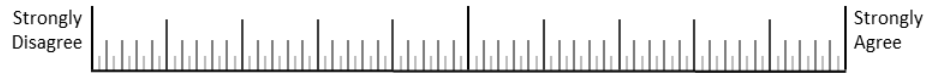
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

4. I was comfortable with the IM PA trail aircraft managing their speeds to achieve the spacing goal assigned by the final controller. (draw a line on the scale)



Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

5. I was confident that I could assess whether separation would be maintained between the IM PA trail aircraft and their Lead Aircraft. (draw a line on the scale)



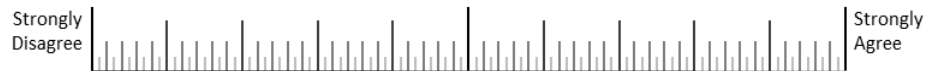
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

6. Did you need to terminate an IM PA operation during this scenario? (circle one)

Yes	No
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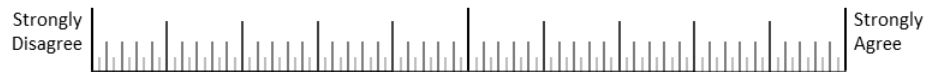
If yes, why? \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

7. Given the IM PA-related tools I had in this scenario, I had sufficient overall traffic situation awareness. (draw a line on the scale)



Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

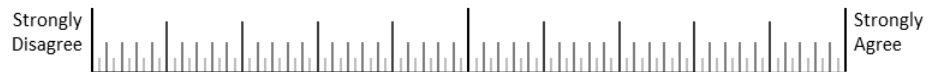
8. Given the appropriate training and the IM PA-related tools provided *in this scenario*, a single monitor controller can effectively ensure separation across both approaches during IM PA operations. (draw a line on the scale)



Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

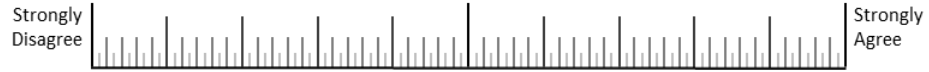
**Displays**

9. With the IM PA-related tools provided in this scenario, I could easily assess the separation *between the IM PA trail aircraft and its lead*, when they were my responsibility. (draw a line on the scale)



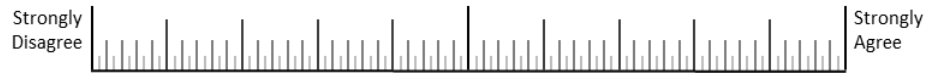
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

10. With the IM PA-related tools provided in this scenario, I could easily assess the separation *among all aircraft* for which I was responsible. (draw a line on the scale)



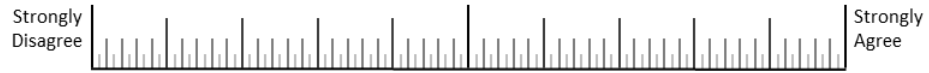
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

11. I could easily assess whether the IM PA trail aircraft would remain behind the CSL during the approach. (draw a line on the scale)



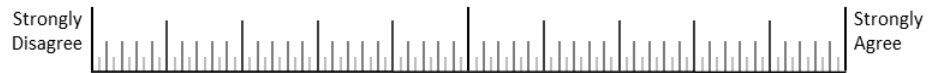
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

12. I could easily assess whether the IM PA trail aircraft would remain forward of the WSL during the approach, when applicable. (draw a line on the scale)



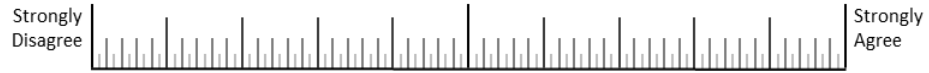
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

13. I could easily assess whether the lead and trail aircraft would remain within their lateral maneuvering bounds during the approach. (draw a line on the scale)



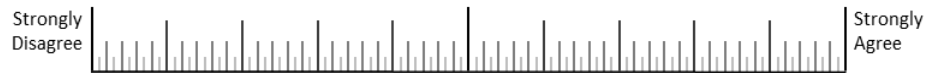
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

14. The IM PA-related tools provided in this scenario allowed for a *timely* detection of any impending exceedance of the WSL or CSL. (draw a line on the scale)



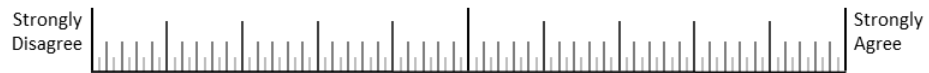
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

15. The IM PA-related tools provided in this scenario allowed for a *timely* detection of any excessive deviation from the approach course by aircraft involved in a PA operation. (draw a line on the scale)



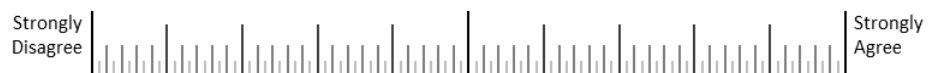
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

16. Given the IM PA-related tools provided in this scenario, I could easily tell when an aircraft would require a WSL later in the approach. (draw a line on the scale)



Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

17. Given the IM PA-related tools provided in this scenario, I was comfortable monitoring IM PA operations when both a CSL and WSL were active *at the same time*. (draw a line on the scale)



Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

18. Was all of the provided IM PA information in this scenario useful, including that in both the Spacing List and data blocks? (circle one)

Yes	No
-----	----

If no, what information was **not** useful and why? \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

19. Was there any operational information *not* provided in this scenario that you would have found helpful? (circle one)

Yes	No
-----	----

If yes, what information and why? \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

**Communications**

20. Did you experience any IM PA-related communication difficulties? (circle one)

Yes	No
-----	----

If yes, explain: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

21. Did you have any issues during communications when the Lead Aircraft call sign was used? (circle one)

Yes	No
-----	----

If yes, describe: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

**Overall**

22. Did you have concerns with any aspect of the IM PA operation in this particular scenario, whether in your area or not? (circle one)

Yes	No
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If yes, please explain: \_\_\_\_\_

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23. If you have any other comments about the IM PA-related **tools** provided in this scenario, please provide them below.

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24. If you have any other comments about this scenario, please provide them below.

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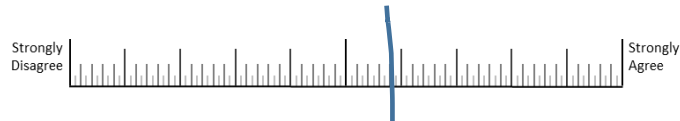
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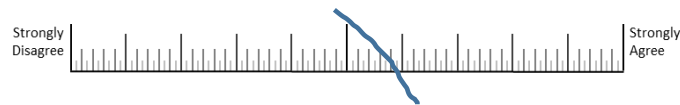
## IM PA HITL POST-RUN QUESTIONNAIRE – 28R FINAL CONTROLLER

**Instructions:** Please answer the questions by drawing a vertical line through the option on each of the scales at the point which matched your experience (as shown below) or circling an option (e.g., yes / no).

Please draw your line like this:



NOT like this:



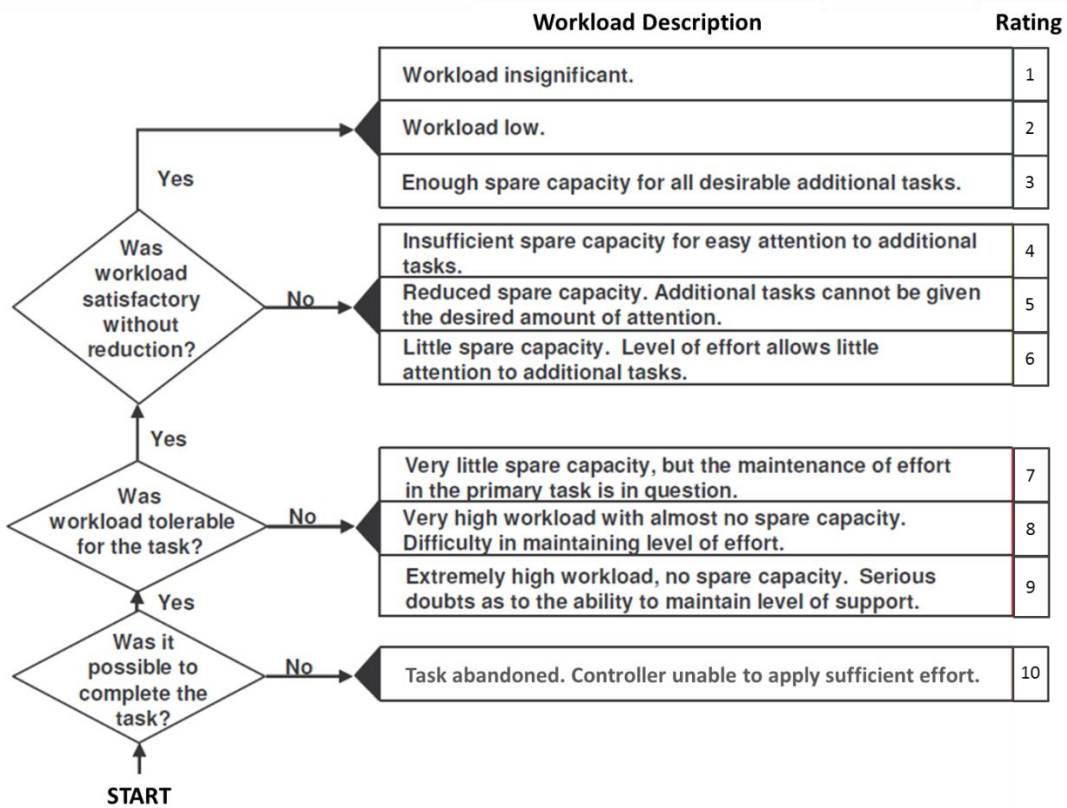
When choosing an option, keep in mind that the IM PA operation is the primary area of interest. Although the simulation used certain elements of the SFO airspace, **your answer should be more of a general consideration of the IM PA operation**, instead of how it might specifically be applied to the SFO environment.

Also, please consider only the time from which the aircraft were in your area to when you transferred them to the local controller.

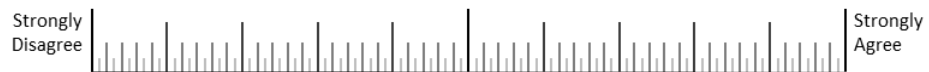
**Please consider only the current scenario when answering.** If you have any questions, please ask the experimenter.

**Workload**

1. Using the chart below, how would you rate your *average* level of workload in this scenario?
  - (a) Working up from the bottom left corner, answer each yes/no question and follow the path.
  - (b) Circle the numerical rating that best reflects your experience.



2. My workload in this scenario was acceptable. (draw a line on the scale)



Comments: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

**Operations**

3. Given the appropriate training, and the IM PA-related tools I had available in **this** scenario, final controllers can acceptably initiate the IM PA operation. (draw a line on the scale)



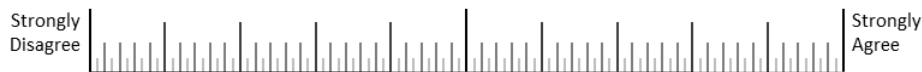
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

4. Once the IM PA aircraft joined the final, I had sufficient time and airspace to initiate IM PA before transferring the aircraft to the local controller. (draw a line on the scale)



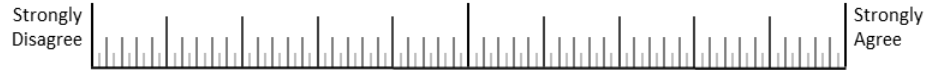
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

5. Given the appropriate training, and the IM PA-related tools I had available in **this** scenario, final controllers can acceptably ensure separation during IM PA operations, before transferring aircraft to the local controller. (draw a line on the scale)



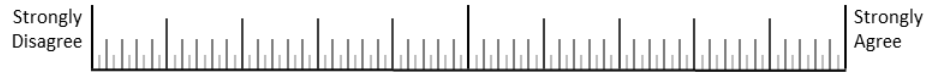
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

6. I was comfortable with the IM PA aircraft managing their speeds to achieve the spacing goal I assigned, while they were in my area. (draw a line on the scale)



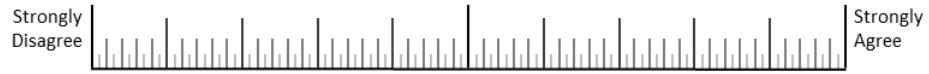
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

7. I was confident that I could assess whether separation would be maintained, in my airspace, between the IM PA aircraft and their Lead Aircraft. (draw a line on the scale)



Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

8. I was comfortable that I was transferring appropriately separated aircraft to the local controller. (draw a line on the scale)



Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

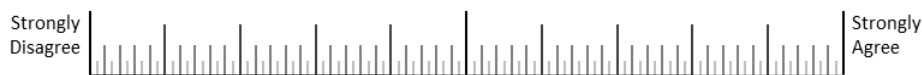
9. Did you need to terminate an IM PA operation in this scenario? (circle one)

Yes	No
-----	----

If yes, why? \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

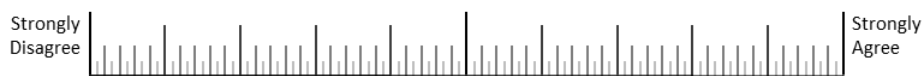
**Displays**

10. In this scenario, I had the necessary display elements to provide the appropriate IM PA clearance information to the trail aircraft in an IM PA pair. (draw a line on the scale)



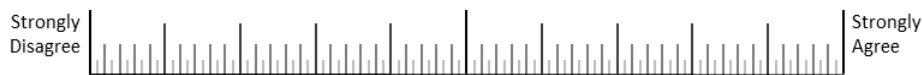
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

11. With the IM PA-related tools provided in this scenario, I could easily assess the separation *between the IM PA trail aircraft and its lead*, when they were my responsibility. (draw a line on the scale)



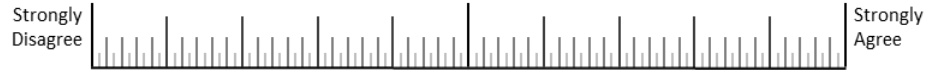
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

12. With the IM PA-related tools provided in this scenario, I could easily assess the separation *among all aircraft* for which I was responsible. (draw a line on the scale)



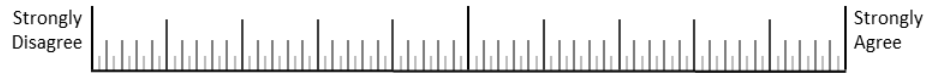
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

13. The IM PA-related tools provided in this scenario allowed for a *timely* detection of any spacing or separation issues. (draw a line on the scale)



Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

14. I could easily assess whether the IM PA trail aircraft would remain behind the CSL during the approach. (draw a line on the scale)



Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

15. Was all of the provided IM PA information in this scenario useful, including that in both the Spacing List and data blocks? (circle one)

Yes	No
-----	----

If no, what information was **not** useful and why? \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

16. Was there any operational information *not* provided in this scenario that you would have found helpful? (circle one)

Yes	No
-----	----

If yes, what information and why? \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

**Communications and Coordination**

17. Did you experience any IM PA-related communication difficulties? (circle one)

Yes	No
-----	----

If yes, explain: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

18. Did you have any issues during communications when the Lead Aircraft call sign was used? (circle one)

Yes	No
-----	----

If yes, describe: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

19. Were there any situations that required coordination with the monitor controller? (circle one)

Yes	No
-----	----

If yes, explain: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

**Overall**

20. Did you have concerns with any aspect of the IM PA operation in this particular scenario, whether in your area or not? (circle one)

Yes	No
-----	----

If yes, please explain: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

21. If you have any other comments about the IM PA-related **tools** provided in this scenario, please provide them below.

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22. If you have any other comments about this scenario, please provide them below.

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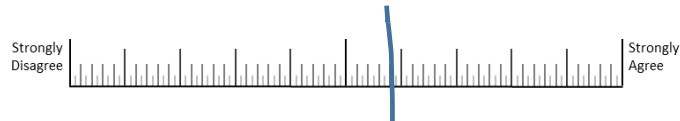
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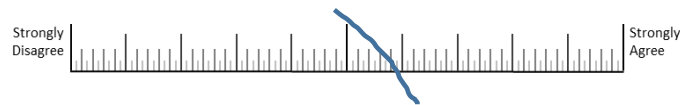
## IM PA HITL POST-RUN QUESTIONNAIRE – DUAL MONITOR CONFIGURATION (28R MONITOR)

**Instructions:** Please answer the questions by drawing a vertical line through the option on each of the scales at the point which matched your experience (as shown below) or circling an option (e.g., yes / no).

Please draw your line like this:



NOT like this:

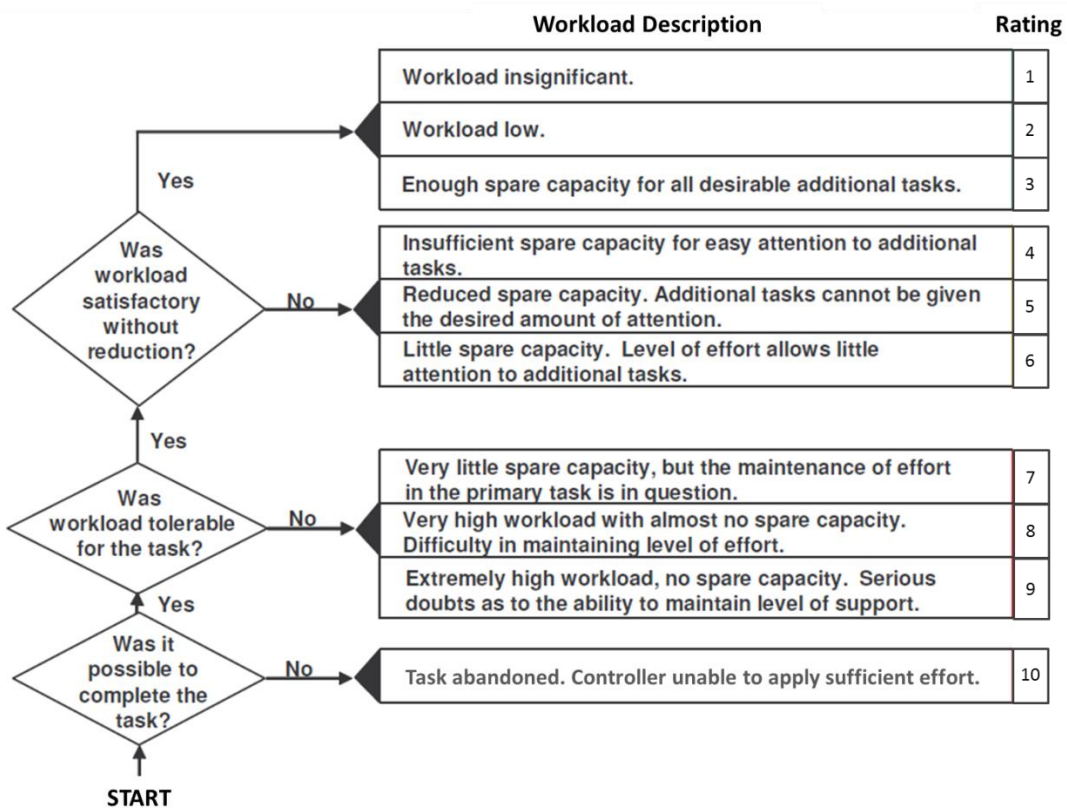


When choosing an option, keep in mind that the general monitoring task for an IM PA operation is the primary area of interest. Although the simulation used certain elements of the SFO airspace, **your answer should be more of a general consideration of the PA monitoring task**, instead of how it might specifically be applied to the SFO environment.

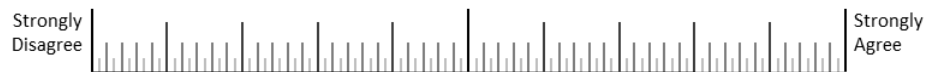
**Please consider only the current scenario when answering.** If you have any questions, please ask the experimenter.

**Workload**

1. Using the chart below, how would you rate your *average* level of workload in this scenario?
  - (a) Working up from the bottom left corner, answer each yes/no question and follow the path.
  - (b) Circle the numerical rating that best reflects your experience.



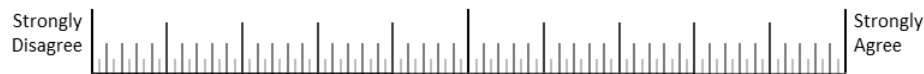
2. My workload in this scenario was acceptable. (draw a line on the scale)



Comments: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

**Operations**

3. As the IM PA aircraft pairs became my responsibility, I had sufficient time to make a first assessment of their separation. (draw a line on the scale)



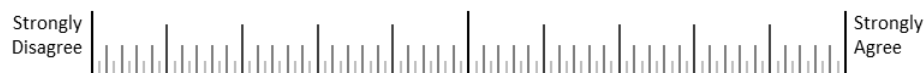
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

4. I was comfortable with the IM PA trail aircraft managing their speeds to achieve the spacing goal assigned by the final controller. (draw a line on the scale)



Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

5. I was confident that I could assess whether separation would be maintained between the IM PA trail aircraft and their Lead Aircraft. (draw a line on the scale)



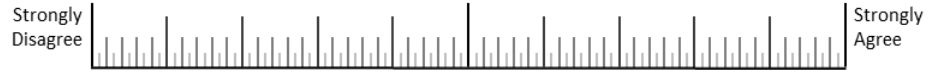
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

6. Did you need to terminate an IM PA operation during this scenario? (circle one)

Yes	No
-----	----

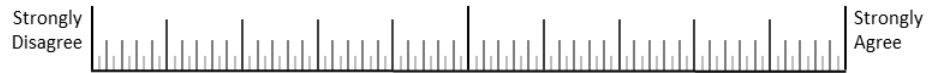
If yes, why? \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

7. Given the IM PA-related tools I had in this scenario, I had sufficient overall traffic situation awareness. (draw a line on the scale)



Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

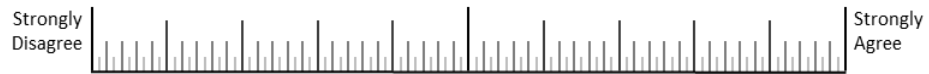
8. I was comfortable monitoring the trail aircraft in an IM PA pair, while another controller monitored the Lead Aircraft. (draw a line on the scale)



Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

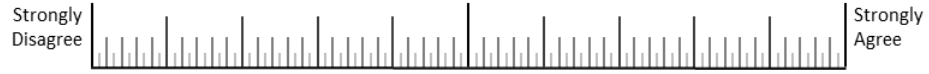
**Displays**

9. With the IM PA-related tools provided in this scenario, I could easily assess the separation *between the IM PA trail aircraft and its lead*, while the IM PA trail aircraft was in my area. (draw a line on the scale)



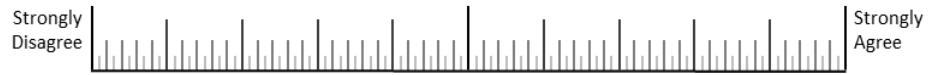
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

10. With the IM PA-related tools provided in this scenario, I could easily assess the separation *among all aircraft* for which I was responsible. (draw a line on the scale)



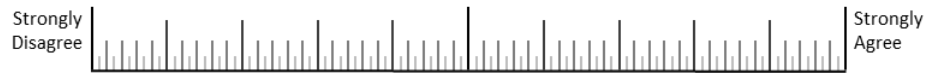
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

11. I could easily assess whether the IM PA trail aircraft would remain behind the CSL during the approach. (draw a line on the scale)



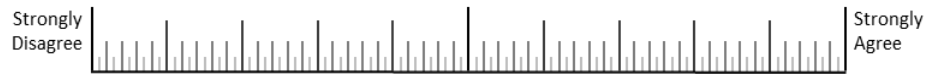
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

12. I could easily assess whether the IM PA trail aircraft would remain forward of the WSL during the approach, when applicable. (draw a line on the scale)



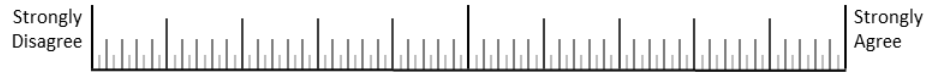
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

13. I could easily assess whether the lead and trail aircraft would remain within their lateral maneuvering bounds during the approach. (draw a line on the scale)



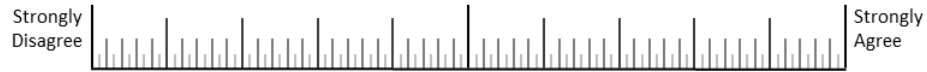
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

14. The IM PA-related tools provided in this scenario allowed for a *timely* detection of any impending exceedance of the WSL or CSL. (draw a line on the scale)



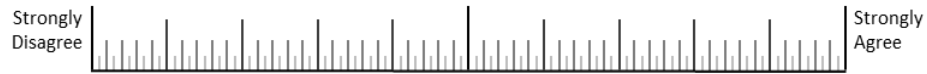
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

15. The IM PA-related tools provided in this scenario allowed for a *timely* detection of any excessive deviation from the approach course by aircraft involved in a PA operation. (draw a line on the scale)



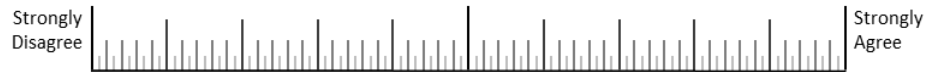
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

16. Given the IM PA-related tools provided in this scenario, I could easily tell when an aircraft would require a WSL later in the approach. (draw a line on the scale)



Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

17. Given the IM PA-related tools provided in this scenario, I was comfortable monitoring IM PA operations when both a CSL and WSL were active *at the same time*. (draw a line on the scale)



Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

18. Was all of the provided IM PA information in this scenario useful, including that in both the Spacing List and data blocks? (circle one)

Yes	No
-----	----

If no, what information was **not** useful and why? \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

19. Was there any operational information *not* provided in this scenario that you would have found helpful? (circle one)

Yes	No
-----	----

If yes, what information and why? \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

**Communications and Coordination**

20. Did you experience any IM PA-related communication difficulties? (circle one)

Yes	No
-----	----

If yes, explain: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

21. Did you have any issues during communications when the Lead Aircraft call sign was used? (circle one)

Yes	No
-----	----

If yes, describe: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

22. Were there any situations that required coordination with the 28L monitor controller? (circle one)

Yes	No
-----	----

If yes, explain: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

**Overall**

23. Did you have concerns with any aspect of the IM PA operation in this particular scenario, whether in your area or not? (circle one)

Yes	No
-----	----

If yes, please explain: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

24. If you have any other comments about the IM PA-related **tools** provided in this scenario, please provide them below.

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

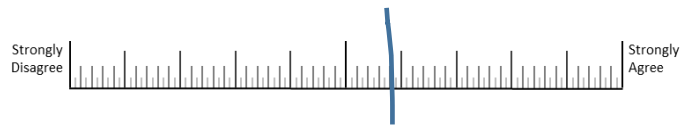
25. If you have any other comments about this scenario, please provide them below.

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

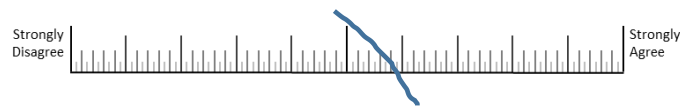
## IM PA HITL POST-RUN QUESTIONNAIRE – DUAL MONITOR CONFIGURATION (28L MONITOR)

**Instructions:** Please answer the questions by drawing a vertical line through the option on each of the scales at the point which matched your experience (as shown below) or circling an option (e.g., yes / no).

Please draw your line like this:



NOT like this:



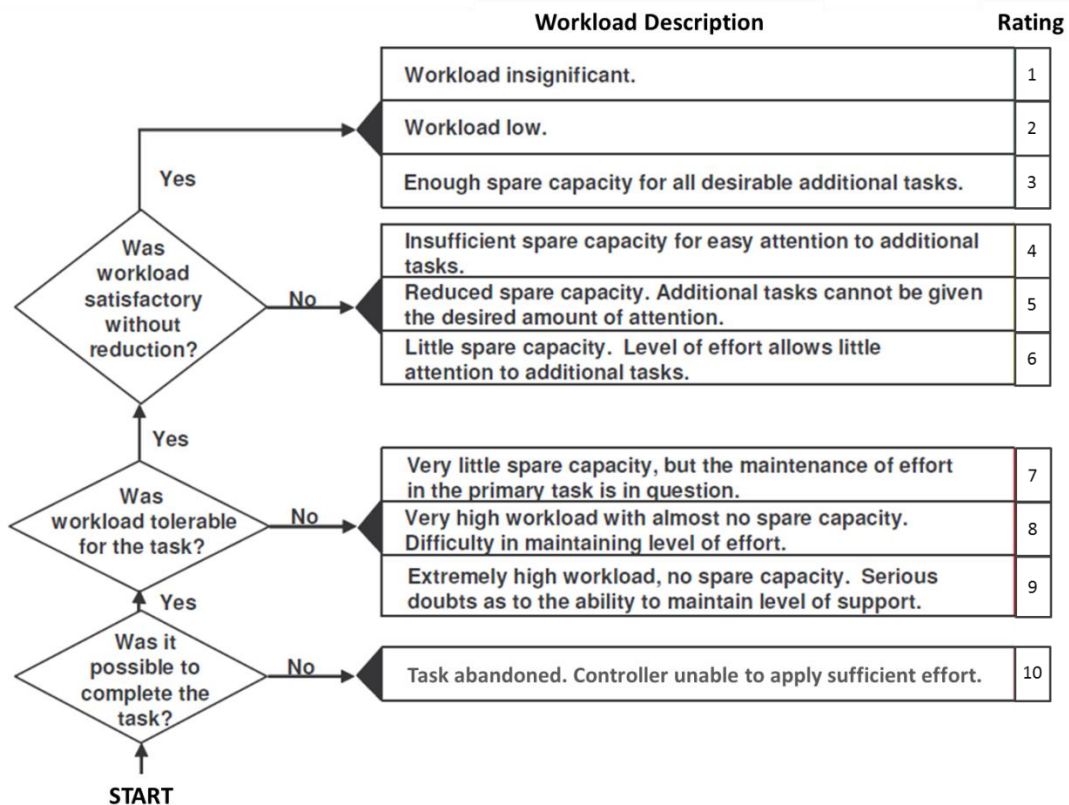
When choosing an option, keep in mind that the general monitoring task for an IM PA operation is the primary area of interest. Although the simulation used certain elements of the SFO airspace, **your answer should be more of a general consideration of the PA monitoring task**, instead of how it might specifically be applied to the SFO environment.

**Please consider only the current scenario when answering.** If you have any questions, please ask the experimenter.

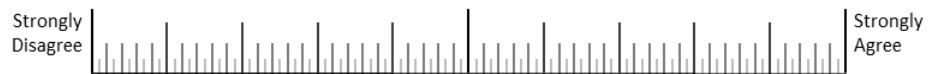
**Workload**

1. Using the chart below, how would you rate your *average* level of workload in this scenario?

- (a) Working up from the bottom left corner, answer each yes/no question and follow the path.
- (b) Circle the numerical rating that best reflects your experience.



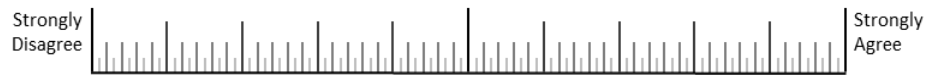
2. My workload in this scenario was acceptable. (draw a line on the scale)



Comments: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

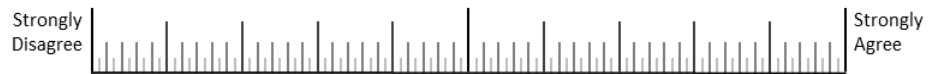
**Operations**

3. As aircraft pairs entered my area, I had sufficient time to make a first assessment of their separation. (draw a line on the scale)



Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

4. I was comfortable with the IM PA trail aircraft managing their speeds to achieve the spacing goal assigned by the final controller. (draw a line on the scale)



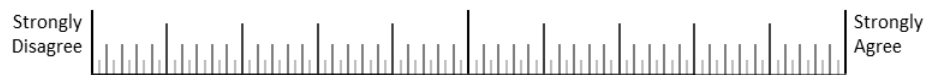
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

5. Did you need to break out an IM PA Lead Aircraft in this scenario? (circle one)

Yes	No
-----	----

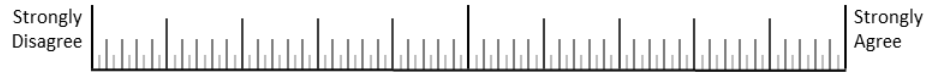
If yes, why? \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

6. Given the tools I had in this scenario, I had sufficient overall traffic situation awareness. (draw a line on the scale)



Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

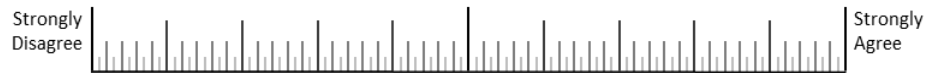
7. I was comfortable monitoring the Lead Aircraft in an IM PA pair, while another controller monitored the trail aircraft. (draw a line on the scale)



Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

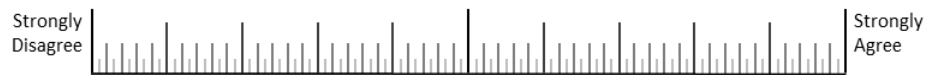
**Displays**

8. With the tools provided in this scenario, I could easily assess the separation *among all aircraft* for which I was responsible. (draw a line on the scale)



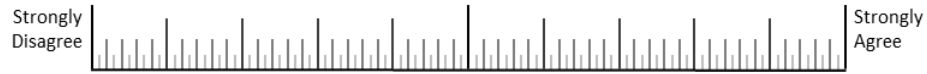
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

9. I could easily assess whether the Lead Aircraft in an IM PA pair would remain within their lateral maneuvering bounds during the approach. (draw a line on the scale)



Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

10. The tools provided in this scenario allowed for a *timely* detection of any excessive deviation from the approach course by aircraft involved in a PA operation. (draw a line on the scale)



Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

11. Was all of the provided IM PA information in this scenario useful, including that in both the Spacing List and data blocks? (circle one)

Yes	No
-----	----

If no, what information was **not** useful and why? \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

12. Was there any operational information *not* provided in this scenario that you would have found helpful? (circle one)

Yes	No
-----	----

If yes, what information and why? \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

**Communications and Coordination**

13. Did you experience any IM PA-related communication difficulties? (circle one)

Yes	No
-----	----

If yes, explain: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

14. Were there any situations that required coordination with the 28R monitor controller? (circle one)

Yes	No
-----	----

If yes, explain: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

**Overall**

15. Did you have concerns with any aspect of the IM PA operation in this particular scenario, whether in your area or not? (circle one)

Yes	No
-----	----

If yes, please explain: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

16. If you have any other comments about the IM PA-related **tools** provided in this scenario, please provide them below.

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

17. If you have any other comments about this scenario, please provide them below.

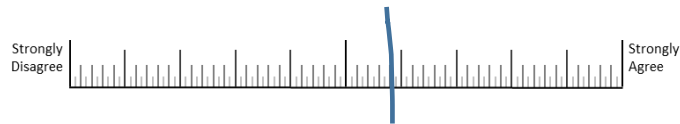
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

## Appendix D Day 1-2 End Questionnaire

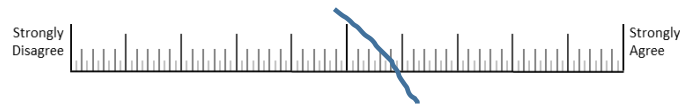
### IM PA HITL QUESTIONNAIRE – DAY 1 END

**Instructions:** Please answer the questions by drawing a vertical line through the option on each of the scales at the point which matched your experience (as shown below) or circling an option (e.g., yes / no).

Please draw your line like this:



NOT like this:

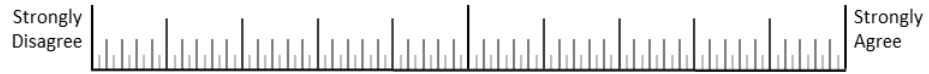


When choosing an option, keep in mind that the general IM PA operation is the primary area of interest. Although the simulation used certain elements of the SFO airspace, **your answer should be more of a general consideration of the IM PA operation**, instead of how it might specifically be applied to the SFO environment.

**Please consider your experience across all of today's scenarios when answering.** If you have any questions, please ask the experimenter.

**For the following questions, please consider your experience ACROSS today's scenarios.**

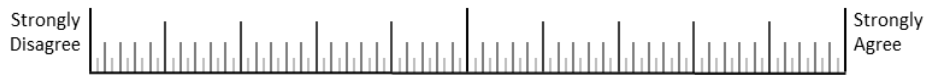
1. My overall workload today was acceptable. (draw a line on the scale)



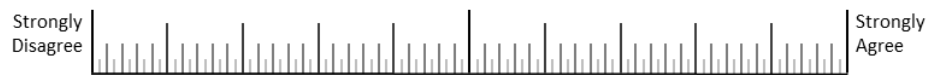
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

2. My overall level of traffic awareness today was acceptable with respect to the: (draw a line on each scale)

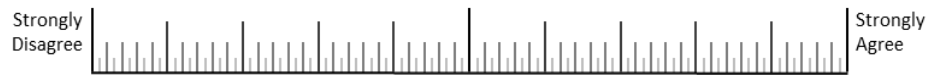
IM PA Lead Aircraft:



IM PA Trail Aircraft:

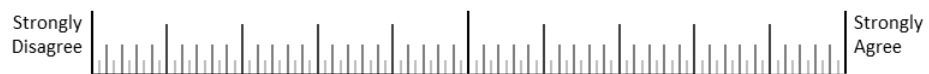


Other Aircraft:



Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

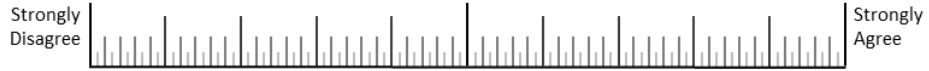
3. Given the appropriate training and IM PA-related tools, IM PA operations can be effectively monitored by the number of positions I experienced today. (draw a line on the scale)



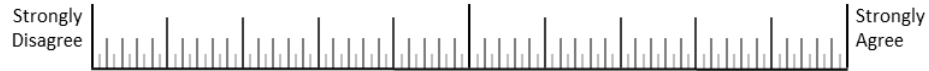
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

4. When monitoring today, my roles and responsibilities were clear with respect to the:  
(draw a line on the scale)

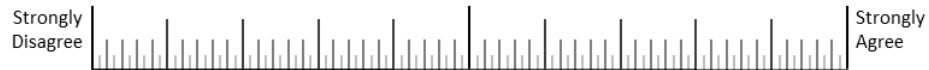
IM PA Lead Aircraft:



IM PA Trail Aircraft:



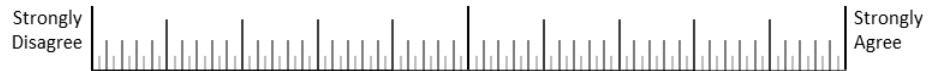
Other Aircraft:



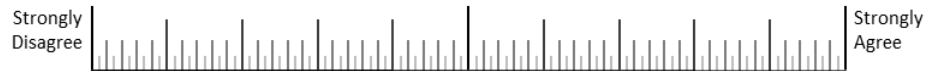
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

5. Overall, I was able to detect in a sufficient amount of time when spacing / separation issues were developing. (draw a line on each scale)

Within an IM PA Aircraft pair:



Between any other aircraft combination:



Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

6. Did you experience IM PA-related coordination challenges today, beyond any you've already noted? (circle one)

Yes	No
-----	----

If yes, explain: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

7. Do you have concerns with any aspect of the IM PA operation you saw today, beyond any you've already noted? (circle one)

Yes	No
-----	----

If yes, please explain: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

8. If you have any additional general comments about the IM PA-related **tools** you saw today, please provide them below.

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9. If you have any other comments about what you saw today overall, please provide them below.

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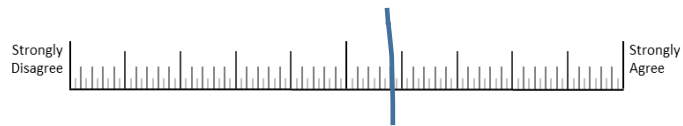
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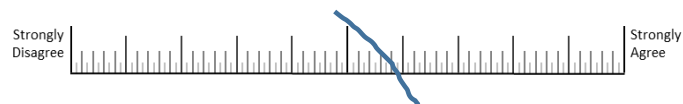
## IM PA HITL QUESTIONNAIRE – DAY 2 END

**Instructions:** Please answer the questions by drawing a vertical line through the option on each of the scales at the point which matched your experience (as shown below) or circling an option (e.g., yes / no).

Please draw your line like this:



NOT like this:



When choosing an option, keep in mind that the general IM PA operation is the primary area of interest. Although the simulation used certain elements of the SFO airspace, **your answer should be more of a general consideration of the IM PA operation**, instead of how it might specifically be applied to the SFO environment.

This questionnaire consists of two parts:

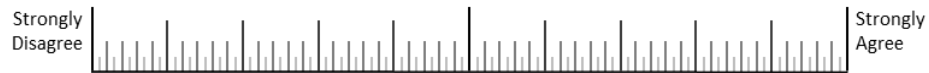
Part 1: When answering, consider your experience across **today's scenarios only**.

Part 2: When answering, consider your experience across **yesterday and today's scenarios**.

If you have any questions, please ask the experimenter.

**Part 1: For the following questions, please consider your experience across today's scenarios ONLY.**

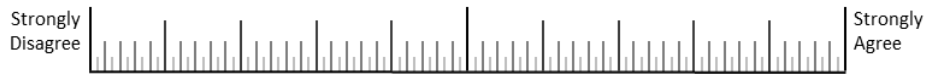
1. My overall workload today was acceptable. (draw a line on the scale)



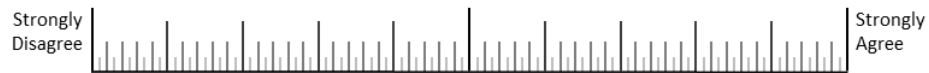
Comments: \_\_\_\_\_

2. My overall level of traffic awareness today was acceptable with respect to the: (draw a line on each scale)

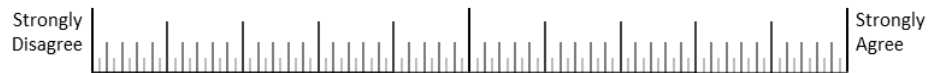
IM PA Lead Aircraft:



IM PA Trail Aircraft:



Other Aircraft:



Comments: \_\_\_\_\_

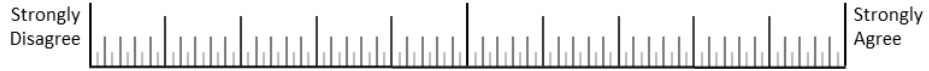
3. Given the appropriate training and IM PA-related tools, IM PA operations can be effectively monitored by the number of positions I experienced today. (draw a line on the scale)



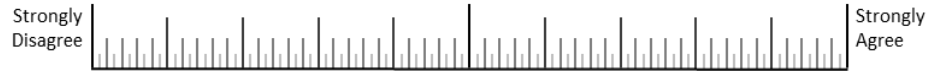
Comments: \_\_\_\_\_

4. When monitoring today, my roles and responsibilities were clear with respect to the:  
(draw a line on the scale)

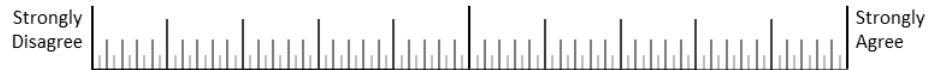
IM PA Lead Aircraft:



IM PA Trail Aircraft:



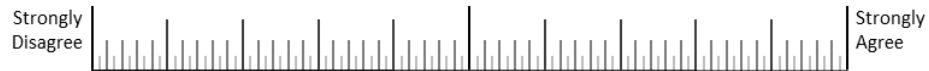
Other Aircraft:



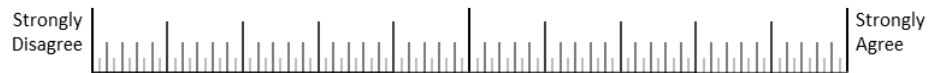
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

5. Overall **today**, I was able to detect in a sufficient amount of time when spacing / separation issues were developing. (draw a line on each scale)

Within an IM PA Aircraft pair:



Between any other aircraft combination:



Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

6. Did you experience IM PA-related coordination challenges today, beyond any you've already noted? (circle one)

Yes	No
-----	----

If yes, explain: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

7. Do you have concerns with any aspect of the IM PA operation you saw today, beyond any you've already noted? (circle one)

Yes	No
-----	----

If yes, please explain: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

8. If you have any additional general comments about the IM PA-related **tools** you saw today, please provide them below.

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9. If you have any other comments about what you saw today overall, please provide them below.

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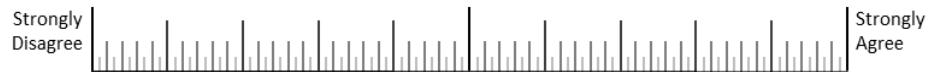
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**Part 2: For the following questions, please consider your experience across ALL scenarios, yesterday AND today.**

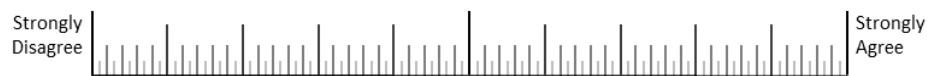
**Monitoring and Operations**

1. IM PA is operationally desirable. (draw a line on the scale)



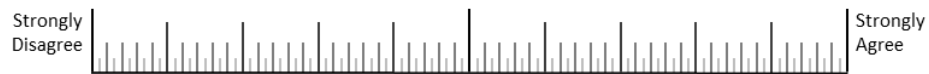
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

2. IM PA is compatible with terminal approach operations. (draw a line on the scale)



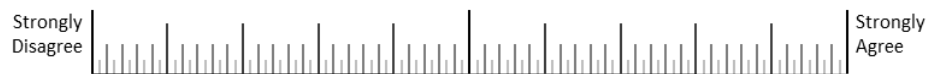
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

3. It is operationally acceptable for the final controller to provide the IM PA spacing goal. (draw a line on the scale)



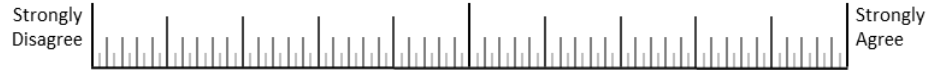
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

4. I was comfortable allowing an IM PA aircraft to manage its own speed to achieve the desired spacing goal at the Final Approach Fix. (draw a line on the scale)



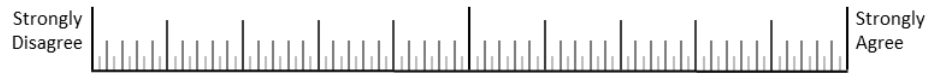
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

5. Given the appropriate training and the IM PA-related tools, a single monitor controller can effectively ensure separation across both approaches during IM PA operations. (draw a line on the scale)



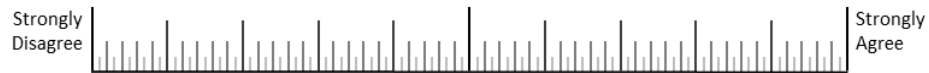
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

6. Overall, I was comfortable monitoring the trail aircraft in an IM PA pair, while another controller monitored the Lead Aircraft. (draw a line on the scale)



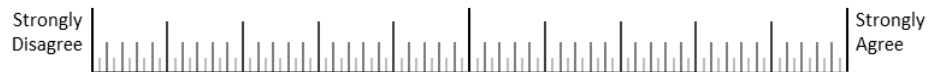
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

7. Overall, I was comfortable monitoring the Lead Aircraft in an IM PA pair, while another controller monitored the trail aircraft. (draw a line on the scale)



Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

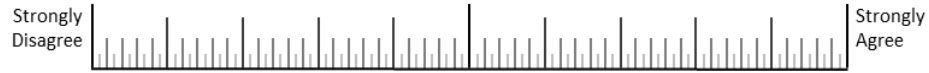
8. Overall, I was confident that I could assess whether the separation between the IM PA trail aircraft and their Lead Aircraft would be maintained. (draw a line on the scale)



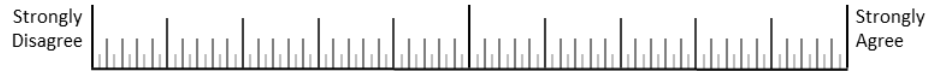
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

9. The tasks required of each simulation position were acceptable. (draw a line on each scale)

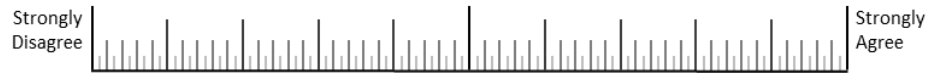
Combined 28L/28R Monitor Position:



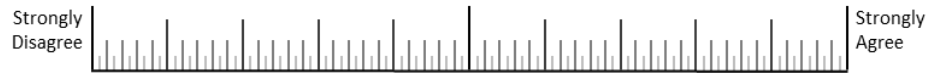
28L Monitor Position only:



28R Monitor Position only:



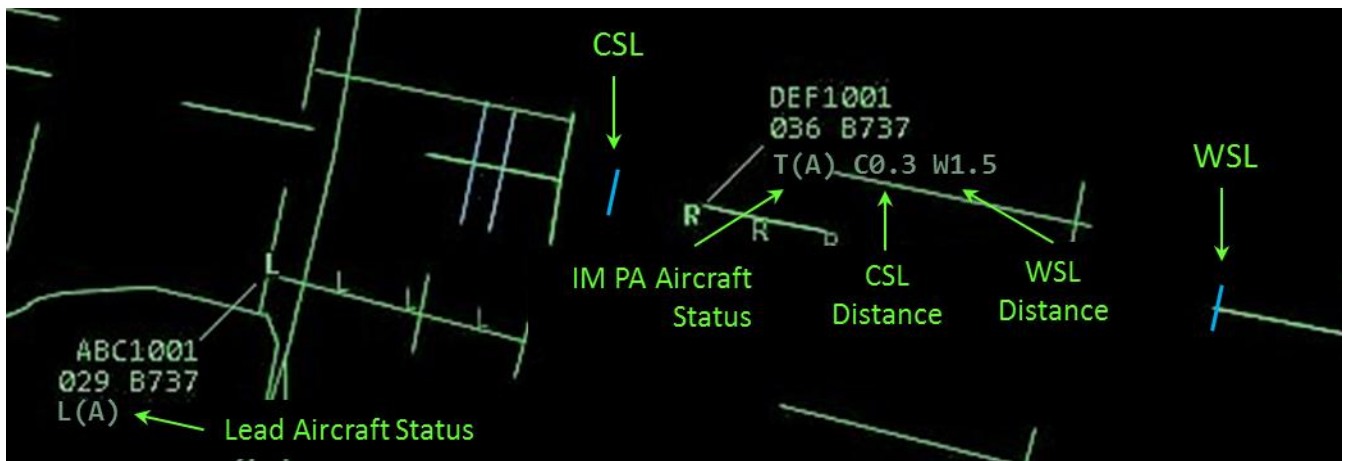
28R Final Position:



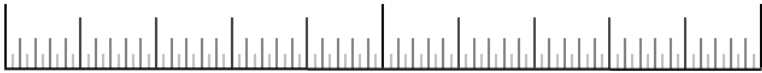
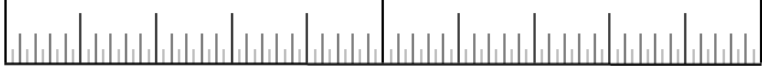
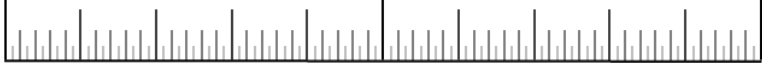
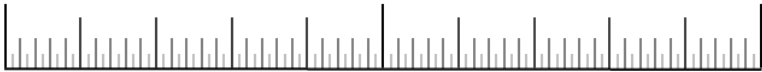
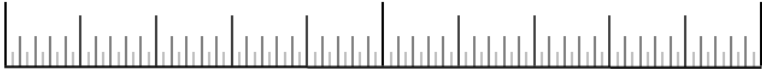
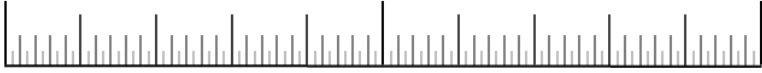
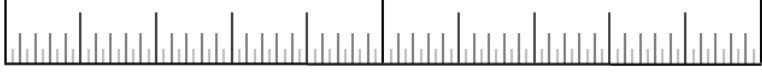
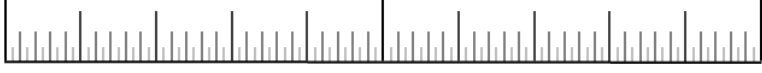
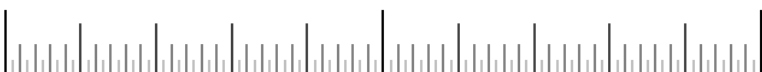
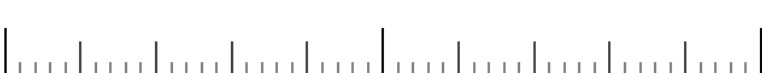

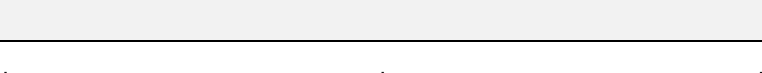

Comments: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

**Displays**

For the following questions, consider the IM PA tools per the below figure.



10. The following tools were useful for the overall IM PA monitoring task. (draw a line on each scale on the next page)

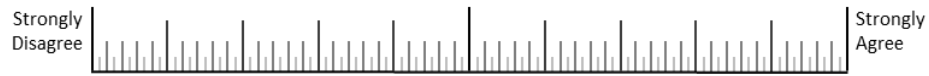
Safety Limits (were useful)	
CSL (Blue Line)	Strongly Disagree  Strongly Agree
WSL (Blue Line)	Strongly Disagree  Strongly Agree
WSL Preview (grey line appearing before blue WSL)	Strongly Disagree  Strongly Agree
Data Block Elements (were useful)	
IM PA (Trail) Aircraft Status (e.g. [T(A)])	Strongly Disagree  Strongly Agree
Lead Aircraft Status [L(A)]	Strongly Disagree  Strongly Agree
CSL Distance	Strongly Disagree  Strongly Agree
WSL Distance	Strongly Disagree  Strongly Agree
WSL Pre-Active Indication ("W")	Strongly Disagree  Strongly Agree
Alerts (were useful)	
IM PA Predictive Alert (Yellow)	Strongly Disagree  Strongly Agree
IM PA Caution Alert (Orange)	Strongly Disagree  Strongly Agree
Spacing List (were useful)	
IM Status (i.e. Eligible, Active, Terminated)	Strongly Disagree  Strongly Agree
Lateral Bounds (were useful)	
Inner Bounds	Strongly Disagree  Strongly Agree
Outer Bounds	Strongly Disagree  Strongly Agree

11. Does the usefulness of any of the tools depend on whether there was single monitor for both approaches, or separate monitors for each approach? (circle one)

Yes	No
-----	----

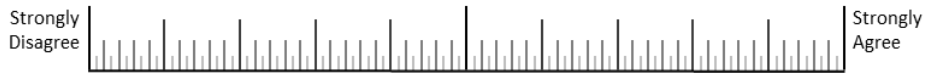
If yes, explain: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

12. If the CSL is shown as a graphic line, the numeric distance to it in the data block is **also** helpful. (draw a line on the scale)



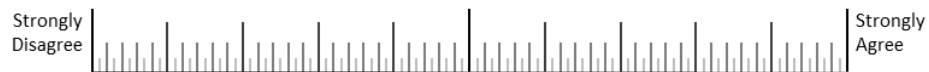
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

13. It was helpful to know whether an aircraft would eventually require an active WSL. (draw a line on the scale)



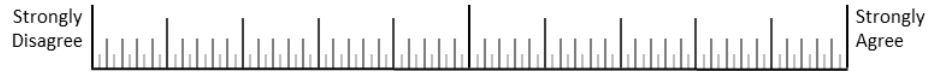
Why? \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

14. If provided the initial WSL "W" indicator in the data block, I do **not** also need the WSL Preview Line. (draw a line on the scale)



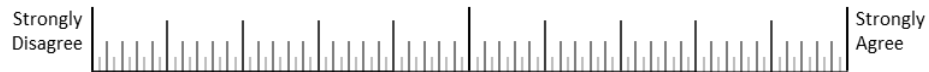
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

15. If provided the WSL Preview Line, I do **not** also need the initial WSL “W” indicator in the data block. (draw a line on the scale)



Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

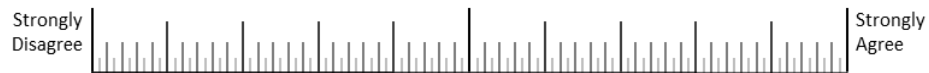
16. In the simulation, the WSL Preview Line first appeared with sufficient lead time to be useful. (draw a line on the scale)



Approximately how many miles prior to the wake safety limit becoming active should the WSL Preview Line start to be displayed? \_\_\_\_\_ NM

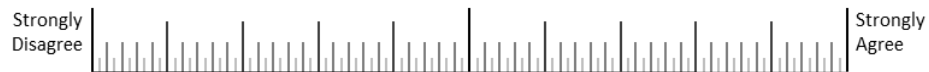
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

17. My responsibilities with respect to a Predictive (yellow) alert were clear. (draw a line on the scale)



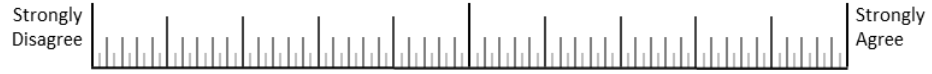
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

18. The predictive (yellow) alert provided sufficient advance notice of an impending caution alert. (draw a line on the scale)



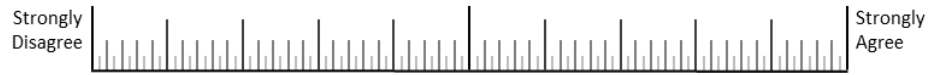
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

19. My responsibilities with respect to a Caution (orange) alert were clear. (draw a line on the scale)



Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

20. The Caution (orange) alert provided sufficient advance notice of an impending loss of separation. (draw a line on the scale)



Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

21. What combination of tools would you recommend for the IM PA **monitor controller**, and should they always be on or user-selectable? (check the appropriate selections in the table, one selection per row)

IM PA Tool	Should always be displayed	User should be able to toggle on or off	Not needed
<b>Safety Limits</b>			
CSL (Blue Line)			
WSL (Blue Line)			
WSL Preview (Grey line)			
<b>Data Block Elements</b>			
IM PA (Trail) Aircraft Status (e.g. [T(A)])			
Lead Aircraft Status [L(A)]			
CSL Distance			
WSL Distance			
WSL Pre-Active Indication ("W")			
<b>Alerts</b>			
IM PA Predictive Alert (45 sec)			
IM PA Caution Alert (24 sec)			
<b>Spacing List</b>			
IM PA Spacing Goal			
Lead Aircraft Call Sign			
Lead Aircraft Runway			
Status: Eligible, Active, Terminated			
<b>Lateral Bounds</b>			
Inner Bounds			
Outer Bounds			

Comments: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

22. Would your selections above comprise an acceptable, *complete* toolset for monitoring an IM PA operation? (circle one)

Yes	No
-----	----

If no, what additional information would you require? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

23. What combination of tools would you recommend to help the IM PA **final controller complete the IM Clearance**, and should they always be on or user-selectable? (check the appropriate selections in the table, one selection per row)

IM PA Tool	Should always be displayed	User should be able to toggle on or off	Not needed
<b>Safety Limits</b>			
CSL (Blue Line)			
WSL (Blue Line)	N/A		
WSL Preview (Grey line)			
<b>Data Block Elements</b>			
IM PA (Trail) Aircraft Status (e.g. [T(A)])			
Lead Aircraft Status [L(A)]			
CSL Distance			
WSL Distance	N/A		
WSL Pre-Active Indication ("W")			
<b>Alerts</b>			
IM PA Predictive Alert (45 sec)			
IM PA Caution Alert (24 sec)			
<b>Spacing List</b>			
IM PA Spacing Goal			
Lead Aircraft Call Sign			
Lead Aircraft Runway			
Status: Eligible, Active, Terminated			
<b>Lateral Bounds</b>			
Inner Bounds			
Outer Bounds			

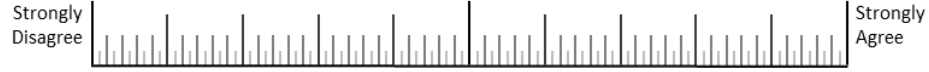
Comments: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

24. Would your selections above comprise an acceptable, *complete* toolset for completing an IM PA clearance? (circle one)

Yes	No
-----	----

If no, what additional information would you require? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

25. The monitor controller should be provided an IM Spacing List. (draw a line on the scale)



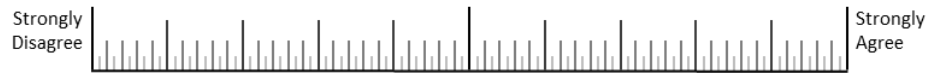
If agree, should it be identical to that of the final controller? (circle one)

Yes	No
-----	----

Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

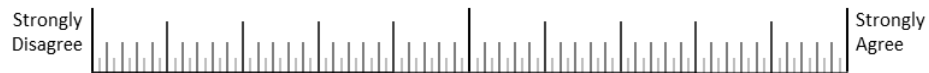
**Communications**

26. The IM PA spacing goal communication was acceptable. (draw a line on the scale)



Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

27. I was comfortable with the use of the Lead Aircraft call sign in the IM Clearance communication. (draw a line on the scale)



Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

**Overall**

28. What was the most difficult situation to deal with when aircraft were conducting IM PA operations?

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29. Was there any aspect of the IM PA operation that you especially liked?

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30. How could the conduct of IM PA operations be improved?

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31. If you have any other comments about IM PA operations, please provide them below.

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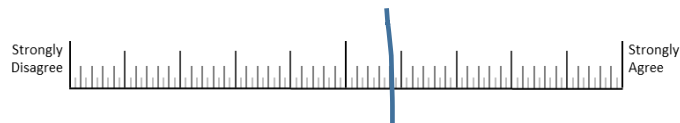
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## Appendix E Alert Timing Questionnaires

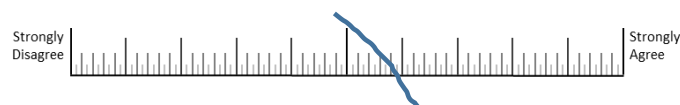
### IM PA HITL POST-RUN QUESTIONNAIRE – ALERT TIMING

**Instructions:** Please answer the questions by drawing a vertical line through the option on each of the scales at the point which matched your experience (as shown below) or circling an option (e.g., yes / no).

Please draw your line like this:



NOT like this:



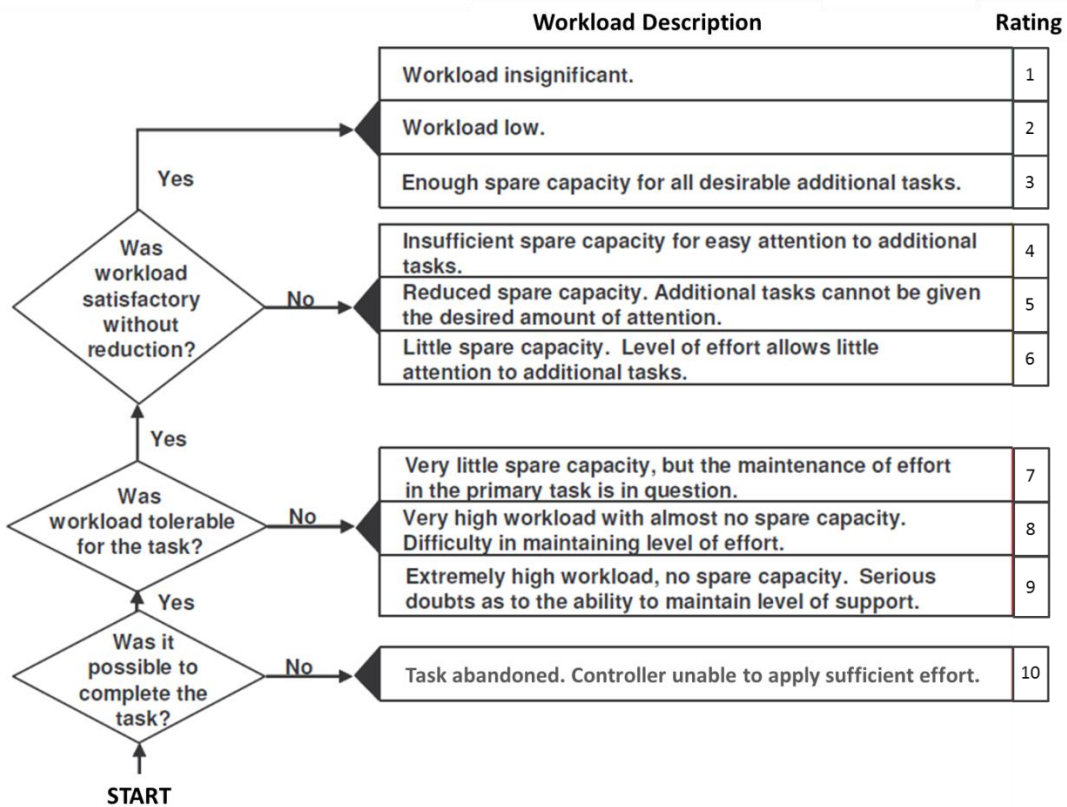
When choosing an option, keep in mind that the general monitoring task for an IM PA operation is the primary area of interest. Although the simulation used certain elements of the SFO airspace, **your answer should be more of a general consideration of the PA monitoring task**, instead of how it might specifically be applied to the SFO environment.

**Please consider only the current scenario when answering.** If you have any questions, please ask the experimenter.

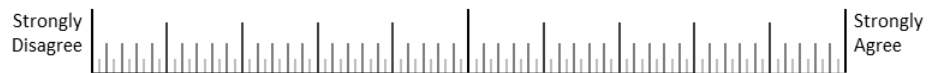
**Workload**

1. Using the chart below, how would you rate your *average* level of workload in this scenario?

- (a) Working up from the bottom left corner, answer each yes/no question and follow the path.
- (b) Circle the numerical rating that best reflects your experience.



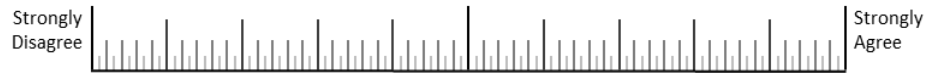
2. My workload in this scenario was acceptable. (draw a line on the scale)



Comments: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

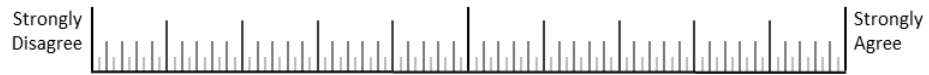
**Operations and Displays**

3. I was confident that I could assess whether separation would be maintained between the IM PA trail aircraft and their Lead Aircraft. (draw a line on the scale)



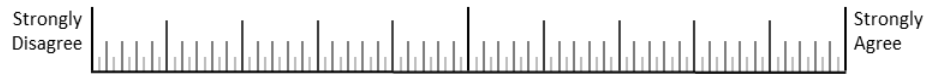
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

4. In this scenario, I could easily assess whether the IM PA trail aircraft would remain *behind the CSL* during the approach. (draw a line on the scale)



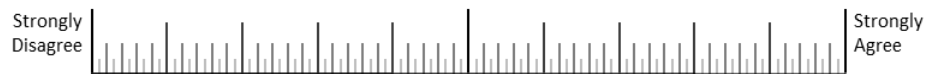
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

5. In this scenario, I could easily assess whether the IM PA trail aircraft would remain *forward of the WSL* during the approach, when applicable. (draw a line on the scale)



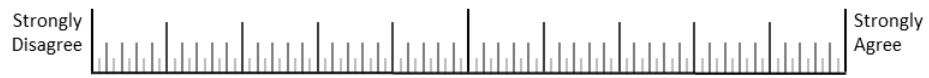
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

6. The predictive (yellow) alert provided sufficient advance notice of an impending caution alert. (draw a line on the scale)



Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

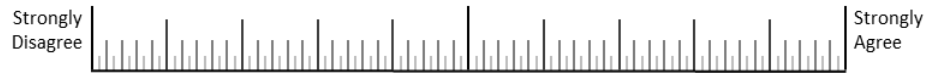
7. The Predictive (yellow) alert was noticeable enough such that I became aware of it without undue delay. (draw a line on the scale)



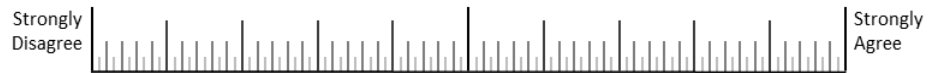
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

8. Was the Predictive alert (yellow) timing about right? (draw a line on each scale)

The timing before the IM PA aircraft crossed the CSL seemed about right:

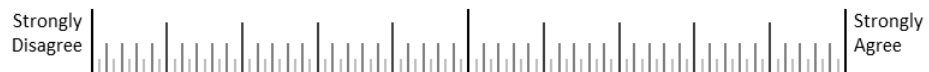


The timing before the IM PA aircraft crossed the WSL seemed about right:



Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

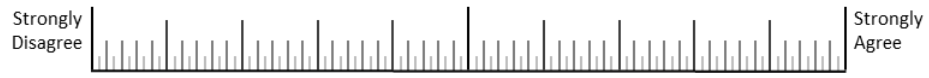
9. The Caution (orange) alert provided sufficient advance notice of an impending loss of separation. (draw a line on the scale)



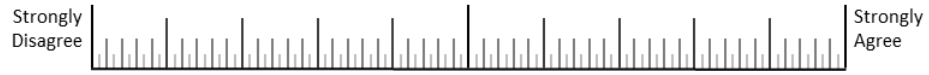
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

10. Was the Caution alert (orange) timing about right? (draw a line on each scale)

The timing before the IM PA aircraft crossed the CSL seemed about right:



The timing before the IM PA aircraft crossed the WSL seemed about right:



Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

**Overall**

11. If you have any other comments about the IM PA **alerts** provided in this scenario, please provide them below.

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

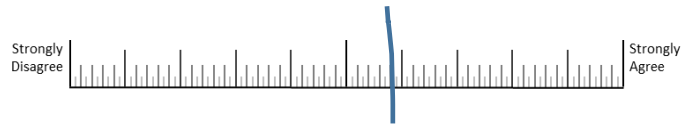
12. If you have any other comments about this scenario, please provide them below.

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

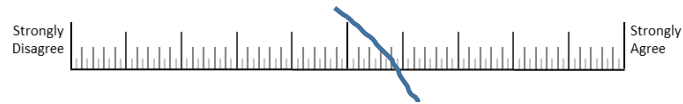
## IM PA HITL FINAL QUESTIONNAIRE – ALERT TIMING

**Instructions:** Please answer the questions by drawing a vertical line through the option on each of the scales at the point which matched your experience (as shown below) or circling an option (e.g., yes / no).

Please draw your line like this:



NOT like this:

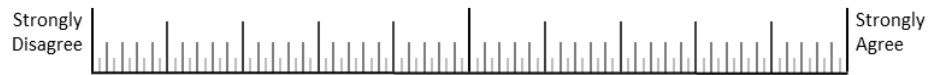


When choosing an option, keep in mind that the general monitoring task for an IM PA operation is the primary area of interest. Although the simulation used certain elements of the SFO airspace, **your answer should be more of a general consideration of the PA monitoring task**, instead of how it might specifically be applied to the SFO environment.

**Please consider all of this morning's scenarios when answering.** If you have any questions, please ask the experimenter.

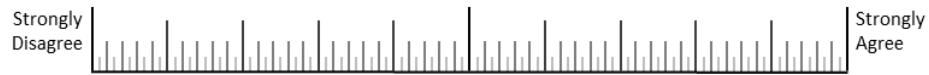
**Operations and Displays**

- 1. Across all timings that I experienced, I was confident that I could assess whether separation would be maintained between the IM PA trail aircraft and their Lead Aircraft. (draw a line on the scale)



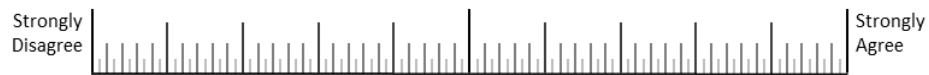
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

- 2. Across all timings that I experienced, I could easily assess whether the IM PA trail aircraft would remain *behind the CSL* during the approach. (draw a line on the scale)



Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

- 3. Across all timings that I experienced, I could easily assess whether the IM PA trail aircraft would remain *forward of the WSL* during the approach, when applicable. (draw a line on the scale)



Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

- 4. How soon before the IM PA aircraft crosses the limit would you like to see the Predictive (yellow) alert? (fill in as needed)  
\_\_\_\_\_ sec before the CSL is crossed  
\_\_\_\_\_ sec before the WSL is crossed

Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

5. How soon before the IM PA aircraft crosses the limit would you like to see the Caution (orange) alert? (fill in as needed)
- \_\_\_\_\_ sec before the CSL is crossed
- \_\_\_\_\_ sec before the WSL is crossed

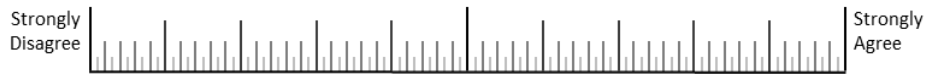
Comments: \_\_\_\_\_

\_\_\_\_\_

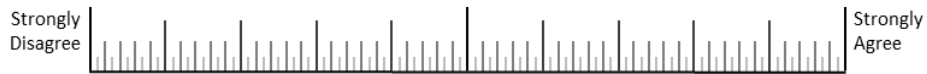
\_\_\_\_\_

6. It was helpful to indicate the Predictive (yellow) alert via the: (draw a line on each scale)

Data Block Line 3 color change:



CSL or WSL line color change:



Comments: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

7. Would you change anything about the Predictive (yellow) alert presentation? (circle one)

Yes	No
-----	----

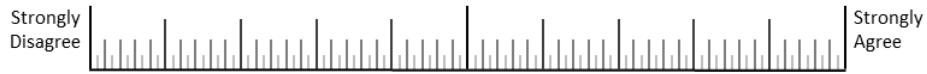
If yes, what would you change? \_\_\_\_\_

\_\_\_\_\_

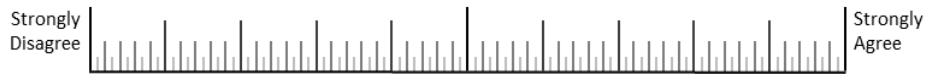
\_\_\_\_\_

8. It was helpful to indicate the Caution (orange) alert via the: (draw a line on each scale)

Data Block Line 3 color change:



CSL or WSL line color change:



Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

9. Would you change anything about the Caution (orange) alert presentation? (circle one)

Yes	No
-----	----

If yes, what would you change? \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

10. In a **combined-monitor configuration** (what you experienced today), at what level should SOP prescribe controller actions to be taken in response to a Caution (orange) alert: (check one)

- The SOP should not constrain the controller's resolution of the impending loss of separation.
- The SOP should specify which aircraft to maneuver in response to any given set of conditions, but not how to maneuver it.
- The SOP should specify which aircraft to maneuver and also specify an initial heading and altitude to use.

Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

11. In a **separate monitor configuration**, at what level should SOP prescribe controller actions to be taken in response to a Caution (orange) alert: (check one)
- The SOP should not constrain the controller's resolution of the impending loss of separation.
  - The SOP should specify which aircraft to maneuver in response to any given set of conditions, but not how to maneuver it.
  - The SOP should specify which aircraft to maneuver and also specify an initial heading and altitude to use.

Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

**Overall**

12. If you have any other comments about the IM PA **alerts** provided in this scenario, please provide them below.

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

13. If you have any other comments about this scenario, please provide them below.

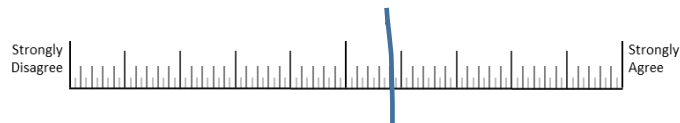
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

## Appendix F Lateral Deviation Questionnaires

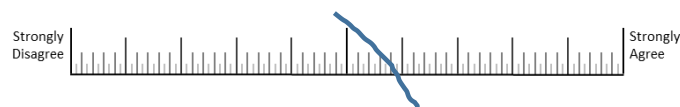
### IM PA HITL POST-RUN QUESTIONNAIRE – LATERAL DEVIATIONS

**Instructions:** Please answer the questions by drawing a vertical line through the option on each of the scales at the point which matched your experience (as shown below) or circling an option (e.g., yes / no).

Please draw your line like this:



NOT like this:

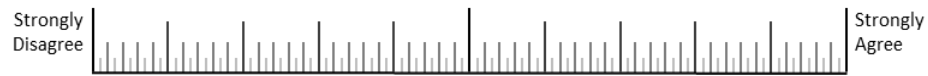


When choosing an option, keep in mind that the general monitoring task for an IM PA operation is the primary area of interest. Although the simulation used certain elements of the SFO airspace, **your answer should be more of a general consideration of the PA monitoring task**, instead of how it might specifically be applied to the SFO environment.

**Please consider only the current scenario when answering.** If you have any questions, please ask the experimenter.

## Workload

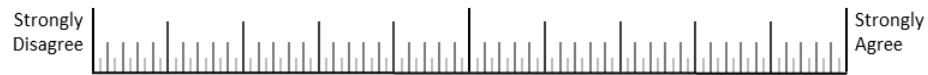
1. My workload in this scenario was acceptable. (draw a line on the scale)



Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

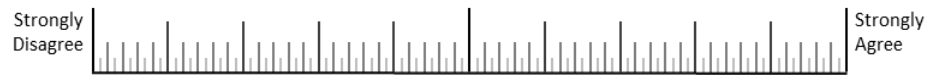
## Operations and Displays

2. I was confident that I could assess whether separation would be maintained between the IM PA trail aircraft and their Lead Aircraft. (draw a line on the scale)



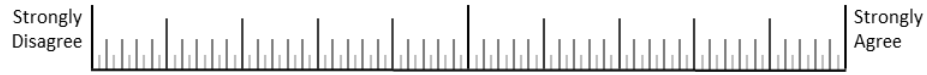
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

3. In this scenario, I could easily assess whether aircraft involved in a PA operation were operating within their lateral bounds. (draw a line on the scale)



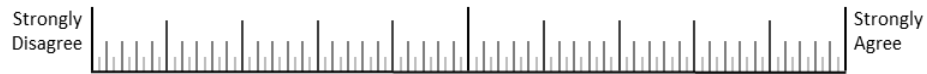
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

4. The warning (red) alert was noticeable enough such that I became aware of it without undue delay. (draw a line on the scale)



Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

5. In this scenario, I felt I had sufficient time and situational awareness to choose and execute appropriate corrective action once the warning (red) alert occurred. (draw a line on the scale)



Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

**Overall**

6. If you have any other comments about the IM PA **alerts** provided in this scenario, please provide them below.

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

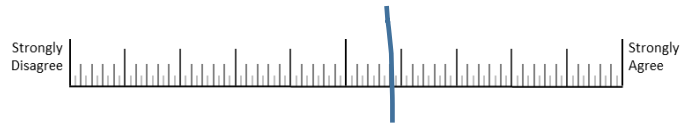
7. If you have any other comments about this scenario, please provide them below.

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

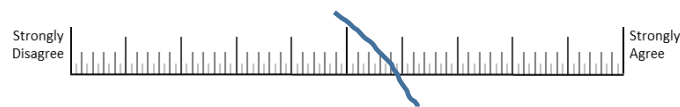
## IM PA HITL FINAL QUESTIONNAIRE – LATERAL DEVIATIONS

**Instructions:** Please answer the questions by drawing a vertical line through the option on each of the scales at the point which matched your experience (as shown below) or circling an option (e.g., yes / no).

Please draw your line like this:



NOT like this:

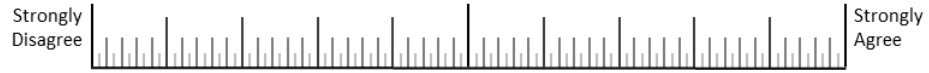


When choosing an option, keep in mind that the general IM PA operation is the primary area of interest. Although the simulation used certain elements of the SFO airspace, **your answer should be more of a general consideration of the IM PA operation**, instead of how it might specifically be applied to the SFO environment.

**Please consider your experience across all of today's lateral deviation scenarios when answering.** If you have any questions, please ask the experimenter.

**For the following questions, please consider your experience ACROSS today's lateral deviation scenarios.**

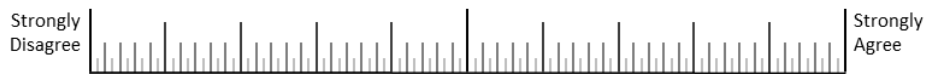
1. My overall workload today was acceptable. (draw a line on the scale)



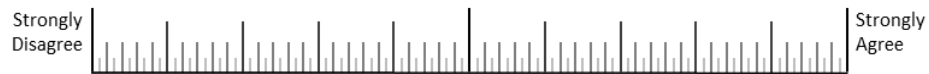
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

2. My overall level of traffic awareness was acceptable with respect to the: (draw a line on each scale)

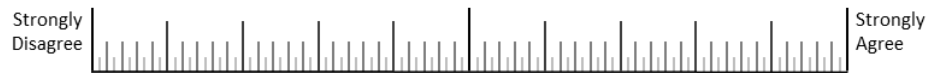
IM PA Lead Aircraft:



IM PA Trail Aircraft:



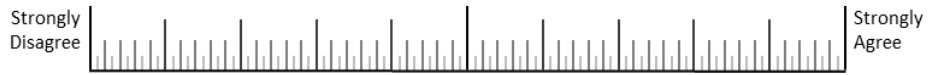
Other Aircraft:



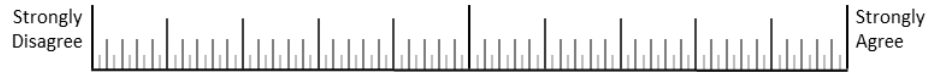
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

3. When monitoring today, my roles and responsibilities were clear with respect to the: (draw a line on the scale)

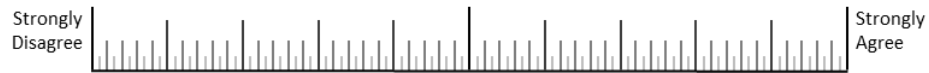
IM PA Lead Aircraft:



IM PA Trail Aircraft:

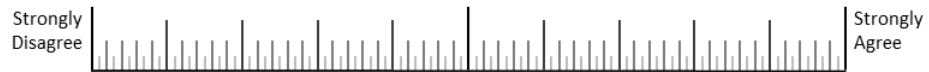


Other Aircraft:



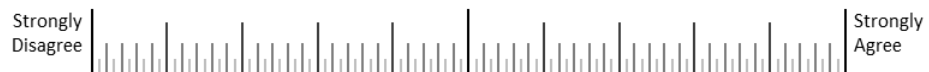
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

4. Overall, the warning (red) alert was noticeable enough such that I became aware of it without undue delay. (draw a line on each scale)



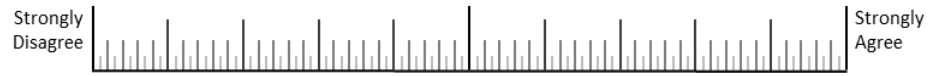
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

5. Advance notice of an impending exceedance of the lateral bounds would have been **helpful**. (draw a line on each scale)



Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

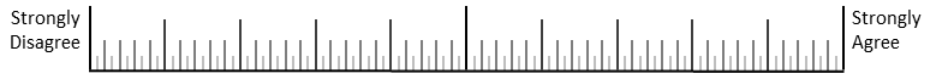
6. Advance notice of an impending exceedance of the lateral bounds would have been **essential**. (draw a line on each scale)



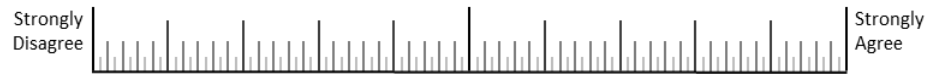
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

7. There is sufficient **time** to choose and execute appropriate corrective action once the warning (red) alert occurs. (draw a line on the scale)

Combined Monitor controller configuration:



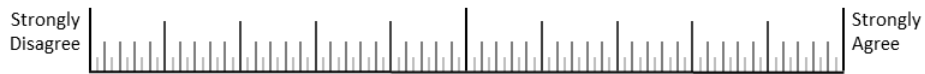
Separate Monitor controller configuration:



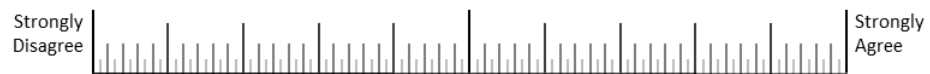
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

8. There is sufficient **situational awareness** to choose and execute appropriate corrective action once the warning (red) alert occurs. (draw a line on the scale)

Combined Monitor controller configuration:



Separate Monitor controller configuration:



Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

9. In terms of handling *lateral deviations*, what combination of tools would you recommend for the IM PA **monitor controller**, and should they always be on or user-selectable? (check the appropriate selections in the table, one selection per row)

IM PA Tool	Should always be displayed	User should be able to toggle on or off	Not needed
<b>Alerts (upon deviation)</b>			
Lateral Deviation Alert (Red Bound Line)			
Red "LAT" (above Data Block)			
<b>Lateral Bounds</b>			
Inner Bounds			
Outer Bounds			

Comments: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

10. Would your selections above comprise an acceptable, *complete* toolset for monitoring for lateral deviations? (circle one)

Yes	No
-----	----

If no, what additional information would you require? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

11. In a **combined-monitor configuration**, at what level should SOP prescribe controller actions to be taken in response to a Lateral Warning (red) alert: (check one)

- \_\_\_\_\_ The SOP should not constrain the controller's resolution of the impending loss of separation.
- \_\_\_\_\_ The SOP should specify which aircraft to maneuver in response to any given set of conditions, but not how to maneuver it.
- \_\_\_\_\_ The SOP should specify which aircraft to maneuver and also specify an initial heading and altitude to use.

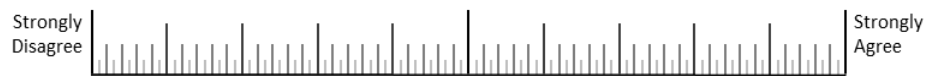
Comments: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

12. In a **separate monitor configuration**, at what level should SOP prescribe controller actions to be taken in response to a Lateral Warning (red) alert: (check one)
- The SOP should not constrain the controller's resolution of the impending loss of separation.
  - The SOP should specify which aircraft to maneuver in response to any given set of conditions, but not how to maneuver it.
  - The SOP should specify which aircraft to maneuver and also specify an initial heading and altitude to use.

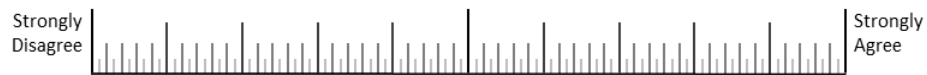
Comments: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

13. Given the available alerts and displays, a monitor controller can effectively detect lateral deviations using the **standard STARS display**. (draw a line on the scale)

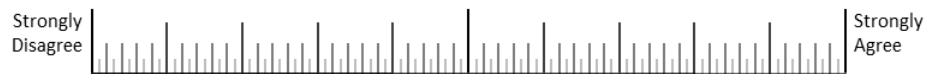
On the RNAV Approach outside of a 2-mile final:



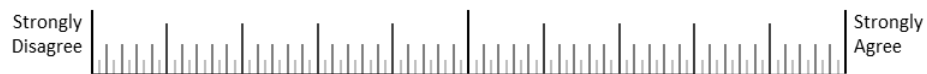
On the ILS Approach on long final:



On the ILS approach closer in (where the lateral bounds narrow):



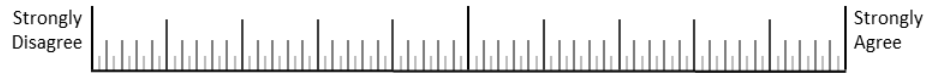
Inside a 2-mile final (where no lateral bounds are shown):



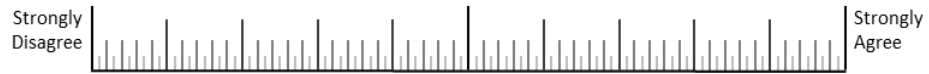
Comments: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

14. Given the available alerts and displays, a monitor controller can effectively detect lateral deviations using the **FMA display**. (draw a line on the scale)

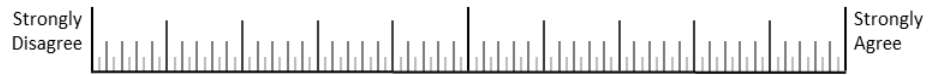
On the RNAV Approach outside of a 2-mile final:



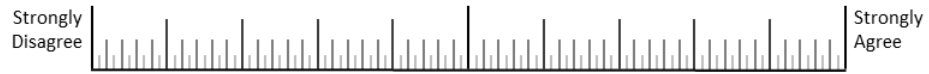
On the ILS Approach on long final:



On the ILS approach closer in (where the lateral bounds narrow):



Inside a 2-mile final (where no lateral bounds are shown):



Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

15. Did you experience coordination challenges related to lateral deviations, beyond any you've already noted? (circle one)

Yes	No
-----	----

If yes, explain: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

16. Do you have additional concerns with respect to the handling of lateral deviations?  
(circle one)

Yes	No
-----	----

If yes, please explain: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

17. Do you have any additional general comments about the lateral deviation displays and alerts you saw today, please provide them below.

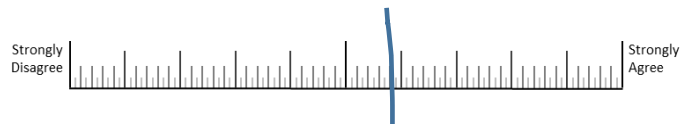
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

# Appendix G Simulation Final (Day 3 End)

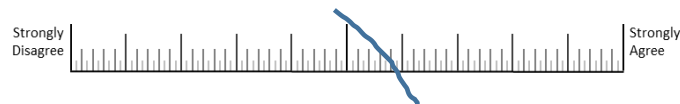
## IM PA HITL FINAL QUESTIONNAIRE

**Instructions:** Please answer the questions by drawing a vertical line through the option on each of the scales at the point which matched your experience (as shown below) or circling an option (e.g., yes / no).

Please draw your line like this:



NOT like this:



When choosing an option, keep in mind that the general monitoring task for an IM PA operation is the primary area of interest. Although the simulation used certain elements of the SFO airspace, **your answer should be more of a general consideration of the PA monitoring task**, instead of how it might specifically be applied to the SFO environment.

**Please consider ALL the scenarios, across ALL three days when answering.** If you have any questions, please ask the experimenter.

## General Operations

1. Does anything you've experienced today change any of your previous positions with respect to: (circle one for each row)

<b>IM PA Desirability</b>	Yes	No	Not Sure
---------------------------	-----	----	----------

If Yes, how? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

<b>IM PA Compatibility with Terminal Operations</b>	Yes	No	Not Sure
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If Yes, how? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

<b>Minimum IM PA Information for Monitoring</b>	Yes	No	Not Sure
---	-----	----	----------

If Yes, how? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

<b>Combined vs. Separate Monitor Positions</b>	Yes	No	Not Sure
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If Yes, how? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

<b>Aircraft Managing their Own Speeds</b>	Yes	No	Not Sure
---	-----	----	----------

If Yes, how? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

<b>Communications / Phraseology</b>	Yes	No	Not Sure
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If Yes, how? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

<b>Controller Coordination</b>	Yes	No	Not Sure
--------------------------------	-----	----	----------

If Yes, how? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

2. Does anything you've experienced today change your position about anything else from the last two days? (circle one)

Yes	No
-----	----

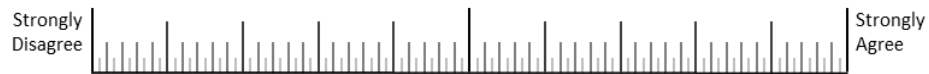
If yes, what and why? \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

3. Which is the most appropriate position to monitor IM PA operations? (circle one)

Final Approach Monitor	Final Approach Control	Local Controller	Other
------------------------	------------------------	------------------	-------

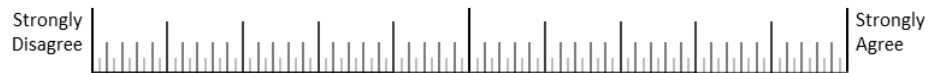
Why? \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

4. I want to be able to see a **longitudinal CSL or WSL exceedance** problem developing, vs. only being provided an alert when I have to take an action. (draw a line on each scale)



Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

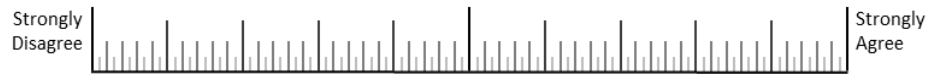
5. I want to be able to see a **lateral deviation** problem developing, vs only being provided an alert when I have to take an action. (draw a line on each scale)



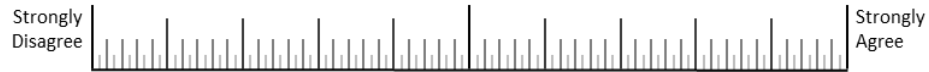
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

6. I would expect to be able to effectively monitor any number of IM PA pairs, up to and including all aircraft pairs performing IM PA (100%). (draw a line on each scale)

Combined Monitor Position for Both Approaches:



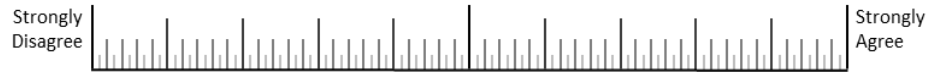
Separate Monitor for Each Approach:



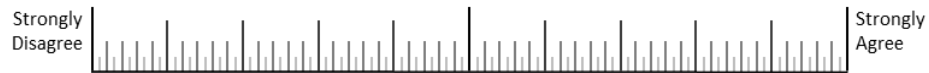
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

7. The more aircraft that are performing IM PA, the easier the overall arrival operation should be to monitor. (draw a line on each scale)

Combined Monitor Position for Both Approaches:



Separate Monitor for Each Approach:



Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

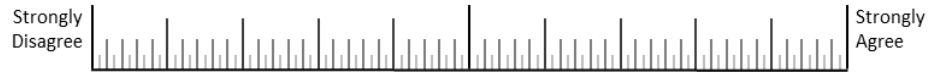
8. If you have any other comments about any aspect of IM PA operations or the HITL that you haven't already noted, please provide them below.

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

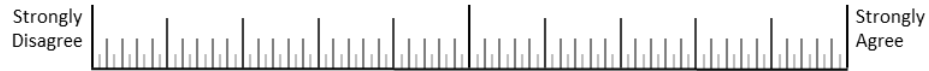
## Simulation Evaluation

1. The training I received was adequate. (draw a line on each scale)

IM Clearance Completion for Initiation:



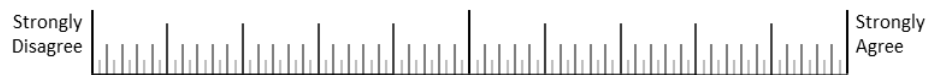
IM PA Monitoring:



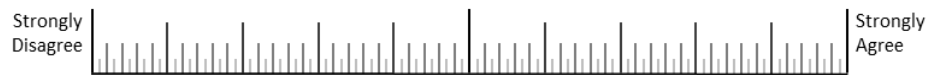
Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

2. The overall activity was effective as a context for evaluating the: (draw a line on the scale)

IM PA Initiation Clearance Completion Task:



IM PA Monitoring Task:



Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

3. Was there anything about the simulation that artificially affected using it as a context for evaluating IM PA operations? (circle one)

Yes	No	No Opinion
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If yes, explain: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

## Debrief Questions

1. Is there anything you would change about the overall IM PA operation?
2. How much do you want to detect a longitudinal or lateral problem developing, vs. waiting for an alert that requires you to take action?
3. Did you notice the CSL value changing over the approach? Did this affect your ability to monitor the aircraft separation?
4. Do you think IM PA could be beneficially employed at your facility?
5. What would be any operational challenges with using IM PA at your facility?
6. What would you change about the HITL, for future participants?
7. Are there any other questions we should have asked, but didn't?

## Notice

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