Enclosure 1

(Ref. Technical Letter H560-L18-024)

MITRE

Center for Advanced
Aviation Systems Development

Second Cancún Human-In-The-Loop Simulation Evaluation

Results

Prepared for

Grupo Aeroportuario de la Ciudad de México

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Principal Acronyms and Abbreviations

AFTN	Aeronautical Fixed Telecommunication Network
AICM	Aeropuerto Internacional de la Ciudad de México
APP N	Approach North
APP S	Approach South
ARR N	Arrival North
ARR S	Arrival South
ATC	Air Traffic Control
ATM	Air Traffic Management
CPL	Coordinated Flight Plan
DEP N	Departure North
DEP S	Departure South
FAC	Final Approach Course
FMA	Final Monitor Aid
FMA N	Final Monitor Aid North
FMA S	Final Monitor Aid South
ft	foot (feet)
GACM	Grupo Aeroportuario de la Ciudad de México
HD	High Definition
HITL	Human-In-The-Loop
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
ILS	Instrument Landing System
Max	Maximum

Min	Minimum
MITRE	The MITRE Corporation
MMCZ	Aeropuerto Internacional de Cozumel (ICAO Code)
MMUN	Aeropuerto Internacional de Cancún (ICAO Code)
NAICM	Nuevo Aeropuerto Internacional de la Ciudad de México
NASA	National Aeronautics and Space Administration
NASA-TLX	NASA-Task Load Index
NM	Nautical Mile(s)
NTZ	No Transgression Zone
PTT	Push-To-Talk
SENEAM	Servicios a la Navegación en el Espacio Aéreo Mexicano
SID	Standard Instrument Departure
STAR	Standard Terminal Arrival Route
TMA	Terminal Maneuvering (Control) Area

1. Introduction

The MITRE Corporation (MITRE) is assisting, through Grupo Aeroportuario de la Ciudad de México (GACM), the aviation authorities of Mexico with the implementation of a new airport, referred to in this document as Nuevo Aeropuerto Internacional de la Ciudad de México (NAICM), to replace the current Aeropuerto Internacional de la Ciudad de México (AICM). The proposed runway layout of NAICM will allow for dual- and triple-independent instrument approach and departure operations. In conjunction with this effort, MITRE is assisting the aviation authorities of Mexico in implementing dual independent instrument approach and departure operations at Aeropuerto Internacional de Cancún (International Civil Aviation Organization [ICAO] Code: MMUN).[1] These operations would be a first within the Mexican Air Traffic Control (ATC) system. The implementation of dual independent operations would allow MMUN to serve as a test-bed location where Mexican air traffic controllers may obtain an understanding of the issues associated with independent operations, and gain valuable experience for the future implementation of such procedures at NAICM. MITRE has held numerous workshops with Servicios a la Navegación en el Espacio Aéreo Mexicano (SENEAM) to assist in its development of an airspace design to support dual independent operations at MMUN, including procedures and sectors for both MMUN and Aeropuerto Internacional de Cozumel (ICAO Code: MMCZ).

The Human-In-The-Loop (HITL) simulation evaluations for MMUN are intended to assist SENEAM with the implementation of dual independent operations. A HITL simulation evaluation is a rigorous experimental process in which participants (in this case, controllers) are introduced to new concepts and/or procedures in a simulated laboratory environment. Each participant partakes in several scenarios[2] designed to simulate different real-world conditions. Participant responses to these scenarios are then used to answer a set of research questions and to identify potential issues that need to be addressed prior to implementation.

The first (out of two) HITL simulation evaluation for MMUN was conducted at MITRE's Air Traffic Management (ATM) Laboratory from 27 February 2017 through 3 March 2017. Refer to Enclosure 2 to MITRE Technical Letter F500-L17-111: *First Cancún Human-In-The-Loop Simulation Evaluation: Results*, dated 3 October 2017, for the results of the first HITL simulation evaluation.

The second HITL simulation evaluation for MMUN was conducted at MITRE's ATM Laboratory from 28 August 2017 through 1 September 2017 (following a dry run week from 7 through 11 August 2017). Cancún Approach Control controllers were asked to handle simulated traffic in specific operational scenarios using instrument procedures and sectors associated with the MMUN airspace design. Refer to Enclosure No. 3 to MITRE Technical Letter F500-L17-111: *Cancún Terminal Maneuvering Area - Airspace Redesign: Informal*

[1] Aeropuerto Internacional de Cancún (MMUN) is sometimes referred to as "Cancún International Airport" or "Cancún" when discussing HITL-related questions that were asked of participants.

[2] A scenario is a time-bound activity (usually 30-60 minutes in duration) that provides a HITL simulation evaluation participant with a sequence of events on a system to meet a specific set of objectives. While realistic, it is a simulated exercise.

Working Notes - Routes and Sectorization, dated 3 October 2017 for details on the airspace design and sectors used in the second HITL simulation evaluation. The above-mentioned HITL simulation evaluated the airspace design by collecting and analyzing information from simulation system data (e.g., aircraft state, user inputs), observations, questionnaires, and discussions with the Cancún Approach Control controllers.

The purpose of the second, and final, HITL simulation evaluation was to examine the appropriateness of the airspace design to support dual independent operations under off-nominal conditions and events, such as the use of holding or changes to the runway configuration at MMUN. Off-nominal events are defined and discussed in more detail in Section 4.1.4. Changes made to the airspace design following the conclusion of the first HITL simulation evaluation were also evaluated. This document discusses the results of the second, and final, HITL simulation evaluation.

The scope of the second HITL simulation evaluation comprised of the Cancún/Cozumel Terminal Maneuvering (Control) Area (TMA), including the use of the Final Monitor position, which will be used during dual independent operations at MMUN. The second HITL simulation evaluation identified potential issues associated with the use of the proposed airspace design (sectors, procedures, and altitude restrictions) for referral to SENEAM for examination and potential modifications.

The major research topics selected for the second HITL simulation evaluation included:

- Workload (a perception by the controller)
- Acceptability of the airspace elements (routes, sectors, and restrictions)
- Preferences (related to procedures as well as the overall airspace design and operation)
- Interactions between the participants and the system and system interfaces
- Issues and observations while managing traffic during various scenarios

Based on these topics, the following questions were used to define the research objectives of the second HITL simulation evaluation:

- Is the proposed airspace design acceptable?
- Does the proposed airspace design support off-nominal events?
- Is the workload (based upon the proposed airspace design) acceptable under off-nominal conditions?
- Does the proposed airspace design increase workload?
- What issues, if any, can be identified with the proposed airspace design?

These questions were used to inform the data collection requirements for both subjective and objective data. After the HITL simulation evaluation, the data collected were analyzed and aggregated to provide answers to the research questions.

This document is structured as follows:

- Section 1 has introduced the project, structure, and the scope of the work
- Section 2 provides background regarding the second HITL simulation evaluation, including information on the hardware, software, traffic data, and participants
- Section 3 describes the experimental design and the scenarios for the second HITL simulation evaluation
- Section 4 presents the results of the second HITL simulation evaluation in the form of subjective and objective metrics
- Section 5 summarizes the results, and presents MITRE's findings

This report constitutes the final Cancún work by MITRE under its contractual obligations, which were in fact exceeded, as all HITLs took place at MITRE. MITRE, however, remains ready for consultation.

2. HITL Simulation Evaluation Background

2.1 MITRE's Simulation Laboratory Environment

MITRE's ATM Laboratory is a mature simulation laboratory that has gone through decades of development that can handle a range of exploratory concepts, while also being realistic enough to evaluate airspace designs. It supports an extensible, scalable, real-time distributed simulation environment that can be configured for customers with different needs. For MMUN, the laboratory was used to conduct a HITL simulation evaluation which allowed controllers to manage simulated traffic in an operationally realistic, but safe, environment, while evaluating the proposed airspace design.

MITRE's HITL simulation laboratory environment consists of hardware and software components (e.g., keyboard, software displays, and functionality) that mimic controller workstations to allow participants to manage traffic in ways similar to their normal working environment. For the second HITL simulation evaluation for MMUN, MITRE developed an ATC workstation that provided a keyboard and a controller display consistent with capabilities and functionality currently in operational use at Cancún Approach Control. See Figure 1.

The hardware for MITRE's HITL simulation evaluation environment consisted of ATC workstations and pseudo-pilot[3] workstations. The ATC workstation was composed of one 2048 x 2048 High Definition (HD) display (the primary control interface), a communications interface, and peripherals. An additional HD flat screen monitor was used to display and interact with the electronic questionnaire.

[3] During the HITL simulation evaluation, pseudo-pilots controlled multiple simulated aircraft and responded to participant-issued commands, clearances and directions. By serving in the role of real pilots, pseudo-pilots provided a more realistic experience for participants.

The pseudo-pilot workstation was comprised of two computer monitors, one for the primary pseudo-pilot control interface (SimPilot) and one for a non-interactive visual feed from the ATC workstation, and peripherals. For more details refer to Enclosure 2 to MITRE Technical Letter F500-L16-059: *Cancún Airport Human-In-The-Loop Simulations - Initial Laboratory Configuration Technical Requirements*, dated 26 September 2016.

Figure 1. MITRE ATM Laboratory Configured for the MMUN HITL

To support dual independent operations at MMUN, MITRE developed two Final Monitor positions using a prototype of a Final Monitor Aid (FMA) display, a high-resolution color monitor with alert algorithms, one for each runway. The Final Monitor controller has four primary responsibilities:

1) Monitor aircraft on the Tower frequency from prior to the point of the Duals Bar (the location where aircraft begin to lose vertical separation when the aircraft begin their descent to intercept the glideslope) until 1 Nautical Mile (NM) from the approach end of the runway
2) Alert aircraft if they are deviating (committing what is referred to as a "blunder") off the Final Approach Course (FAC)
3) Initiate breakout procedures in the event an aircraft enters the No Transgression Zone (NTZ)[4]
4) Maintain longitudinal separation between aircraft on the same runway and issue breakout instructions if the required separation cannot be maintained

The FMA display contains various elements as shown in Figures 2 through 4. The display in Figure 2 depicts:

[4] A 2000 feet (ft)-wide zone, centered between the parallel runways, and equidistant to each one.

- The runways, including an extended runway centerline, which is represented as a dashed line; each dash along the extended runway centerline is 1 NM long and the space between the dashes is also 1 NM
- An NTZ
- The final approach fix, as defined by the Instrument Landing System (ILS) approach
- A Duals Bar
- Horizontal lines, spaced 200 ft apart and parallel to the extended runway centerline, which allow controllers to determine how far aircraft are deviating from the FAC

The FMA display is configured with a 4:1 aspect ratio. This "exaggerated" ratio causes the side-by-side, or horizontal distance, to be enhanced four times the longitudinal distance thus allowing controllers to identify deviations from the FAC more readily.

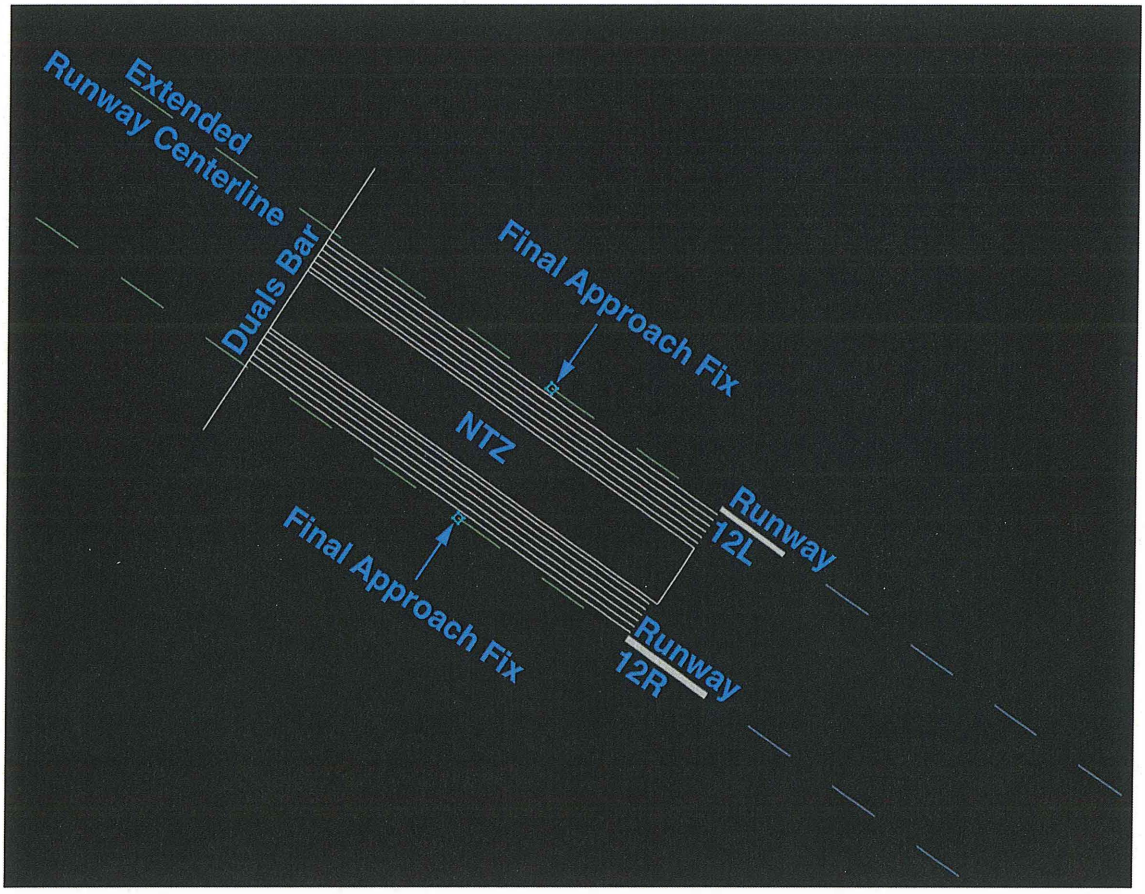

Figure 2. Annotated FMA Prototype for MMUN Runways 12L/R

If an aircraft is predicted to enter the NTZ, the aircraft target will be depicted in yellow and the NTZ will turn yellow, as shown in Figure 3. A caution aural alert will also be issued to the controller (i.e., "CAUTION, INTERJET THREE-FOUR-ZERO").

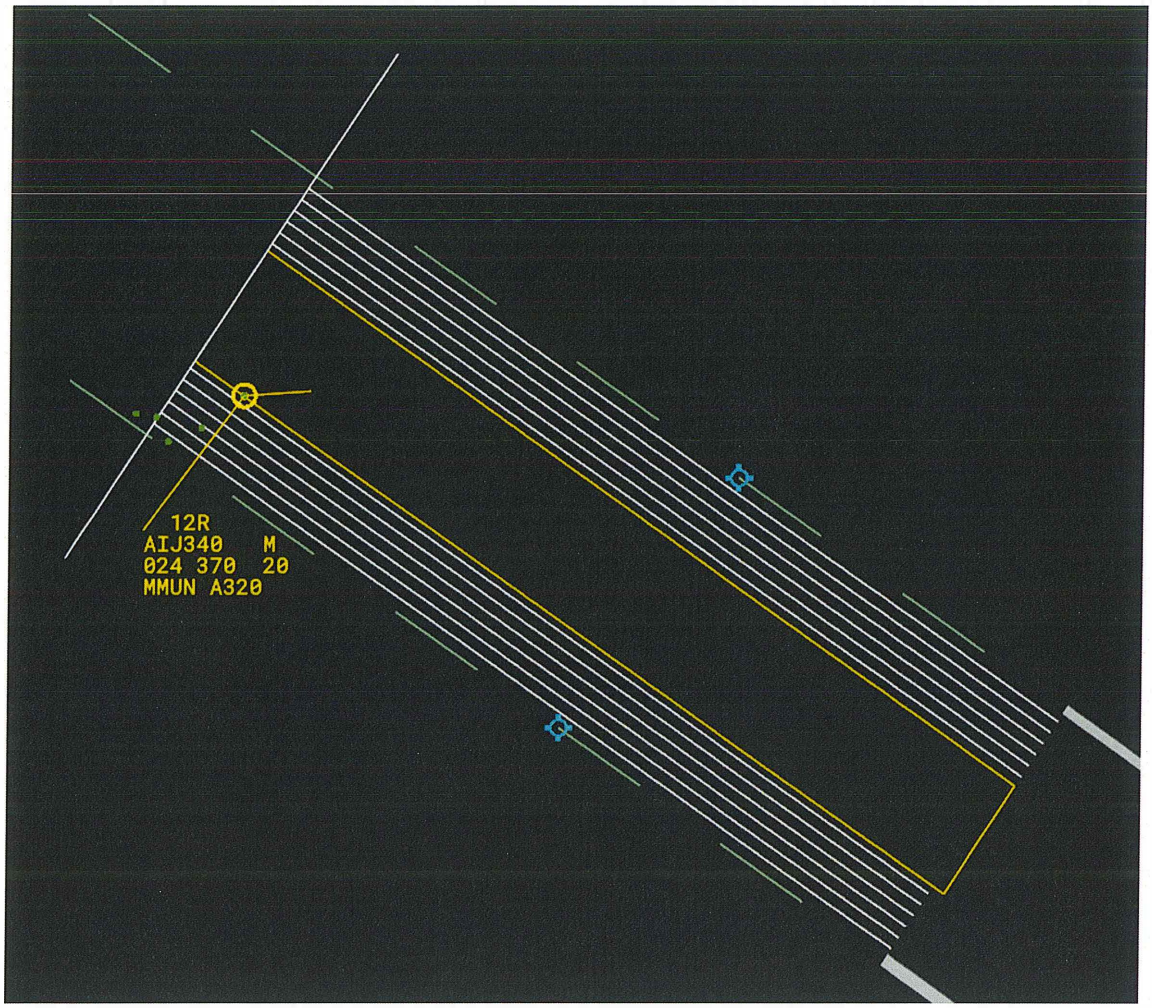

Figure 3. FMA Prototype in Caution State for MMUN Runways 12L/R

If the aircraft continues into the NTZ, the aircraft target will be depicted in red and the NTZ will turn red and an aural warning will be issued (i.e., "WARNING, INTERJET THREE-FOUR-ZERO"). See Figure 4.

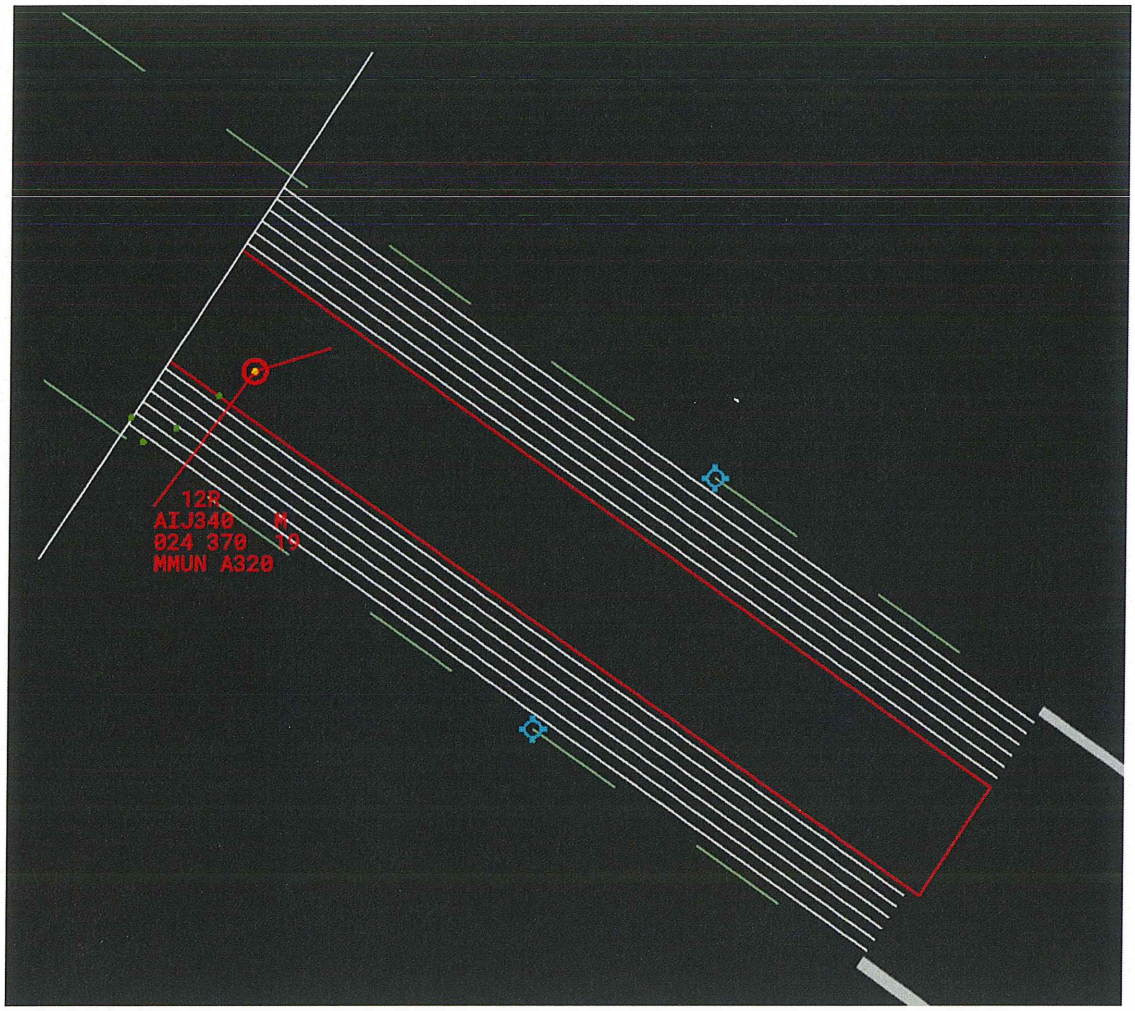

Figure 4. FMA Prototype in Warning State for MMUN Runways 12L/R

2.2 Second HITL Simulation Evaluation Scenario Development

HITL simulation evaluation scenarios typically contain specific objectives, sectors, procedures, runway configurations, traffic, and controller positions (e.g., Arrival, Approach, Final Monitor, and Departure, as appropriate).

An early June 2017 airspace design workshop provided an opportunity for SENEAM and MITRE to develop scenarios for the second HITL simulation evaluation. The scenario development sessions focused on determining the objectives of each scenario, which off-nominal events to test, which runway configurations to use, and which operating positions inside of the Cancún Approach Control should be active.

SENEAM and MITRE identified six scenarios to be used to familiarize SENEAM participants with the HITL simulation evaluation procedures and the Cancún/Cozumel TMA airspace design. An additional 20 scenarios were developed to evaluate the proposed Cancún/Cozumel TMA airspace design during off-nominal conditions. Tables A-1 through A-6

in Appendix A show the details of the scenarios that were developed for the second HITL simulation evaluation.

2.3 Second HITL Simulation Evaluation: Traffic Data

SENEAM provided MITRE with Aeronautical Fixed Telecommunication Network (AFTN) Coordinated Flight Plan (CPL) data that were used as the basis for creating the simulated traffic in the HITL simulation evaluation scenarios. The dates of the CPL data provided by SENEAM were March 2016 through April 2016. These data were converted to a MITRE internal format and provided a realistic baseline for traffic before they were edited (replicated, time shifted, deleted), as required, to generate the situations and traffic levels needed to meet scenario objectives for the HITL simulation evaluation.

2.4 Second HITL Simulation Evaluation: Participants

Four MMUN air traffic controllers participated in the second HITL simulation evaluation. The participants were required to have radar experience in the Cancún/Cozumel TMA and to have actively controlled terminal traffic, either real or simulated, within the preceding 12 months. CTA. Augusto Gómez acted as a Supervisor and observer, and provided key oversight.

2.4.1 Participant Responsibilities

As part of the introductory briefing, participants were informed of their responsibilities during the HITL simulation evaluation. Their primary task was to control simulated traffic using the proposed airspace design. Their secondary task was to evaluate the proposed airspace design for acceptability under off-nominal operating conditions.

Prior to each simulation evaluation scenario, participants were provided with a briefing to remind them of the runway configuration, procedures, and restrictions in use, the off-nominal events that would occur, and to allow them to ask any questions they had. Participants were assigned sectors for each simulation evaluation scenario and had opportunities to rotate through sector positions to manage traffic in different sectors throughout the HITL simulation evaluation. Table 1 shows the positions (Arrival, Approach, Departure, and Final Monitor) staffed by each participant, the number of times each participant staffed a position during a scenario, as well as the total number of times that position was included in a scenario. Additional sectors were sometimes staffed by MITRE personnel for coordination purposes; data were not collected on those sectors.

Table 1. Position Assignment Summary and Number of Times at Position

Position	Total Number of Scenarios	Participant 1	Participant 2	Participant 3	Participant 4
Arrival North (ARR N)	16	4	4	4	4
Arrival South (ARR S)	16	4	4	4	4
Approach North (APP N)	20	5	5	5	5
Approach South (APP S)	20	5	5	5	5
Final Monitor Aid North (FMA N)	4	1	1	1	1
Final Monitor Aid South (FMA S)	4	1	1	1	1
Departure North (DEP N)	4	1	1	1	1
Departure South (DEP S)	4	1	1	1	1

For each simulation scenario, all participants were given a Ready Reference Packet (which provided them with details of procedures, restrictions, and sectors in use for each scenario) and a list of adjacent sector frequencies for the sector that they were assigned to evaluate.

After each scenario, MITRE staff administered an electronic questionnaire to participants to gather feedback and perceptions on the airspace design. A complete list of the questions presented to participants in the questionnaires is provided in Appendix B. Following the questionnaire, open debrief discussions were held with all participants and MITRE personnel to review any questions, issues, or items worthy of additional discussion, as they pertained to the proposed airspace design.

3. Experimental Design and Scenarios

The experimental design for the second HITL simulation evaluation was a repeated-measures design, meaning each participant experienced the same set of data collection scenarios. In other words, all participants took part in each test condition in the HITL simulation evaluation.

All scenarios were presented in blocks, consisting of two runs, with the same traffic files for the block but with participant position assignments rotated, so that participants experienced each scenario twice. Practice scenarios were used prior to data collection scenarios to introduce

different aspects of the airspace design and operation to the participants. The practice scenarios allowed participants to become familiar with the scenarios prior to data collection.

Counterbalancing, or alternating the order of conditions (by way of rotating positions for the participants), was used to minimize the potential for order effects, such as anticipation of traffic behavior and familiarization from presentation order. Other methods used to minimize order effects included modifications to call signs within traffic files, and adjustments to timing and distribution of traffic loads.

3.1 Airspace and Procedure Changes

Several changes were made to both airspace and procedure designs following the conclusion of the first HITL simulation evaluation in February/March 2017. The changes included the addition of airspace to Arrival North and all Approach sectors, the movement of existing Standard Terminal Arrival Routes (STARs) and Standard Instrument Departures (SIDs), and the addition of altitude restrictions on existing routes. Refer to Enclosure 2 to MITRE Technical Letter F500-L17-111: *First Cancún Human-In-The-Loop Simulation Evaluation: Results*, dated 3 October 2017 for details on the changes recommended after the first HITL simulation evaluation.

Figure 5 shows the new airspace design that includes additional airspace given to the Approach sectors for both Runway 12 and Runway 30 operations to allow additional room for vectoring arrivals on the NOSAT/AMITA STARs (Approach North) and LOKMA/SIGMA/DANUL/CHETU STARs (Approach South).

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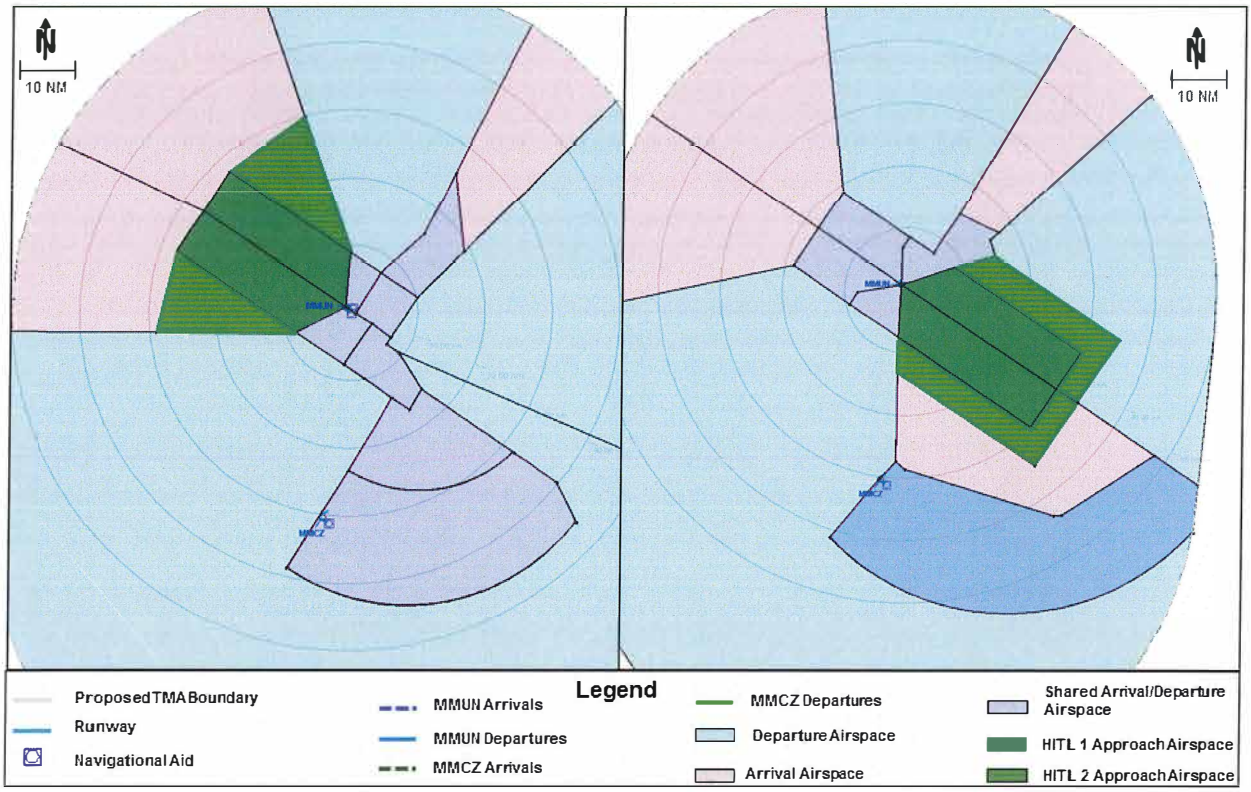

Figure 5. Modifications to Approach Sectors

The MMCZ EMOSA STAR was moved east to provide additional lateral spacing with the MMUN NOSAT STAR, as shown in Figure 6. This procedure modification required a procedural change between the Arrival North and Departure North sectors (as shown), where point-outs are required between the two sectors for arrivals on the MMCZ EMOSA STAR. An additional altitude restriction (at or below 14,000 ft) was also added on the NOSAT STAR at fix UN526 to force NOSAT arrivals below the EMOSA arrivals.

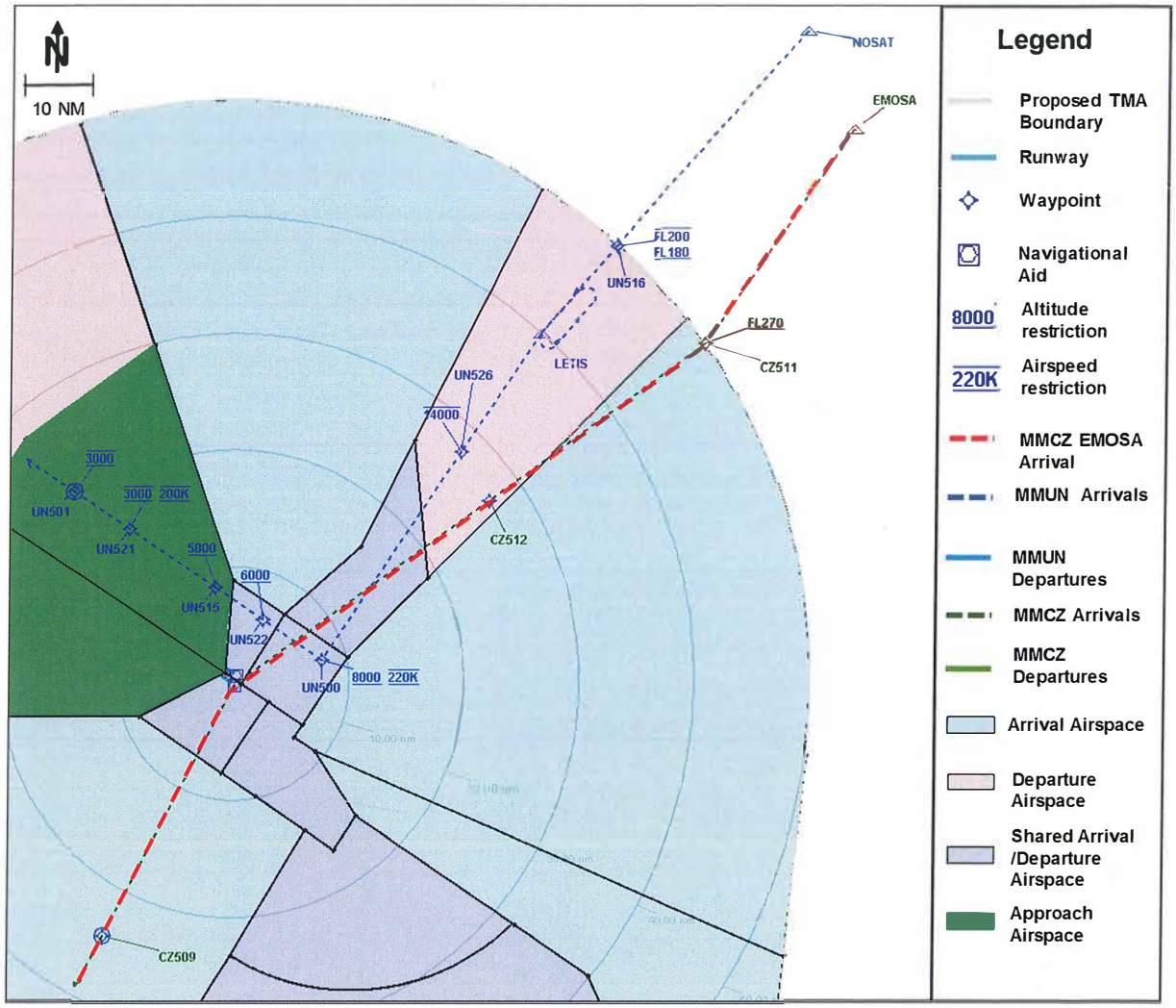

Figure 6. Modification to MMCZ EMOSA STAR

Figure 7 depicts the modification made to the MMUN DANUL STAR for Runway 12 operations. The merge for the DANUL STAR traffic was moved to waypoint UN523 so that three STARs did not merge at the same waypoint (UN511). An additional altitude restriction (at or above 16,000 ft) was also added on the SIGMA STAR at fix UN527 to ensure vertical separation between traffic merging from the DANUL STAR and the SIGMA STAR.

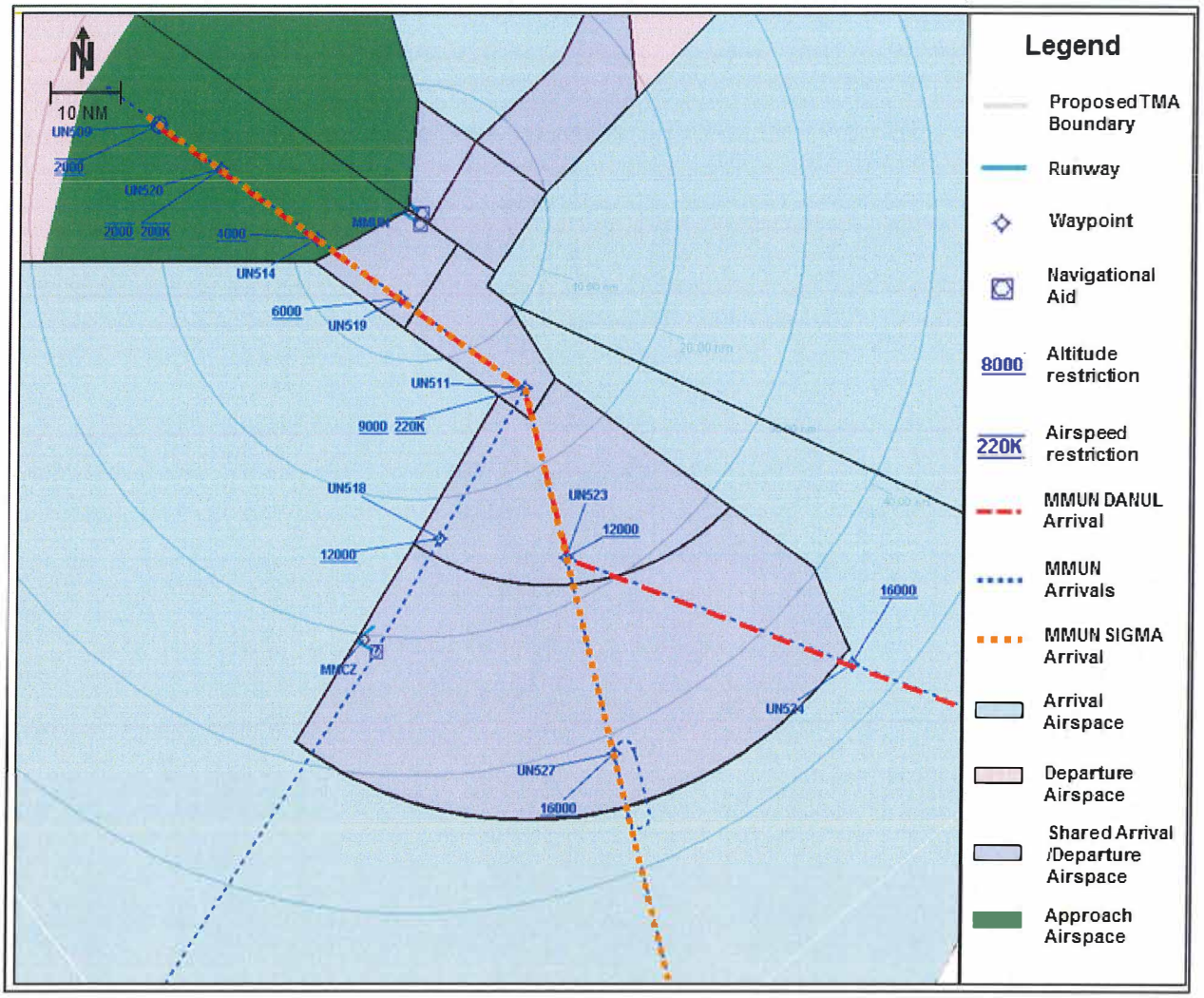

Figure 7. Modification to DANUL and SIGMA STARs for Runway 12 Operations

The ROTGI STAR for Runway 12L operations was moved west, reducing the separation between the MMUN NOSUG SID and MMUN ROTGI SID for Runway 12 operations, as shown in Figure 8.

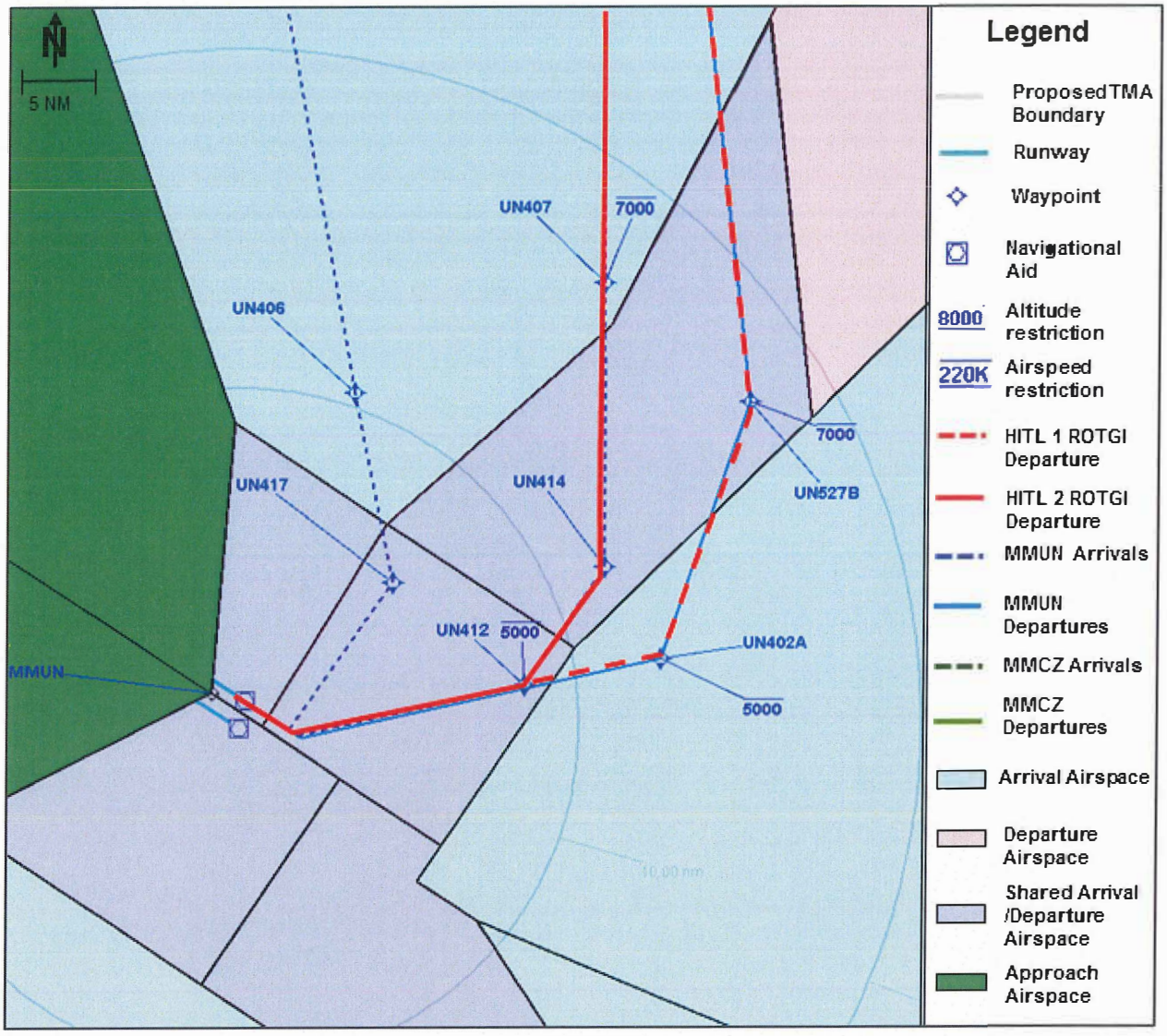

Figure 8. Modification to ROTGI STAR for Runway 12L Operations

Lastly, a new MMCZ CZ500C SID was added for Runway 11 and Runway 29 operations. The MMCZ CZ500C SID is shown in Figure 9.

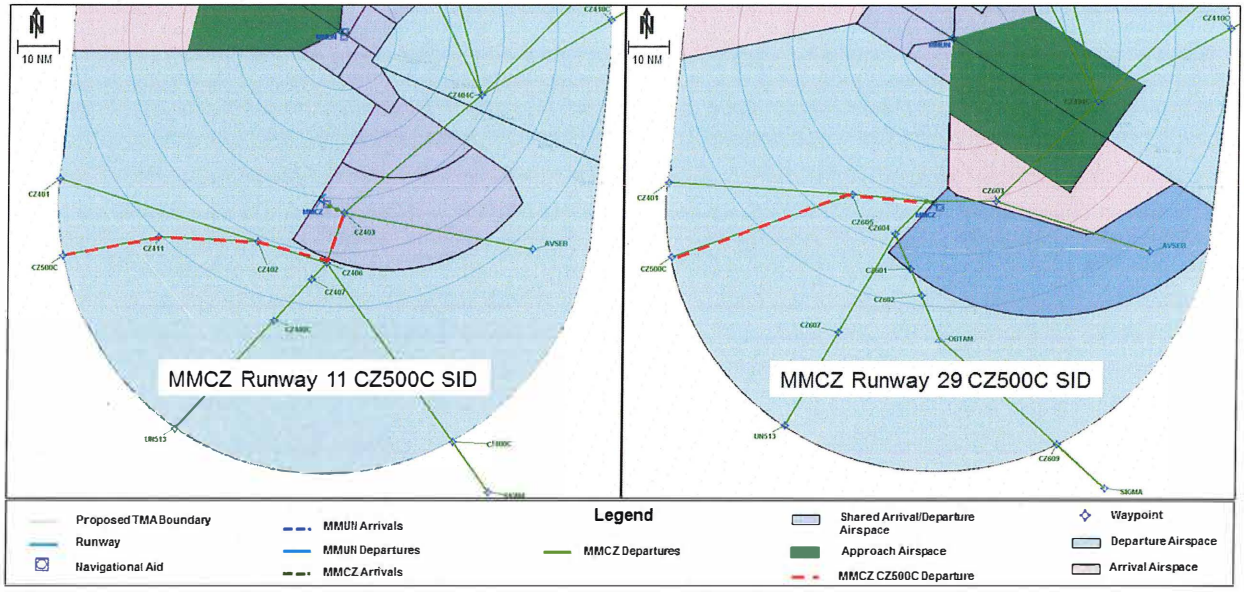

Figure 9. Addition of MMCZ CZ500C SID for Runway 11 and Runway 29 Operations

3.2 Scenario Descriptions

Scenarios were designed to represent the full spectrum of possible runway configuration operations, such as MMUN Runway 12L/R and MMCZ Runway 11, or MMUN Runway 30L/R and MMCZ Runway 29. Each individual scenario contained traffic situations designed to allow participants to evaluate the airspace design and determine its suitability during off-nominal events. Scenarios were designed to be between 30 and 45 minutes in length, with four sectors being evaluated in each scenario. See Appendix A for detailed scenario descriptions.

In all scenarios, controllers were asked to evaluate the acceptability of the proposed airspace design with respect to the sector position they worked in that scenario. Participants were also asked to assess their workload at each sector/position.

Scenario sector configurations included:

- Arrival sectors with Approach sectors
- Arrival sectors and Approach sectors with Departure sectors, and
- Approach sectors with Final Monitor positions

These configurations were simulated in scenarios with low traffic density, moderate traffic density, high traffic density, and under opposite-direction operations (where MMUN and MMCZ operate in opposite-direction runway configurations). Scenarios involving Arrival and Approach sectors evaluated procedures for use of holding patterns and runway configuration changes, procedure locations, altitudes, and speeds, and merge points for various streams. Scenarios involving Arrival and Approach and Departure sectors evaluated the airspace during movement from independent to dependent operations, including interactions between STARs and SIDs for both MMUN and MMCZ, interactions between MMUN and MMCZ traffic, and procedures for locations, altitudes, and speeds. Scenarios involving Approach sectors with Final Monitor

positions evaluated missed approach procedures, breakouts and blunders on the FAC, and the location, speeds, and altitudes of base legs and downwind feeds, as well as the function of the Final Monitor position and the FMA prototype display, including the function of the Duals Bar. Intentional errors (missed approaches, breakouts and blunders) were scripted in real time for the Final Monitor positions to give participants an opportunity to react to different aspects of the FMA prototype display (i.e., aural and visual alerts presented when an aircraft deviated from the FAC).

3.3 Simulation Scenario Presentation Order

Table 2 shows the order in which the simulation scenarios were presented to participants during the second HITL simulation evaluation. As shown in the table, some simulation scenarios are shown twice. Four of the 20 data collection scenarios were repeated (Scenarios 5, 6, 7, and 8, respectively) to accommodate changes made to the maps after the original data collection run[5]. Two additional runs of Scenarios 13 and 14 were conducted to obtain additional data for the NOSUG and ROTGI SIDs.

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[5] Data from the initial runs of Scenarios 5 through 8 were not included in the data analysis, as the maps needed to be modified.

Table 2. Scenario Presentation Order During the Second HITL Simulation Evaluation

Monday (8/28)	Tuesday (8/29)	Wednesday (8/30)	Thursday (3/2)	Friday (3/3)
Practice 1	Scenario 3	Scenario 9	Scenario 7_2	Scenario 13_2
Practice 2	Scenario 4	Scenario 10	Scenario 8_2	Scenario 14_2
Practice 3	Scenario 3 and 4 Debrief	Scenario 9 and 10 Debrief	Scenario 13	Scenario 17
Practice 4	Scenario 5	Scenario 5_2	Scenario 14	Scenario 18
Practice 5	Scenario 6	Scenario 6_2	Scenario 13 and 14 Debrief	Scenario 17 and 18 Debrief
Practice 6	Scenario 5 and 6 Debrief	Scenario 11	Scenario 15	Scenario 19
Scenario 1	Scenario 7	Scenario 12	Scenario 16	Scenario 20
Scenario 2	Scenario 8	Scenario 11 and 12 Debrief	Scenario 15 and 16 Debrief	Scenario 19 and 20 Debrief
Scenario 1 and 2 Debrief	Scenario 7 and 8 Debrief			

3.4 Data Collection: Subjective and Objective Measures

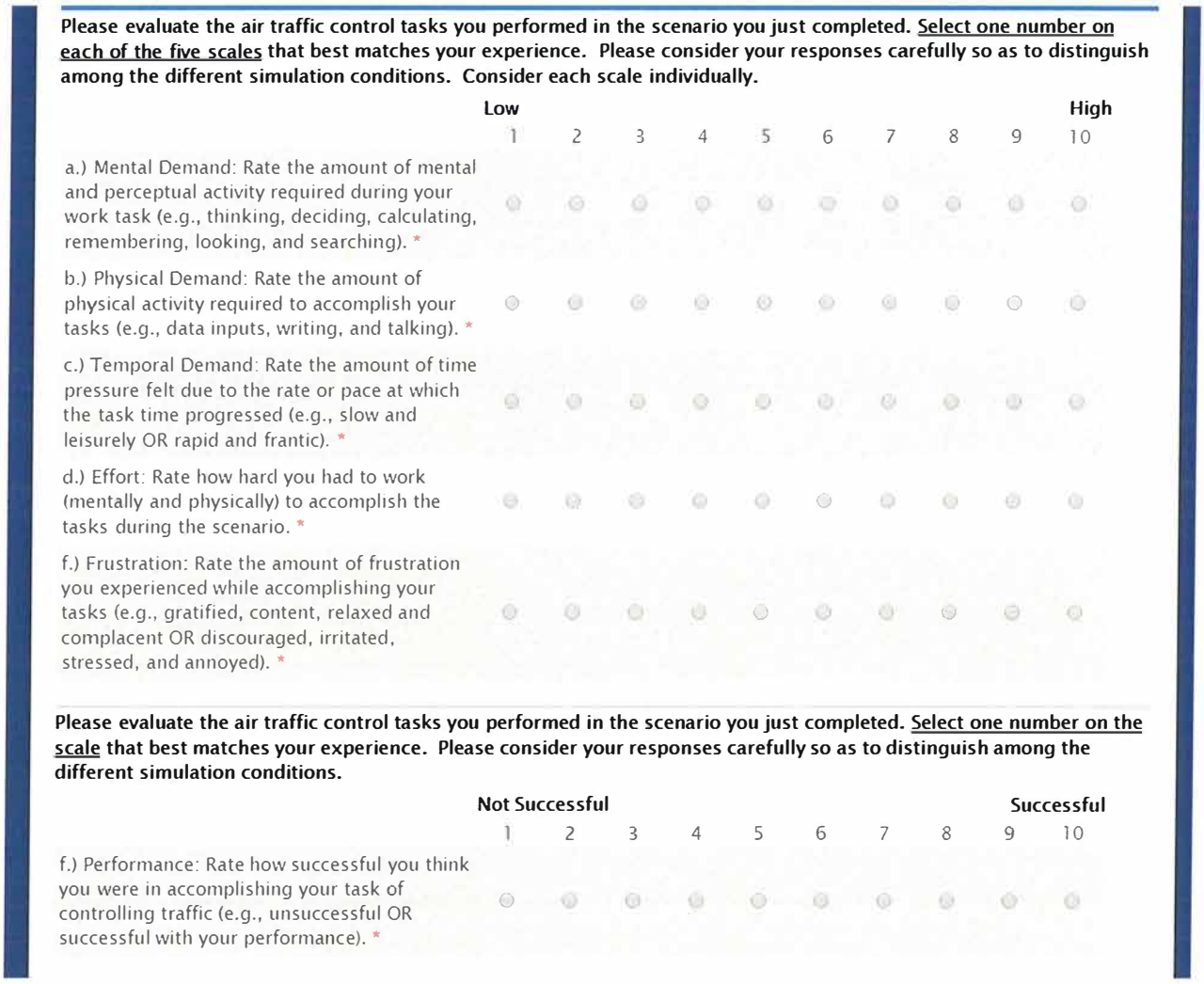
Two types of metrics were collected from each participant during the HITL simulation evaluation: subjective measures and objective measures. Subjective measures refer to perceived metrics based upon participant experience or interpretation, such as participant responses to a survey question on perceived workload or comments from a participant. Objective measures are observed metrics of direct performance, such as the number of communications between a controller and aircraft within that controller's sector, or the number of command inputs into the ATC workstation, such as reroutes or flight plan changes.

Three methods of data collection were used in this simulation activity: electronic questionnaires, system-recorded data/voice, and observations. Questionnaires were administered electronically on MITRE-provided devices after each scenario. The surveys included questions that sought to gather subjective data on participants' operational experience, and experiences during the HITL simulation evaluation scenarios, including perceived workload, acceptability, preferences, interactions, and issues. The questionnaires included questions from the National Aeronautics and Space Administration (NASA) Task Load Index (NASA-TLX) workload measurement tool, as well as the end-anchored Likert scale, yes/no, and open-ended questions. Most questions had a comment field that was dynamically available dependent upon the answer provided by the participant; negative responses would typically activate the comment field and present a follow-on question requesting more information from the participant.

3.5 Subjective Analysis Methods

The subjective results are based upon responses to the NASA-TLX, comments documented during debriefing sessions, and behaviorally-anchored questions from the questionnaires.

The NASA-TLX is a subjective, multi-dimensional tool used to measure workload. Participants provide scores on a scale of one to ten regarding their perception of workload within six sub-scales: Mental Demand, Physical Demand, Temporal Demand, Performance, Effort, and Frustration. An example of the NASA-TLX tool used during the HITL simulation evaluation is provided in Figure 10.



Please evaluate the air traffic control tasks you performed in the scenario you just completed. Select one number on each of the five scales that best matches your experience. Please consider your responses carefully so as to distinguish among the different simulation conditions. Consider each scale individually.

	Low 1	2	3	4	5	6	7	8	9	High 10
a.) Mental Demand: Rate the amount of mental and perceptual activity required during your work task (e.g., thinking, deciding, calculating, remembering, looking, and searching). *										
b.) Physical Demand: Rate the amount of physical activity required to accomplish your tasks (e.g., data inputs, writing, and talking). *										
c.) Temporal Demand: Rate the amount of time pressure felt due to the rate or pace at which the task time progressed (e.g., slow and leisurely OR rapid and frantic). *										
d.) Effort: Rate how hard you had to work (mentally and physically) to accomplish the tasks during the scenario. *										
f.) Frustration: Rate the amount of frustration you experienced while accomplishing your tasks (e.g., gratified, content, relaxed and complacent OR discouraged, irritated, stressed, and annoyed). *										

Please evaluate the air traffic control tasks you performed in the scenario you just completed. Select one number on the scale that best matches your experience. Please consider your responses carefully so as to distinguish among the different simulation conditions.

	Not Successful 1	2	3	4	5	6	7	8	9	Successful 10
f.) Performance: Rate how successful you think you were in accomplishing your task of controlling traffic (e.g., unsuccessful OR successful with your performance). *										

Figure 10. Example of NASA-TLX Tool

In addition to providing feedback via the NASA-TLX, participants were also asked to provide subjective feedback regarding workload, situational awareness, communications, and the concept of operations or concept of use for the proposed airspace design and procedures under off-nominal conditions. Most response scale questions consisted of a seven-point Likert scale, and the questions were presented as statements to which participants were asked to indicate or

rate how strongly they agreed or disagreed. Examples of questions using the seven-point scale are provided in Figure 11. Remaining questions were either yes/no or open-ended (text) questions.

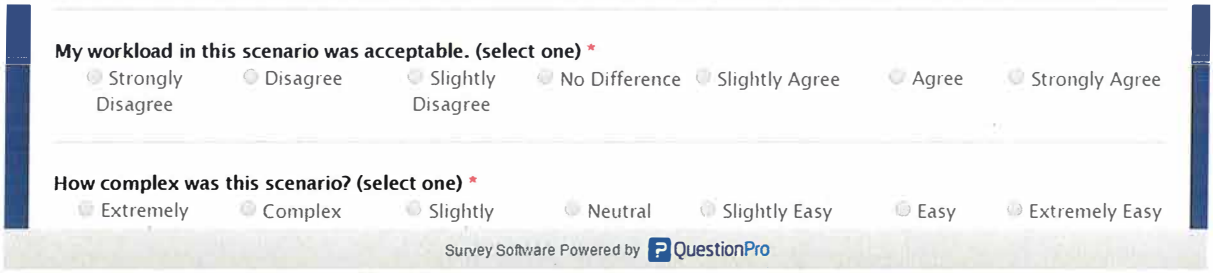


Figure 11. Examples of Questions Using Seven-Point Likert Scales

The questionnaires were very similar across all participants. The first question required participants to identify the scenario they had just completed, and the second question required participants to identify the position they worked in the scenario. Next, a base set of 18 questions were presented that were identical and repeated on each questionnaire. An additional 24 questions were scenario-specific and position-specific; that is, certain questions were only asked on specific scenarios, and were only presented to participants, as applicable, based upon their response to the first question of what position they staffed in the preceding scenario. The final question was open-ended and always appeared as the last question to each survey, with the intent of capturing any comments that participants wanted to provide after the questionnaire.

Because there were only four participants in the second HITL simulation evaluation, subjective ratings from the questionnaires are summarized as means, or averages. A mean is a statistical term that refers to the average of a set of numbers. Standard deviation, another statistical term, is a measure that is used to quantify the amount of variation or dispersion of a set of data values. Range depicts the difference between the largest (maximum) and smallest (minimum) values in a set of data. Means, ranges, and standard deviations are graphically represented in the results (see Section 4).

In some instances, all participant responses fell on the same end of the scale; in those cases, responses will be reported in aggregate, accordingly. For example, if two participants answered "agree," another participant answered "completely agree," and the final participant answered "somewhat agree," the result may be summarized in aggregate as "all participants agreed …" for that question.

Relevant comments included in the open-ended questions are reported, along with any relevant comments made in the debrief discussions, as well as any applicable events noted by observers.

3.6 Objective Analysis Methods

Data for the objective results were automatically recorded by the simulation platform and included: time on frequency, aircraft counts, and arrival/departure counts. Objective data are also summarized as means (averages). Objective data will be used, where needed, to provide additional details in response to the research questions.

System-recorded data/voice collection included command and system inputs from participants, track and aircraft state data (such as speed, vector, and altitude changes), pseudo-pilot control inputs, audio frequency loading, and individual channel recordings, including Push-to-Talk (PTT) logs from the various workstations. Simulation observers, from MITRE and SENEAM (as available), circulated among participants during data collection runs and took notes to capture any significant or unusual communications or actions visually or physically observed during the scenarios.

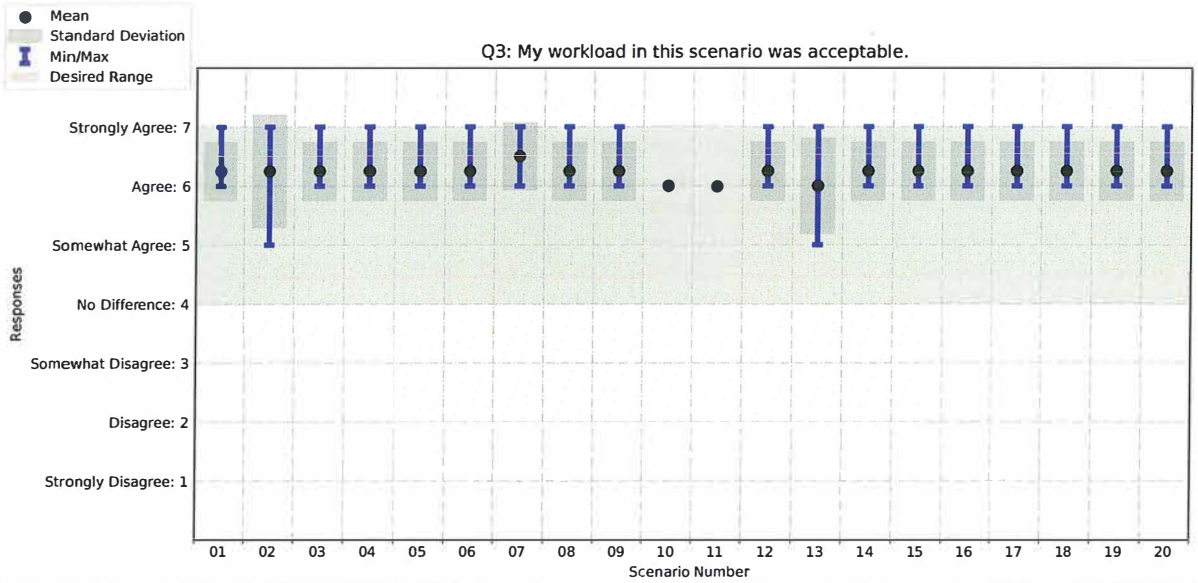
4. Results

4.1 Subjective Results: Questionnaires

The following graphs provide a visual representation of the questionnaire data replies, so that results can be easily understood. As shown in the example provided (Figure 12), the graphs use a black dot to depict the mean of the subjective ratings obtained from the four participants for each question in each applicable scenario. The graphs show the standard deviation in the form of grey shaded vertical blocks and minimum (min) and maximum (max) range values in the form of blue error bars. A depiction of the desired range, or an area where mean values, range values and standard deviation values would optimally appear, is provided for each question in the form of a shaded green area.

It is worth noting that, while averages always fall within the rating scale (i.e., Likert scale) used for each question, standard deviation values may extend beyond that rating scale, dependent upon both the mean value and the spread of the answers received from participants. As such, there are occasions where the error bars appear to extend beyond the axis value of the chart. The Y-axis values of the charts were kept consistent with the rating scales used for each question, as modifying them would artificially skew the appearance of the data.

It is also important to note that, while question numbers are provided for each question and graph, the question numbers were for data tracking purposes only. Because the question order was randomized, the questions were not always presented sequentially; similarly, the results are also not presented sequentially. Instead, question data are grouped together within topic area (e.g., Workload, Communications, Concept of Operations, etc.).

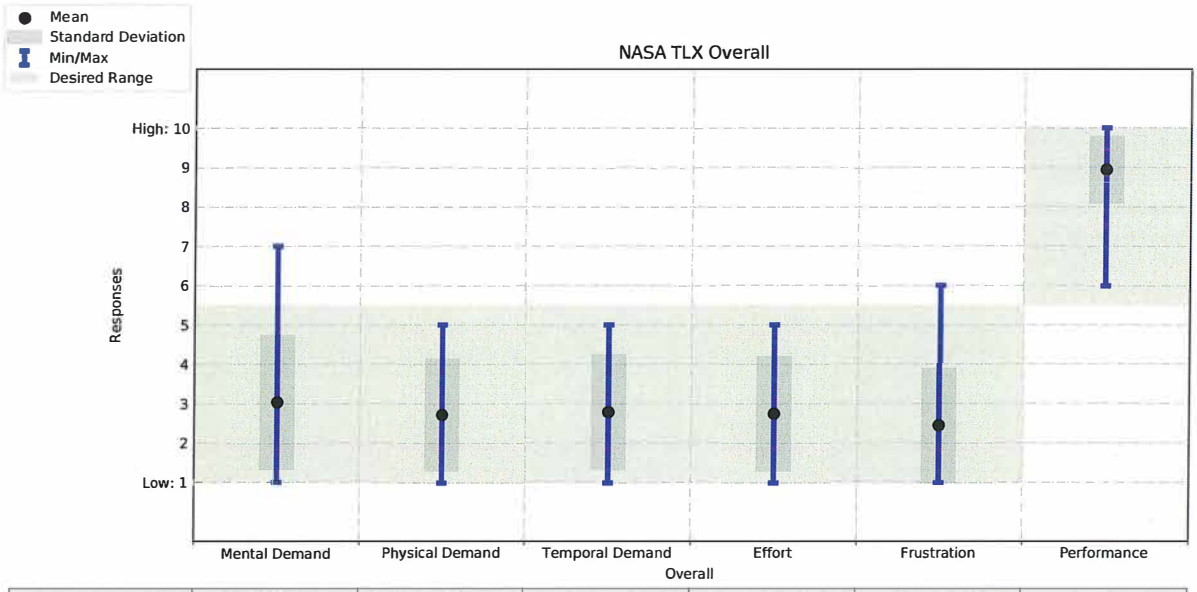


Scenario	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20
Mean	6.25	6.25	6.25	6.25	6.25	6.25	6.5	6.25	6.25	6.0	6.0	6.25	6.0	6.25	6.25	6.25	6.25	6.25	6.25	6.25
Standard Deviation	0.5	0.96	0.5	0.5	0.5	0.5	0.58	0.5	0.5	0.0	0.0	0.5	0.82	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Max	7	7	7	7	7	7	7	7	7	6	6	7	7	7	7	7	7	7	7	7
Min	6	5	6	6	6	6	6	6	6	6	6	6	5	6	6	6	6	6	6	6

Figure 12. Example Graph Showing Means, Standard Deviations, Min/Max Range Values, and Desired Range

4.1.1 Workload/Situational Awareness

Figure 13 provides an aggregate presentation of the mean values, standard deviations, and range values of each of the six subscales of the NASA-TLX across all scenarios. As shown, the mean values and standard deviations indicate that participants provided generally favorable workload ratings across all subscales of the NASA-TLX in all scenarios.



	Mental Demand	Physical Demand	Temporal Demand	Effort	Frustration	Performance
Mean	3.04	2.72	2.79	2.75	2.45	8.94
Standard Deviation	1.7	1.43	1.47	1.46	1.45	0.86
Max	7	5	5	5	6	10
Min	1	1	1	1	1	6

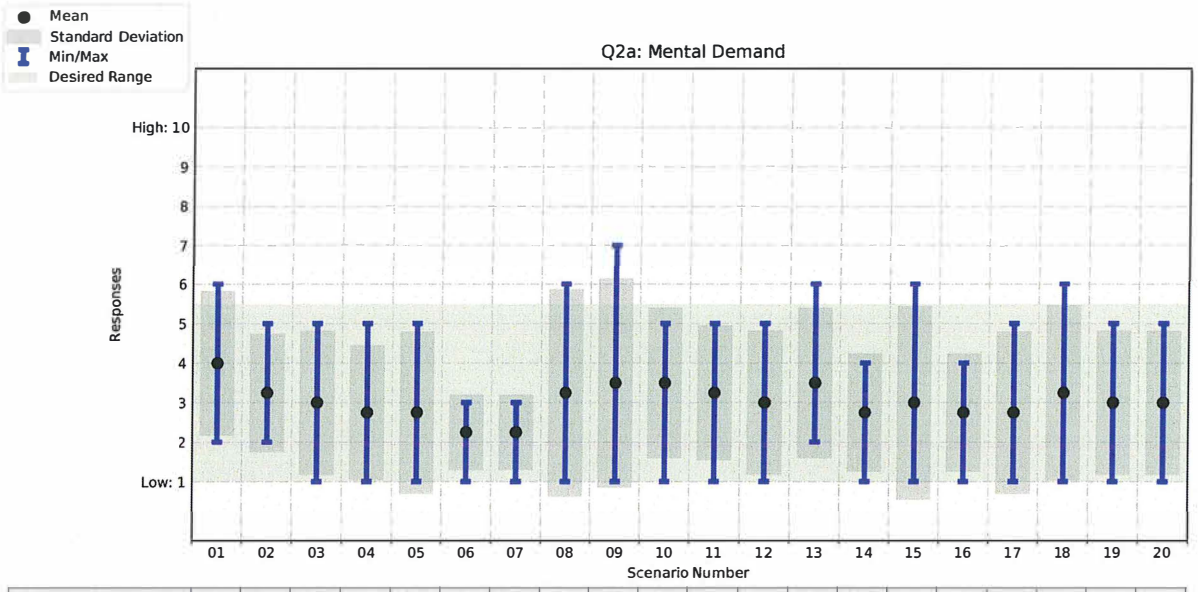
Figure 13. NASA-TLX Overall Results Across all Scenarios

Overall mean scores for Mental Demand, Physical Demand, Temporal Demand, Frustration, and Effort were below 4 (where the desired range is 5.5 or less). This suggests that participants generally felt that the demands of the tasks were ***acceptable***, required low effort, and their level of frustration was low throughout the scenarios.

The overall mean rating for the Performance subscale was above 8 (where the desired range is 5.5 or greater), which suggests that participants generally felt they were ***successful*** in managing tasks across all scenarios.

Mental Demand refers to the amount of mental exertion a participant experienced while controlling traffic.

Figure 14 shows that the mean ratings for Mental Demand were below 5.5 for all scenarios. The data points suggest that participants generally felt their Mental Demand was ***acceptable*** across most scenarios. The slightly higher mean value for Scenario 1 may have been an effect of it being the first data collection scenario run during the second HITL simulation evaluation.

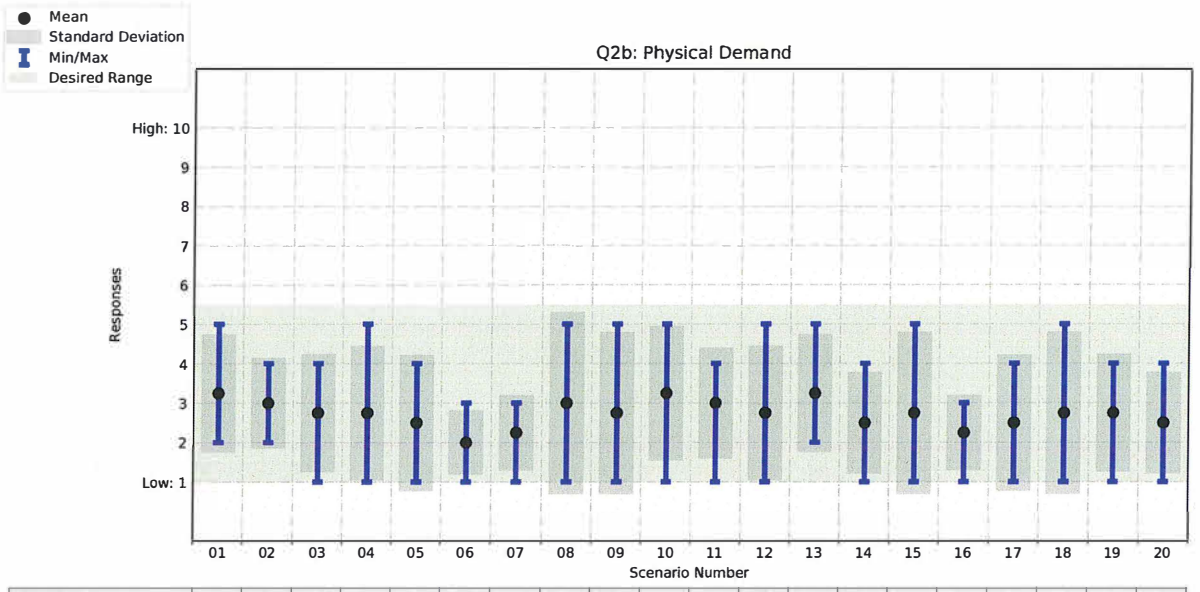


Scenario	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20
Mean	4.0	3.25	3.0	2.75	2.75	2.25	2.25	3.25	3.5	3.5	3.25	3.0	3.5	2.75	3.0	2.75	2.75	3.25	3.0	3.0
Standard Deviation	1.83	1.5	1.83	1.71	2.06	0.96	0.96	2.63	2.65	1.91	1.71	1.83	1.91	1.5	2.45	1.5	2.06	2.22	1.83	1.83
Max	6	5	5	5	5	3	3	6	7	5	5	5	6	4	6	4	5	6	5	5
Min	2	2	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1

Figure 14. Results for Question 2a: Mental Demand (NASA-TLX)

Although the mean ratings for Mental Demand were below 5.5 for all scenarios, the maximum range values were above the desired range for six of the 20 scenarios. In these instances, comments provided pointed to vectoring tasks (mostly at Arrival North, but also at Approach North and Approach South) as a probable cause for the higher maximum range values.

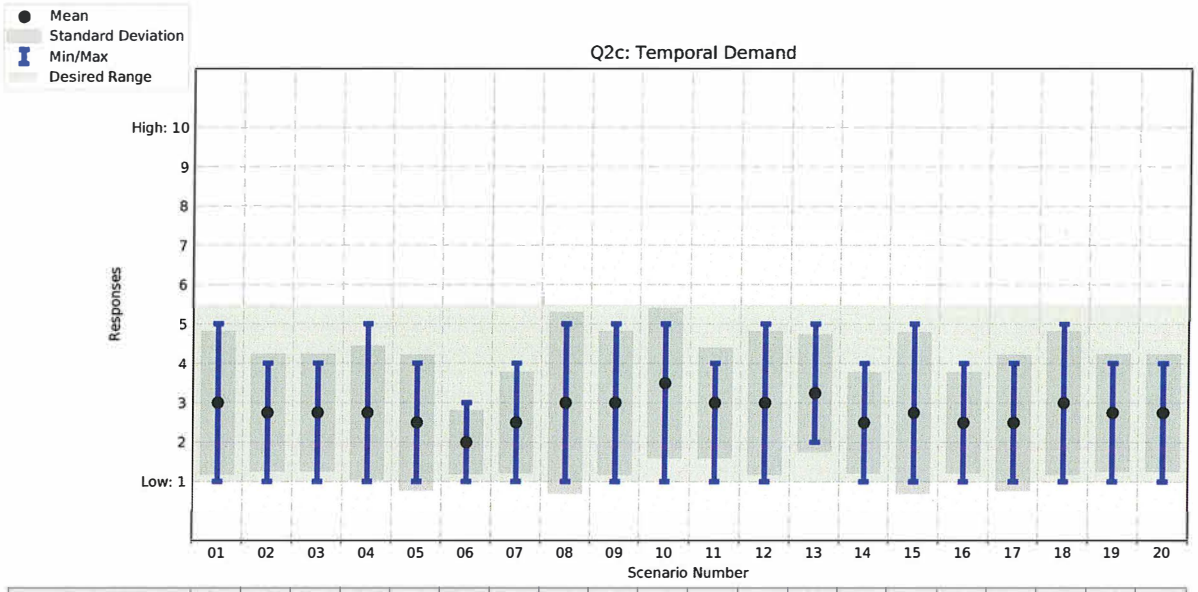
Physical Demand refers to how hard the participant works to interface with the ATC system. Figure 15 shows that the mean ratings for Physical Demand were below 5.5 for all scenarios, and the range for all scenarios was also within the desired range (below 5.5). Standard deviations were also within the desired range (of less than 5.5). In all, the data suggest that participants felt that physical demands of data inputs, writing and talking were within the ***acceptable*** range for all scenarios, regardless of the focus of the scenario or the position being worked.



Scenario	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20
Mean	3.25	3.0	2.75	2.75	2.5	2.0	2.25	3.0	2.75	3.25	3.0	2.75	3.25	2.5	2.75	2.25	2.5	2.75	2.75	2.5
Standard Deviation	1.5	1.15	1.5	1.71	1.73	0.82	0.96	2.31	2.06	1.71	1.41	1.71	1.5	1.29	2.06	0.96	1.73	2.06	1.5	1.29
Max	5	4	4	5	4	3	3	5	5	5	4	5	5	4	5	3	4	5	4	4
Min	2	2	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1

Figure 15. Results for Question 2b: Physical Demand (NASA-TLX)

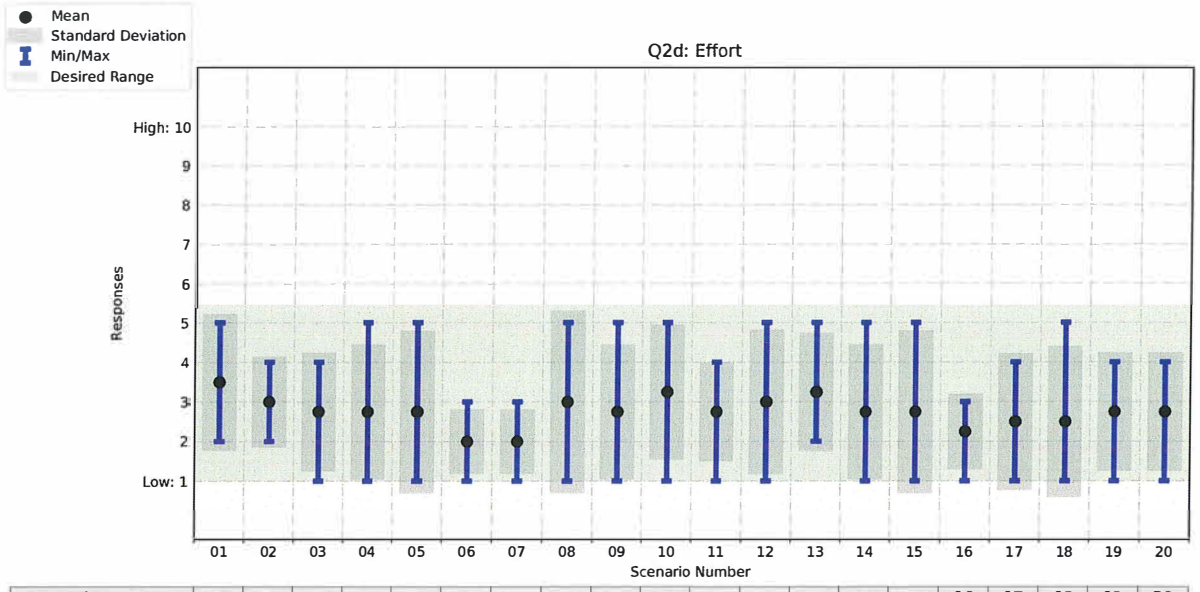
Temporal Demand refers to the amount of time pressure or pace of the tasks perceived by the participants. Figure 16 shows that the mean ratings for Temporal Demand were below 5.5 for all scenarios. The standard deviations and range values were also within the desired range (of less than 5.5) for all scenarios. Overall, the data appear to indicate that participants felt that the time pressure or pace of the tasks was ***low***.



Scenario	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20
Mean	3.0	2.75	2.75	2.75	2.5	2.0	2.5	3.0	3.0	3.5	3.0	3.0	3.25	2.5	2.75	2.5	2.5	3.0	2.75	2.75
Standard Deviation	1.83	1.5	1.5	1.71	1.73	0.82	1.29	2.31	1.83	1.91	1.41	1.83	1.5	1.29	2.06	1.29	1.73	1.83	1.5	1.5
Max	5	4	4	5	4	3	4	5	5	5	4	5	5	4	5	4	4	5	4	4
Min	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1

Figure 16. Results for Question 2c: Temporal Demand (NASA-TLX)

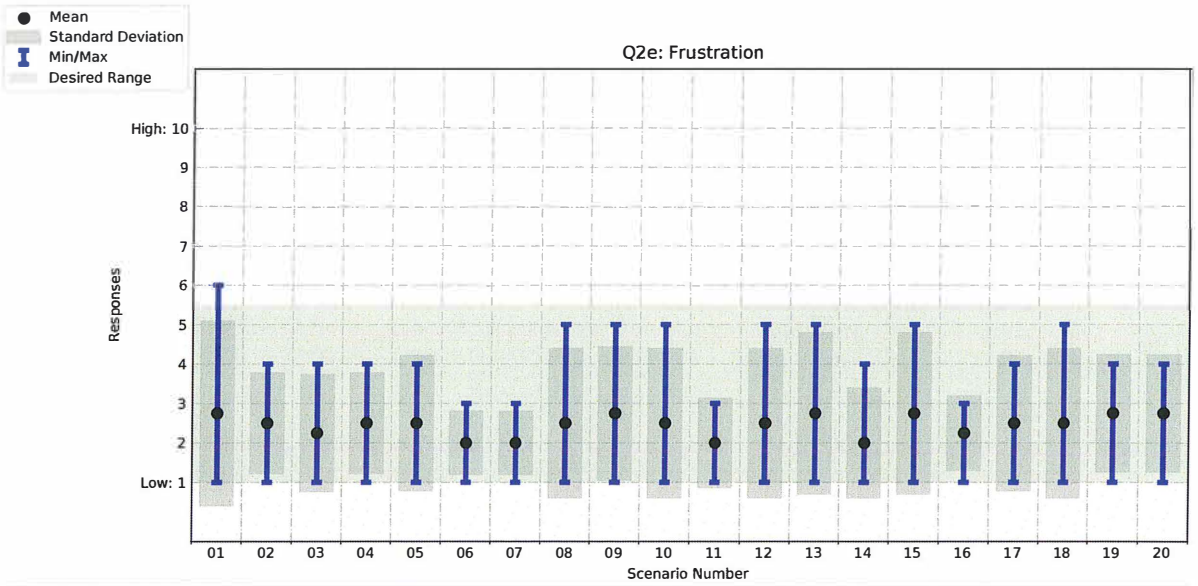
As shown in Figure 17, participant ratings of Effort, or the mental and physical exertion required to accomplish tasks, were below 4 for all scenarios, where the desired range is less than 5.5. Standard deviations and range values were also within the desired range for all scenarios. This indicates that participants felt that effort was within the ***acceptable*** range across all scenarios.



Scenario	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20
Mean	3.5	3.0	2.75	2.75	2.75	2.0	2.0	3.0	2.75	3.25	2.75	3.0	3.25	2.75	2.75	2.25	2.5	2.5	2.75	2.75
Standard Deviation	1.73	1.15	1.5	1.71	2.06	0.82	0.82	2.31	1.71	1.71	1.26	1.83	1.5	1.71	2.06	0.96	1.73	1.91	1.5	1.5
Max	5	4	4	5	5	3	3	5	5	5	4	5	5	5	5	3	4	5	4	4
Min	2	2	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1

Figure 17. Results for Question 2d: Effort (NASA-TLX)

Frustration is a measure of how gratified, content, relaxed and complacent versus discouraged, irritated, stressed or annoyed a participant was with a task. Figure 18 shows that the mean ratings for Frustration were below 3 for all scenarios. Standard deviations were within the desired range of 5.5 or below. Range values were mostly within the desired range, except for the maximum range value for Scenario 1, which was 6. The maximum range value above the desired range (of 5.5) was likely an effect of it being the first data collection scenario run during the second HITL simulation evaluation.

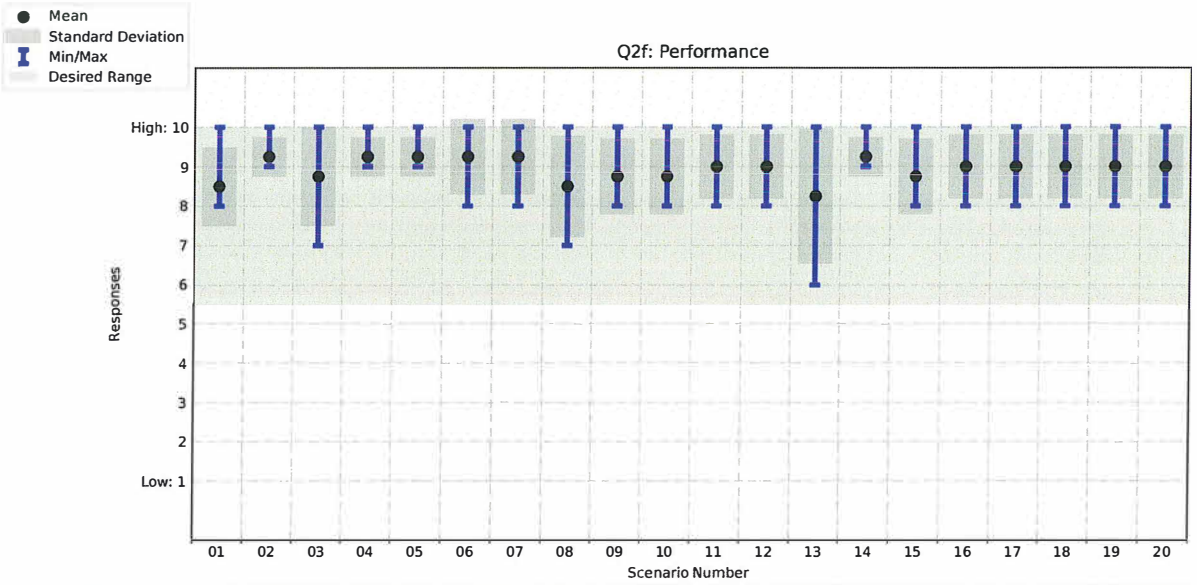


Scenario	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20
Mean	2.75	2.5	2.25	2.5	2.5	2.0	2.0	2.5	2.75	2.5	2.0	2.5	2.75	2.0	2.75	2.25	2.5	2.5	2.75	2.75
Standard Deviation	2.36	1.29	1.5	1.29	1.73	0.82	0.82	1.91	1.71	1.91	1.15	1.91	2.06	1.41	2.06	0.96	1.73	1.91	1.5	1.5
Max	6	4	4	4	4	3	3	5	5	5	3	5	5	4	5	3	4	5	4	4
Min	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Figure 18. Results for Question 2e: Frustration (NASA-TLX)

The Performance subscale asks participants to rate how successful they feel they were in accomplishing their tasks. Whereas the desired range on previous subscales was 5.5 or below, the desired range for the Performance subscale is 5.5 or above.

Figure 19 shows that the mean ratings for Performance were above 8 for all scenarios. Standard deviations and range values were within the desired range as well. The data indicate that participants felt they were ***successful*** in completing their tasks, regardless of the focus of the scenarios or scenario configurations.



Scenario	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20
Mean	8.5	9.25	8.75	9.25	9.25	9.25	9.25	8.5	8.75	8.75	9.0	9.0	8.25	9.25	8.75	9.0	9.0	9.0	9.0	9.0
Standard Deviation	1.0	0.5	1.26	0.5	0.5	0.96	0.96	1.29	0.96	0.96	0.82	0.82	1.71	0.5	0.96	0.82	0.82	0.82	0.82	0.82
Max	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Min	8	9	7	9	9	8	8	7	8	8	8	8	6	9	8	8	8	8	8	8

Figure 19. Results for Question 2f: Performance (NASA-TLX)

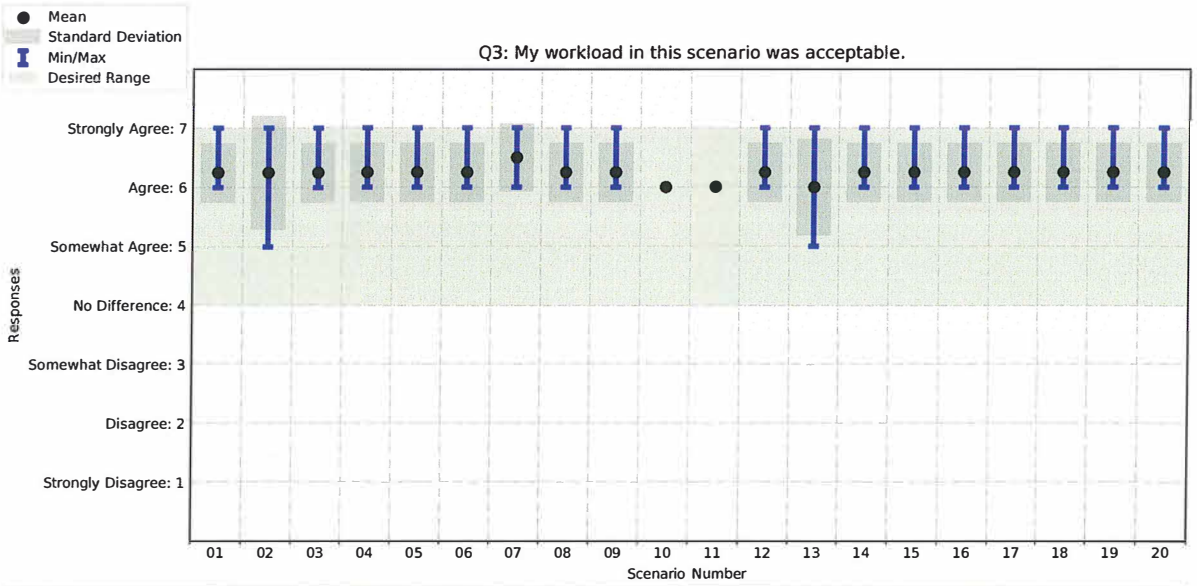
As shown in Figure 14 through Figure 19, analysis of individual (scenario-specific) data yielded similar findings to that of workload/situational awareness, as follows:

- Mental Demand, Physical Demand, Temporal Demand, Effort and Frustration ratings averaged 4 or below across all individual scenarios, where the desired range was 5.5 or below
- Performance ratings averaged above 8 across all individual scenarios

In all scenarios, participants were asked to provide comments describing any excessive mental demands, physical demands, temporal demands, effort or frustration they experienced in the scenario if they rated those subscale items outside of the desired range. Out of 80 instances where rating inputs were obtained from participants, 91% of those ratings (73 ratings in all) fell within the desired range. Seven ratings fell outside of the desired range, and all seven comments provided indicated that vectoring and sequencing (due to an off-nominal event) caused excessive demands. No direct correlation could be drawn between the nature of the off-nominal event or the scenario configuration and these ratings or comments, meaning that the ratings occurred across several different scenarios with varied off-nominal events and configurations.

Following each scenario, participants were asked how much they agreed with the statement "My workload in this scenario was acceptable." As shown in Figure 20, mean values across all scenarios were 6 or higher (where the desired range is 4 or higher). Similarly, standard deviations and range values were all within the desired range. Overall, participants ***agreed*** that

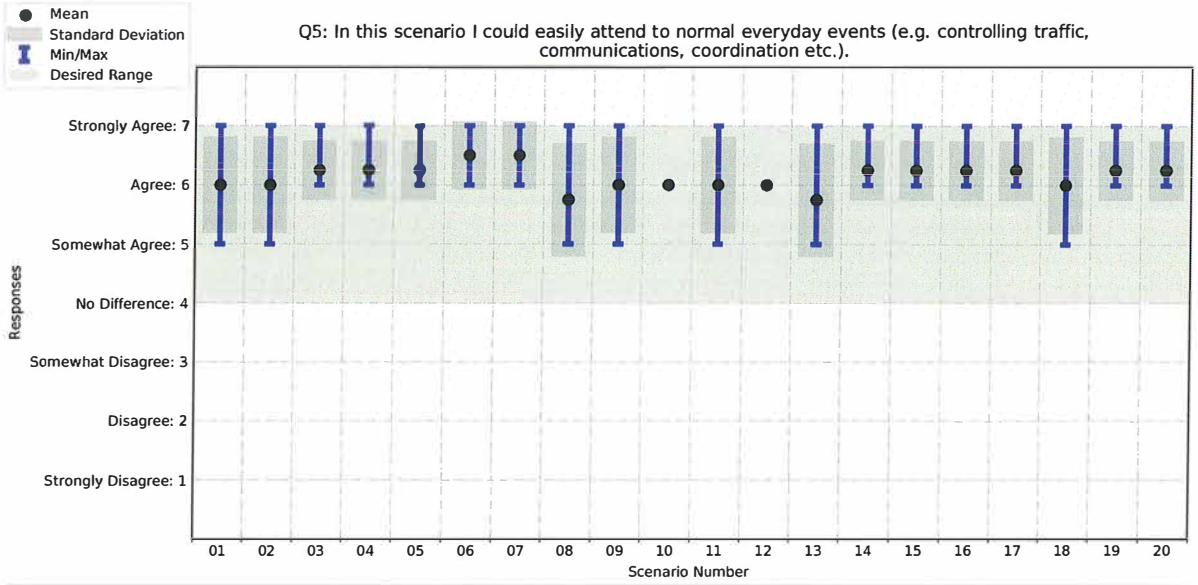
that their workload was acceptable, regardless of the position they worked or the focus of the scenario.



Scenario	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20
Mean	6.25	6.25	6.25	6.25	6.25	6.25	6.5	6.25	6.25	6.0	6.0	6.25	6.0	6.25	6.25	6.25	6.25	6.25	6.25	6.25
Standard Deviation	0.5	0.96	0.5	0.5	0.5	0.5	0.58	0.5	0.5	0.0	0.0	0.5	0.82	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Max	7	7	7	7	7	7	7	7	7	6	6	7	7	7	7	7	7	7	7	7
Min	6	5	6	6	6	6	6	6	6	6	6	6	5	6	6	6	6	6	6	6

Figure 20. Results for Question 3

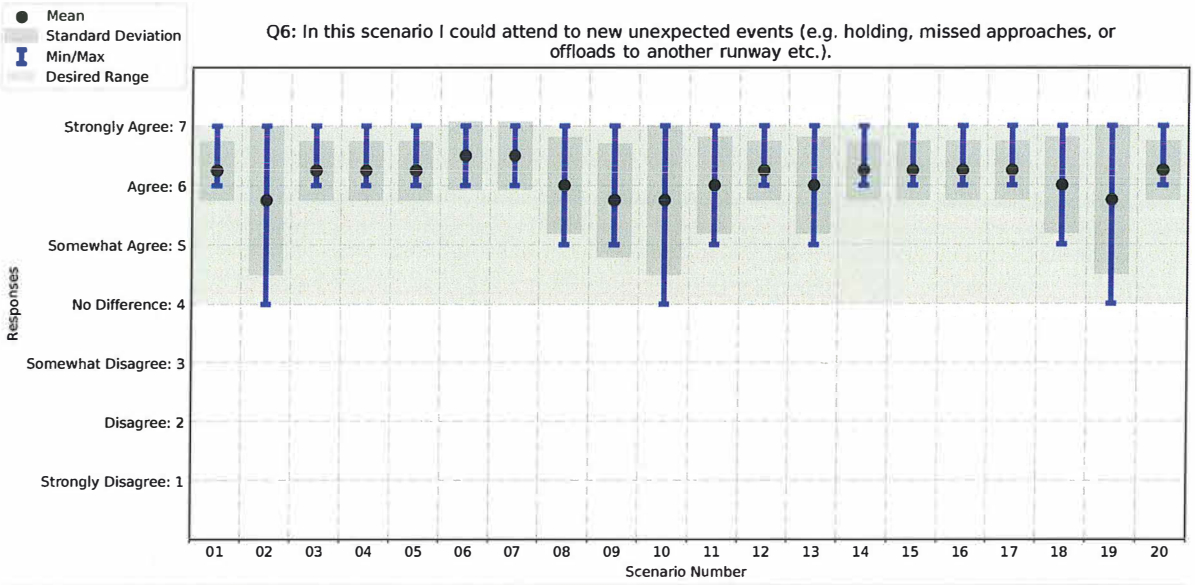
Participants were also asked to rate their level of agreement with the following statement: "In this scenario, I could easily attend to normal, everyday events (e.g., controlling traffic, communications, coordination, etc.)." As seen in Figure 21, the mean values are above 5 in all scenarios (with the desired range being 4 or above). This indicates that across all scenarios, participants ***agreed*** that they could attend to normal, everyday events.



Scenario	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20
Mean	6.0	6.0	6.25	6.25	6.25	6.5	6.5	5.75	6.0	6.0	6.0	6.0	5.75	6.25	6.25	6.25	6.25	6.0	6.25	6.25
Standard Deviation	0.82	0.82	0.5	0.5	0.5	0.58	0.58	0.96	0.82	0.0	0.82	0.0	0.96	0.5	0.5	0.5	0.5	0.82	0.5	0.5
Max	7	7	7	7	7	7	7	7	7	6	7	6	7	7	7	7	7	7	7	7
Min	5	5	6	6	6	6	6	5	5	6	5	6	5	6	6	6	6	5	6	6

Figure 21. Results for Question 5

Participants were also asked to provide their level of agreement with this statement: "In this scenario, I could attend to new, unexpected events (e.g., holding, missed approaches, or offloads to another runway, etc.)." As shown in Figure 22, mean values were above 5 across all scenarios, with the desired range being 4 or higher. Range values and standard deviations were within the desired range as well, indicating that participants ***agreed*** that they could attend to new, unexpected events.

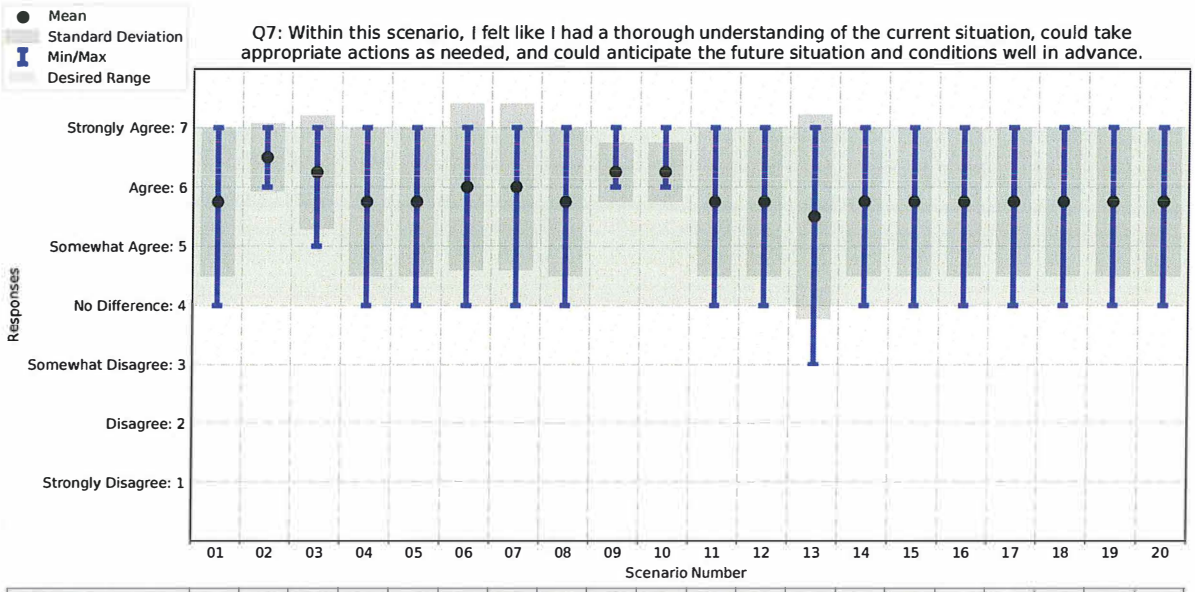


Scenario	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20
Mean	6.25	5.75	6.25	6.25	6.25	6.5	6.5	6.0	5.75	5.75	6.0	6.25	6.0	6.25	6.25	6.25	6.25	6.0	5.75	6.25
Standard Deviation	0.5	1.26	0.5	0.5	0.5	0.58	0.58	0.82	0.96	1.26	0.82	0.5	0.82	0.5	0.5	0.5	0.5	0.82	1.26	0.5
Max	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Min	6	4	6	6	6	6	6	5	5	4	5	6	5	6	6	6	6	5	4	6

Figure 22. Results for Question 6

Following each scenario, participants were asked to rate their perceived level of situational awareness, by indicating their level of agreement with the following statement: "Within this scenario, I felt like I had a thorough understanding of the current situation, could take appropriate actions as needed and could anticipate the future situation and conditions well in advance."

Figure 23 shows that the mean values were well within the desired range (4 or above) across all scenarios. The range values were mostly within the desired range, except for Scenario 13, where one participant somewhat disagreed. The standard deviation values were also mostly within the desired range, except for Scenario 13, in which a participant indicated he had an excessive amount of traffic, which impacted his situational awareness. Overall, the data indicates that participants generally ***agreed*** that they maintained situational awareness across all scenarios.

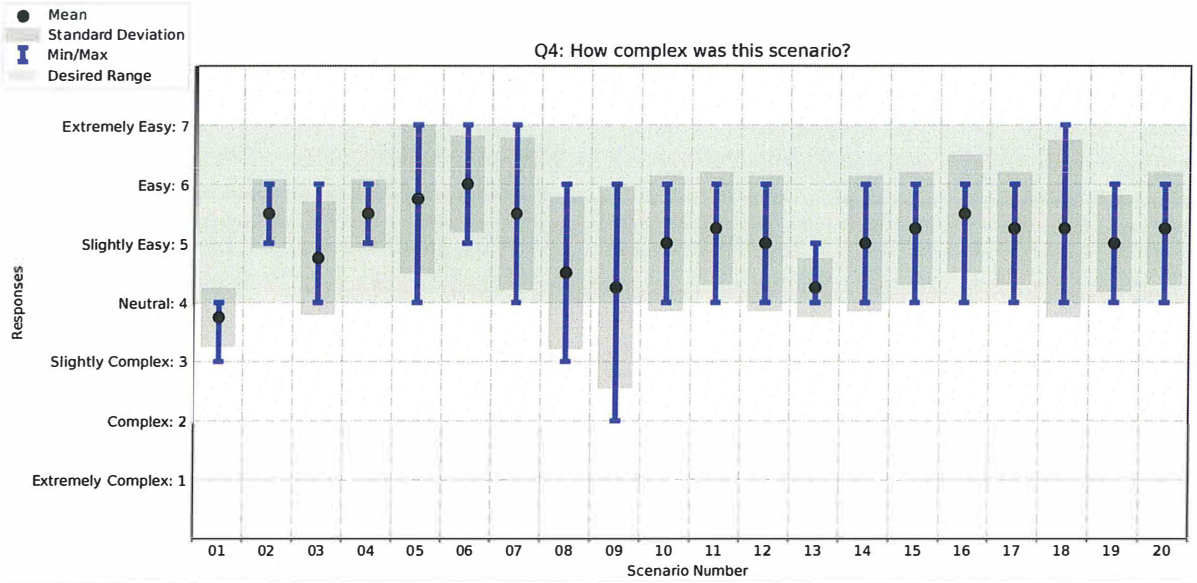


Scenario	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20
Mean	5.75	6.5	6.25	5.75	5.75	6.0	6.0	5.75	6.25	6.25	5.75	5.75	5.5	5.75	5.75	5.75	5.75	5.75	5.75	5.75
Standard Deviation	1.26	0.58	0.96	1.26	1.26	1.41	1.41	1.26	0.5	0.5	1.26	1.26	1.73	1.26	1.26	1.26	1.26	1.26	1.26	1.26
Max	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Min	4	6	5	4	4	4	4	4	6	6	4	4	3	4	4	4	4	4	4	4

Figure 23. Results for Question 7

Participants were asked to rate the complexity of each scenario. Across most scenarios, participants rated the scenarios as ***slightly easy to easy***, as shown in Figure 24.

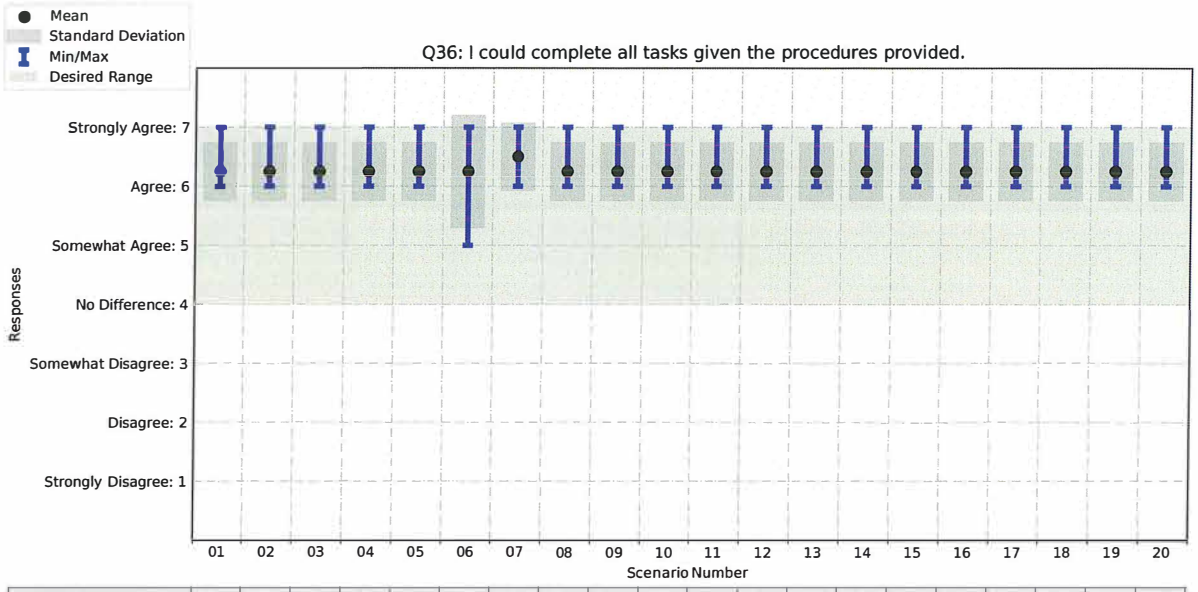
Participants felt that some scenarios were more in the neutral to slightly complex or complex range; however, these indications appear to be mostly limited to first-run scenarios (where participants were still familiarizing themselves with off-nominal procedures). Further review of the comments associated with this question corroborate this supposition, detailing the impacts of vectoring, holding, and missed approaches on workload or describing the need for assigned altitudes for published holds.



Scenario	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20
Mean	3.75	5.5	4.75	5.5	5.75	6.0	5.5	4.5	4.25	5.0	5.25	5.0	4.25	5.0	5.25	5.5	5.25	5.25	5.0	5.25
Standard Deviation	0.5	0.58	0.96	0.58	1.26	0.82	1.29	1.29	1.71	1.15	0.96	1.15	0.5	1.15	0.96	1.0	0.96	1.5	0.82	0.96
Max	4	6	6	6	7	7	7	6	6	6	6	6	5	6	6	6	6	7	6	6
Min	3	5	4	5	4	5	4	3	2	4	4	4	4	4	4	4	4	4	4	4

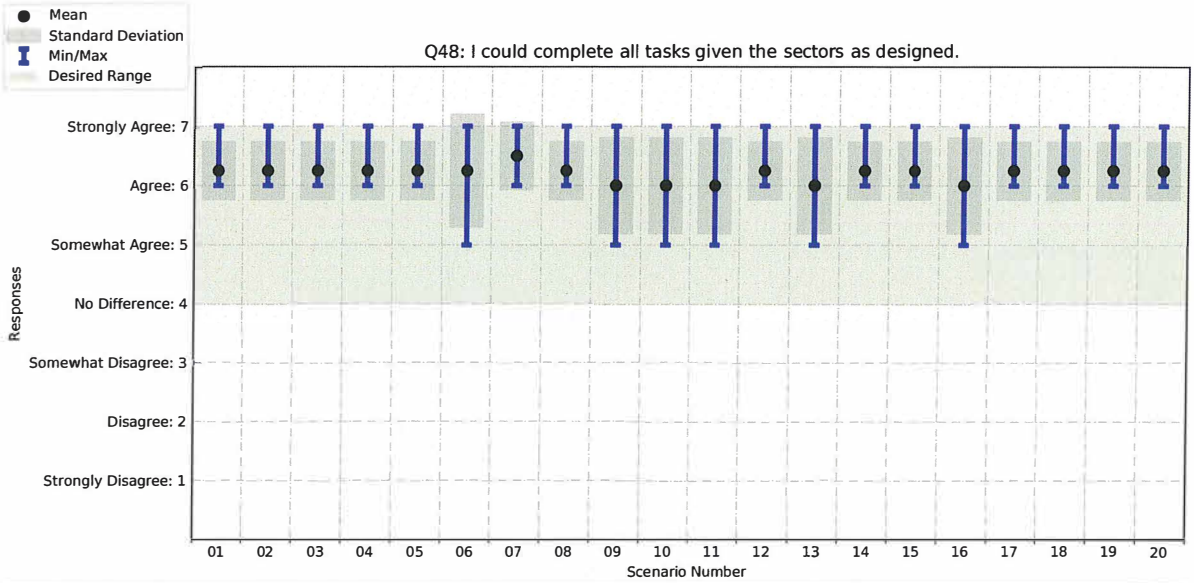
Figure 24. Results for Question 4

Participants were asked to rate their level of agreement with two statements related to whether they could successfully complete tasks. Mean values, standard deviations, and range values for both questions were within the desired range of 5.5 or greater. The results, as shown in Figure 25 and Figure 26, indicate that participants were able to complete all tasks using the procedures provided and that participants were able to complete all tasks given the sectors as designed.



Scenario	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20
Mean	6.25	6.25	6.25	6.25	6.25	6.25	6.5	6.25	6.25	6.25	6.25	6.25	6.25	6.25	6.25	6.25	6.25	6.25	6.25	6.25
Standard Deviation	0.5	0.5	0.5	0.5	0.5	0.96	0.58	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Max	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Min	6	6	6	6	6	5	6	6	6	6	6	6	6	6	6	6	6	6	6	6

Figure 25. Results for Question 36



Scenario	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20
Mean	6.25	6.25	6.25	6.25	6.25	6.25	6.5	6.25	6.0	6.0	6.0	6.25	6.0	6.25	6.25	6.0	6.25	6.25	6.25	6.25
Standard Deviation	0.5	0.5	0.5	0.5	0.5	0.96	0.58	0.5	0.82	0.82	0.82	0.5	0.82	0.5	0.5	0.82	0.5	0.5	0.5	0.5
Max	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Min	6	6	6	6	6	5	6	6	5	5	5	6	5	6	6	5	6	6	6	6

Figure 26. Results for Question 48

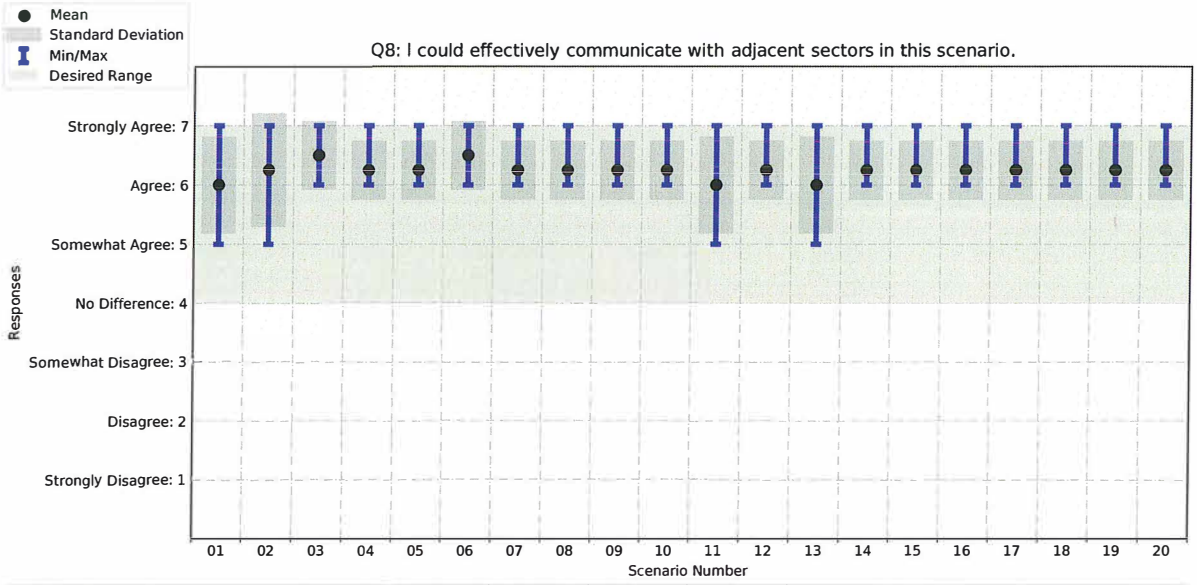
4.1.2 Communications

As shown in Figure 27 and Figure 28, overall ratings for communications were generally positive. Across all scenarios, participants *agreed* that they could effectively communicate with adjacent sectors (Question 8). Across all scenarios, participants generally *agreed* that they could effectively communicate with pseudo-pilots (Question 9). To ensure that any issues with pseudo-pilot performance were identified and captured, participants were also asked if they had any issues or problems with pseudo-pilot performance during each scenario (Question 53). The results, as shown in Figure 29, indicate that, despite indicating that they could effectively communicate with pseudo-pilots during most scenarios, participants experienced problems with psuedo-pilot performance in four scenarios: Scenario 1, Scenario 2, Scenario 3, and Scenario 11.

In Scenario 1, one participant indicated difficulty communicating with pseudo-pilots and elaborated that instructions given to the pilots did not correspond to the performance of the aircraft (the aircraft made unusual turns and climbs). In Scenario 2, another participant indicated "No Difference" with reference to communicating with pseudo-pilots. Additional comments provided indicated that the participant issued holding exit and direct-to-fix instructions to aircraft, but the aircraft did not follow those instructions.

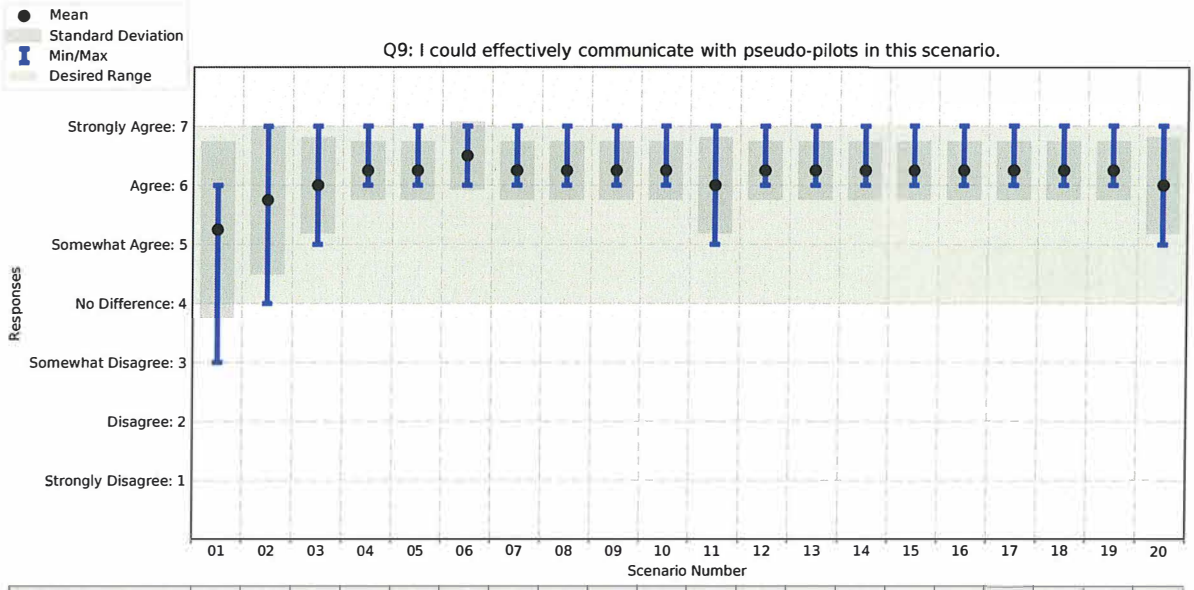
In Scenario 3, although all participants indicated that they could communicate with the pseudo-pilots, two participants indicated that they experienced problems with the pseudo-pilot performance during the scenario (Question 53). In their comments for Question 53, they indicated that, although the pseudo-pilots seemed to understand the instructions, some aircraft did not follow the instructions given (they did not intercept the ILS as expected, for example). These participants went on to indicate that they suspected that there may be system error issues (problems with the programmed command keys used by the pseudo-pilots). The command keys were subsequently tested and updated.

In Scenario 11, again, all participants indicated that they could communicate with the pseudo-pilots; however, one participant indicated experiencing problems with pseudo-pilot performance during the scenario. In the follow-up comments, this participant again raised concerns about system errors related to the programmable command keys. The keys were tested again, and no further incidents of this type were noted for the remainder of the second HITL simulation evaluation.



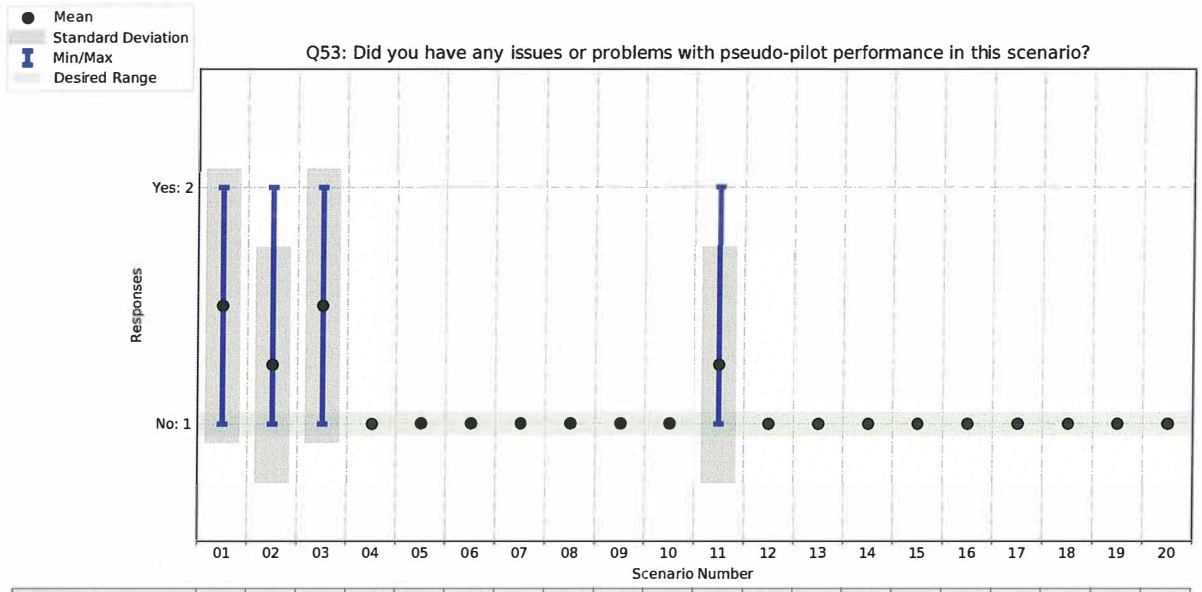
Scenario	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20
Mean	6.0	6.25	6.5	6.25	6.25	6.5	6.25	6.25	6.25	6.25	6.0	6.25	6.0	6.25	6.25	6.25	6.25	6.25	6.25	6.25
Standard Deviation	0.82	0.96	0.58	0.5	0.5	0.58	0.5	0.5	0.5	0.5	0.82	0.5	0.82	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Max	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Min	5	5	6	6	6	6	6	6	6	6	5	6	5	6	6	6	6	6	6	6

Figure 27. Results for Question 8



Scenario	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20
Mean	5.25	5.75	6.0	6.25	6.25	6.5	6.25	6.25	6.25	6.25	6.0	6.25	6.25	6.25	6.25	6.25	6.25	6.25	6.25	6.0
Standard Deviation	1.5	1.26	0.82	0.5	0.5	0.58	0.5	0.5	0.5	0.5	0.82	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.82
Max	6	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Min	3	4	5	6	6	6	6	6	6	6	5	6	6	6	6	6	6	6	6	5

Figure 28. Results for Question 9

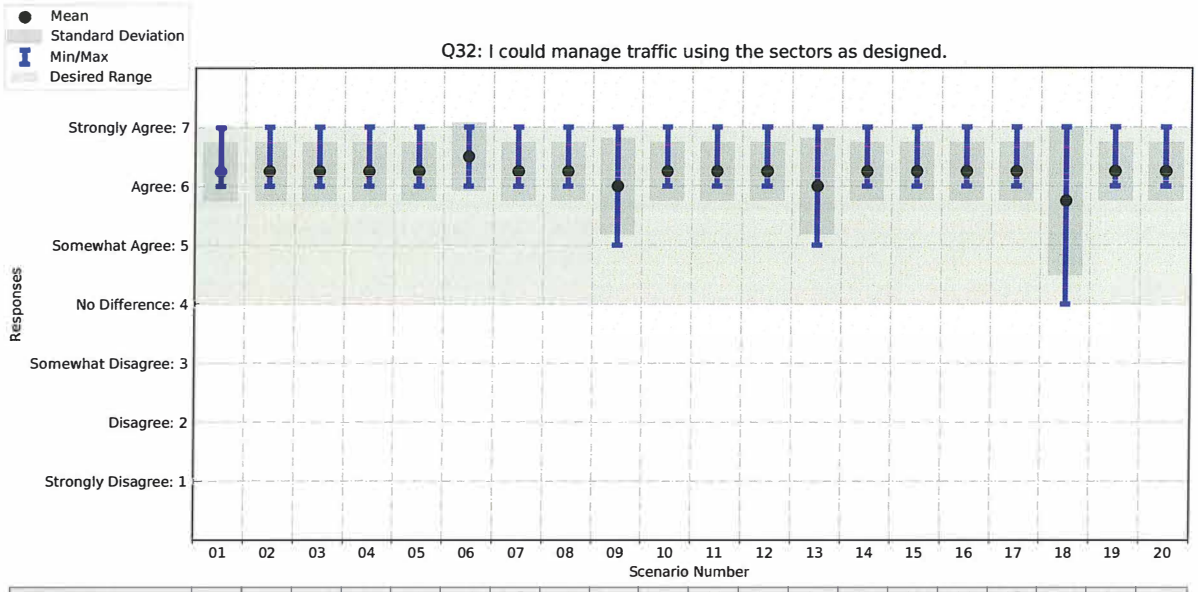


Scenario	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20
Mean	1.5	1.25	1.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.25	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Standard Deviation	0.58	0.5	0.58	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Max	2	2	2	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1
Min	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Figure 29. Results for Question 53

4.1.3 Concept of Operations

Participants were asked questions on the topic of Concept of Operations; that is, questions regarding the proposed airspace design and its associated procedures. Five questions were repeated questions, or questions that were asked of each participant after every scenario. Participants were asked to rate their level of agreement with the following statement: "I could manage traffic using the sectors as designed." Mean values, range values, and standard deviations were in the desired range (4 or above) in all scenarios, as shown in Figure 30.

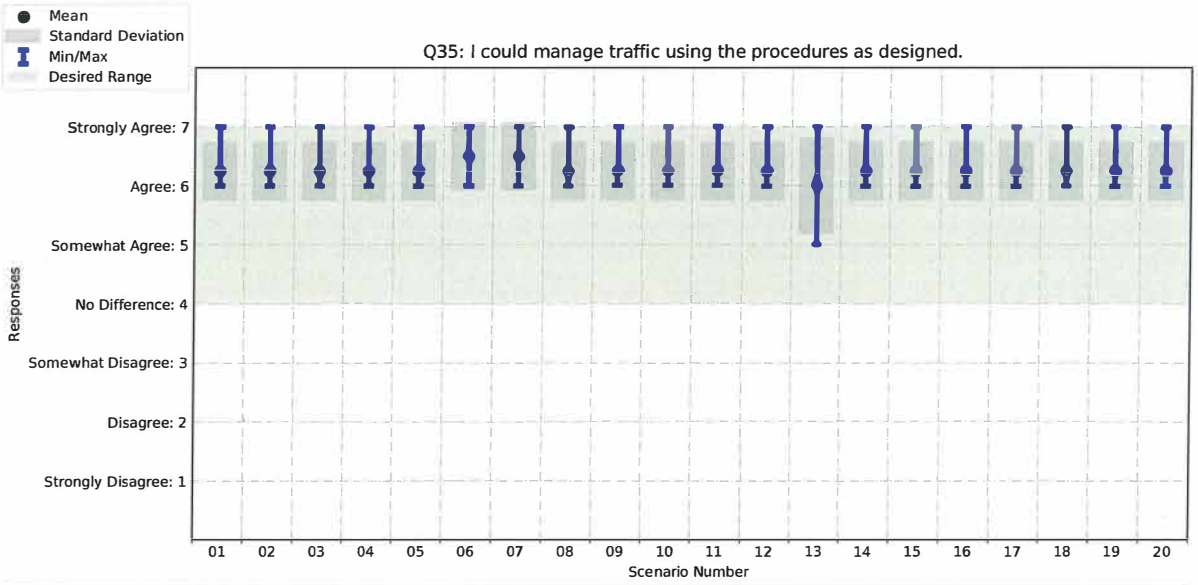


Scenario	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20
Mean	6.25	6.25	6.25	6.25	6.25	6.5	6.25	6.25	6.0	6.25	6.25	6.25	6.0	6.25	6.25	6.25	6.25	5.75	6.25	6.25
Standard Deviation	0.5	0.5	0.5	0.5	0.5	0.58	0.5	0.5	0.82	0.5	0.5	0.5	0.82	0.5	0.5	0.5	0.5	1.26	0.5	0.5
Max	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Min	6	6	6	6	6	6	6	6	5	6	6	6	5	6	6	6	6	4	6	6

Figure 30. Results for Question 32

Similarly, participants were asked if they could manage traffic using the procedures as designed. As shown in Figure 31, the mean values, range values, and standard deviations were all within the desired range, which was 4 or greater, for all scenarios.

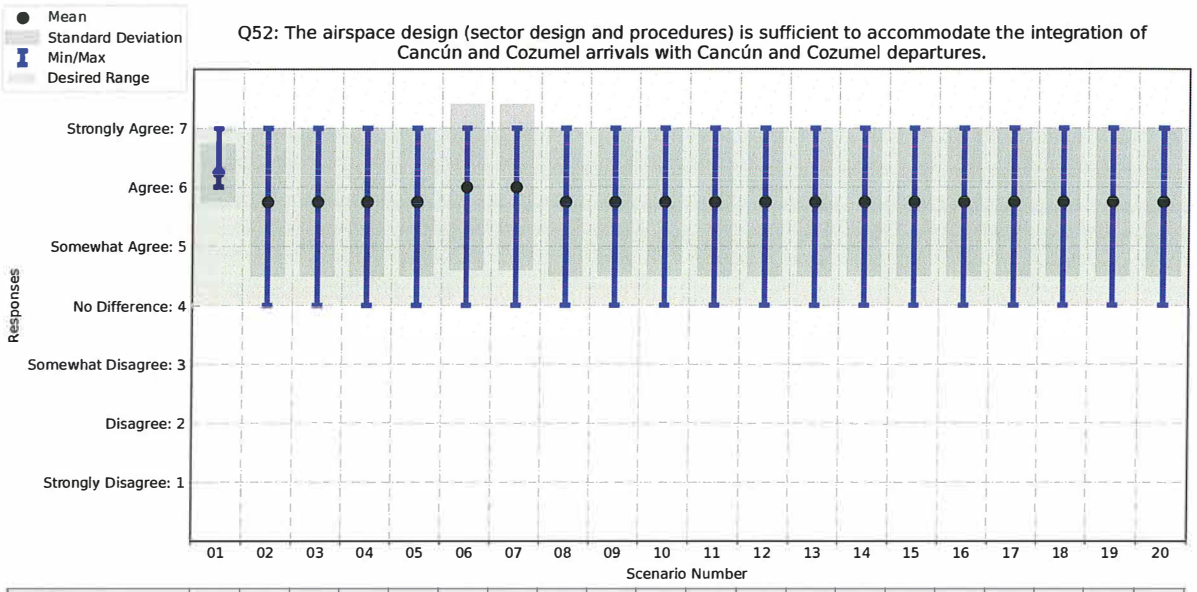
Collectively, the data indicate that participants ***could*** manage traffic using the sectors and procedures as designed.



Scenario	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20
Mean	6.25	6.25	6.25	6.25	6.25	6.5	6.5	6.25	6.25	6.25	6.25	6.25	6.0	6.25	6.25	6.25	6.25	6.25	6.25	6.25
Standard Deviation	0.5	0.5	0.5	0.5	0.5	0.58	0.58	0.5	0.5	0.5	0.5	0.5	0.82	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Max	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Min	6	6	6	6	6	6	6	6	6	6	6	6	5	6	6	6	6	6	6	6

Figure 31. Results for Question 35

Participants were asked if the airspace design provided in the second HITL simulation evaluation was sufficient to accommodate the integration of MMUN and MMCZ arrivals with MMUN and MMCZ departures. The data, as presented in Figure 32, show that participants ***agree*** that the sector designs and procedures provided are sufficient to accommodate the interaction between MMUN and MMCZ arrival and departure traffic.



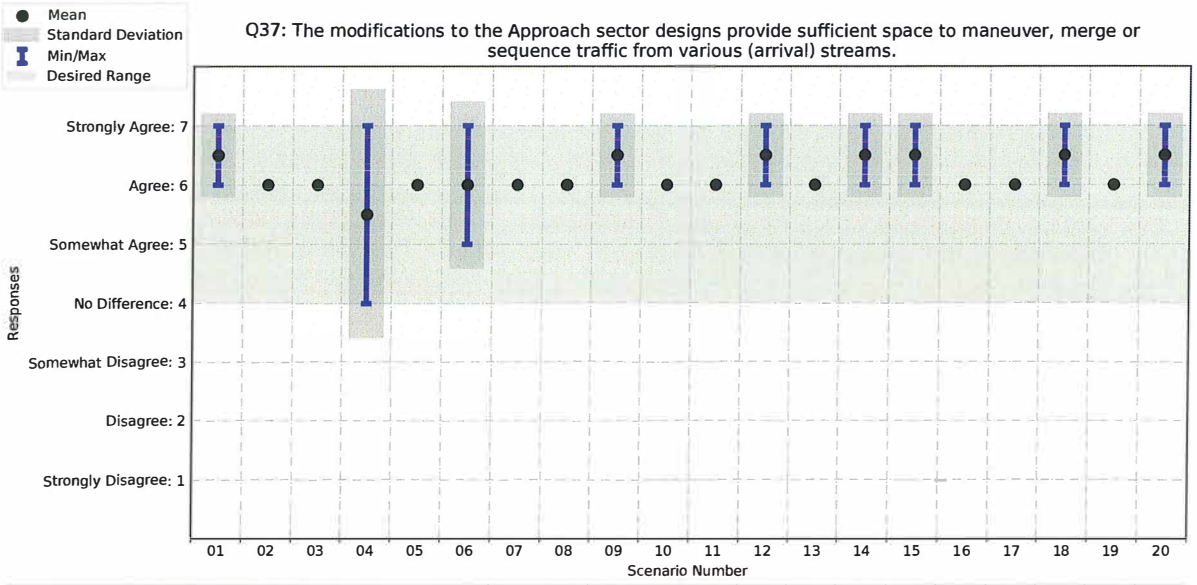
Scenario	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20
Mean	6.25	5.75	5.75	5.75	5.75	6.0	6.0	5.75	5.75	5.75	5.75	5.75	5.75	5.75	5.75	5.75	5.75	5.75	5.75	5.75
Standard Deviation	0.5	1.26	1.26	1.26	1.26	1.41	1.41	1.26	1.26	1.26	1.26	1.26	1.26	1.26	1.26	1.26	1.26	1.26	1.26	1.26
Max	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Min	6	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4

Figure 32. Results for Question 52

Four additional questions on Concept of Operations, which were scenario- and position-specific, were also presented to participants. These questions focused on topics or design aspects that only applied to specific positions (e.g., Approach Sector) under specific conditions (e.g., Runway 30L/R operations). The questions were only presented to participants to whom the questions applied (i.e., if the question was specific to an intersection in the Approach South sector, it was only presented to that participant using logic embedded in the questionnaire software, based upon the participants identification of the position they worked in that scenario).

4.1.3.1 Approach Sectors (North or South): Additional Airspace

Following the first HITL simulation evaluation, additional airspace was added to all Approach sectors to allow additional airspace for Approach to maneuver or sequence aircraft for the approach. Participants working Approach sectors (North or South) were asked to indicate their level of agreement with the following statement: "The modifications to the Approach sector designs provide sufficient space to maneuver, merge, or sequence traffic from various (arrival) streams." As shown in Figure 33, mean values and range values were in the desired range (4 or above) for all scenarios. Standard deviations were in the desired range for most scenarios. Collectively, the data indicate that all participants ***agreed*** that the modifications to the Approach sector designs provide sufficient space to maneuver, merge, or sequence traffic from various arrival streams.



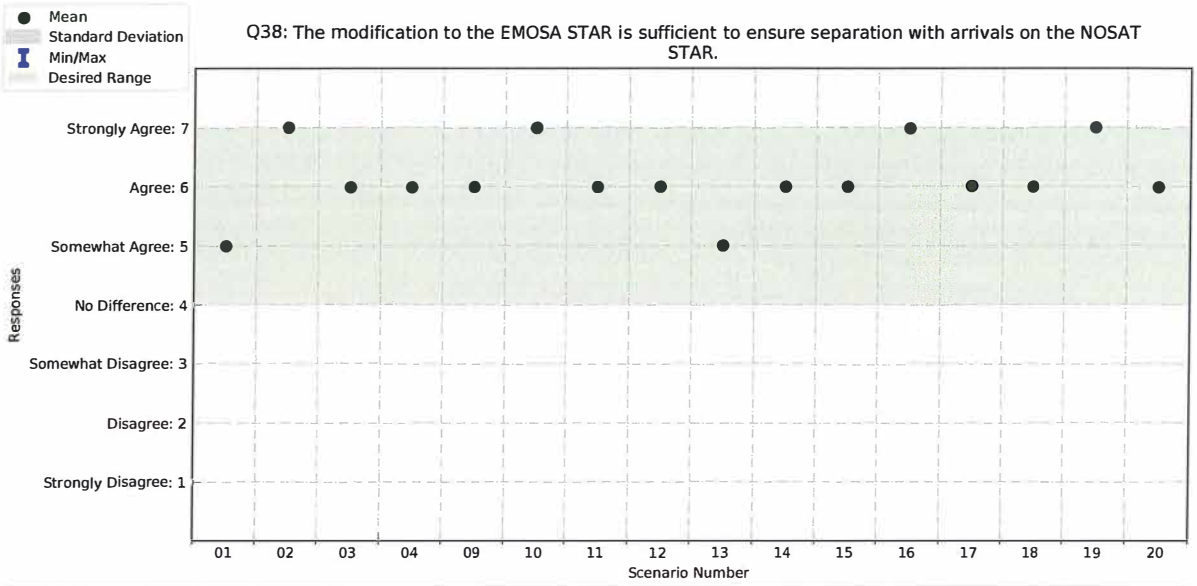
Scenario	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20
Mean	6.5	6.0	6.0	5.5	6.0	6.0	6.0	6.0	6.5	6.0	6.0	6.5	6.0	6.5	6.5	6.0	6.0	6.5	6.0	6.5
Standard Deviation	0.71	0.0	0.0	2.12	0.0	1.41	0.0	0.0	0.71	0.0	0.0	0.71	0.0	0.71	0.71	0.0	0.0	0.71	0.0	0.71
Max	7	6	6	7	6	7	6	6	7	6	6	7	6	7	7	6	6	7	6	7
Min	6	6	6	4	6	5	6	6	6	6	6	6	6	6	6	6	6	6	6	6

Figure 33. Results for Question 37

4.1.3.2 Arrival North Sector: EMOSA STAR Modification

Due to findings from the first HITL simulation evaluation, the EMOSA STAR for MMCZ was modified to ensure separation with aircraft on the NOSAT STAR for MMUN. Participants working Arrival North sectors were asked to indicate their level of agreement with a statement that the modification to the EMOSA STAR was sufficient to ensure separation with NOSAT STAR arrivals.

As shown in Figure 34, mean values for this question were within the desired range (4 or higher) for all scenarios. Because this question was presented to only one participant per scenario (the participant assigned to the Arrival North sector), range values, and standard deviation data are not applicable. The data show participants ***agreed*** that the modification to the EMOSA STAR is sufficient to ensure separation with arrivals on the NOSAT STAR.

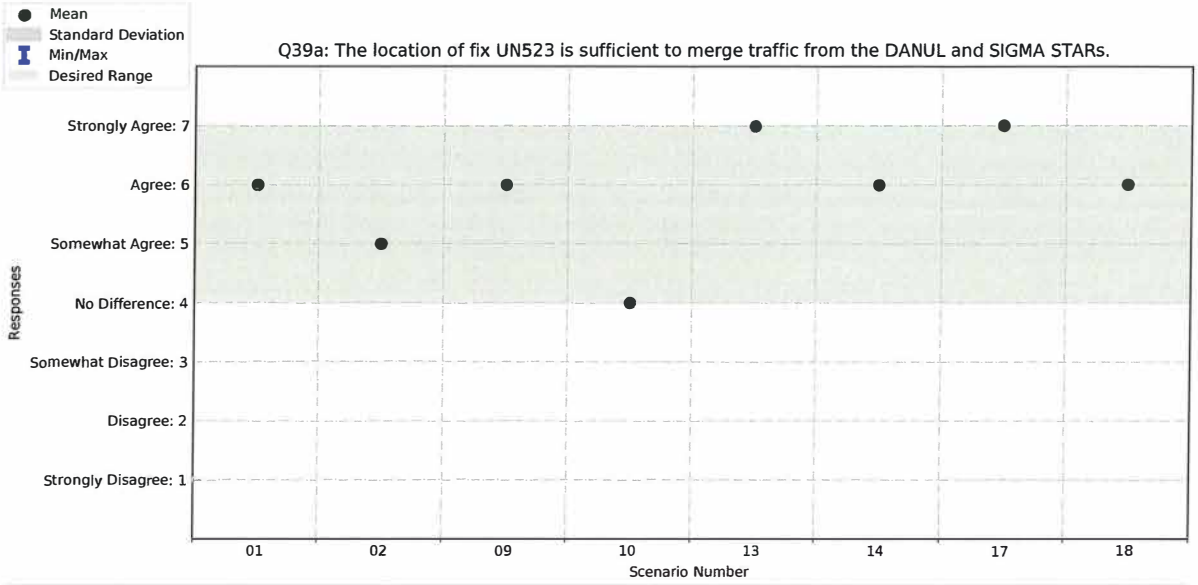


Scenario	01	02	03	04	09	10	11	12	13	14	15	16	17	18	19	20
Mean	5.0	7.0	6.0	6.0	6.0	7.0	6.0	6.0	5.0	6.0	6.0	7.0	6.0	6.0	7.0	6.0
Standard Deviation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Max	5	7	6	6	6	7	6	6	5	6	6	7	6	6	7	6
Min	5	7	6	6	6	7	6	6	5	6	6	7	6	6	7	6

Figure 34. Results for Question 38

4.1.3.3 Arrival South Sectors: DANUL and SIGMA STARs

Participants working Arrival South during Runway 12R operations were asked to indicate their level of agreement with the following statement: "The location of fix UN523 is sufficient to merge traffic from the DANUL and SIGMA STARs." The data shown in Figure 35 indicate that most participants ***agreed*** that the location of UN523 was sufficient to merge traffic from the DANUL and SIGMA STARs. Mean values were within the desired range (4 or above) for all scenarios. A detailed review of the comments associated with Scenario 10 was inconclusive in determining why the participant indicated "No Difference" in response to this question.

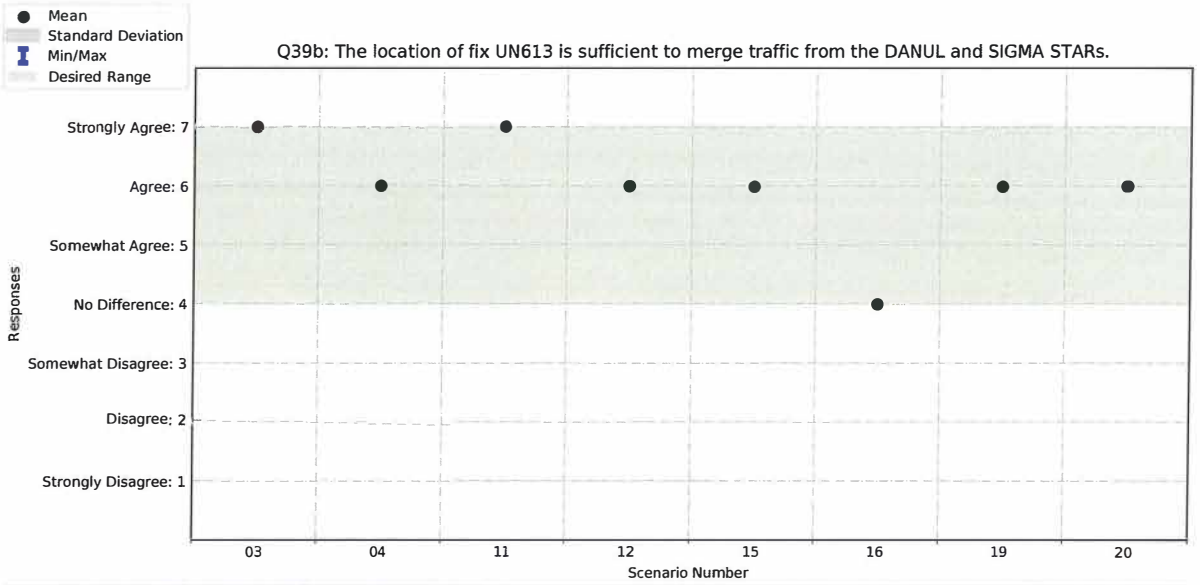


Scenario	01	02	09	10	13	14	17	18
Mean	6.0	5.0	6.0	4.0	7.0	6.0	7.0	6.0
Standard Deviation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Max	6	5	6	4	7	6	7	6
Min	6	5	6	4	7	6	7	6

Figure 35. Results for Question 39a

Participants working Arrival South during Runway 30L operations were asked to indicate their level of agreement with the following statement: "The location of fix UN613 is sufficient to merge traffic from the DANUL and SIGMA STARs."

The data shown in Figure 36 indicate that most participants ***agreed*** that the location of UN613 was sufficient to merge traffic from the DANUL and SIGMA STARs. Mean values and ranges were within the desired range (4 or above) for all scenarios except Scenario 16. A detailed review of the comments associated with Scenario 16 was inconclusive in determining why the participant indicated "No Difference" in response to this question.



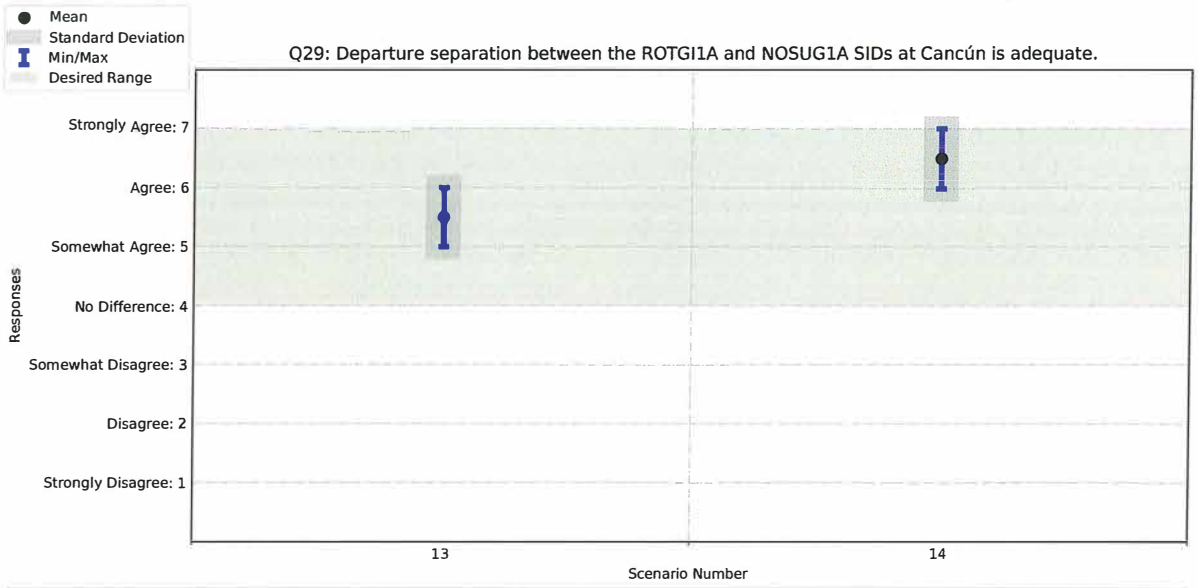
Scenario	03	04	11	12	15	16	19	20
Mean	7.0	6.0	7.0	6.0	6.0	4.0	6.0	6.0
Standard Deviation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Max	7	6	7	6	6	4	6	6
Min	7	6	7	6	6	4	6	6

Figure 36. Results for Question 39b

4.1.3.4 Departure North Sector

Following the conclusion of the first HITL simulation evaluation, departure separation between the NOSUG and ROTGI SIDs was discussed with SENEAM in detail. SENEAM reviewed the design of the ROTGI departure and made some changes to waypoint locations. These changes were re-evaluated during the second HITL simulation evaluation. Participants working the Departure North sector during Runway 12L operations were asked if departure separation between the ROTGI and NOSUG SIDs was adequate[6]. Figure 37 shows that participants ***agreed*** that the departure separation between the ROTGI1A and NOSUG1A SIDs at MMUN was adequate.

[6] In the second HITL simulation evaluation design, only two participants were planned to be asked this question, as there would only be two scenarios in which Runway 12 operations were in effect for departures. However, in the end, it was determined that it would be beneficial to obtain input from all four controller participants on this topic, versus only two. Therefore, two additional runs were conducted with the remaining controller participants, and their input to this specific question was obtained and included in the analysis. No additional questionnaire data from the additional runs were included in the analysis of the second HITL simulation evaluation.

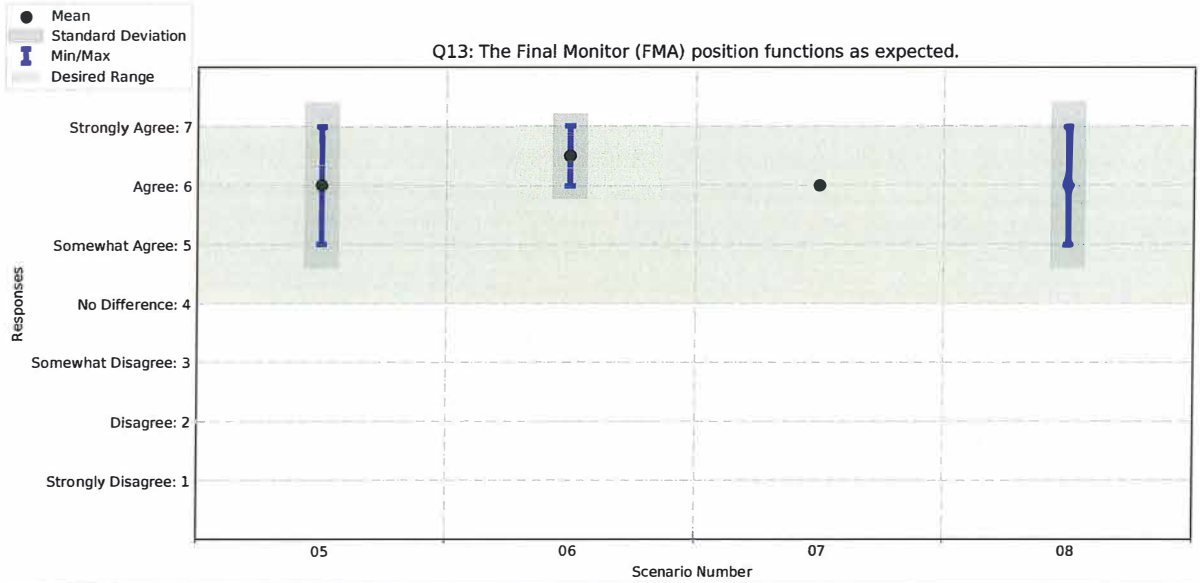


Scenario	13	14
Mean	5.5	6.5
Standard Deviation	0.71	0.71
Max	6	7
Min	5	6

Figure 37. Results for Question 29

4.1.3.5 Final Monitor Position

Participants working Final Monitor positions were asked to indicate their level of agreement with the following statement: "The Final Monitor (FMA) position functions as expected." Figure 38 shows that participants ***agreed*** that the Final Monitor position functioned as they had anticipated. Mean values, standard deviations, and range values were within the desired range (4 or greater) across all scenarios.



Scenario	05	06	07	08
Mean	6.0	6.5	6.0	6.0
Standard Deviation	1.41	0.71	0.0	1.41
Max	7	7	6	7
Min	5	6	6	5

Figure 38. Results for Question 13

4.1.4 Off-Nominal Events

As mentioned before, the purpose of the second HITL simulation evaluation was to determine the acceptability and feasibility of the airspace design to support dual independent operations *under off-nominal conditions*. As such, participants were exposed to scenarios that involved holding operations, missed approaches, breakouts and blunders at the Final Monitor position, runway configuration changes, transitions from independent to dependent operations and offloads for runway balancing.

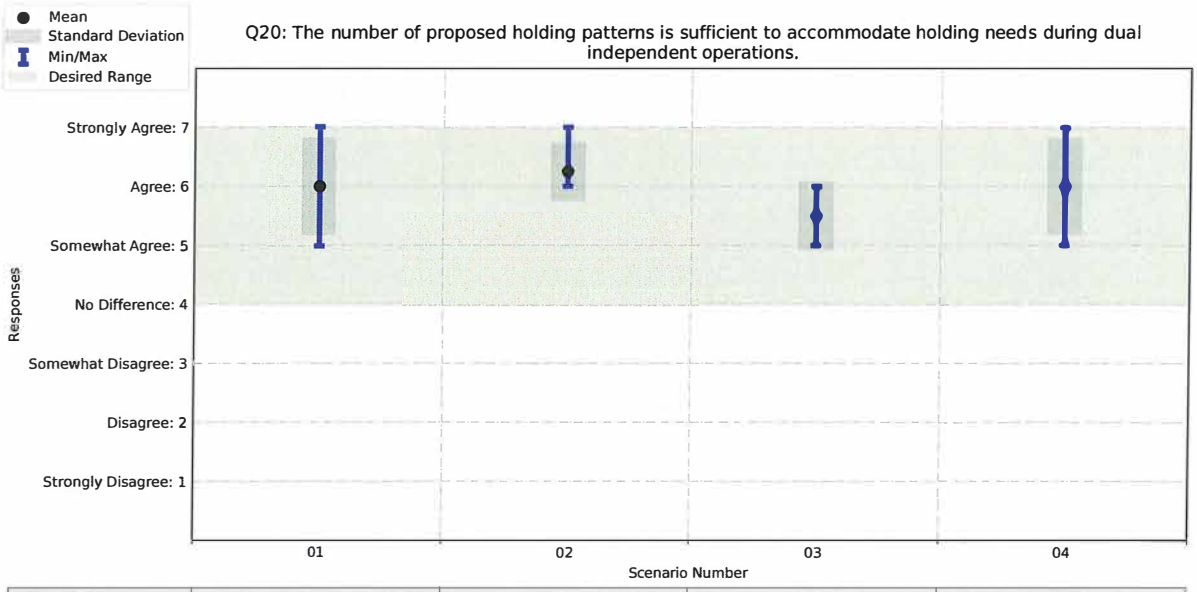
4.1.4.1 Holding

A holding pattern for instrument flight rules (IFR) aircraft is usually a racetrack pattern based on a holding fix, where the holding fix is the start of the first turn of the racetrack pattern (aircraft will fly towards the fix and, once there, will enter a predefined racetrack pattern). The primary use of holding is to delay aircraft that have arrived at their destination but cannot land yet because of traffic congestion, poor weather, or runway unavailability (i.e., during an emergency). Several aircraft may fly the same holding pattern at the same time, separated vertically by 1000 ft or more.

Scenarios 1 through 4 focused on holding, or operations which incorporated a holding pattern into each of the four main arrival streams into MMUN.

Participants working Arrival sectors and Approach sectors during Scenario 1 through Scenario 4 were asked to indicate their level of agreement with the following statement: "The

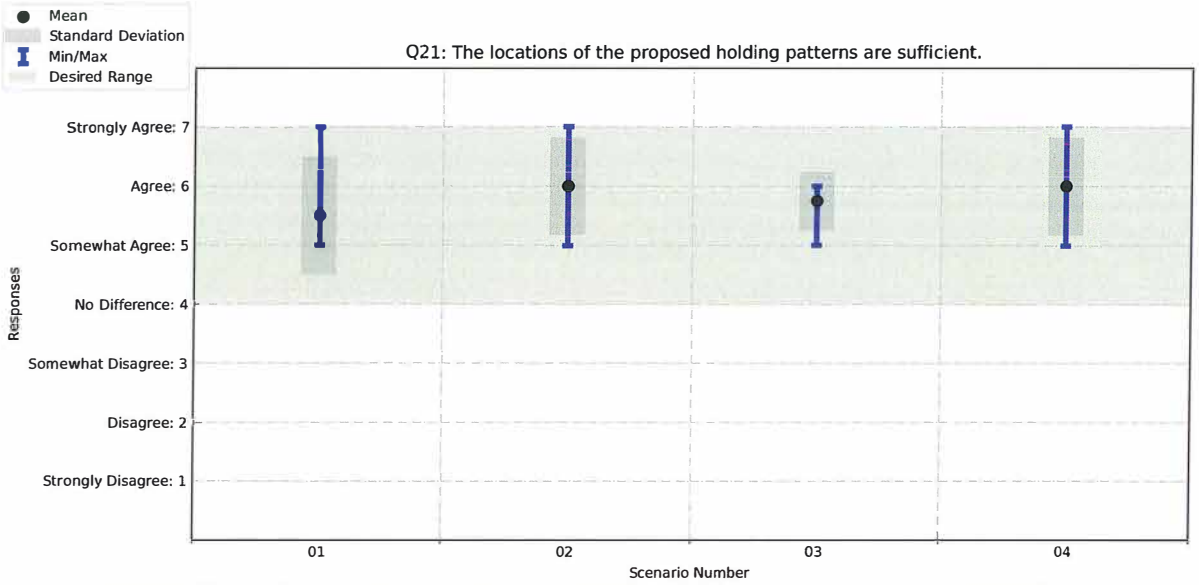
number of proposed holding patterns is sufficient to accommodate holding needs during dual independent operations." Figure 39 shows that participants ***agreed*** that the number of proposed holding patterns was sufficient to accommodate holding needs during dual independent operations. Mean values, standard deviations and range values were within the desired range (4 or greater) across all scenarios involving holding operations.



Scenario	01	02	03	04
Mean	6.0	6.25	5.5	6.0
Standard Deviation	0.82	0.5	0.58	0.82
Max	7	7	6	7
Min	5	6	5	5

Figure 39. Results for Question 20

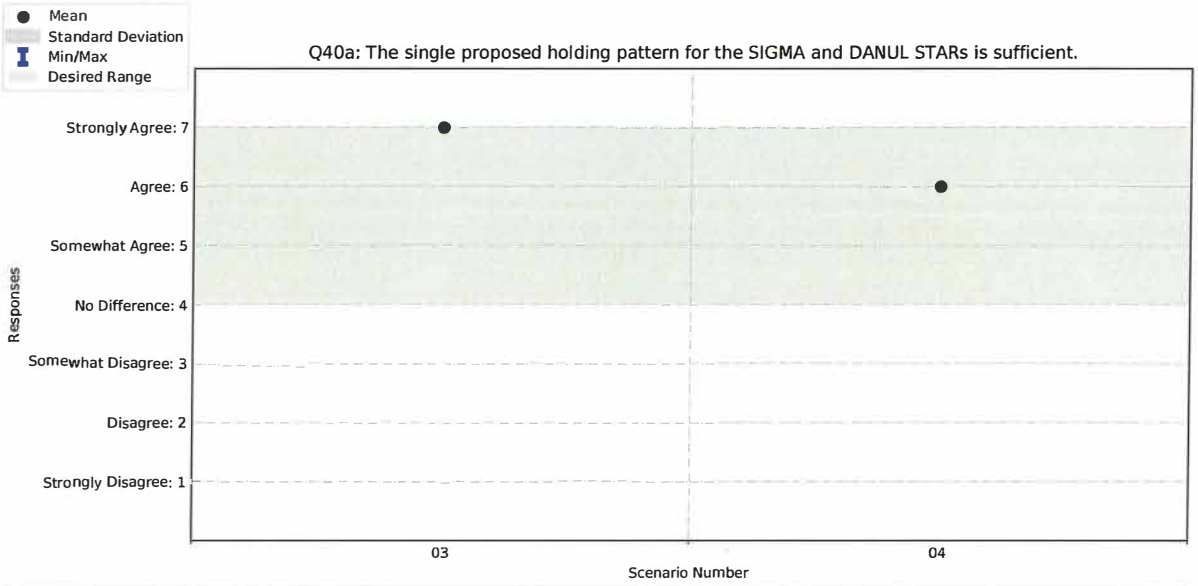
Participants working Arrival sectors and Approach sectors during Scenario 1 through Scenario 4 were also asked if the locations of the proposed holding patterns were sufficient. Participants indicated that the locations of the proposed holding patterns were sufficient, as shown in Figure 40. Mean values, standard deviations, and range values were within the desired range (4 or greater) across all scenarios involving holding operations.



Scenario	01	02	03	04
Mean	5.5	6.0	5.75	6.0
Standard Deviation	1.0	0.82	0.5	0.82
Max	7	7	6	7
Min	5	5	5	5

Figure 40. Results for Question 21

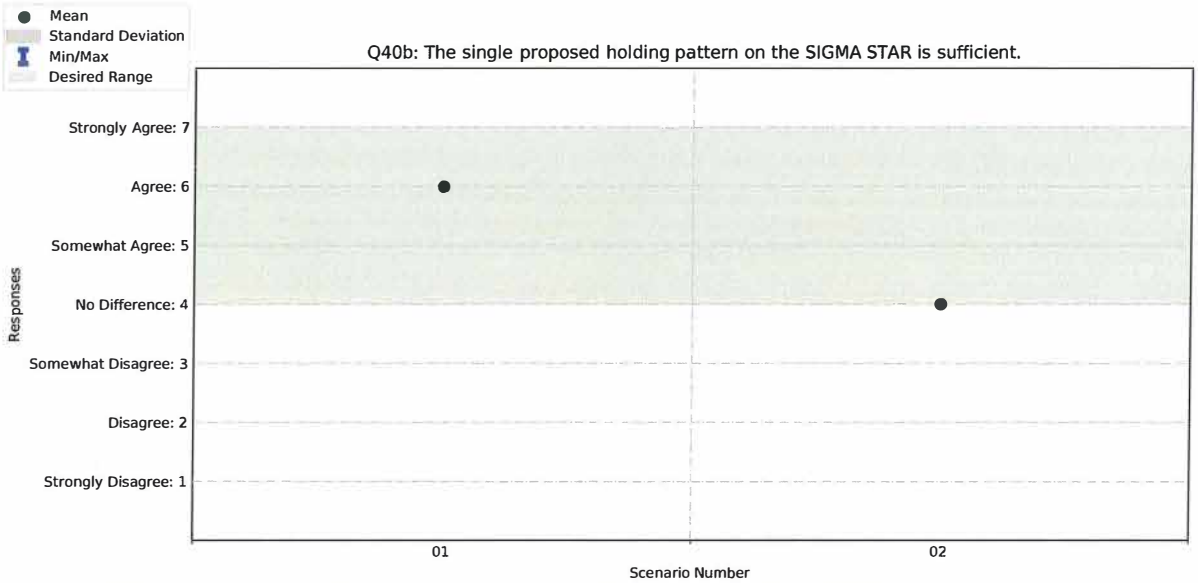
Participants working Approach South sectors during Runway 30L operations (Scenario 3 and Scenario 4) were asked if a single proposed holding pattern for the SIGMA and DANUL STARs was sufficient. As shown in Figure 41, participants ***agreed*** that the single proposed holding pattern for the SIGMA and DANUL STARs was sufficient. Response values were within the desired range (4 or greater) across these two scenarios.



Scenario	03	04
Mean	7.0	6.0
Standard Deviation	0.0	0.0
Max	7	6
Min	7	6

Figure 41. Results for Question 40a

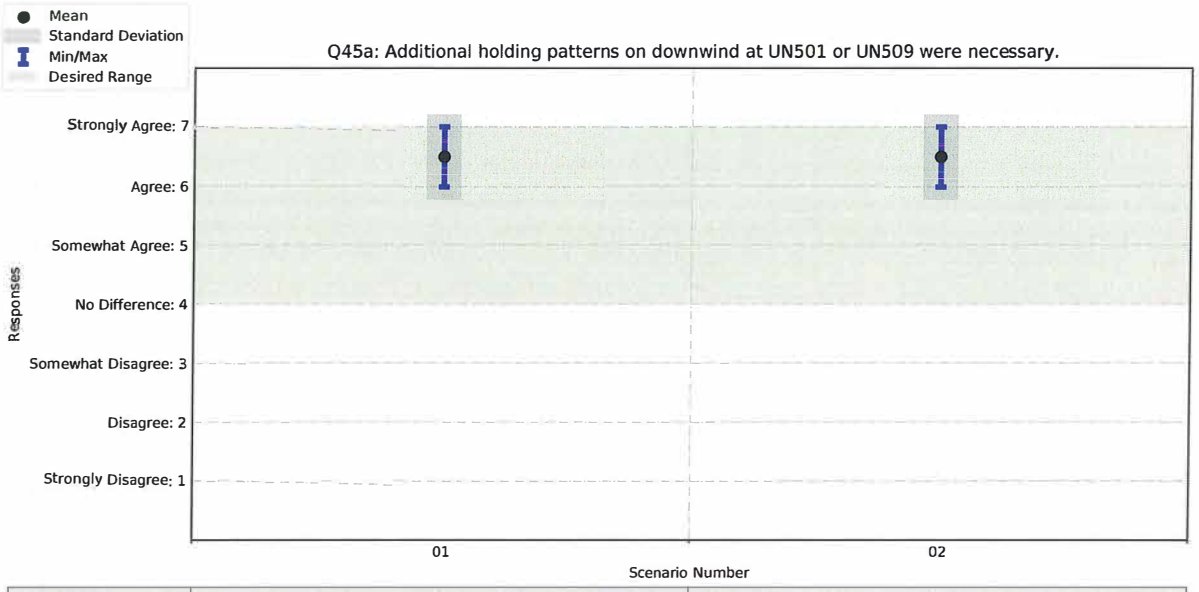
Similarly, participants working Approach South sectors during Runway 12R operations (Scenario 1 and Scenario 2) were asked if a single proposed holding pattern on the SIGMA STAR was sufficient. As shown in Figure 42, participants ***agreed*** that the single proposed holding pattern on the SIGMA STARs was sufficient to accommodate holding needs for the SIGMA, DANUL, and CHETU STARs. Response values were within the desired range (4 or greater) across these two scenarios.



Scenario	01	02
Mean	6.0	4.0
Standard Deviation	0.0	0.0
Max	6	4
Min	6	4

Figure 42. Results for Question 40b

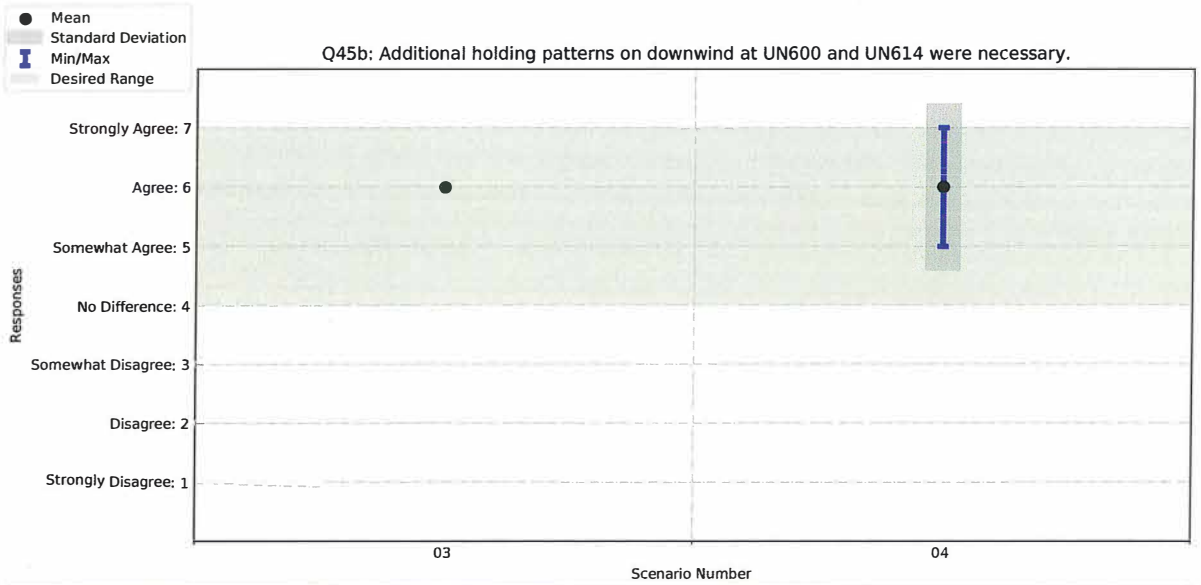
Participants assigned to Approach sectors were asked if additional holding patterns on the downwind legs of the approach were necessary. Participants working Approach sectors during Runway 12 operations were asked to indicate their level of agreement that: "Additional holding patterns on downwind at UN501 and UN509 were necessary." Figure 43 shows that participants ***agreed*** that additional holding patterns at UN501 and UN509 were necessary during Runway 12 operations.



Scenario	01	02
Mean	6.5	6.5
Standard Deviation	0.71	0.71
Max	7	7
Min	6	6

Figure 43. Results for Question 45a

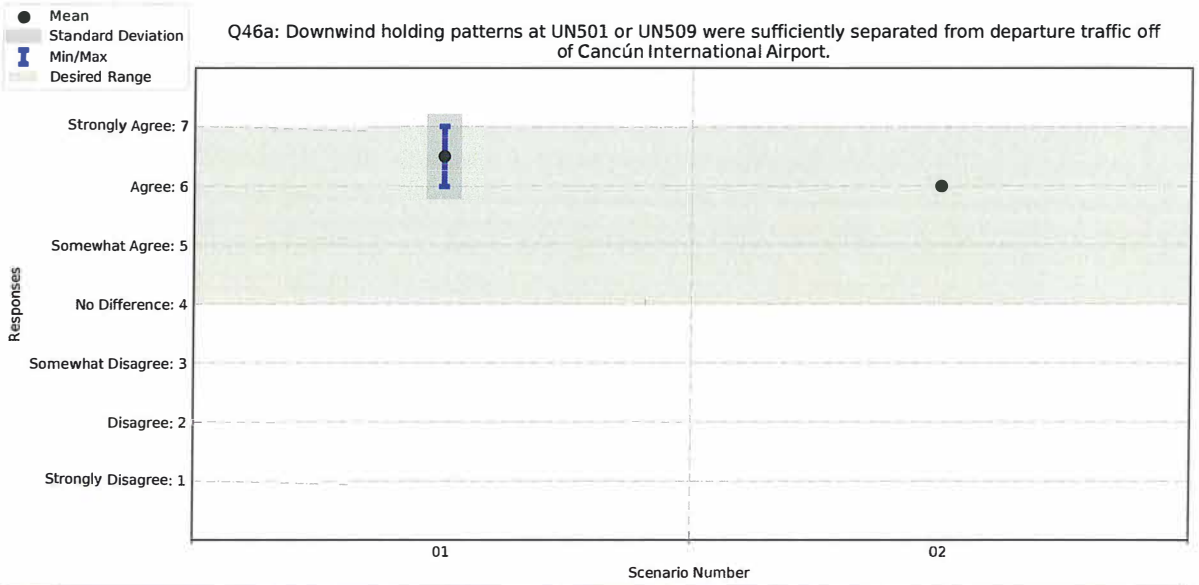
Participants working Approach sectors during Runway 30 operations were asked to indicate their level of agreement that: "Additional holding patterns on downwind at UN600 and UN614 were necessary." Figure 44 shows that participants ***agreed*** that additional holding patterns at UN600 and UN614 were necessary during Runway 30 operations.



Scenario	03	04
Mean	6.0	6.0
Standard Deviation	0.0	1.41
Max	6	7
Min	6	5

Figure 44. Results for Question 45b

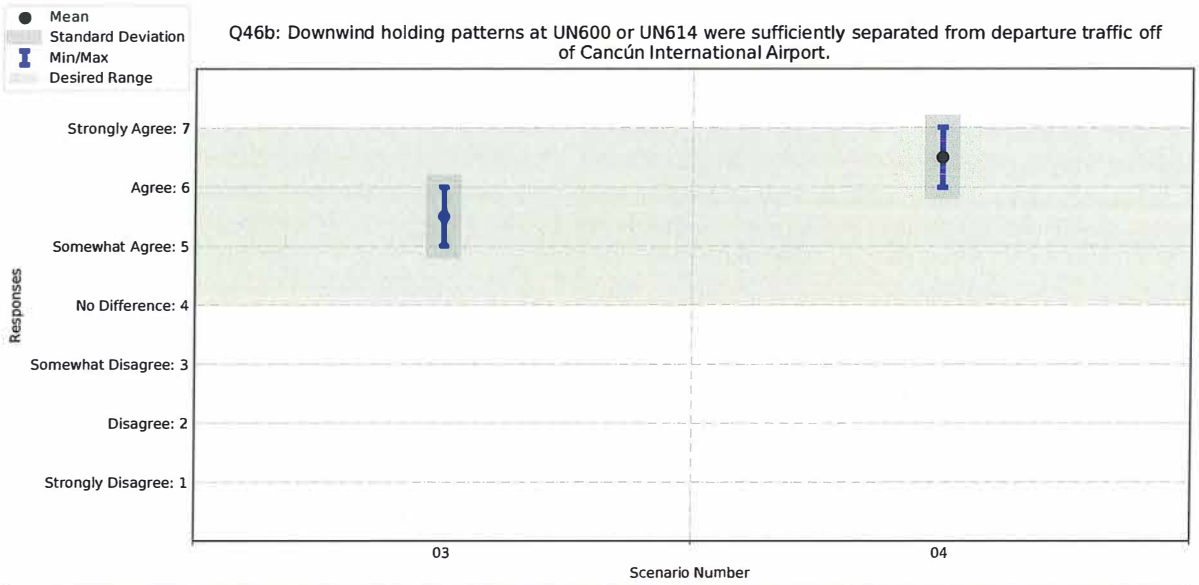
Participants assigned to the Approach sectors were also asked if the additional holding patterns on the downwind legs of the approach were adequately separated from departure traffic from MMUN. Participants working Approach sectors during Runway 12 operations were asked to indicate their level of agreement that: "Downwind holding patterns at UN501 or UN509 were sufficiently separated from departure traffic off of Cancún International Airport." Figure 45 shows that participants ***agreed*** that the downwind holding patterns at UN501 or UN509 were sufficiently separated from MMUN departure traffic during Runway 12 operations.



Scenario	01	02
Mean	6.5	6.0
Standard Deviation	0.71	0.0
Max	7	6
Min	6	6

Figure 45. Results for Question 46a

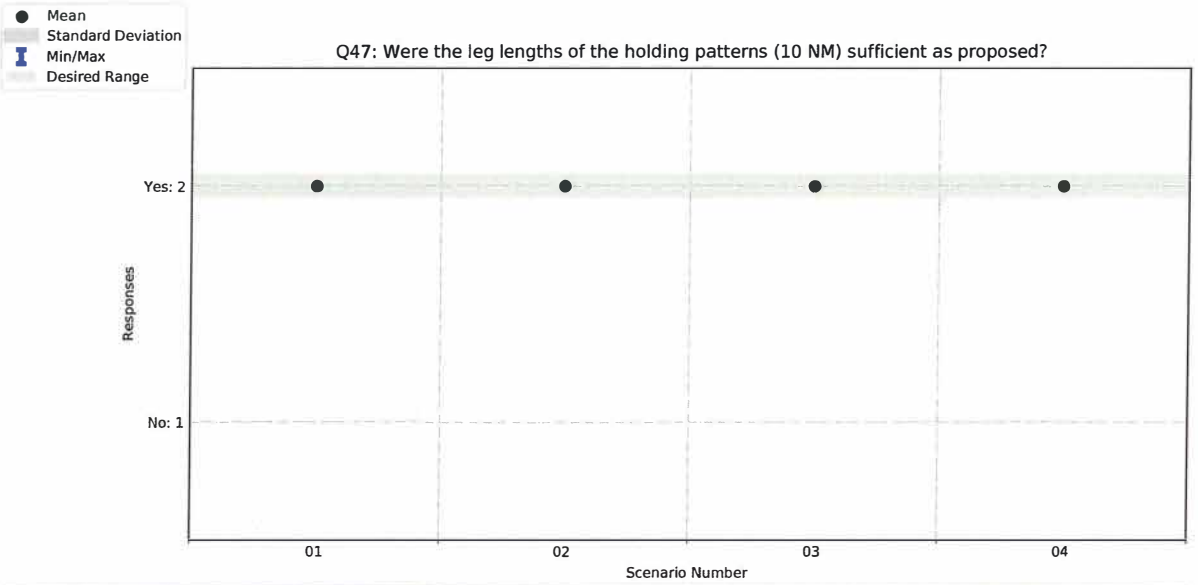
Participants working Approach sectors during Runway 30 operations were asked to indicate their level of agreement that: "Downwind holding patterns at UN600 or UN614 were sufficiently separated from departure traffic off of Cancún International Airport." Figure 46 shows that participants ***agreed*** that the downwind holding patterns at UN600 or UN614 were sufficiently separated from MMUN departure traffic during Runway 30 operations.



Scenario	03	04
Mean	5.5	6.5
Standard Deviation	0.71	0.71
Max	6	7
Min	5	6

Figure 46. Results for Question 46b

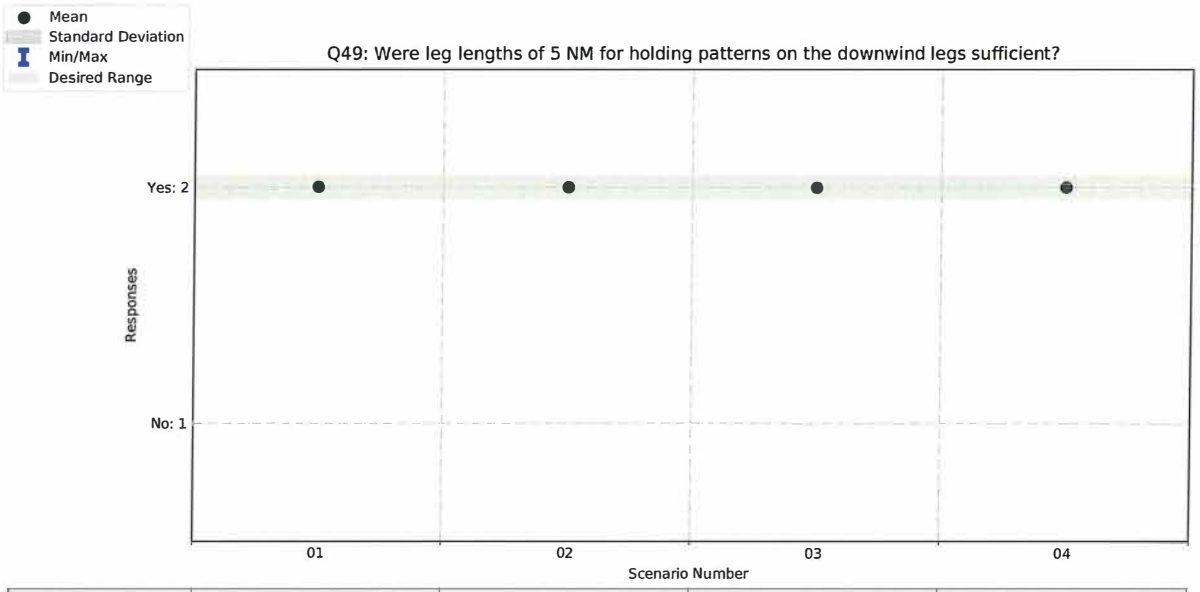
Participants were then asked about the sufficiency of the leg lengths of the various holding patterns proposed in the simulation. Participants working Arrival or Approach sectors for Scenario 1 through Scenario 4 were asked if the leg lengths of 10 NM for the normal holding patterns were sufficient as proposed. As shown Figure 47, all participants indicated ***yes***, that the 10 NM leg lengths on the normal proposed holding patterns were sufficient as proposed.



Scenario	01	02	03	04
Mean	2.0	2.0	2.0	2.0
Standard Deviation	0.0	0.0	0.0	0.0
Max	2	2	2	2
Min	2	2	2	2

Figure 47. Results for Question 47

Participants were also asked if the leg lengths of 5 NM for the downwind holding patterns were sufficient. Figure 48 shows that all participants indicated ***yes***, the leg lengths of 5 NM for the downwind holding patterns were sufficient as proposed.



Scenario	01	02	03	04
Mean	2.0	2.0	2.0	2.0
Standard Deviation	0.0	0.0	0.0	0.0
Max	2	2	2	2
Min	2	2	2	2

Figure 48. Results for Question 49

4.1.4.2 Missed Approaches, Blunders, and Breakouts

A missed approach is a maneuver conducted by flight crews when an instrument approach cannot be completed to a landing. The procedure is published on an instrument approach procedure chart that specifies a point where the missed approach begins, and a point or an altitude/height where it ends. The missed approach procedure considers de-confliction from ground obstacles and from other air traffic flying instrument procedures in the airfield vicinity. Only one missed approach procedure is established for each instrument approach procedure.

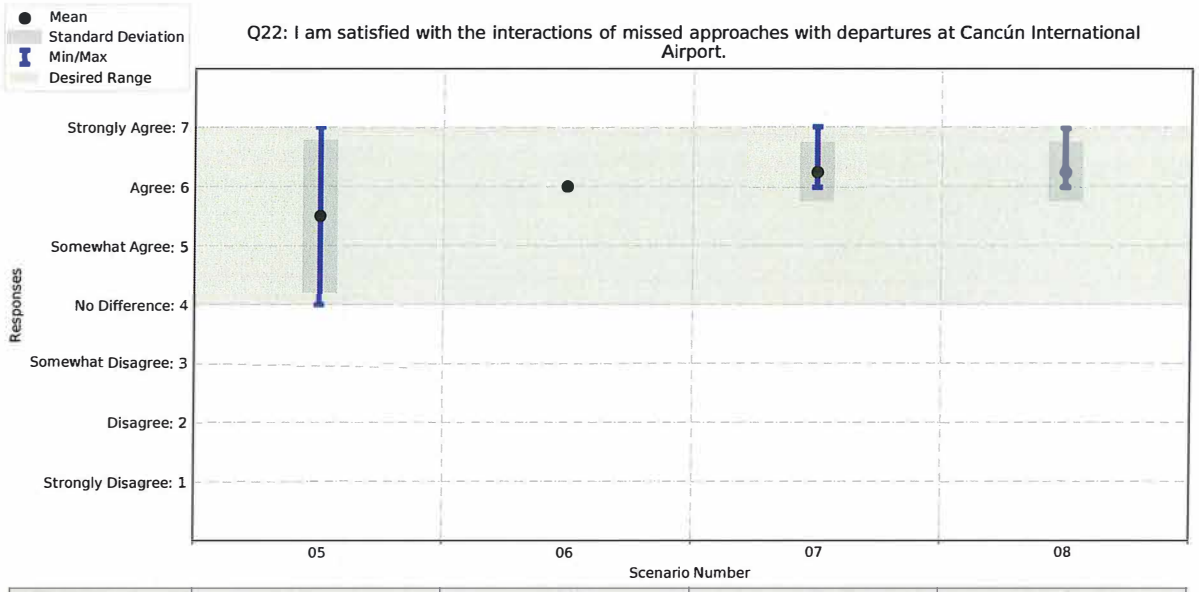
A blunder is an unplanned maneuver with an aircraft conducting a simultaneous independent approach which could result in a conflict with an adjacent aircraft on a parallel final approach course.

A breakout is a technique used by air traffic control to direct aircraft off the final approach course. Breakouts are planned maneuvers, and are generally assigned to ensure separation, comply with pilot requests, or to break aircraft off the final approach course for weather or other deviation purposes. Because of the proximity of aircraft on adjacent final approach courses during independent approach operations, if an aircraft on approach to one runway blunders into the NTZ, the aircraft on the adjacent approach will be given breakout instructions by ATC.

Scenarios 5 through 8 focused on missed approaches, blunders, and breakouts at the Final Monitor position.

In Scenarios 5 through 8, participants working Approach sectors and Final Monitor positions were asked to indicate their level of agreement with the following statement: "I am satisfied with

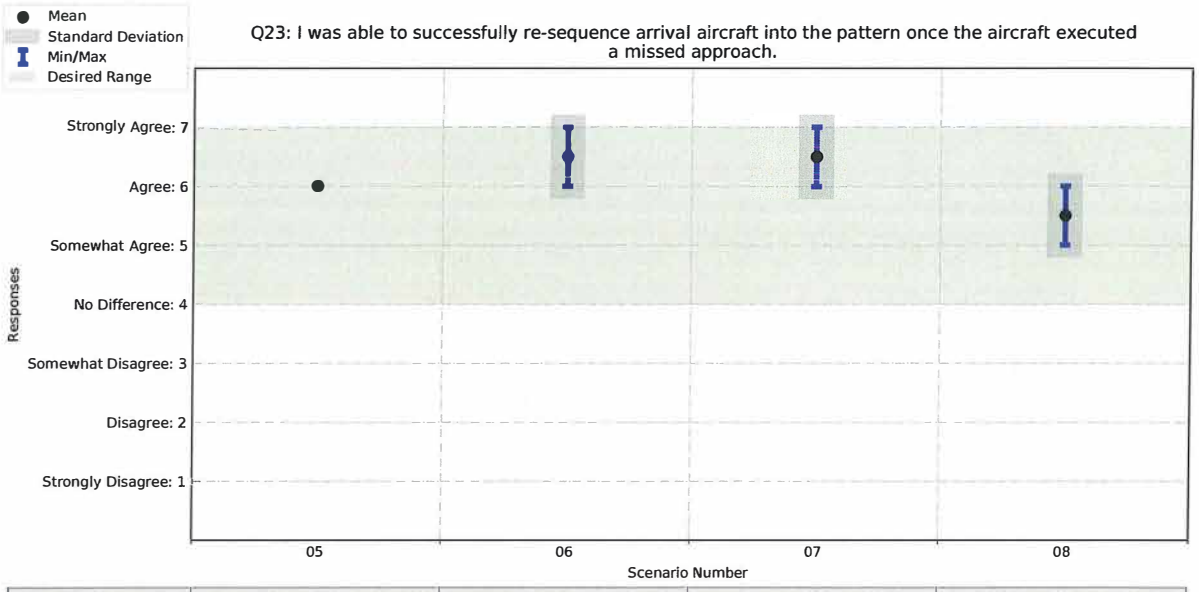
the interactions of missed approaches with departures at Cancún International Airport."
Figure 49 shows that participants generally ***agreed*** that they were satisfied with the interactions of missed approaches and departures at MMUN. Mean values, standard deviations, and range values were within the desired range (4 or greater) across all scenarios.



Scenario	05	06	07	08
Mean	5.5	6.0	6.25	6.25
Standard Deviation	1.29	0.0	0.5	0.5
Max	7	6	7	7
Min	4	6	6	6

Figure 49. Results for Question 22

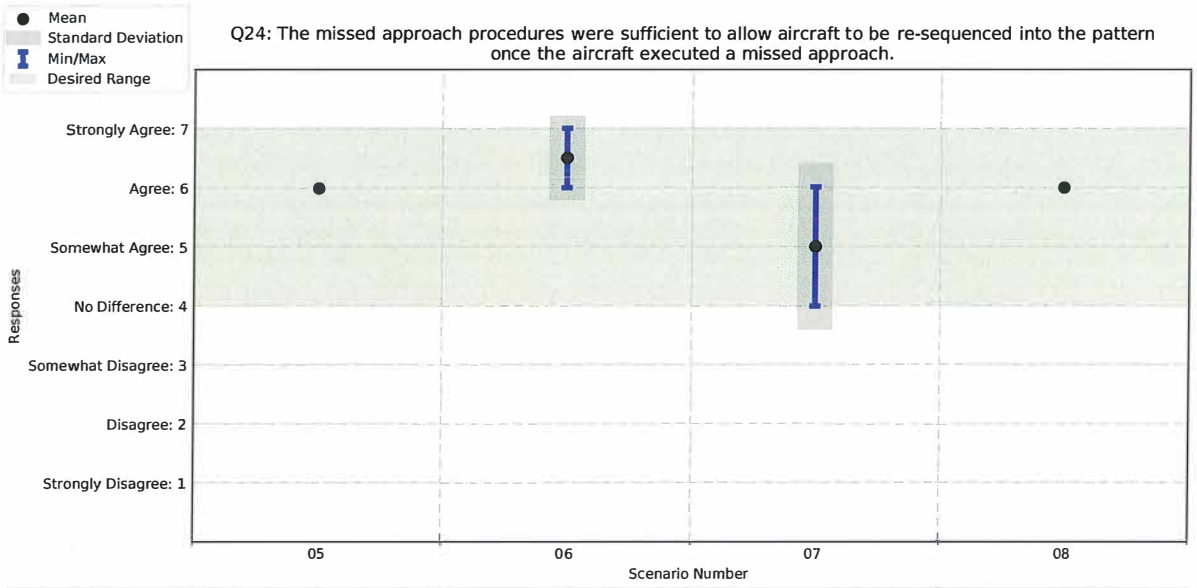
Participants working Approach sectors were asked if they could successfully re-sequence arrival aircraft into the pattern once the aircraft executed a missed approach. Figure 50 shows that participants felt they could re-sequence arrival aircraft into the pattern once the aircraft executed a missed approach. Mean values, standard deviations, and range values were within the desired range (4 or greater) across all scenarios.



Scenario	05	06	07	08
Mean	6.0	6.5	6.5	5.5
Standard Deviation	0.0	0.71	0.71	0.71
Max	6	7	7	6
Min	6	6	6	5

Figure 50. Results for Question 23

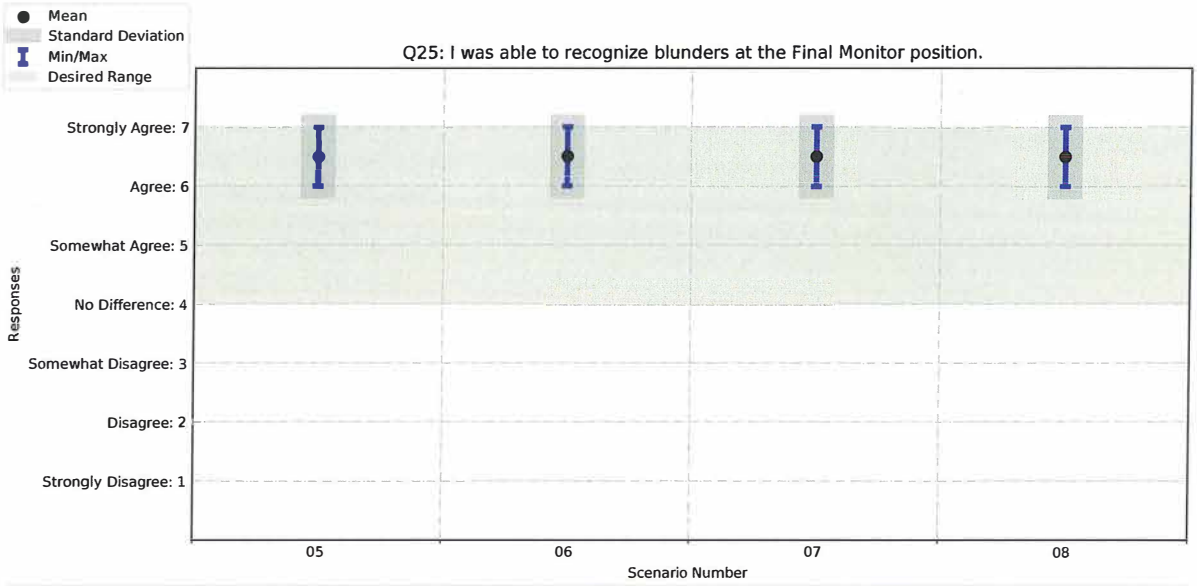
Participants working Approach sectors were asked if the missed approach procedures were sufficient to allow aircraft to be re-sequenced into the pattern once the aircraft executed a missed approach. Figure 51 shows that participants felt that the procedures were sufficient to allow aircraft to be re-sequenced into the pattern once the aircraft executed a missed approach. Mean values and range values were within the desired range (4 or greater) across all scenarios. A detailed review of the comments associated with Scenario 7 was inconclusive in determining why the participant indicated "No Difference" in response to this question.



Scenario	05	06	07	08
Mean	6.0	6.5	5.0	6.0
Standard Deviation	0.0	0.71	1.41	0.0
Max	6	7	6	6
Min	6	6	4	6

Figure 51. Results for Question 24

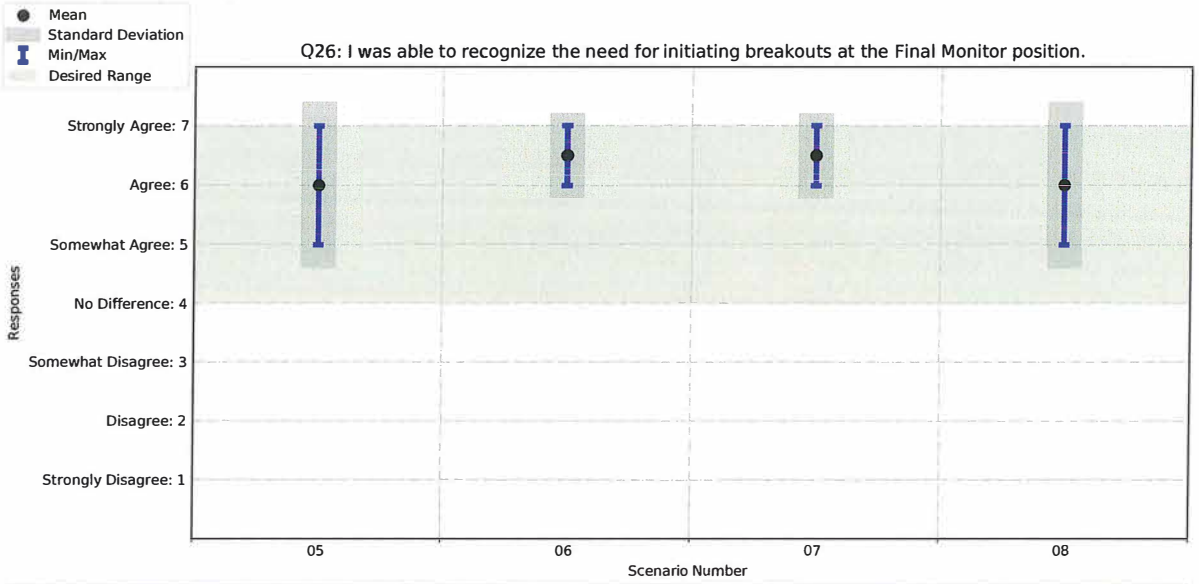
Participants working Final Monitor positions were asked if they could recognize blunders at the Final Monitor position. Figure 52 shows that participants felt they could recognize blunders at the Final Monitor position. Mean values, standard deviations, and range values were within the desired range (4 or greater) across all scenarios.



Scenario	05	06	07	08
Mean	6.5	6.5	6.5	6.5
Standard Deviation	0.71	0.71	0.71	0.71
Max	7	7	7	7
Min	6	6	6	6

Figure 52. Results for Question 25

Participants working Final Monitor positions were asked if they could recognize the need for initiating breakouts at the Final Monitor position. Figure 53 shows that participants felt they could recognize the need for initiating breakouts at the Final Monitor position. Mean values, standard deviations, and range values were within the desired range (4 or greater) across all scenarios.



Scenario	05	06	07	08
Mean	6.0	6.5	6.5	6.0
Standard Deviation	1.41	0.71	0.71	1.41
Max	7	7	7	7
Min	5	6	6	5

Figure 53. Results for Question 26

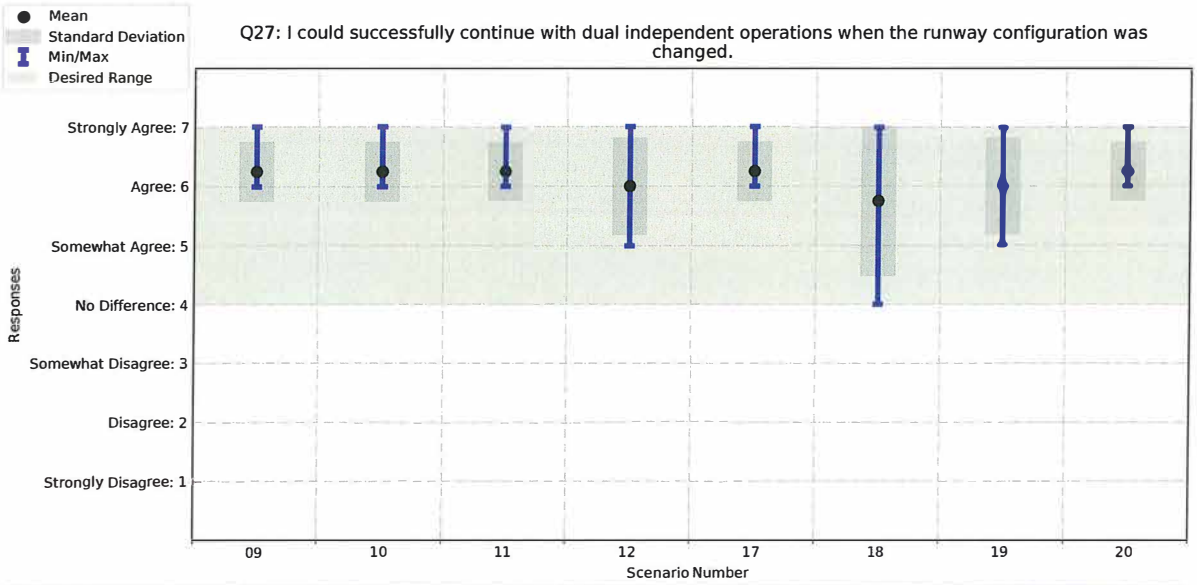
4.1.4.3 Runway Configuration Changes

Runway configuration changes refer to the ATC procedures needed to change the active runways in use at an airport. Active runway configuration selection can be determined by various factors, including changes to wind, weather, or other conditions at the airport. Such changes can be planned or can occur dynamically, as conditions require. When the runway configuration at an airport is changed, departure aircraft are held on the ground and arrival aircraft are vectored or re-routed to a new STAR procedure for the new active runway configuration.

Scenarios 9 through 12 and Scenarios 17 through 20 focused on changes to the runway configuration at MMUN. In these scenarios, MITRE HITL personnel would notify the participants that a runway configuration change would be occurring at some point in the future, or should occur immediately. From the point of the runway configuration change, all departures in the simulation were automatically held on the ground, and all arrival aircraft outside of the Cancún/Cozumel TMA were rerouted to the new STAR by the automation. Participants were responsible for vectoring or re-routing any arrival aircraft within their sectors within the Cancún/Cozumel TMA airspace.

All participants in scenarios involving runway configuration changes were asked if they could continue with dual independent operations when the runway configuration was changed. The mean values were above 5, and range and standard deviation values were also within the desired range (4 or above) across all scenarios, as shown in Figure 54. The data indicate that all

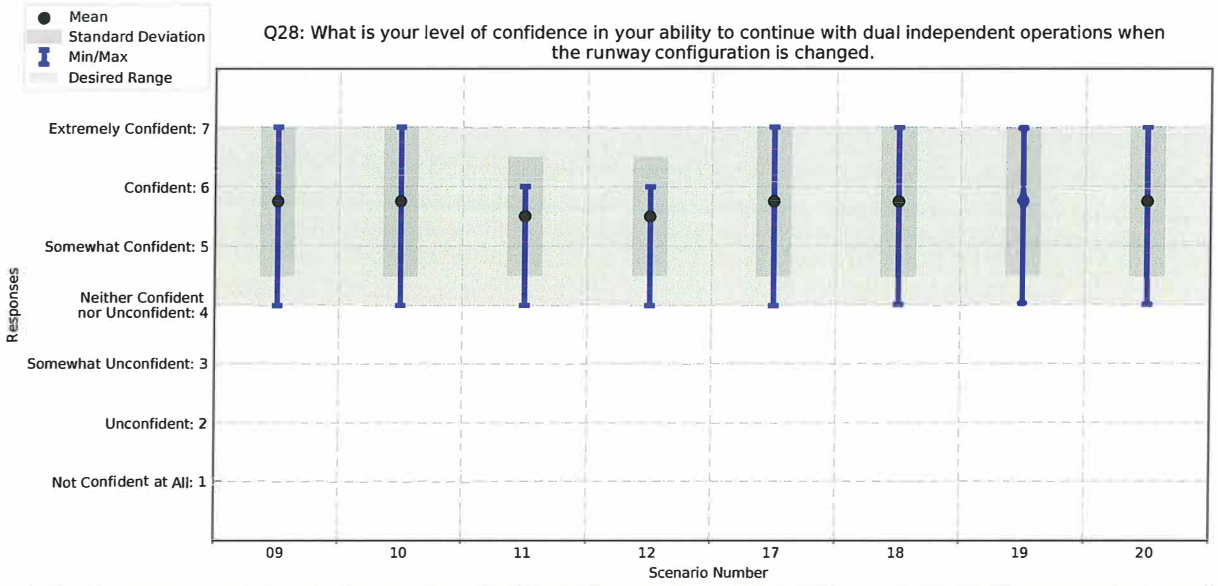
participants ***agreed*** that they could successfully continue with dual independent operations when the runway configuration was changed.



Scenario	09	10	11	12	17	18	19	20
Mean	6.25	6.25	6.25	6.0	6.25	5.75	6.0	6.25
Standard Deviation	0.5	0.5	0.5	0.82	0.5	1.26	0.82	0.5
Max	7	7	7	7	7	7	7	7
Min	6	6	6	5	6	4	5	6

Figure 54. Results for Question 27

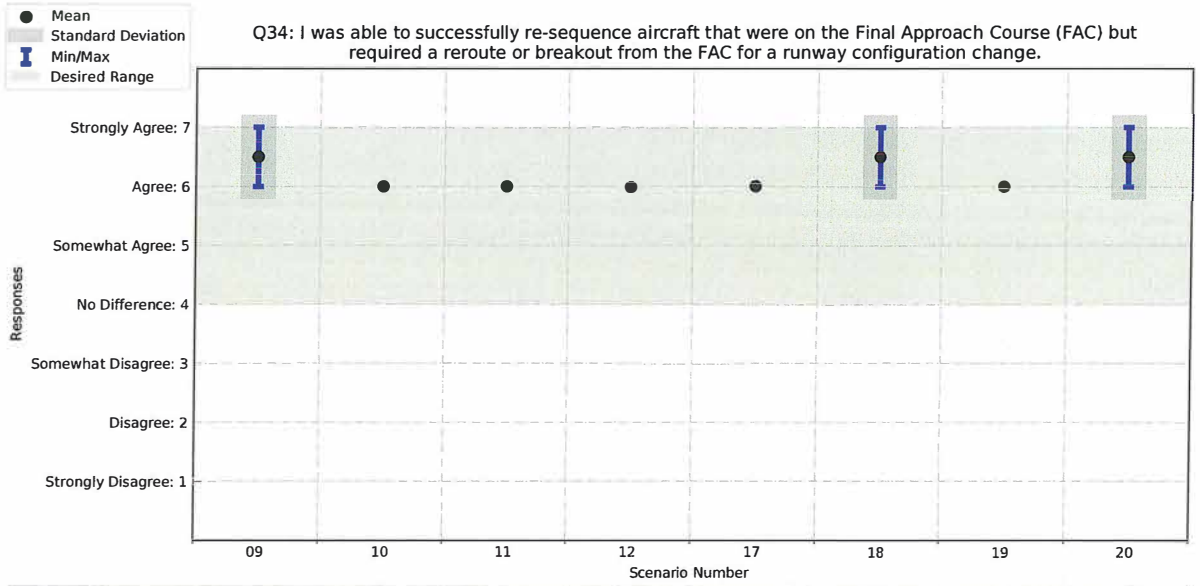
All participants in scenarios involving runway configuration changes were asked to indicate their level of confidence to the following question: "What is your level of confidence in your ability to continue with dual independent operations when the runway configuration is changed?" The mean values were above 5, and range and standard deviation values were also within the desired range (4 or above) across all scenarios, as shown in Figure 55. The data indicate that all participants were ***confident*** in their ability to continue with dual independent operations when the runway configuration was changed.



Scenario	09	10	11	12	17	18	19	20
Mean	5.75	5.75	5.5	5.5	5.75	5.75	5.75	5.75
Standard Deviation	1.26	1.26	1.0	1.0	1.26	1.26	1.26	1.26
Max	7	7	6	6	7	7	7	7
Min	4	4	4	4	4	4	4	4

Figure 55. Results for Question 28

Participants working Approach sectors during scenarios involving runway configuration changes were asked to indicate their level of agreement with the following statement: "I was able to successfully re-sequence aircraft that were on the Final Approach Course (FAC) but required a reroute or breakout from the FAC for a runway configuration change." The mean values were above 6, and range and standard deviation values were also within the desired range (4 or above) across all scenarios, as shown in Figure 56. The data indicate that all participants ***agreed*** that they could successfully re-sequence aircraft that were on the FAC but required a route change or a breakout from the FAC due to a runway configuration change.



Scenario	09	10	11	12	17	18	19	20
Mean	6.5	6.0	6.0	6.0	6.0	6.5	6.0	6.5
Standard Deviation	0.71	0.0	0.0	0.0	0.0	0.71	0.0	0.71
Max	7	6	6	6	6	7	6	7
Min	6	6	6	6	6	6	6	6

Figure 56. Results for Question 34

4.1.4.4 Independent to Dependent Operations

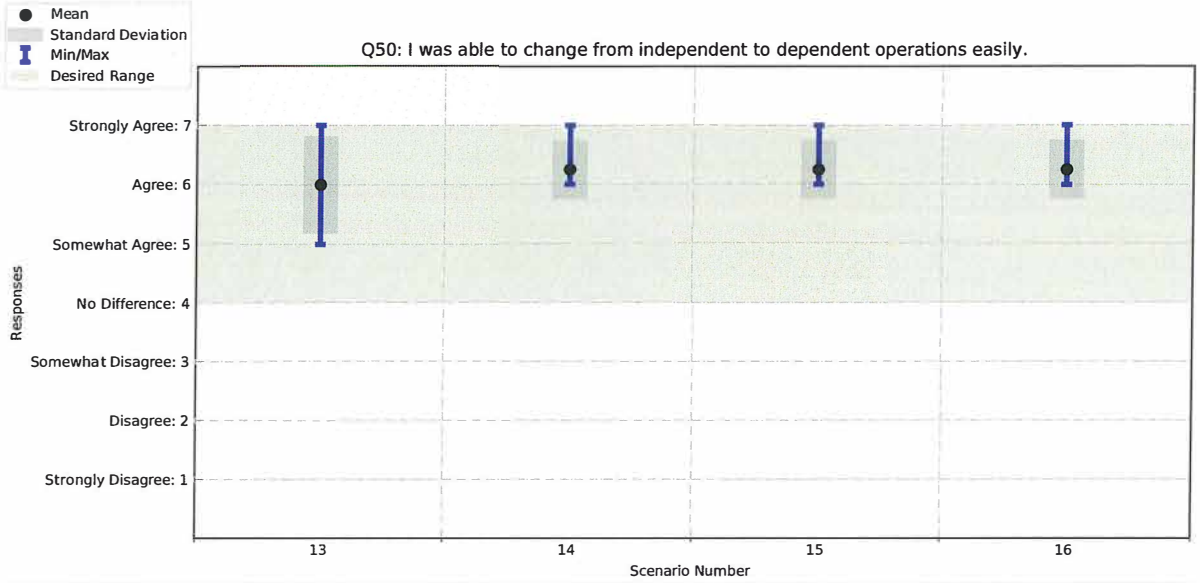
On occasion, conditions such as traffic demand or weather will mandate that operations in the TMA and at the airport change from independent to dependent, or vice versa. In these circumstances, sectors can be combined to single sectors, or, if already combined, can be split into individual sectors for various positions (Arrival, Approach, Departure).

Scenarios 13 through 16 focused on changing from independent to dependent operations at MMUN. In these scenarios, participants initially staffed four sectors for independent operations: Arrival North, Arrival South, Approach North, and Approach South. Departure sectors were staffed by MITRE confederate[7] controllers. Participants then were told that positions would be combined to move to dependent operations. Arrival North would combine into Arrival South to make a single Arrival sector, and Approach North would combine into Approach South to make a single Approach sector. Each participant from the north sectors was reassigned to a Departure sector: Arrival North went to Departure South, and Approach North went to Departure North.

In scenarios where operations transitioned from independent to dependent, participants were asked if they could change from independent to dependent operations easily. As shown in Figure 57, the mean values, standard deviations, and ranges were above 5 (where the desired

[7] Confederate (i.e., non-participant) controllers refer to MITRE staff who manage simulated aircraft at non-evaluation sectors, as necessary, to ensure proper movement of simulated traffic through adjacent sectors for coordination purposes.

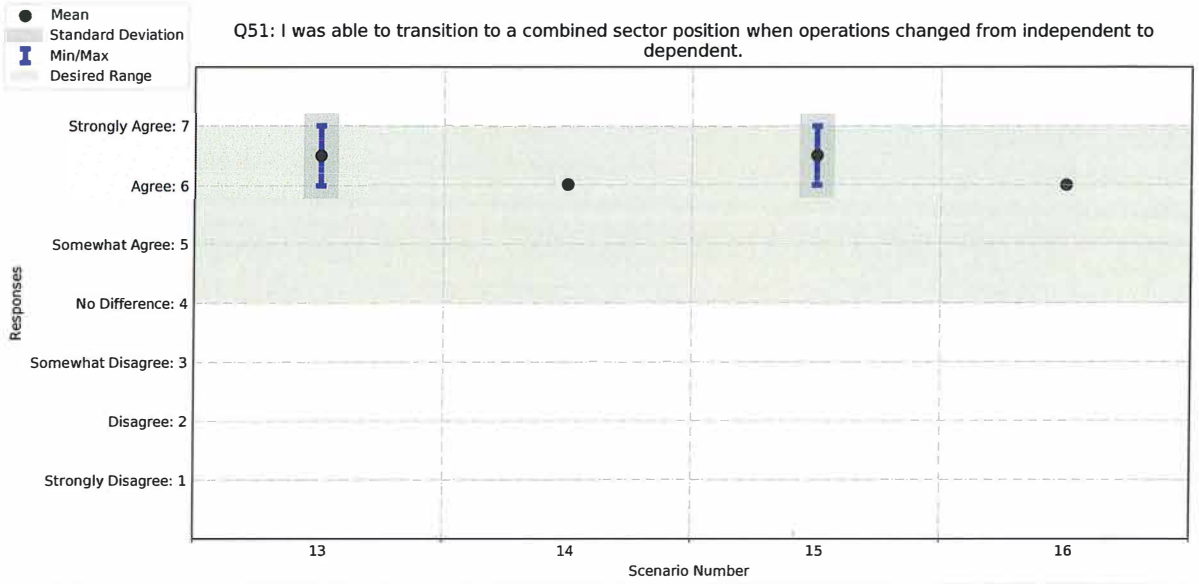
range was 4 or higher) across all scenarios. Overall, the data showed that all participants ***agreed*** that they could change from independent to dependent operations easily.



Scenario	13	14	15	16
Mean	6.0	6.25	6.25	6.25
Standard Deviation	0.82	0.5	0.5	0.5
Max	7	7	7	7
Min	5	6	6	6

Figure 57. Results for Question 50

In scenarios where operations transitioned from independent to dependent, participants working the Arrival South or Approach South sectors were asked if they could transition to a combined sector position when operations changed from independent to dependent. As shown in Figure 58, the mean values, standard deviations, and ranges were above 6 (where the desired range was 4 or higher) across these scenarios. Overall, the data showed that all participants in these scenarios ***agreed*** that they could transition to a combined sector position when operations changed from independent to dependent.



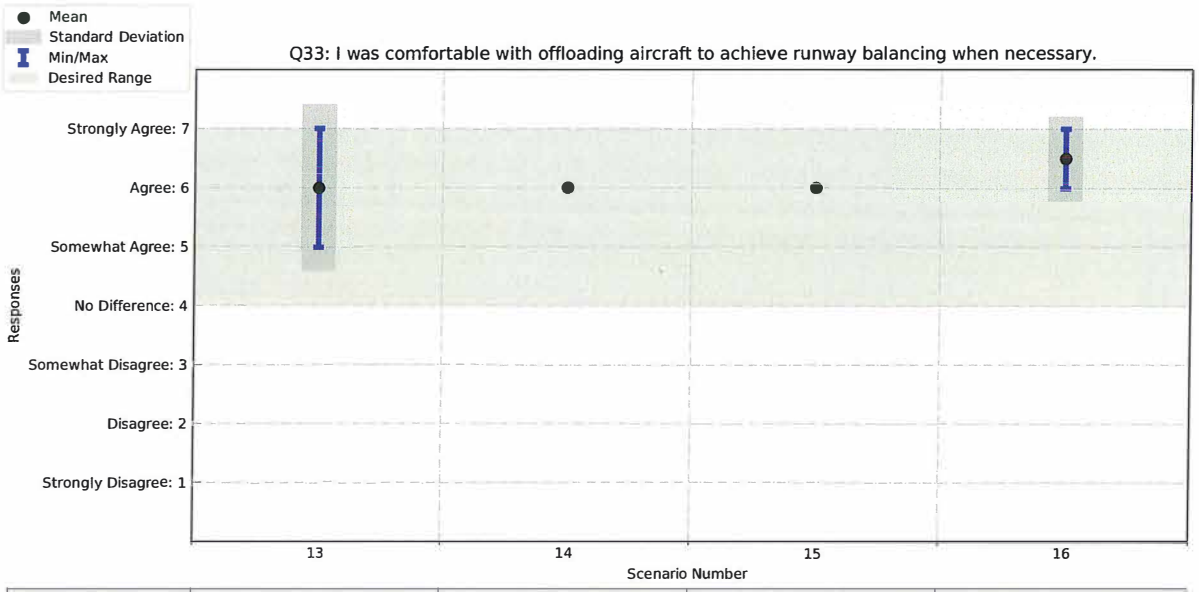
Scenario	13	14	15	16
Mean	6.5	6.0	6.5	6.0
Standard Deviation	0.71	0.0	0.71	0.0
Max	7	6	7	6
Min	6	6	6	6

Figure 58. Results for Question 51

4.1.4.5 Offloads

Scenarios 13 through 16 also included opportunities for offloads. Offloads describe the process by which an aircraft on an approach procedure for one runway will be sent or cleared to land on an adjacent runway to achieve runway balancing.

In Scenarios 13 through 16, participants working Arrival sectors were asked to indicate their level of agreement with the following statement: "I was comfortable with offloading aircraft to achieve runway balancing when necessary." Mean values were 6 or above across these scenarios. Standard deviations and range values were also within the desired range (of 4 or higher). As shown in Figure 59, the data indicate that all participants ***agreed*** that they were comfortable with offloading aircraft to achieve runway balancing when necessary.



Scenario	13	14	15	16
Mean	6.0	6.0	6.0	6.5
Standard Deviation	1.41	0.0	0.0	0.71
Max	7	6	6	7
Min	5	6	6	6

Figure 59. Results for Question 33

4.1.5 Open-Ended Questions

Participants were presented with two open-ended questions after each scenario: one asking them to describe the most difficult situation they encountered within the respective scenario, and another asking for final comments and feedback on that scenario. Comments from participants are presented in this section[8].

The first open-ended question (Question 17) was "What was the most difficult situation to deal with in this exercise?" Participants were instructed to enter "none" or "N/A" if they felt they did not experience any difficult situations in the exercise. There were 80 opportunities for participants to leave comments; 89 percent of the time participant comments were "none" or "N/A." The remaining 11 percent, 9 comments in total, are provided in Table 3.

The comments yielded two common themes related to difficult situations: missed approaches and vectors. Vectoring appeared to be identified as a difficult situation across scenarios involving missed approaches, independent-to-dependent operations, and runway configuration changes as the off-nominal events. Similarly, missed approaches were identified not only in scenarios involving missed approaches specifically, but also in scenarios focused on holding operations.

[8] Not all responses are presented verbatim. In some cases, they have been edited here for clarity.

Table 3. Responses to Question 17
("What was the most difficult situation to deal with in this exercise?)

Comment #	Scenario	Response
1	2	Missed approaches
2	2	That the pilot follows the instructions as requested
3	9	Vectoring to integrate a new sequence to Runway 30R
4	8	Vectoring to re-sequence the missed approaches
5	8	Re-assignment to another sector for traffic on missed approach
6	13	Vectoring
7	13	Traffic
8	15	Speed adjustments and vectoring
9	18	Speed adjustments and vectoring

The final question presented to all participants after each scenario was the second open-ended question (Question 18), which read: "Please provide any final comments you have regarding the simulation scenario you just experienced, including comments on automation, procedures, workload, training, tasking, or any other aspects of the simulation exercise." Again, there were 80 possible comments in all, and 81 percent of the responses (65 out of the 80) were "no comment" or "none." The remaining 19 percent (15 comments) are presented in Table 4. Thirty percent of the comments mentioned missed approaches, but the remaining comments yielded no common theme.

Table 4. Responses to Question 18
("Please provide any final comments you have regarding the simulation scenario you just experienced, including comments on automation, procedures, workload, training, tasking, or any other aspects of the simulation exercise.")

Comment Number	Scenario	Response
1	1	It seemed difficult for the pilot to transfer communications and to follow instructions
2	3	I understand what the problem was
3	3	I felt I needed one more holding pattern
4	9	Aircraft was cleared via UN507 for the 12R approach, but it turned to a 076 heading instead of 096 heading; that is a direct heading to intercept the localizer.
5	10	Workload was good, the test for the runway configuration change was good
6	5	The missed approach altitude must be 2,000 ft
7	5	I did not have time to check altitudes between missed approaches and departures
8	6	Workload was good and procedures were good; the controller should coordinate the altitude of the missed approach to be sure departure separation is adequate.
9	12	There seemed to be an excessive amount of traffic
10	12	Heavy flow of traffic, but not too complex to handle
11	7	The controller must pay attention to the missed approach with the altitude of traffic on the downwind
12	8	No problem with missed approaches on the left side (30L), but we have to be careful with the missed approaches on the right side (30R)
13	13	There seemed to be an excessive amount of traffic
14	13	Offloads worked well
15	14	This was the first time that I worked Approach North and Approach South as a combined sector

4.2 Objective Results

Objective results, such as time on sector frequency, and aircraft counts, are used to answer research questions regarding efficiency. Objective data also lend support to subjective results used to answer research questions regarding acceptability and operational suitability.

In this section, several objective metric results are presented, including total time on frequency, average of total time on frequency, aircraft counts, mean time on frequency, and arrival and departure counts. These values can serve as indicators of workload, depictions of

controller and pilot communications, or can indicate how much processing time may be required by participants.

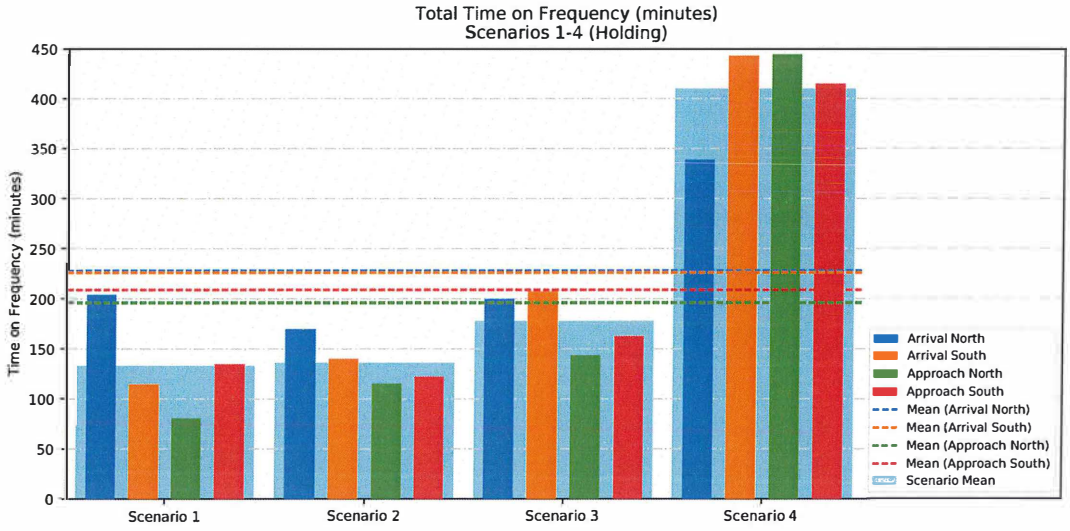
4.2.1 Time on Frequency

Time on frequency can be presented as total time (sum of all aircrafts' time on each active sector frequency), average of total time (averages of total time on frequency per sector, and scenario), or as mean time (total time on frequency divided by the number of aircraft in the sector). Figure 60 through Figure 64 show the total time of all aircraft on each active sector/position's frequency for each scenario, as well as the averages for each scenario and sector/position. The graphs are grouped into scenario blocks focused on similar scenario conditions (holding scenarios, missed approach scenarios, runway configuration change scenarios, and independent-to-dependent operations scenarios).

Although each scenario was 30-45 minutes long, the total time on frequency refers to the sum of each individual aircraft's time on the frequency. Therefore, the total time on frequency may be considerably more than the duration of the scenario, as this value is a function of the number of aircraft worked by each sector. Aircraft counts and mean time on frequency are discussed in subsequent sections.

Figure 60 shows the total time of aircraft on frequency for holding scenarios (Scenarios 1 through 4). The total time on frequency for holding scenarios was between 81 minutes (Approach North, Scenario 1) and 444 minutes (Approach North, Scenario 4).

The table for Figure 60 also shows the mean of total time on frequency per position (sector) and per scenario for holding scenarios. As shown, the average time for the Arrival North sector was only slightly higher than other sectors in these scenarios. The mean time for Scenario 4 was markedly higher than for Scenarios 1 through 3. A review of associated subjective (questionnaire) data for Scenario 4, including inputs for workload, communications, concept of operations, off-nominal events, and comments, yielded no additional insight into the significantly higher frequency time for Scenario 4 overall as well as for any individual sectors within Scenario 4.

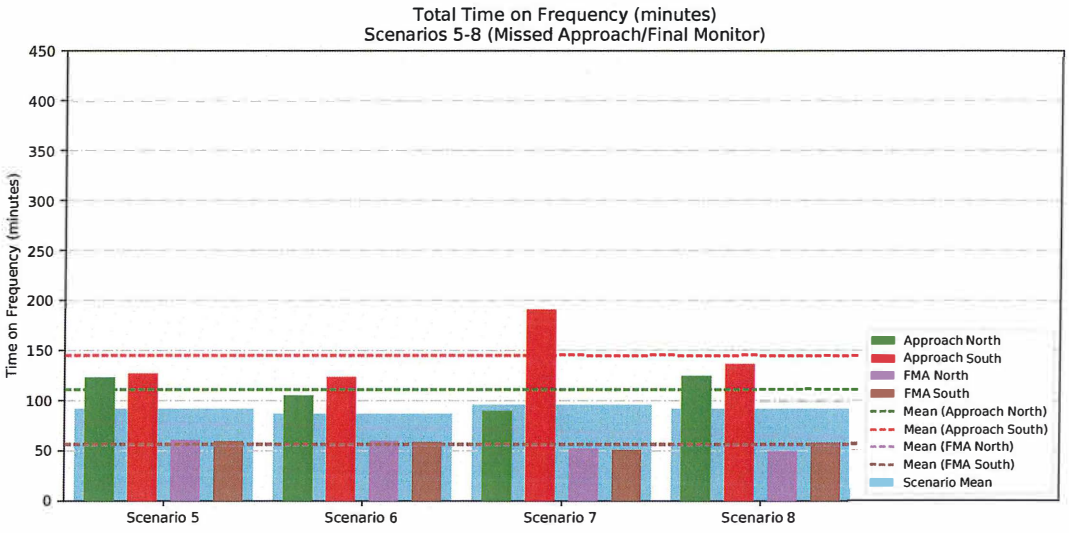


	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Position Mean
Arrival North	204	170	200	339	228
Arrival South	115	140	207	443	226
Approach North	81	115	144	444	196
Approach South	135	122	163	415	209
Scenario Mean	133	136	178	410	

Figure 60. Total Time on Frequency for Scenarios 1 through 4 (Holding), per Sector

Figure 61 shows the total time of aircraft on frequency for missed approach and final monitor scenarios. The total time on frequency for missed approach and final monitor scenarios was between 50 minutes (FMA North, Scenario 8) and 191 minutes (Approach South, Scenario 7).

The table for Figure 61 shows the mean total time on frequency per position and per scenario for missed approach and final monitor scenarios. As shown, the mean time for the Approach South sector was slightly higher than for Approach North, and the scenario averages were relatively consistent across all scenarios. A review of associated subjective (questionnaire) data for the Approach South sector indicated that vectoring for missed approaches may have contributed to the higher total time on frequency for that sector.

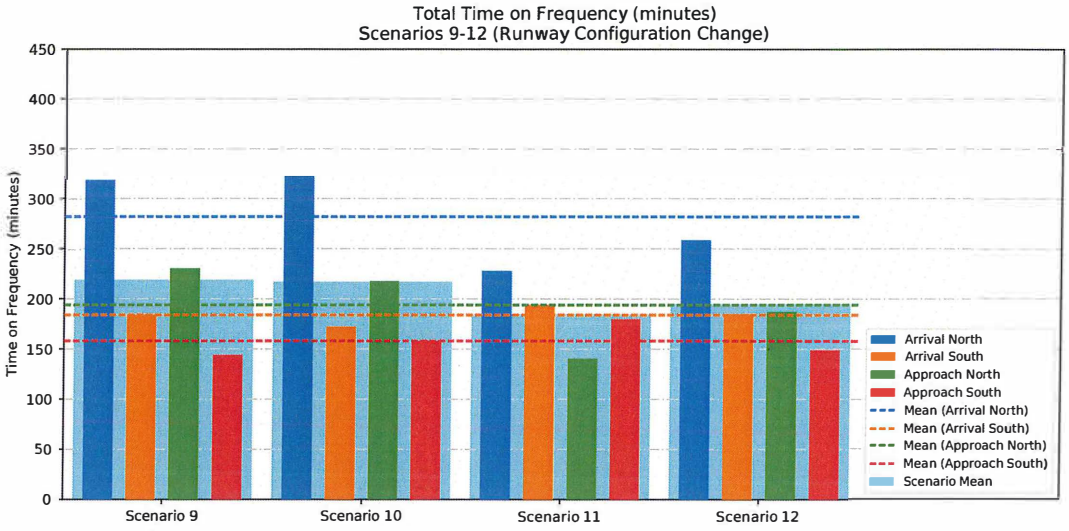


	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Position Mean
Approach North	123	105	90	125	111
Approach South	127	124	191	137	145
FMA North	61	60	53	50	56
FMA South	60	59	51	59	57
Scenario Mean	92	87	96	92	

Figure 61. Total Time on Frequency for Scenarios 5 through 8 (Missed Approach/Final Monitor), per Sector

Figure 62 shows the total time of aircraft on frequency for runway configuration change scenarios. The total time on frequency for Scenarios 9 through 12 was between 141 minutes (Approach North, Scenario 11) and 323 minutes (Arrival North, Scenario 10).

The table for Figure 62 shows the mean total time on frequency per position and per scenario for runway configuration change scenarios (Scenarios 9 through 12). As shown, the average time for the Arrival North sector was higher than other sectors in these scenarios, while the scenario averages were relatively consistent across all scenarios. A review of associated subjective (questionnaire) data for the Arrival North sector was inconclusive, but it is assumed that the larger sector and higher traffic volume in Arrival North may account for the slightly elevated average time on frequency for that sector.

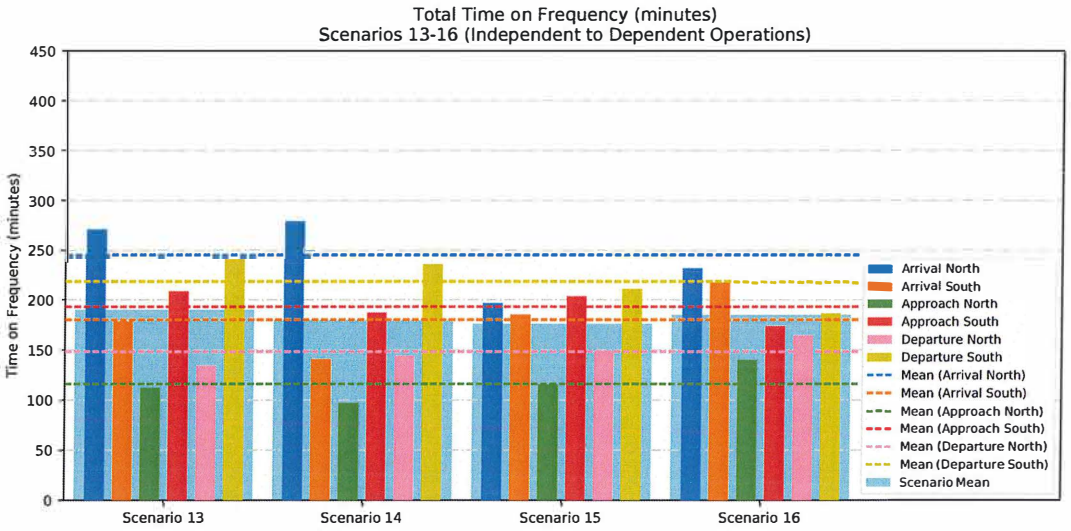


	Scenario 9	Scenario 10	Scenario 11	Scenario 12	Position Mean
Arrival North	318	323	228	259	282
Arrival South	184	172	194	185	184
Approach North	230	218	141	187	194
Approach South	144	158	180	149	158
Scenario Mean	219	217	185	195	

Figure 62. Total Time on Frequency for Scenarios 9 through 12 (Runway Configuration Change), per Sector

Figure 63 shows the total time of aircraft on frequency for independent to dependent operations scenarios. The total time on frequency for Scenarios 13 through 16 was between 98 minutes (Approach North, Scenario 14) and 279 minutes (Arrival North, Scenario 14).

The table for Figure 63 shows the mean total time on frequency per position and per scenario for independent to dependent operations scenarios. As shown, the average time for the Arrival North sector was higher than other sectors in these scenarios, while the scenario averages were relatively consistent across all scenarios. The disparity between average sector times for the Arrival North sector is believed to be a function of sector size and higher traffic volume for that sector.

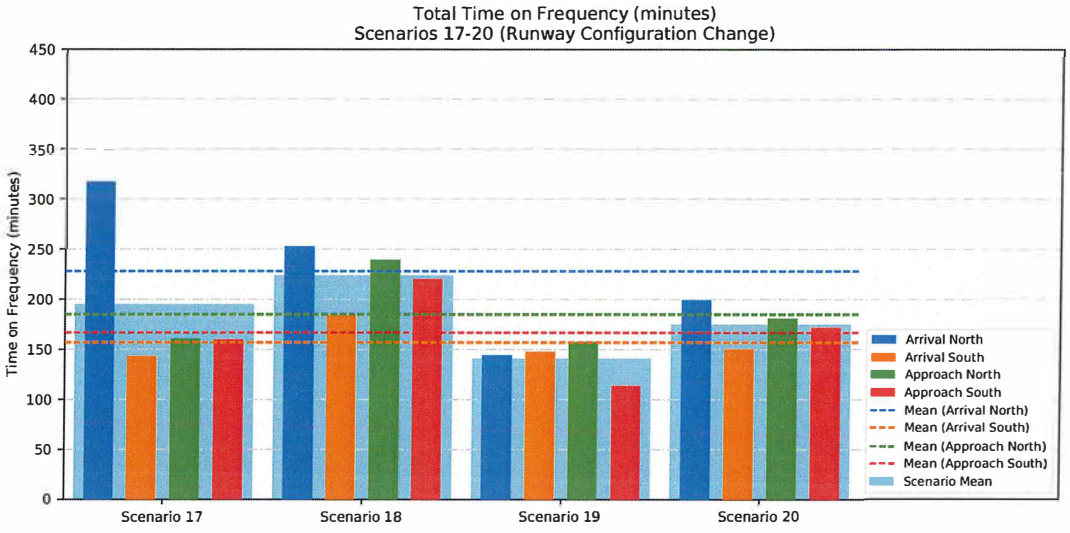


	Scenario 13	Scenario 14	Scenario 15	Scenario 16	Position Mean
Arrival North	271	279	196	231	245
Arrival South	178	141	185	217	180
Approach North	112	98	116	140	116
Approach South	209	188	204	174	193
Departure North	134	144	149	165	148
Departure South	240	235	211	186	218
Scenario Mean	190	180	176	185	

Figure 63. Total Time on Frequency for Scenarios 13 through 16 (Independent to Dependent Operations), per Sector

Figure 64 shows total time of aircraft on frequency for runway configuration change scenarios. The total time on frequency for Scenarios 17 through 20 was between 114 minutes (Approach South, Scenario 19) and 317 minutes (Arrival North, Scenario 17).

The table for Figure 64 shows the mean total time on frequency per position and per scenario for runway configuration change scenarios (Scenarios 13 through 16). As shown, the average time for sectors was higher for Arrival North, and the average time for scenarios was higher for Scenario 18. A review of associated subjective (questionnaire) data for Scenario 18 indicated that vectoring and speed adjustments may have contributed to higher total times on frequency for that scenario. It is also assumed that the larger sector and higher traffic volume in Arrival North may account for the slightly elevated average time on frequency for that sector across all scenarios.



	Scenario 17	Scenario 18	Scenario 19	Scenario 20	Position Mean
Arrival North	317	253	144	199	228
Arrival South	144	185	148	150	157
Approach North	161	239	158	181	185
Approach South	160	221	114	172	167
Scenario Mean	195	224	141	175	

Figure 64. Total Time on Frequency for Scenarios 17 through 20 (Runway Configuration Change), per Sector

4.2.2 Aircraft Counts and Mean Time on Frequency

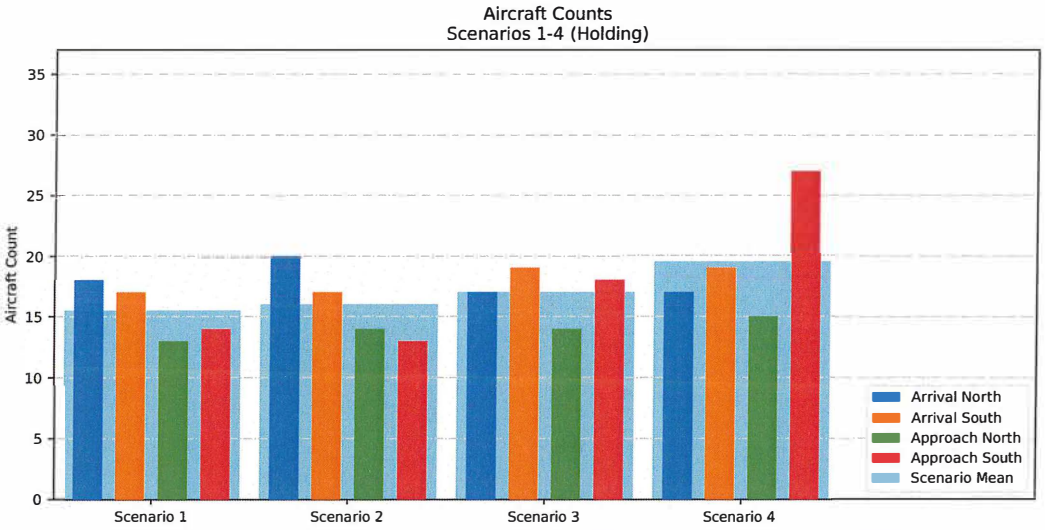
Figure 65 through Figure 69 show the total number of aircraft per sector/position for each scenario. These totals refer to the sum of aircraft with unique call signs that the simulation determined were on a specific sector frequency during the scenario run. Although total scenario aircraft arrival and departure counts are mostly a function of scenario design, determining the aircraft count *per sector* allows the mean time on frequency per sector and per scenario to be calculated. This ensures that no one sector is overloaded given the proposed airspace design, and that scenario times are consistent with their intended complexity levels.

Figure 65 also shows the total number of aircraft for Scenarios 1 through 4, which involved holding operations. The range of the total aircraft count for holding scenarios was between 13 (Approach North, Scenario 1 and Approach South, Scenario 2) and 27 (Approach South, Scenario 4).

The table for Figure 65 shows the mean time on frequency per aircraft/per scenario and the mean time on frequency per aircraft/per position for holding scenarios. As shown, the average time per aircraft per scenario was markedly higher for Scenario 4 (21 minutes per aircraft) and the average time per aircraft per sector was slightly higher for Approach North (14 minutes per aircraft).

The aircraft count in the Approach South sector for Scenario 4 appeared high and inconsistent with other counts for similar scenarios, and the average time per aircraft per scenario

was also inconsistent. These findings led to a detailed review of the traffic file, scenario data and questionnaire data. The arrival rates for the traffic file used in Scenario 4 were identical to the arrival rates for the traffic files used for Scenarios 1 through 3. A review and analysis of Scenario 4 performance data showed that the entry and exit methods used for the holding aircraft in the Approach South sector were somewhat inefficient, resulting in an excessive number of aircraft within the Approach South sector during Scenario 4. The higher total aircraft count in this sector, in turn, led to a higher average time per aircraft per frequency. The questionnaire data, however, indicated that the participant felt no impacts of the additional traffic in terms of workload, complexity, or situational awareness. Further, the participants indicated that the holding procedures (e.g., leg lengths, locations, etc.) were acceptable. The conclusion is that the holding procedures, including standard entry and exit methods, are acceptable as proposed and require no further adjustments.



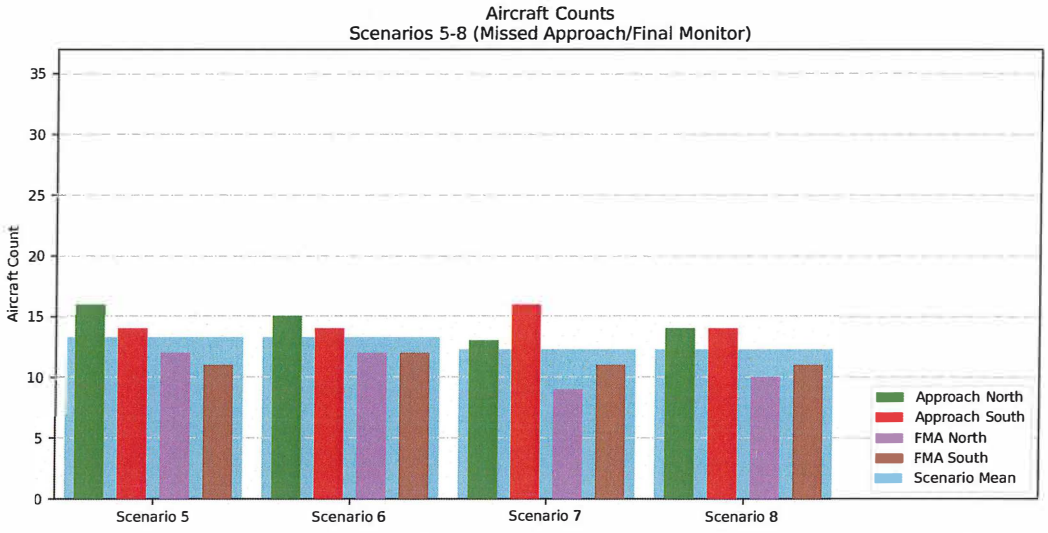
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Mean time on frequency
Arrival North	18	20	17	17	12.7 min per aircraft
Arrival South	17	17	19	19	12.6 min per aircraft
Approach North	13	14	14	15	14.0 min per aircraft
Approach South	14	13	18	27	11.6 min per aircraft
Mean time on frequency	8.6 min per aircraft	8.5 min per aircraft	10.5 min per aircraft	21.0 min per aircraft	

Figure 65. Aircraft Counts and Aircraft Mean Time on Frequency for Scenarios 1 through 4 (Holding), per Sector and per Scenario

Figure 66 shows the total number of aircraft for Scenarios 5 through 8, which included missed approach, and final monitor operations. The range of the total aircraft count for Scenarios 5 through 8 was between 9 (FMA North, Scenario 7) and 16 (Approach North, Scenario 5 and Approach South, Scenario 7).

The table for Figure 66 shows the mean time on frequency per aircraft/per scenario and the mean time on frequency per aircraft/per position for missed approach/final monitor scenarios. As shown, the average time per aircraft per scenario was consistent across Scenarios 5 through 8. The average time per aircraft per sector was slightly higher for Approach South (10 minutes per

aircraft). The total aircraft count in Approach South during Scenarios 5 through 8 may account for the slightly higher mean time on frequency per aircraft across scenarios. A detailed review of questionnaire data revealed that vectoring and integration of missed approaches for Approach South may have also contributed to higher mean time on frequency values.

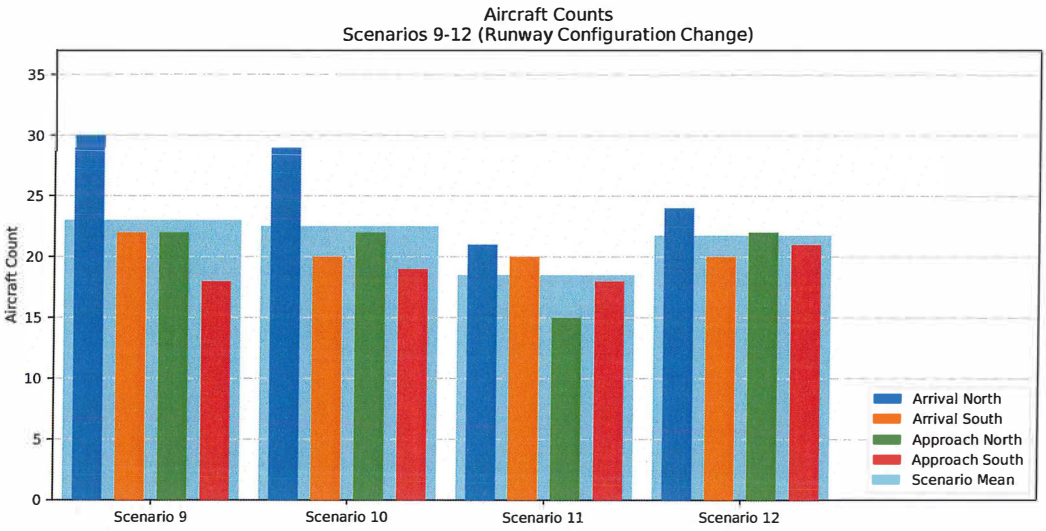


	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Mean time on frequency
Approach North	16	15	13	14	7.6 min per aircraft
Approach South	14	14	16	14	10.0 min per aircraft
FMA North	12	12	9	10	5.2 min per aircraft
FMA South	11	12	11	11	5.1 min per aircraft
Mean time on frequency	7.0 min per aircraft	6.6 min per aircraft	7.9 min per aircraft	7.5 min per aircraft	

Figure 66. Aircraft Counts and Aircraft Mean Time on Frequency for Scenarios 5 through 8 (Missed Approach/Final Monitor), per Sector and per Scenario

Figure 67 shows the total number of aircraft for Scenarios 9 through 12, which included changes to runway configuration. The range of the total aircraft count for Scenarios 9 through 12 was between 15 (Approach North, Scenario 11) and 30 (Arrival North, Scenario 9).

The table for Figure 67 shows the mean time on frequency per aircraft/per scenario and the mean time on frequency per aircraft/per position for runway configuration change scenarios. As shown, the average time per aircraft per scenario was consistent across Scenarios 9 through 12. The average time per aircraft per sector was also consistent across all positions for Scenarios 9 through 12.

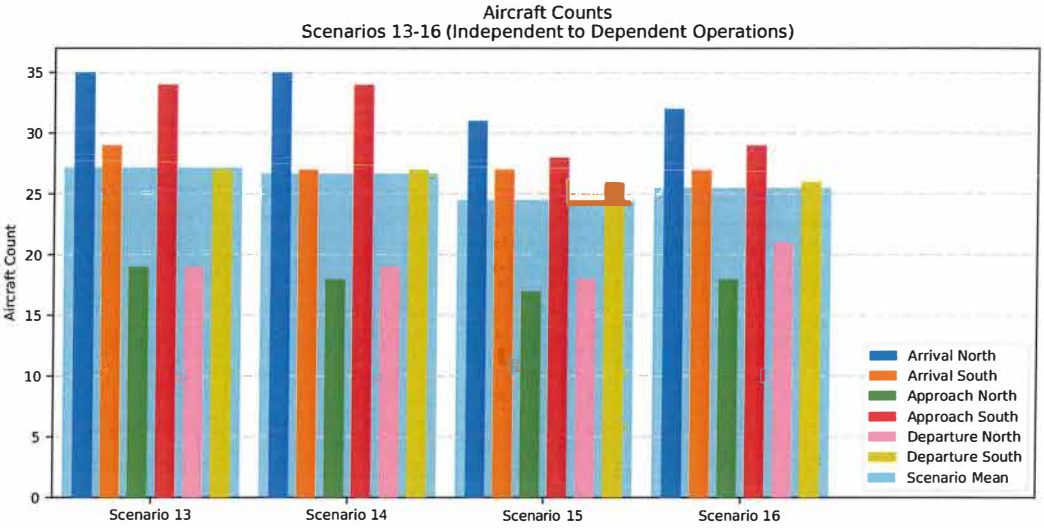


	Scenario 9	Scenario 10	Scenario 11	Scenario 12	Mean time on frequency
Arrival North	30	29	21	24	10.8 min per aircraft
Arrival South	22	20	20	20	9.0 min per aircraft
Approach North	22	22	15	22	9.6 min per aircraft
Approach South	18	19	18	21	8.3 min per aircraft
Mean time on frequency	9.5 min per aircraft	9.7 min per aircraft	10.0 min per aircraft	9.0 min per aircraft	

Figure 67. Aircraft Counts and Aircraft Mean Time on Frequency for Scenarios 9 through 12 (Runway Configuration Change), per Sector and per Scenario

Figure 68 shows the total number of aircraft for Scenarios 13 through 16, which included changes from independent to dependent operations. The range of the total aircraft count for Scenarios 9 through 12 was between 17 (Approach North, Scenario 15) and 35 (Arrival North, Scenarios 13 and 14).

The data table for Figure 68 shows the mean time on frequency per aircraft/per scenario and the mean time on frequency per aircraft/per position for independent to dependent operations scenarios. As shown, the average time per aircraft per scenario was consistent across Scenarios 13 through 16. The average time per aircraft per sector was also consistent across all positions for Scenarios 13 through 16.

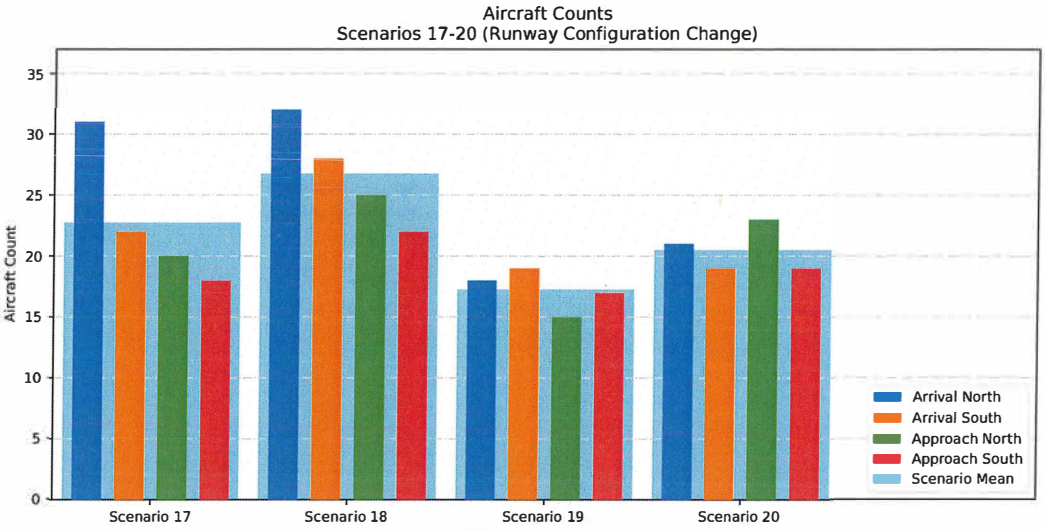


	Scenario 13	Scenario 14	Scenario 15	Scenario 16	Mean time on frequency
Arrival North	35	35	31	32	7.4 min per aircraft
Arrival South	29	27	27	27	6.6 min per aircraft
Approach North	19	18	17	18	6.5 min per aircraft
Approach South	34	34	28	29	6.2 min per aircraft
Departure North	19	19	18	21	7.7 min per aircraft
Departure South	27	27	26	26	8.2 min per aircraft
Mean time on frequency	7.0 min per aircraft	6.8 min per aircraft	7.2 min per aircraft	7.3 min per aircraft	

Figure 68. Aircraft Counts and Aircraft Mean Time on Frequency for Scenarios 13 through 16 (Independent to Dependent Operations), per Sector and per Scenario

Figure 69 shows the total number of aircraft for Scenarios 17 through 20, which included changes to runway configuration. The range of the total aircraft count for Scenarios 17 through 20 was between 15 (Approach North, Scenario 19) and 32 (Arrival North, Scenario 18).

The table for Figure 69 shows the mean time on frequency per aircraft/per scenario and the mean time on frequency per aircraft/per position for runway configuration change scenarios. As shown, the average time per aircraft per scenario was consistent across Scenarios 17 through 20. The average time per aircraft per sector was also consistent across all positions for Scenarios 17 through 20.



	Scenario 17	Scenario 18	Scenario 19	Scenario 20	Mean time on frequency
Arrival North	31	32	18	21	9.0 min per aircraft
Arrival South	22	28	19	19	7.1 min per aircraft
Approach North	20	25	15	23	8.9 min per aircraft
Approach South	18	22	17	19	8.8 min per aircraft
Mean time on frequency	8.6 min per aircraft	8.4 min per aircraft	8.2 min per aircraft	8.6 min per aircraft	

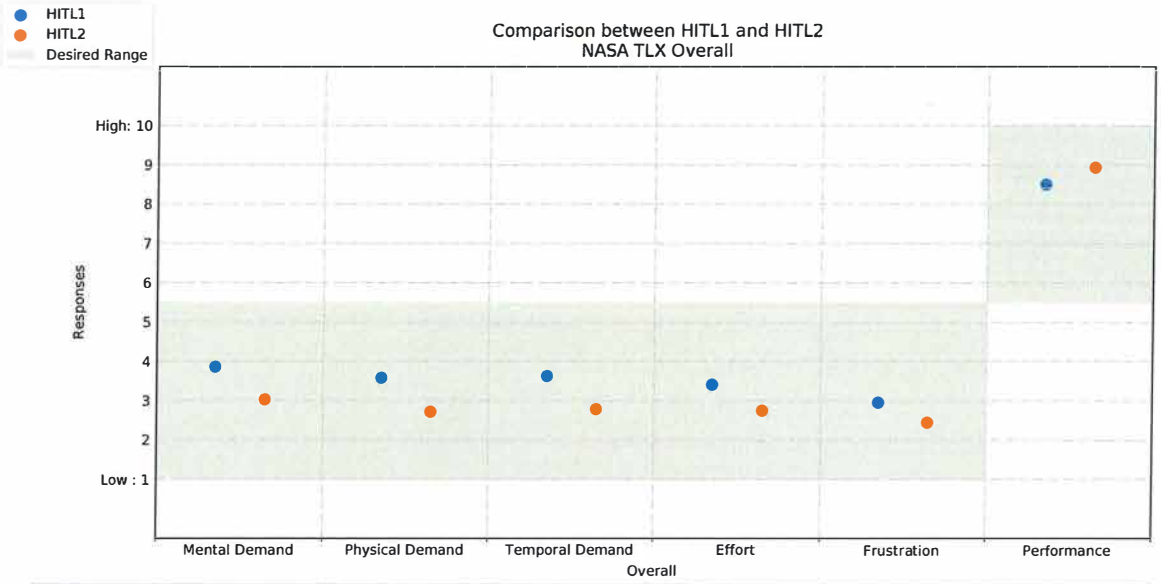
Figure 69. Aircraft Counts and Aircraft Mean Time on Frequency for Scenarios 17 through 20 (Runway Configuration Change), per Sector and per Scenario

4.3 Comparative Analysis

Eight[9] questions in the second HITL simulation evaluation were repeat questions from the first HITL simulation evaluation; that is, they are questions that were asked of all participants in each scenario of both HITLs. The answers to the nine questions in the first HITL simulation evaluation were compared to the answers to the same nine questions in the second HITL simulation evaluation to determine any general trends between the two HITL simulation evaluations. The results of these comparisons are discussed in this section.

The NASA-TLX was used to measure workload for all participants across all scenarios in both the first and second HITL simulation evaluations. The NASA-TLX is made up of six subscales; the overall mean value for each of those six subscales for the first and second HITL simulation evaluations are presented in Figure 70. As shown, the overall mean values for each of the workload subscales improved from the first HITL simulation to the second HITL simulation.

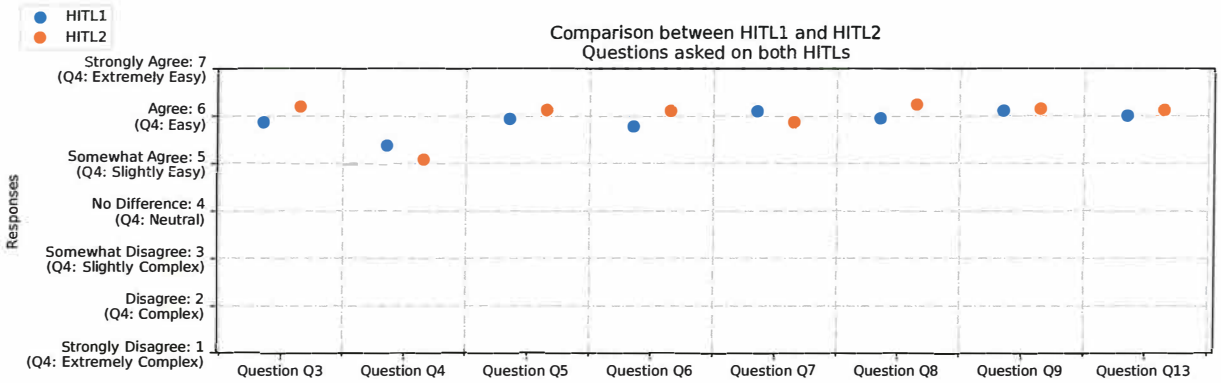
[9] A ninth question is also included in the comparative analysis, but it was only provided to participants operating Departure North sectors in scenarios involving Runway 12L operations at MMUN.



Scenario	Mental Demand	Physical Demand	Temporal Demand	Effort	Frustration	Performance
HITL1 - Mean	3.86	3.58	3.63	3.41	2.95	8.5
HITL2 - Mean	3.04	2.72	2.79	2.75	2.45	8.94

Figure 70. Comparison of Overall NASA-TLX in the First and the Second HITL Simulation Evaluations

Figure 71 presents a comparison of the overall mean values for seven additional questions which were asked of all participants across all scenarios in both the first and second HITL simulation evaluations. These questions included workload, complexity, ability to attend to normal and unusual events, situational awareness, and communication. As shown, improvements were seen in workload, the ability to attend to normal and unusual events, and communications. Overall complexity appeared to increase slightly, which would be expected given the addition of off-nominal events. Situational awareness also appears to have decreased between the first and second HITL simulation evaluations; again, this is likely caused by the introduction of off-nominal events.

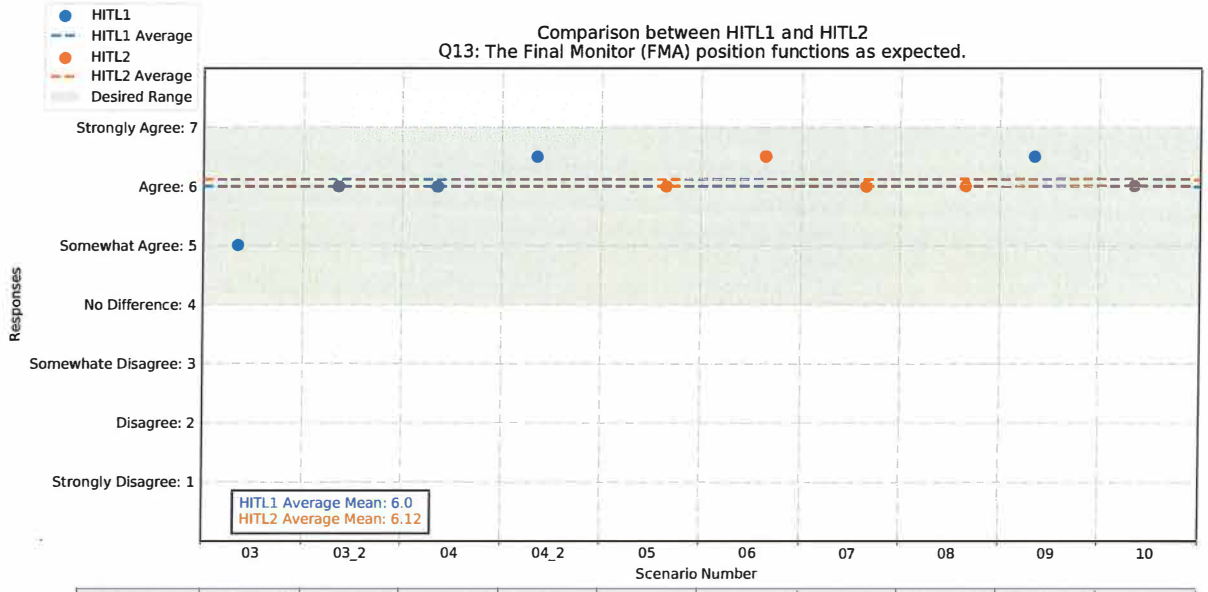


Question Text	Q3:My workload in this scenario was acceptable.	Q4:How complex was this scenario?	Q5:In this scenario I could easily attend to normal everyday events (e.g. controlling traffic, communications, coordination etc.).	Q6:In this scenario I could attend to new unexpected events (e.g. holding, missed approaches, or offloads to another runway etc.).	Q7:Within this scenario, I felt like I had a thorough understanding of the current situation, could take appropriate actions as needed, and could anticipate the future situation and conditions well in advance.	Q8:I could effectively communicate with adjacent sectors in this scenario.	Q9:I could effectively communicate with pseudo-pilots in this scenario.	Q13:The Final Monitor (FMA) position functions as expected.
HITL1	5.88	5.38	5.95	5.79	6.1	5.96	6.1	6.0
HITL2	6.22	5.08	6.14	6.12	5.88	6.24	6.15	6.12

Figure 71. Comparison Between Overall Mean Values of Questions Asked in Both the First and the Second HITL

During the first HITL simulation evaluation, participants indicated that the data blocks on the FMA display presented information in a way that was inconsistent with data block information presentation on ATC displays at other sector positions. The data block design was modified to emulate the data block on other displays during the first HITL simulation evaluation, and the updated data block format for the FMA display was also used in the second HITL simulation evaluation.

A comparison of the results for Question 13 is provided in Figure 72. Question 13 asked participants if the FMA position functioned as expected. Responses between the first HITL simulation evaluation and the second HITL simulation evaluation indicated that there was a slight improvement in the position meeting expectations.



Scenario	03	03_2	04	04_2	05	06	07	08	09	10
HITL1 - Mean	5.0	6.0	6.0	6.5					6.5	6.0
HITL2 - Mean					6.0	6.5	6.0	6.0		

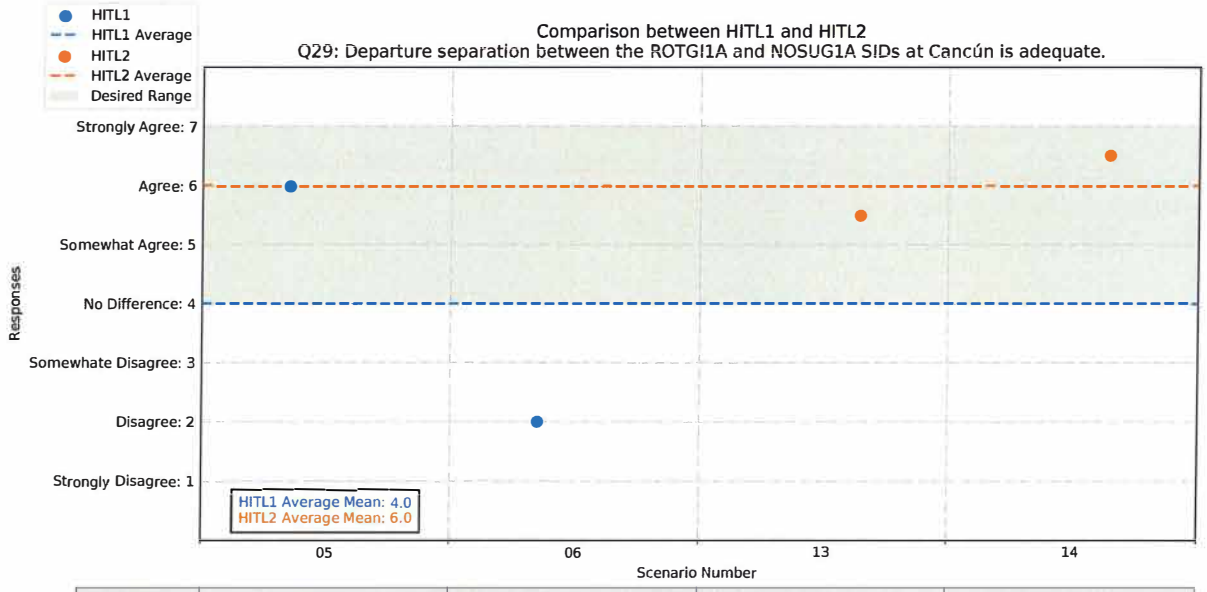
Figure 72. Comparison of Mean Values for Question 13 in Both the First and Second HITL Simulation Evaluations

Following the conclusion of the first HITL simulation evaluation, departure separation between the NOSUG and ROTGI SIDs was discussed with SENEAM in detail. SENEAM reviewed the design of the ROTGI departure and made some changes to waypoint locations, based upon the findings of the first HITL simulation evaluation. These changes were then re-evaluated during the second HITL simulation evaluation.

A comparison of the results for Question 29 is provided in Figure 73. Question 29 asked participants to provide feedback on the sufficiency of departure separation between the ROTGI and NOSUG departures during Runway 12 operations. Responses were split for Scenarios 5 and 6 during the first HITL simulation evaluation: one participant agreed that departure separation was adequate, while another participant disagreed indicating that departure separation between the ROTGI and NOSUG SIDs was not adequate. For the second HITL simulation evaluation, all participants[10] agreed that the departure separation for the ROTGI and NOSUG

[10] In the second HITL simulation evaluation design, only two participants were planned to be asked this question, as there would only be two scenarios in which Runway 12 operations were in effect for departures. In the end, it was determined that it would be beneficial to obtain input from all four controller participants on this topic, versus only two. Therefore, two additional runs were conducted with the remaining controller participants, and their input to this specific question was obtained and included in the analysis. No additional questionnaire data from the additional runs were included in the analysis of the second HITL simulation evaluation.

SIDs during Runway 12L operations at MMUN was adequate, despite the departure design changes resulting in less space between the SIDs in the second HITL simulation evaluation than in the first HITL simulation evaluation.



Scenario	05	06	13	14
HITL1 - Mean	6.0	2.0		
HITL2 - Mean			5.5	6.5

Figure 73. Comparison of Overall Mean Values for Question 29 in Both the First and Second HITL Simulation Evaluations

5. Conclusions

5.1 Summary of the Study

A new airspace design for the Cancún/Cozumel TMA has been developed to support dual independent operations for MMUN. The implementation of dual independent operations at MMUN will establish the Cancún/Cozumel TMA as an operational test-bed so that controllers may gain valuable experience in conducting such complex operations and be better prepared for managing dual- and triple-independent operations at NAICM. The purpose of the second HITL simulation evaluation was to study whether the airspace design could support dual independent operations at MMUN under off-nominal conditions. It is worth adding that, ultimately, MMUN itself will benefit by its ability to operate independent operations.

The objective of this second HITL simulation evaluation was to identify any potential issues associated with use of the proposed airspace design during off-nominal events and to assist in the resolution of any issues discovered. The simulation allowed Cancún Approach Control controllers to evaluate the new airspace design interactively by controlling simulated traffic in

specific operational situations, or scenarios. Using many diverse scenarios, the proposed airspace design was evaluated under off-nominal operating conditions.

Within the second HITL simulation evaluation, the airspace design was evaluated using perceived (or subjective) measures, as well as observed (or objective) measures. The second HITL simulation evaluation also sought to examine user acceptability and viability of the proposed airspace design during off-nominal events, such as use of holding or changes to runway configuration at MMUN. Beyond researching and collecting data on the impact of the airspace design on situation awareness and workload, subjective data were also collected regarding communications, operational suitability of the concept of use, and interactions with the system.

As previously mentioned, the research questions investigated during this study were:

- Is the proposed airspace design acceptable?
- Does the proposed airspace design support off-nominal events?
- Is workload based upon the proposed airspace design acceptable under off-nominal conditions?
- Does the proposed airspace design increase workload?
- What issues, if any, can be identified with the proposed airspace design?

5.2 Findings

5.2.1 Finding #1: The results of the study point to controller acceptance of the proposed airspace design for dual independent operations

Participants indicated that the proposed airspace design is adequate to support dual independent operations at MMUN, even under off-nominal conditions. The results showed:

- Participants could complete all tasks given the procedures and the sectors as designed
- The airspace design was sufficient to accommodate the integration or sequencing of traffic and modifications to the sector airspace provided sufficient airspace to maneuver, merge, and sequence traffic from various arrival streams
- The design was sufficient to accommodate the interaction between MMUN and MMCZ arrival and departure traffic
- The Final Monitor position and FMA display functioned as anticipated

5.2.2 Finding #2: Based upon the subjective and objective data collected during the simulation, the proposed airspace design supports off-nominal events

In scenarios focused on holding, or operations which incorporated a holding pattern into each of the four main arrival streams into MMUN, participants agreed that the number of proposed holding patterns (four) was sufficient to accommodate holding needs during dual independent operations, including the use of a single holding pattern on the SIGMA STAR for arrivals to MMUN from the southeast. Participants felt that the locations of the holding patterns were

sufficient, and that 10 NM leg lengths were adequate. Additional holding patters were also provided at specific fix locations on downwind (to accommodate holds for arrival traffic that had passed the initial holding patterns). Participants agreed that these downwind holding patterns were necessary, and these holding patterns were added to the final airspace design. Participants also indicated that leg lengths of 5 NM for downwind holding patterns were sufficient and that the downwind holding patterns were sufficiently separated from MMUN departure traffic.

In scenarios involving missed approaches, blunders, and breakouts, participants felt the procedures were sufficient to allow them to re-sequence arrival aircraft into the pattern once an aircraft executed a missed approach. They were also satisfied with the interactions of missed approaches and departures at MMUN. Participants could recognize blunders at the Final Monitor position and successfully recognized the need for initiating breakouts at the Final Monitor position.

Participants were confident in their ability to continue with dual independent operations during scenarios where runway configurations were changed at MMUN. They were successful in maintaining dual independent operations after the change, including re-sequencing aircraft that were on the FAC, but required a route change or breakout with vectors to the new runway configuration in use.

Participants were successfully able to change from independent to dependent operations using the proposed airspace design and procedures.

Participants indicated that they were comfortable with offloading arrival aircraft to achieve runway balancing when necessary.

5.2.3 Finding #3: Controllers rated their workload within the proposed airspace design as acceptable across all scenarios, regardless of the position they worked or the focus of the scenario

Participants felt they were successful in managing tasks across all scenarios. Controllers rated their workload as acceptable in terms of mental demand, physical demand, temporal demand, effort, frustration, and performance across all scenarios. Participants indicated they could communicate with adjacent sectors and pseudo-pilots, although they did report experiencing problems with pseudo-pilot performance in four scenarios. (The pseudo-pilot performance issues were a combination of pseudo-pilot errors and simulation platform errors.) Participants agreed that they could maintain situational awareness across all scenarios. Most participants indicated that they did not deal with difficult situations within the scenarios.

5.2.4 Finding #4: Based upon the subjective and objective data collected during the simulation, the proposed airspace design would not increase workload

The participants successfully managed aircraft under various configurations of dual independent operations at MMUN. The participants:

- Indicated that they could respond to normal events, as well as new, unexpected events; similarly, they could respond to and resolve abnormal situations whenever necessary
- Felt they were successful in completing their tasks, overall

- Indicated that all scenarios were manageable and easy, despite the off-nominal events simulated
- Felt that the demands of the tasks were acceptable, did not require excessive effort, and their level of frustration was low across all scenarios

The subjective data collected during the second HITL simulation evaluation indicated that participants found the workload to be acceptable using the proposed airspace design at operation rates consistent with current operational levels, even under off-nominal conditions. Further, their level of frustration appeared relatively consistent over the duration of the HITL simulation evaluation, which suggests that participants were comfortable with the airspace design and were not impacted by variables in the simulation (e.g., off-nominal events).

5.2.5 Finding #5: Previously suggested modifications to the airspace design were successfully implemented and no new issues with the proposed airspace design were noted

After the first HITL simulation evaluation, several issues were identified with the original proposed airspace design. As a result, several changes were made to the airspace prior to the execution of the second HITL simulation evaluation. Those changes included addition of airspace to arrival and approach sectors, addition of restrictions to accommodate merging traffic, updates to interface presentations on the FMA display, and the movement of procedure routes to avoid potential conflicts. In addition to evaluating the impact of off-nominal events on the airspace design, these changes were also evaluated in the second HITL simulation evaluation.

The results of the second HITL simulation evaluation indicate that the issues identified during the first HITL simulation evaluation were resolved. Further, no new issues of significance related to the proposed airspace design were identified by participants during the second HITL simulation evaluation. Finally, a review of comments obtained from the questionnaires and group discussions did not yield any new data regarding concerns.

5.3 Closing Remarks

The second HITL simulation evaluations were successful and all objectives were met. Overall, the Cancún controllers expressed to be pleased and satisfied with the airspace design. The entire HITL work took place at MITRE out of contractual scope and at no charge. **With this delivery, MITRE's Cancún-related HITL simulation evaluation contractual obligation has been completed**.

Additionally, **MITRE's contractual obligations concerning assistance to SENEAM on the planned implementation of dual independent test-bed operations at Cancún have been completed**. MITRE, however, remains available for consultation. Furthermore, MITRE would be available, during the dual independent operation testing phase after appropriate equipment, such as the FMA, is installed.

Appendix A

Second HITL Simulation Evaluation Scenarios

The following contains detailed information on each scenario evaluated during the second HITL simulation evaluation. The information presented in the following tables includes the scenario name, the individual scenario objectives, the runway direction, the list of sectors that were evaluated, and the number of positions/sectors in the scenario.

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Table A-1. Second HITL Simulation Evaluation Practice Scenarios: 1 Through 6

Scenario #	Scenario Name	Objective: What is (are) the Question(s) to be Answered?	Main Airports Runway Flow Direction	List of "Connected" Positions to be Run Simultaneously	Number of Sectors/Positions in HITL
Practice Scenarios 1 and 2	MMUN Runway 12 Arrival and Approach	1. Re-familiarize TMA controllers with dual independent procedures including Duals Bar 2. Re-familiarize TMA controllers with new arrival and approach airspace 3. Introduce runway balancing options for arrival controllers 4. Re-familiarize TMA controllers with Continuous Descent Operations (CDO) altitudes and procedures	MMUN 12	Arrival North Approach North Arrival South Approach South	4
Practice Scenarios 3 and 4	3A/4A MMUN Runway 12 MMCZ Runway 11 3B/4B MMUN Runway 30 MMCZ Runway 29	1. Re-familiarize TMA controllers with new departure airspace 2. Introduce interactions between MMUN and MMCZ procedures	MMUN 12 and MMCZ 11 or MMUN 30 and MMCZ 29	Departure North Departure South	2
Practice Scenarios 5 and 6	MMUN Runway 30 Arrival and Approach	1. Re-familiarize TMA controllers with dual independent procedures including Duals Bar 2. Re-familiarize TMA controllers with new arrival and approach airspace 3. Introduce runway balancing options for arrival controllers 4. Re-familiarize TMA controllers with Continuous Descent Operations (CDO) altitudes and procedures	MMUN 30	Arrival North Approach North Arrival South Approach South	4

Table A-2. Second HITL Simulation Evaluation Actual Scenarios: 1 Through 4

Scenario #	Scenario Name	Objective: What is (are) the Question(s) to be Answered?	Main Airports Runway Flow Direction	List of "Connected" Positions to be Run Simultaneously	Number of Sectors/Positions in HITL
Actual Scenarios 1 and 2	Holding MMUN Runway 12 Arrival and Approach	1. Evaluate airspace design for each sector/position 2. Evaluate placing aircraft in the holding patterns inside the Cancún/Cozumel TMA and taking aircraft out of the holding pattern 3. Evaluate the holding patterns proposed by MITRE located on the downwind legs	MMUN 12	Arrival North Approach North Arrival South Approach South	4
Actual Scenarios 3 and 4	Holding MMUN Runway 30 Arrival and Approach	1. Evaluate airspace design for each sector/position 2. Evaluate placing aircraft in the holding patterns inside the Cancún/Cozumel TMA and taking aircraft out of the holding pattern 3. Evaluate the holding patterns proposed by MITRE located on the downwind legs	MMUN 30	Arrival North Approach North Arrival South Approach South	4

Table A-3. Second HITL Simulation Evaluation Actual Scenarios: 5 Through 8

Scenario #	Scenario Name	Objective: What is (are) the Question(s) to be Answered?	Main Airports Runway Flow Direction	List of "Connected" Positions to be Run Simultaneously	Number of Sectors/Positions in HITL
Actual Scenarios 5 and 6	Missed Approaches, Breakouts, Blunders MMUN Runway 12 Approach and Final Monitor	1. Evaluate airspace design for each sector/position 2. Evaluate interactions between missed approaches and departures 3. Revisit Final Monitor position with pronounced breakouts and blunders	MMUN 12	Approach North Final Monitor North Approach South Final Monitor South	4
Actual Scenarios 7 and 8	Missed Approaches, Breakouts, Blunders MMUN Runway 30 Approach and Final Monitor	1. Evaluate airspace design for each sector/position 2. Evaluate interactions between missed approaches and departures 3. Revisit Final Monitor position with pronounced breakouts and blunders	MMUN 30	Approach North Final Monitor North Approach South Final Monitor South	4

Table A-4. Second HITL Simulation Evaluation Actual Scenarios: 9 Through 12

Scenario #	Scenario Name	Objective: What is (are) the Question(s) to be Answered?	Main Airports Runway Flow Direction	List of "Connected" Positions to be Run Simultaneously	Number of Sectors/Positions in HITL
Actual Scenarios 9 and 10	MMUN and MMCZ Landing Direction Change (Flip) MMUN Runway 12 to Runway 30 MMCZ Runway 11 to Runway 29 Arrival and Departure	1. Evaluate airspace design for each sector/position 2. Evaluate changing the runway operating direction with dual independent operations for both airports	MMUN 12 and MMCZ 11 flipped to MMUN 30 and MMCZ 29	Arrival North Departure North Arrival South Departure South	4
Actual Scenarios 11 and 12	MMUN and MMCZ Landing Direction Change (Flip) MMUN Runway 30 to Runway 12 MMCZ Runway 29 to Runway 11 Arrival and Departure	1. Evaluate airspace design for each sector/position 2. Evaluate changing the runway operating direction with dual independent operations for both airports	MMUN 30 and MMCZ 29 flipped to MMUN 12 and MMCZ 11	Arrival North Departure North Arrival South Departure South	4

Table A-5. Second HITL Simulation Evaluation Actual Scenarios 13 Through 16

Scenario #	Scenario Name	Objective: What is (are) the Question(s) to be Answered?	Main Airports Runway Flow Direction	List of "Connected" Positions to be Run Simultaneously	Number of Sectors/Positions in HITL
Actual Scenarios 13 and 14	Independent to Dependent Approaches, Offload STARs; Combining Sectors MMUN Runway 12 MMCZ Runway 11 Arrival, Approach, Departure	1. Evaluate airspace design for each sector/position 2. Evaluate changing the operating mode of the airport from independent to dependent operations 3. Evaluate the offload STARs 4. Evaluate combining sectors	MMUN 12 and MMCZ 11	Arrival North Approach North Arrival South Approach South switching to Combined Arrival North/South Combined Approach North/South Departure North Departure South	4
Actual Scenarios 15 and 16	Independent to Dependent Approaches, Offload STARs; Combining Sectors MMUN Runway 30 MMCZ Runway 29 Arrival, Approach, Departure	1. Evaluate airspace design for each sector/position 2. Evaluate changing the operating mode of the airport from independent to dependent operations 3. Evaluate the offload STARs 4. Evaluate combining sectors	MMUN 30 and MMCZ 29	Arrival North Approach North Arrival South Approach South switching to Combined Arrival North/South Combined Approach North/South Departure North	4

Table A-6. Second HITL Simulation Evaluation Actual Scenarios 17 Through 20

Scenario #	Scenario Name	Objective: What is (are) the Question(s) to be Answered?	Main Airports Runway Flow Direction	List of "Connected" Positions to be Run Simultaneously	Number of Sectors/Positions in HITL
Actual Scenarios 17 and 18	MMUN Landing Direction Change (Flip) MMUN Runway 12 to Runway 30 MMCZ Runway 11 Arrival and Departure	1. Evaluate airspace design for each sector/position 2. Evaluate changing the runway operating direction with dual independent operations for both airports	MMUN 12 and MMCZ 11 flipped to MMUN 30 and MMCZ 11	Arrival North Approach North Arrival South Approach South	4
Actual Scenarios 19 and 20	MMUN Landing Direction Change (Flip) MMUN Runway 30 to Runway 12 MMCZ Runway 11 Arrival and Departure	1. Evaluate airspace design for each sector/position 2. Evaluate changing the runway operating direction with dual independent operations for both airports	MMUN 30 and MMCZ 11 flipped to MMUN 12 and MMCZ 11	Arrival North Approach North Arrival South Approach South changing after flip to Arrival North Departure North Arrival South Departure South	4

Appendix B

Questionnaires

This appendix describes the questions that were asked to the participants during the second HITL simulation evaluations.

The first question required participants to identify the scenario they had just completed, and the second question required participants to identify the position they worked in the scenario. A base set of 18 questions were presented that were identical and repeated on each questionnaire. Twenty-four additional questions were scenario-specific and position-specific; that is, certain questions were only asked on specific scenarios, and were only presented to participants, as applicable, based upon their response to the first question of what position they staffed in the preceding scenario. The final question was open-ended and always appeared as the last question to each survey, with the intent of capturing any comments that participants wanted to provide after the questionnaire.

The full list of all possible questions[11] is provided in Table B-1 below.

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[11] Some questions have been slightly modified for clarity from what was presented to participants during the HITL simulation evaluations.

Table B-1. Full Questionnaire List

Question Identification #	Question Text
BASE QUESTIONS	
Q0	Please identify the scenario number.
Q1*[12]	What was your role in this simulation scenario?
Q2*	Please evaluate the air traffic control tasks you performed in the scenario you just completed. Select one number on each of the five scales that best matches your experience. Please consider your responses carefully so as to distinguish among the different simulation conditions. Consider each scale individually.
Q2(a)*	Mental Demand: Rate the amount of mental and perceptual activity required during your work task (e.g., thinking, deciding, calculating, remembering, looking, and searching).
Q2(b)*	Physical Demand: Rate the amount of physical activity required to accomplish your tasks (e.g., data inputs, writing, and talking).
Q2 (c)*	Temporal Demand: Rate the amount of time pressure felt due to the rate or pace at which the task time progressed (e.g., slow and leisurely OR rapid and frantic).
Q2 (d)*	Effort: Rate how hard you had to work (mentally and physically) to accomplish the tasks during the scenario.
Q2 (e)*	Frustration: Rate the amount of frustration you experienced while accomplishing your tasks (e.g., gratified, content, relaxed, and complacent OR discouraged, irritated, stressed, and annoyed).
Q2 (f)*	Performance: Rate how successful you think you were in accomplishing your task of controlling traffic (e.g., unsuccessful OR successful with your performance).
Q3*	My workload in this scenario was acceptable.
Q4*	How complex was this scenario?

[12] An asterisk (*) designates that the question is a repeat question; that is, it was a question previously asked in the first HITL simulation evaluation.

Question Identification #	Question Text
Q5*	In this scenario, I could easily attend to normal, everyday events (e.g., controlling traffic, communications, coordination, etc.).
Q6*	In this scenario, I could attend to new, unexpected events (e.g., unanticipated changes to traffic, such as moving an aircraft from the north runway to the south runway, etc.).
Q7*	The term "situation awareness" refers to what is commonly known as "staying ahead of the curve," where a user has a thorough understanding of the current situation, can take appropriate action as necessary, and can anticipate future decisions well in advance. Given the conditions in this scenario (traffic l evels, sector design, STARs/SIDs), please indicate on the scale your level of agreement with the following statement: Within this scenario, I felt like I had a thorough understanding of the current situation, could take appropriate actions as needed, and could anticipate the future situation and conditions well in advance.
Q8*	I was able to effectively communicate with adjacent sectors in this scenario.
Q9*	I was able to effectively communicate with pseudo-pilots in this scenario.
Q32	I could manage the traffic using the sectors as designed.
Q35	I could manage the traffic using the procedures as designed.
Q36	I could complete all tasks given the procedures provided.
Q48	I could complete all tasks given the sectors as designed.
Q53	Did you have any issues or problems with pseudo-pilot performance in this scenario?
SCENARIO AND POSITION-SPECIFIC QUESTIONS	
General Questions	
Q13*	The Final Monitor position functions as expected.

Question Identification #	Question Text
Q37	The modifications to the Approach sector designs provide sufficient space to maneuver, merge, or sequence traffic from various (arrival) streams.
Q38	The modification to the EMOSA STAR is sufficient to ensure separation with arrivals on the NOSAT STAR.
Q39a	The location of fix UN523 is sufficient to merge traffic from the DANUL and SIGMA STARs.
Q39b	The location of fix UN613 is sufficient to merge traffic from the DANUL and SIGMA STARs.
Q52	The airspace design (sector design, procedures) is sufficient to accommodate the integration of Cancún [MMUN] and Cozumel [MMCZ] arrivals with Cancún [MMUN] and Cozumel [MMCZ] departures.
Q29*	Departure separation between the ROTGI1A and NOSUG1A SIDs at MMUN (shown below) is adequate.
Holding Questions	
Q20	The number of proposed holding patterns is sufficient to accommodate holding needs during dual independent operations.
Q21	The locations of the proposed holding patterns are sufficient.
Q40a	The single proposed holding pattern for the SIGMA and DANUL STARs is sufficient.
Q40b	The single proposed holding pattern on the SIGMA STAR is sufficient.
Q45a	Additional holding patterns on downwind at UN501 or UN509 were necessary.
Q45b	Additional holding patterns on downwind at UN600 and UN614 were necessary.
Q46a	Downwind holding patterns at UN501 or UN509 were sufficiently separated from departure traffic off of Cancún International Airport [MMUN].

Question Identification #	Question Text
Q46b	Downwind holding patterns at UN600 or UN614 were sufficiently separated from departure traffic off of Cancún International Airport [MMUN].
Q47	Were the leg lengths of the holding patterns (10 NM) sufficient as proposed?
Q49	Were the leg lengths of 5 NM for holding patterns on the downwind legs sufficient?
Missed Approach Questions	
Q22	I am satisfied with the interactions of missed approaches with departures at Cancún International Airport [MMUN].
Q23	I was able to successfully re-sequence arrival aircraft into the pattern once the aircraft executed a missed approach.
Q24	The missed approach procedures were sufficient to allow aircraft to be re-sequenced into the pattern once the aircraft executed a missed approach.
Runway Configuration Change Questions	
Q27	I could successfully continue with dual independent operations when the runway configuration was changed.
Q28	What is your level of confidence in your ability to continue with dual independent operations when the runway configuration is changed?
Q34	I was able to successfully re-sequence aircraft that were on the Final Approach Course (FAC), but required a reroute or breakout from the FAC for a runway configuration change.
Final Monitor Questions	
Q25	I was able to recognize blunders at the Final Monitor position
Q26	I was able to recognize the need for initiating breakouts at the Final Monitor position
Independent to Dependent Operations Questions	
Q50	I was able to change from independent to dependent operations easily.

Question Identification #	Question Text
Q51	I was able to transition to a combined sector position when operations changed from independent to dependent.
Offloads Questions	
Q33	I was comfortable with offloading aircraft to achieve runway balancing, when necessary.
OPEN-ENDED QUESTIONS	
Q17*	What was the most difficult situation to deal with in this exercise? (If you felt you did not experience any difficult situations in this exercise, please enter "none" or "N/A.")
Q18*	Please provide any final comments you have regarding the simulation scenario you just experienced, including comments on automation, procedures, workload, training, tasking or any other aspects of the simulation exercise.