Enclosure 3

(Ref. Technical Letter F500-L16-028)

MITRE

Center for Advanced
Aviation System Development

Human-In-The-Loop (HITL) Simulations

A General Overview

Prepared for

Aeropuertos y Servicios Auxiliares

March 2016

Principal Acronyms and Abbreviations

ACC	Area Control Center
ATC	Air Traffic Control
BADA	Base of Aircraft Data
FAA	Federal Aviation Administration
HITL	Human-in-the-Loop
ICAO	International Civil Aviation Organization
KOAK	Oakland International Airport (ICAO Code)
KSFO	San Francisco International Airport (ICAO Code)
KSJC	San Jose International Airport (ICAO Code)
MITRE	The MITRE Corporation
MMUN	Aeropuerto Internacional de Cancún (ICAO Code)
NAICM	Nuevo Aeropuerto Internacional de la Ciudad de México
NM	Nautical Mile
NORCAL	Northern California TRACON
PBN	Performance-Based Navigation
SENEAM	Servicios a la Navegación en el Espacio Aéreo Mexicano
SID	Standard Instrument Departure
STAR	Standard Terminal Arrival Route
TRACON	Terminal Radar Approach Control
U.S.	United States

1. Introduction

The MITRE Corporation (MITRE) is assisting Aeropuertos y Servicios Auxiliares and the aviation authorities of Mexico in the development of a new airport, referred to in this document as Nuevo Aeropuerto Internacional de la Ciudad de México (hereinafter, NAICM), to replace the current Aeropuerto Internacional de la Ciudad de México. The proposed runway layout of NAICM will ultimately allow dual- and triple-independent arrival and departure operations. In order to help Mexico prepare for the implementation of independent parallel operations at NAICM, MITRE is assisting the authorities with the implementation of independent parallel arrival and departure operations at Aeropuerto Internacional de Cancún (hereinafter, Cancún) to and from its two existing parallel runways. This would provide a significant increase in capacity for Cancún. Moreover, it would also allow Cancún to serve as a test-bed location where Mexican air traffic controllers could 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 been working closely with Servicios a la Navegación en el Espacio Aéreo Mexicano (SENEAM) by providing important guidance and support regarding the transition to independent operations in Mexico. For example, MITRE provided information on the principal requirements for surveillance, display, and communications for conducting dual- and triple-independent operations, as well as important airspace and Air Traffic Control (ATC) elements to be considered in preparing NAICM and Cancún for conducting such complex operations.

To support the implementation of dual independent operations, the airspace design that will be developed by SENEAM, with MITRE's assistance, needs to be evaluated by local controllers. This evaluation will identify issues with the airspace design that can only be identified through a hands-on handling of simulated aircraft "flying" the newly-developed routes/procedures through newly-developed sectors. Adjustments to the airspace design can then be made and re-evaluated. In recent years such evaluations are normally performed through the use of real-time simulations, known as Human-in-the-Loop (HITL) simulations. HITL simulations can be used either for research and evaluation (this is what MITRE is proposing for NAICM and Cancún) or for training and education. Research and evaluation HITL simulations deal with new aviation concepts and technology that have not yet been fielded, while training and education HITL simulations are for training controllers using existing airspace designs, or familiarizing them with airspace modifications that are soon to be fielded.

The intent of this document is to explain the key differences between the various uses of HITL simulations and provide SENEAM with a better understanding of those differences. The differences will be highlighted through five key areas: environment, ATC system data, human resources, data collection capability, and hardware/software. This document is structured as follows:

- Section 1 provides background and context for MITRE's airspace work
- Section 2 provides a description of research and evaluation HITL simulations
- Section 3 provides a description of training and education HITL simulations

- Section 4 provides a case study of a United States (U.S.) Federal Aviation Administration (FAA) research and evaluation HITL simulation
- Section 5 provides a summary of the differences between the two types of HITL simulations

2. Research and Evaluation Through HITL Simulations

This section provides a description of research and evaluation through HITL simulations, which are used to test new ATC procedures, airspace infrastructure, and concepts in a safe and repeatable environment. Examples of applications of this type of HITL simulation include:

- Testing of proposed ATC procedures and/or sectorization
- Refining ideas and concepts
- Obtaining buy-in by the controller workforce on proposed changes to ATC operations
- Determining use and system acceptability
- Exploring upstream effects of procedure and airspace changes
- Assisting with requirements development of new technology
- Providing input to benefits analysis

The rest of this section is divided into subsections that correspond to five key areas of comparison.

2.1 Environment

The environment for a HITL simulation relates to the fidelity of the display and functionality of the system. For research and evaluation HITL simulations, the environment is designed for concept exploration and maturing of prototype ATC tools. This requires the HITL simulation to be dynamic and flexible to allow for many different scenarios. For instance, the environment could be used for concept exploration one day and evaluation of an airspace design the next. Due to this need for flexibility, the simulation is considered to be of medium fidelity, which means that it is close enough to the actual controllers' system (but is not an exact replica) that they can evaluate the proposed airspace or ATC concept or new technology, but still allow for easy modification of the environment to accommodate changes or modifications, such as changes to sector boundaries, traffic routings or volumes, or expanding the simulation from a single position to multiple positions.

2.2 ATC System Data

The ATC System Data are the files that govern and define each of the waypoints, fixes, routes, procedures, airways, sectors, other airspace boundaries, aircraft performance, and altitude restrictions used to recreate the airspace system. Without these files, the simulated aircraft would not be able to "fly". The modification of these files generally takes (in time) just a few minutes to a single day, which allows for the rapid changing of the environment. These data are

used to represent airspace elements for the currently published elements or for futuristic elements that are not currently fielded. The aircraft performance is initially based on information from the Base of Aircraft Data (BADA)[1] and modified based on the specific aircraft performance experienced at individual airports. For instance, the performance of a Boeing aircraft B737 is different at sea level airports than it is at high altitude airports (such as Mexico City). In addition, the traffic demand level from one scenario to the next can be modified easily and, if necessary, in real time.

2.3 Human Resources

HITL simulations are a complex endeavor that require a variety of specialized staff including human factors engineers, technical staff, and subject matter experts. MITRE human factors engineers are trained in the design, operation, and evaluation of research and evaluation HITL simulations. They oversee the simulation design and running of the simulation, and ensure that the data collected are able to answer the research questions being studied. Technical staff are responsible for designing and updating the software used to operate the simulation. Subject matter experts are experts in aviation (usually former pilots and controllers) who work with the technical staff and human factors engineers to validate and create the experimental and scenario designs. During the simulation design process, "dry runs", which are full rehearsals of a simulation, are scheduled to help validate and refine the experimental design prior to commencing evaluation. Both the dry runs and the actual HITL simulations require a set of simulation pilots (also referred to as pseudo-pilots) who respond to the commands that are given by the controllers participating in these events. During dry runs the subject matter experts will serve as controllers for concept validation.

2.4 Data Collection Capability

Research and evaluation HITL simulation platforms collect numerous metrics. These metrics include objective metrics such as counts of aircraft, number of hand-offs, time simulated aircraft have spent at specific altitudes, time spent in a sector, and audio recordings of the scenario. In addition, subjective metrics such as "workability" of traffic on routes and observations on pilot and controller workload are collected by the human factors engineers to obtain measures that are not directly calculated by data collection mechanics in the simulation. Besides metrics, video, audio, screen captures, and eye tracking capabilities exist for the research and evaluation HITL simulations. At the end of a HITL simulation, human factors engineers will analyze the collected data to determine the answer to the experimental question. For example, the data could be used to determine whether there are any modifications required to an experimental airspace design, or whether a new procedure will introduce too much additional controller workload.

2.5 Hardware and Software

Research and evaluation HITL simulation utilize special hardware and software to help create an immersive environment for participants. Both can be adapted to different ATC environments as needed for an evaluation. For example, on a certain day a simulation of the Atlanta Area Control Center (ACC) sectors can be conducted and the next day Cancún Approach

[1] BADA is an aircraft performance model developed and maintained by EUROCONTROL, and used for trajectory modeling in ATC simulations (among other things).

Control sectors can be simulated; or a current ATC environment can be simulated one day and the next day a totally new future ATC concept simulated. Each simulated ATC environment has different controller displays, button functionality, and hardware set up. The displays and button functionality are governed by the software, and the software technicians make changes to the program code to adapt to the different requirements. Due to the need for great flexibility, only those features that are required for the HITL simulation are implemented, which is why it is necessary for those features to be agreed upon and refined during the preparation for a HITL simulation. The goal of a research and evaluation environment is not to completely mirror the actual environment, but to create a reasonable enough facsimile during which controllers can manage different environments, while still being able to provide feedback and comments to meet the objectives of the simulation. For example, if controllers regularly use only 35 out of 200 possible features available on their existing ATC system, then only these 35 features need to be simulated as the cost to implement all 200 functions would be excessive and serve little or no purpose in relation to the simulation objectives.

3. Training and Education Through HITL Simulations

This section provides a description of training and education through HITL simulations, which are used to train new controllers, educate controllers on new airspace designs, and allow controllers to practice their skills. This is a reliable way to familiarize staff with the operational environment in the field and to expose controllers to situations that do not occur frequently (e.g., emergencies, partial equipment failures, unusual runway configurations).

3.1 Environment

For training and education purposes, the environment (i.e., the fidelity and the functionality of the HITL simulation) is required to be either an exact replica of the current ATC system and operational environment or very close, and therefore of high fidelity. Due to the requirement of a realistic operational environment that will allow controllers to become familiar and comfortable with the fielded system, it is often difficult to quickly or easily modify the simulator. Modifications such as adding additional positions can be time consuming and difficult. As major changes to the ATC environment are typically rare events that occur only one every several years, there is no need for a flexible system.

3.2 ATC System Data

The ATC System Data are similar, and in some cases, identical to the files that exist for the research and evaluation HITL simulation. The computer requires the airspace elements and aircraft performance to be defined whether they are for the training system or the operational system. Unlike the research and evaluation HITL simulation, the system data files for training and education are definitions of airspace elements that are either published or about to be published. The information is specific for that location and is not easily modified. The aircraft performance data are preset to fit that location and are also usually difficult to manipulate. In addition, adjusting the traffic demand level from one simulation scenario to the next is a time-consuming manual operation, and therefore the traffic demand level is typically set close to current peak traffic volumes or lower.

3.3 Human Resources

As the training and education HITL simulations are generally static, there is less of a need for numerous people to be involved. The job of scenario development still needs to be accomplished, but this is the same in both types of simulations. For the actual training portion, only the trainee, trainer, and simulation pilots or other controllers are necessary. If the training is for multiple positions, then this number would be increased. In addition, a system operator is needed to make sure that the system and scenario are running properly. Unlike the research and evaluation simulations, human factor engineers are not needed as no analytical evaluation is required.

3.4 Data Collection Capability

The purpose of the training and education HITL simulations is to educate, rather than evaluate. Therefore, these HITL simulation platforms are not required to have the same capability to collect metrics as a research platform. The only exception is for the subjective metrics that are generally collected outside of the simulation system itself; however, since the purpose of the HITL simulation is different, these subjective metrics are often not collected.

3.5 Hardware and Software

As with the research and evaluation HITL simulations, training and education HITL simulations would not be possible without the hardware and software that help create the environment for the participants. Unlike the research and evaluation HITL simulations, the hardware and software are specialized for one location and have the look and feel of the currently fielded operational positions. Generally, training platforms can be used, if necessary, on the operations room floor if one of the operational positions malfunctions. All of the features that are in the operational system must be functional in the HITL simulation.

4. U.S. FAA Research and Evaluation Through HITL Simulations: A Case Study

The U.S. FAA has been implementing Performance-Based Navigation (PBN) procedures at airports across the U.S. The objective of these procedures is often to attempt to decrease fuel burn and reduce aircraft mileage flown as well as improve traffic operations in large metropolitan areas. One of metropolitan areas under study is the San Francisco Bay area, which has numerous airports in close proximity. The Northern California (NORCAL) Terminal Radar Approach Control (TRACON) is responsible for managing traffic flying in this metropolitan area, and includes Oakland International Airport (ICAO code: KOAK), San Francisco International Airport (ICAO code: KSFO), and San José International Airport (ICAO code: KSJC), as well as aircraft flying to and from multiple satellite airports. The redesign of the airspace in this complex environment consisted of introducing multiple new Standard Instrument Departure (SID) and Standard Terminal Arrival Route (STAR) procedures and modifications to the airspace sector boundaries. MITRE used research and evaluation HITL simulations to evaluate and validate the airspace redesign, both from the controller and airline pilot perspectives.

The objective of one of the evaluation HITL simulation scenarios that were conducted at MITRE was to evaluate the interactions between all KSFO arrival and departure procedures to and from the north and northwest, specifically the KSFO STAR from the north (BDEGA). Other elements for the evaluation included specifying:

- Type of aircraft on the BDEGA STAR: A320
- Airport runways used: Runway 10L or Runway 10R
- Distance between aircraft: 10 nautical mile (NM) on the traffic flow being transferred from Oakland ACC to NORCAL TRACON
- Arrival rate for the airport (KSFO): 60 aircraft per hour
- Sectors/Positions required: 2 positions in the NORCAL TRACON and 1 enroute sector

During the HITL evaluation, the design of the BDEGA STAR was modified based on the input from the HITL participants, which was also evaluated. The ability to do this is an example of the rapid modification capabilities of the simulator.

This type of HITL simulator allows for modifications to be done easily and quickly, and therefore allowed the controllers and pilots to re-evaluate a newly modified (i.e., relocated) STAR by introducing these modification in the later stages of the evaluation program.

5. Summary

Research and evaluation HITL simulations are typically used for concept exploration where there is a need for modifiable and flexible hardware and software with short lead times to complete changes. They require specialized hardware and a greater number of human resources. Research and evaluation HITL simulations are the type of HITLs planned for NAICM and Cancún in order to evaluate airspace design matters.

Training and education HITL simulations are used to train and educate trainees and licensed controllers on currently fielded or soon to be fielded hardware and software. It is important to mention that MITRE is not associated with actual training matters. The training of controllers is the responsibility of SENEAM. However, SENEAM may want to utilize HITLs in training controllers.

This document provided explanations of the differences between the two types of HITL simulations in five key areas, which are summarized in Figure 1.

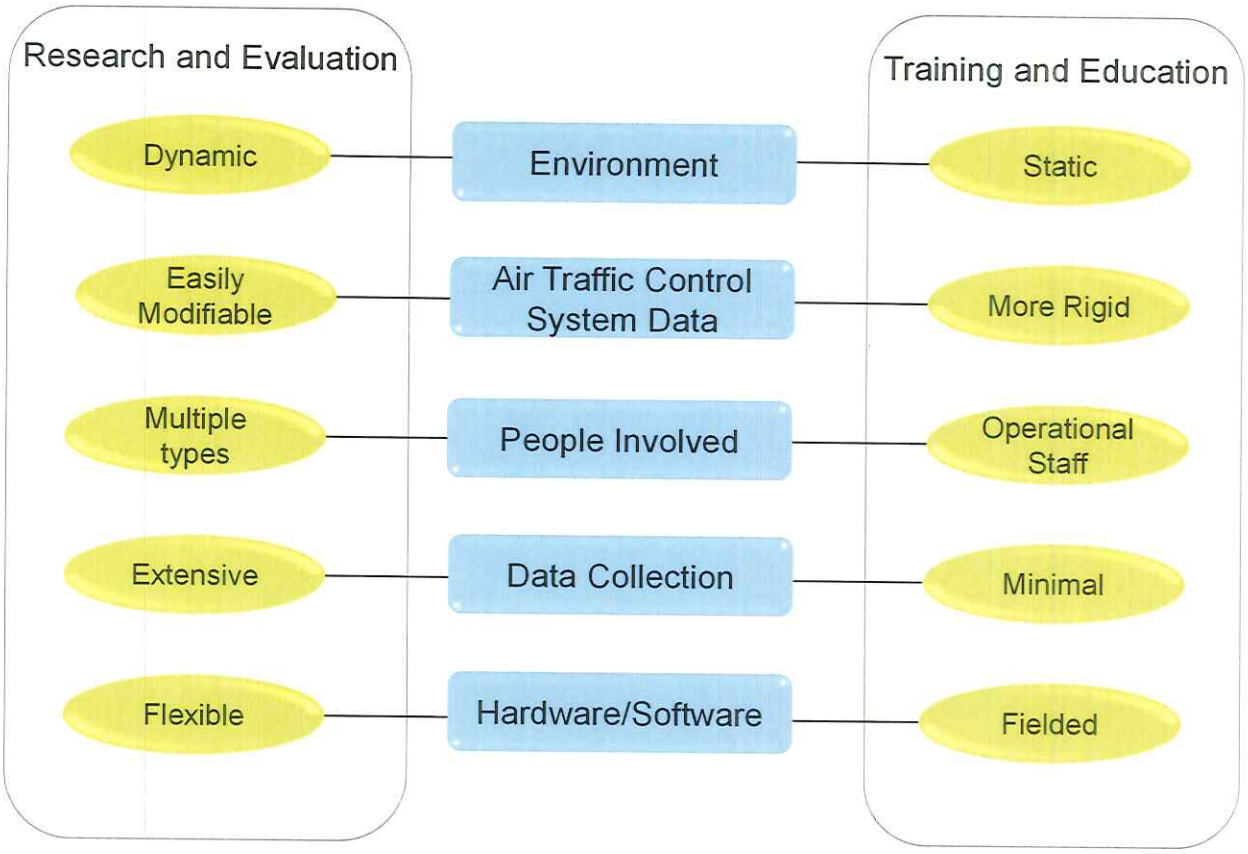

Figure 1. Summary of HITL Simulation Differences

The requirements of the hardware and software as well as the human resources are very different between the two types of HITL simulations. As each HITL simulation type is built for different purposes, it is difficult to use a training and education HITL simulation platform for research and evaluation and vice versa. The type of simulation desired should dictate which simulation platform needs to be acquired. The latter needs substantial advance planning.