Developing a High-Fidelity Simulation and Training to Improve Coordination between Aerospace Specializations

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Abstract. This paper describes the various technological elements used to create and support a simulated flight operations control center for the purpose of collegiate aviation training. The simulation center also serves as a platform to research team dynamics, educational efficacy, and individual occupational stereotypes. The simulation facility relies on the harmonious integration of technologies to meet operational requirements including realism, flexibility, and capability

Keywords: aerospace, aviation, airline, operations, multi-team, training, simulation.

1 Introduction

This paper presents the theoretical background behind the development of a simulated flight operations center for training of aerospace specialties and research conducted in that center. The nature of simulation and training is discussed, including a summary of ongoing research efforts and future developments.

2 Theoretical Background

A variety of highly-trained professionals are needed to operate an airline. These include pilots, flight dispatchers, meteorologists, crew schedulers, ramp controllers, and maintenance coordinators. Airline employees in these roles must not only be proficient in their respective specializations, they must also work together in a coordinated manner. Effective teamwork is essential for optimal airline operations. This is especially true when irregular events and disruptions occur ([1], [8], [13]). Previous research suggests that newly hired aviation professionals often do not possess high levels of interpositional knowledge required for highly coordinated action [6]. Poor

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coordination can lead to costly flight delays, inefficiencies, and may even compromise safety. Flight delays and cancellations result in inconvenienced passengers, disruptions in business activities, and downstream operational problems for airlines. The negative economic impact resulting from airline delays and cancelations in the U.S. is estimated to exceed $31 billion annually [10]. While disruptions and mistakes cannot be eliminated entirely, more effective coordination among differing specializations of aviation professionals can reduce their frequency, duration, and impact. In order to improve interpositional understanding, decision-making, and group situational awareness, we utilize a series of high-fidelity simulations that incorporate both routine and non-routine work situations. We also engage teams in after-action reviews to further enhance the educational benefits of the simulations. Theory and research on group processes, group/team performance, and multi-team systems provide perspectives from which to view and improve the coordination needed to maintain optimal airline performance.

As effective teamwork is important for optimal levels of group performance, multi-person simulations that reinforce essential task and teamwork functions are considered to be an effective approach to team training ([4], [11], [12]). Despite the fact that training on complex tasks facilitates transfer, most of the training literature tends to focus on relatively simple, routine tasks rather than complex, dynamic tasks requiring adaptation [5].

3 Simulation and Technology

3.1 Participants

Participants are senior-level Aviation Science students enrolled in a culminating capstone course. Students are assigned to 10-member teams according to their aviation specialization. The following degree specializations are represented in each team: professional pilot, flight dispatch, maintenance management, aerospace administration, and aviation technology. All participants have completed extensive coursework in his or her respective specialization, but may lack knowledge of, and experience working with, other specializations.

3.2 Setting

Simulated flight operations are conducted in a multi-room lab facility called the Flight Operations Center Unified Simulation (FOCUS) lab. This facility includes the main flight operations control center, adjacent ramp tower, pseudo-pilot room, CRJ flight simulator, and an observation and control room. To the greatest extent possible, the creators of the lab sought to replicate key elements typically found in airline operations centers.

The FOCUS lab has multiple workstations, each with unique responsibilities. Many of the world's largest airlines operations centers are comprised of twenty or more separate departments of differing roles. For the purposes of the FOCUS lab, eight key roles were identified that students could serve based on their chosen educational specializations. These roles are: *Flight Operations Coordinator, Meteorology, Crew Scheduling, Aircraft Loading, Schedule and Flight Tracking, Maintenance Control, Ramp Tower, and Flight Crew*.

In the FOCUS lab, students are positioned in an elongated round-table configuration. This encourages face-to-face communication, though headset and text communications are also available. Six large screen monitors are wall-mounted, three behind each long side of the tables so that each side displays pertinent information. This includes the flight schedule, a radar view of the flights in the air, and a weather map. All of this information is updated in real time as the simulation progresses. Finally, each workstation is equipped with a computer and dual monitors to accommodate all information relevant to that position.

Observation Room. In addition to the student roles listed above, several faculty and student observers monitor team performance and interact with the positions as needed to facilitate the delivery of scenarios, realistic events, consequences, and other external communication. These observers constantly oversee the condition of flight statuses, decision-making, routine tasks, and response to unusual circumstances. They also play external roles within the company such as upper level management, gate agents, and base mechanics, for example. This interaction contributes significantly to the realism and depth of the simulation.

The **ramp control tower** is in an adjacent room and simulates the operation of one of the airline's hub airports (Nashville). The ramp control specialist directs arriving and departing flights to appropriate taxiways and gates and provides notification when a flight is ready for pushback. This room contains three wall-mounted large screen monitors providing panoramic real-time views of the gates, runways, and taxiways. Another display shows a radar view of flights preparing for landing and takeoff, and a computer allows the operator to direct the planes to gates and taxiways. The ramp control specialist can communicate with the flight operations coordinator via headset or text.

The **pseudo-pilot room** consists of a workstation where flights within the service area are 'flown' by an operator. The pseudo pilot monitors and controls multiple flights and communicates with flight operations and simulation controllers as necessary. This location consists of a single computer station for controlling flights and another for communications and information-sharing utilities.

3.3 Student Roles

- The *Flight Operations Coordinator* (FOC) has the most central role and has final decision making authority for the airline's operations. In order to make effective decisions, this person utilizes information from all other simulation participants. The FOC collects information from the other positions to lead the team, set operational strategies and policy, and manage disruptions as they arise.
- The *Meteorologist* reviews current and forecasted weather conditions for all flights prior to departure. He/she shares the responsibility of ensuring weather conditions are acceptable for each flight to safely and legally depart. The meteorologist also monitors weather trends and unfavorable weather conditions to relay pertinent

information to flight crews, dispatchers, or the flight operations coordinator as needed.

- *Crew Schedulers* manage flight crews and monitor their duty times, currencies, and qualifications. They may reposition or reassign line and reserve pilots and their routes as needed.
- *Aircraft Loading* personnel review passenger and cargo manifests, allocate fuel, and ensure the proper weight and balance of each aircraft prior to departure.
- S*chedule and Flight Managers* monitor the status and progress of flights while they are enroute to their destinations. They also make data entries into a schedule management system that other team members rely on for accurate flight status information.
- *Maintenance Controllers* manage the aircraft fleet by assigning aircraft to flight routes, coordinating scheduled and unscheduled repair work with maintenance bases, and even help flight crews in-flight if necessary.
- *Ramp Tower Operators* manage the gate and ramp activity at large airline hubs. They facilitate the smooth flow of inbound and outbound traffic, especially during a period of high traffic volume, commonly referred to as a 'push'. Tower Operators maximize resource utilization, especially gates, ground personnel and related equipment.
- *Flight Crews* fly simulated flights along predetermined flight routes. In the simulation, pilots act either as 'Pseudo Pilots' or an actual flight crew, piloting a full-size professional flight simulator.

3.4 Implementation

To the greatest extent possible, the creators of the FOCUS lab sought to replicate the look, feel, and utility of a typical operations center. As these centers rely heavily on technology to accomplish organizational tasks, so did the FOCUS lab. However, since many of the technological tools used by airlines were not commercially available, and since a training facility of this type had never been created elsewhere, a number of existing technological tools had to be adapted and merged to accomplish the intended project goals. The following sections describe the hardware and software components used in the lab.

3.5 Hardware Components

As discussed, there are six main positions in the main operations center. Each station is outfitted with desktop computer workstations. Each workstation drives dual 19-inch LCD monitors, effectively increasing desktop space and allowing simultaneous viewing of multiple information and communication windows. The monitors are positioned to their lowest vertical orientation to allow for direct visual contact with other team members and other information sources in the room. Stations are also outfitted with monaural headsets for voice communication. There are six 55-inch high definition (1920x1080) displays mounted to opposing walls in the control center. The displays are arranged in two banks of three: three displays on each wall. They display common-use information including the flight status board, aircraft tracking, and weather radar. The displays are driven by a bank of three desktop class PCs and are controlled by central positions. For example, the Schedule and Flight Managers manipulate data on the flight status board that is displayed for others' reference.

The display computers do not directly connect to the displays themselves. Since the distance from the displays to their driving computers exceeded the maximum recommend cable length for DVI-D signals (10m), DVI signal extenders were used. The signal extenders accept DVI signals at the source unit and send reprocessed signals over a CAT6 STP cable to a receiving unit, which outputs the original signal. The DVI extenders were sourced from Smart-AVI™ Inc. and include model numbers DVX-RX200 and DVX-TX200 for the receiver and transmitter units respectively.

The displays also feature the ability to switch to any source computer output dynamically. This allows students to arrange pertinent information on any of the six screens. This required the use of a DVI matrix switch. Before signals are sent to DVI extender units, seven DVI outputs from display computers connect to input banks on the matrix switch. The DVI extender units are then connected to the output banks of the matrix switch, which connect to the corresponding displays. The 8x8 matrix switch is sourced from Smart-AVI™ Inc, model DVR8X8S.

A major component of the FOCUS lab is the custom-built NexSim suite. The NexSim suite is a contained subsystem of computers, support equipment, and software that simulate flights traveling throughout the preprogrammed service area. The NexSim Suite is intended for air traffic control training, but for the purposes of flight operations, was altered by the vendor, Computer Sciences Corporation (CSC), to meet our specific requirements. The installed NexSim suite includes six desktop class computers, and nine rack mounted computers, each with unique roles. For example, four computers generate the virtual airport environment, while others host external communication data or display airport environment and control screens. The NexSim suite also incorporates a proprietary voice communication protocol and is controlled by LCD touch panels at each station. The ramp tower room is solely comprised of NexSim equipment and features three 47-inch displays depicting a 150-degree view of the airport environment.

The FOCUS lab also features a full-size, professional flight training device (FTD) or flight simulator. This simulator is sourced from Frasca International and replicates the flight deck of a Canadair Regional Jet (CRJ) 200 series aircraft. Student pilots act as captain and first officer crews in the simulator and perform functions exactly like those in a real jet aircraft. The Frasca CRJ200 simulator and the NexSim suite exhibit the unique ability to electronically interface to share aircraft position data, despite the fact that the CRJ simulator is physically located 5 miles away from campus at the local municipal airport. This is accomplished with the use of two client computers, one each for NexSim and Frasca, and one server computer that manages and hosts the information exchange. Both the CRJ simulator and the NexSim suite publish and read decoded, nonproprietary data across a private network up to 60 times per second. This is accomplished using a sophisticated VPN architecture, developed by the two respective simulation vendors. This benefits both companies, because the connection doesn't require access to protected software code. The connection therefore allows

CRJ pilots to integrate seamlessly with the other computerized flights in the operations center. It appears both as a radar target and a photorealistic aircraft in the ramp tower. The connection also allows students in the operations center to have direct VoIP communication to pilots in the CRJ simulator.

3.6 Software Components

The FOCUS lab requires a number of software components to support the various jobs performed by students. Software in the lab falls into three main categories: simulation, communication, and information management.

Simulation Software primarily consists of the NexSim application, which is a proprietary program designed for air traffic control purposes. NexSim also employs Microsoft ESP—a professional flight simulation package used to create the visualizations of the airport environment. Users interact with the NexSim application to launch scenarios, monitor and control flights, and collect flight status information. FOCUS lab administrators also have the ability to customize scenarios to their needs. Weather conditions, flight volume, destinations, routes, altitudes, aircraft types and airports are a few examples of user-definable variables within NexSim script files. Two strings of software code used in the script file are listed below as an example:

```
00:00 SPAWN LTN1227 CRJ7/G 0 KMEM P1549 D1549 0 130
KMEM..JKS..BNA NEXT=LTN2227 PARK=C12
00:00 NEXT LTN2227 CRJ7/G 0 BNA P0015 D0015 0 150
BNA..SYI..RMG..KATL NEXT=LTN3227 PARK=C12
```

These lines are read by the NexSim application and tell the computers how flights should behave. The first line instructs the system to spawn a CRJ700 with flight number "LTN1227" 00:00 (MM:SS) after scenario launch. Its origin is Memphis (KMEM) at a proposed departure time of 15:49UTC. It will cruise at 13,000ft to Nashville (BNA) via the JKS VOR. Upon arrival, the flight will park at gate C12, and become flight LTN2227. The next line dictates instructions for flight 2227 and so on.

Communication software was needed to allow students the ability to communicate using voice, text, or by sharing screens. A number of potential solutions were considered, Skype was ultimately selected because it was scalable and flexible enough for our changing needs. Skype is installed on all computers other than those running NexSim. Each workstation has a unique username that allow for quick access. The usernames follow a naming protocol that list the station name followed by ".focus.mtsu". The application's flexibility allows for single and multi-party voice and text communications, facilitating improved problem solving within teams. Observation and control staff also use Skype to play external roles in the simulation and monitor team interactions.

Aside from the voice and text capability Skype offers, a web-based application, 'join.me' is used extensively. Join.me shares the host computers screen(s) with others who have a unique 9-digit access code. All computer workstations in the flight operations room run join.me in the background. Observers join these sessions and can monitor the work being done at each station. Screens can be viewed by on mobile devices as well. This technology allows the lab to quickly and easily expand as needed without the need for expensive duplication hardware.

Information Management Software represents one of the largest components of the FOCUS lab. All stations in the main flight operations control room use some form of information management software. Because each position has unique roles and responsibilities, each position utilizes an equally unique software module.

First, the maintenance control position uses web-based software from Talon Systems called Resource Maintenance System (RMS). This system allows maintenance controllers to monitor scheduled maintenance events, aircraft parts inventories, manage required legal maintenance logs, and keep maintenance records. Since it is web-based, observers can embed repair scenarios and monitor changes from any location.

The Flight Operations Coordinator, Meteorologist, Crew Scheduler, Aircraft Loading Manager, and Flight Status Manager all utilize 'modules' contained in a single network-shared Microsoft Excel file. This file has been in development for over two years, and contains twelve worksheets. Students interact with five of these worksheets or 'modules' to perform their jobs, while the remaining worksheets are used to store large quantities of backstory data pertaining to the airline. For example, two worksheets are used to house and interpret raw weather data periodically collected from the National Weather Service online database. Others are used to calculate aircraft performance, flight route times, financial performance, passenger lists, and crew schedules. The five student-use modules collect, return, and interpret data from the support modules.

The master Excel file is approximately 100MB in size, due to the large quantities of background data it contains. The modules also make extensive use of Visual Basic macros and conditional formatting. The file has over two hundred unique macros and approximately 1,500 conditional formatting instructions. We also extensively use stacked logic functions and cell referencing. Macros, conditional formatting, and complex formulas allow for a degree of automation to be built in to each module. Stacked IF, OR, and AND functions, working with cell referencing, creates powerful student-use tools that allow them to manage, enter, and interpret data quickly.

We elected to write our own software for two reasons. First, commercial airline operations software from vendors like Sabre® are extremely expensive, customized for each airline, and consequently unavailable. Second, although these professional systems are highly detailed and capable, we needed software that was quick to learn, easy to use, and yet still offered similar capabilities. This requirement stemmed from curriculum limitations that only gave students 10 hours of exposure in the FOCUS lab. Creating our own modules also gave us the flexibility to make changes and improvements as project goals evolved. This is difficult to do with licensed software.

4 Execution

Students participate in the FOCUS lab as employees of a fictional regional airline called "Universal E-Lines". The airline serves 14 airports from its two hubs and is comprised of a fleet of 30 regional jet aircraft. During each simulation session, approximately 70 flight events (takeoffs and landings) occur. Much of the activity involves routine handling of flight operations. However, unexpected disruptions (also known as irregular operations) occur and further increase the need for communication, information transfer, coordinated action, and adaptation. When this happens, critical decisions must be made to mitigate disruptions while maintaining a safe, efficient, and on-time operation. Often, student operators are required to draw upon their specific knowledge and that of others to quickly consider the likelihood, scope, and execution of dozens of possible strategies, while constantly being mindful of the ever-changing conditions of the airline, as well as possible downstream implications of a proposed decision. Students also feel added pressure to make decisions quickly, and often without complete or accurate information.

Student exposure to the lab consists of a series of simulation components: orientation, task-specific training, initial simulation, initial after-action review, second simulation, a second after-action review, a third simulation, and a third after action review.

Orientation. A 45-minute presentation and discussion provides a description of the lab and the various work roles. At the conclusion of the orientation, participants are informed of their team assignments and given a schedule of training activities.

Task Specific Training. During this 45-minute to one-hour session, teams are taken into the lab and provided with individual instruction, demonstration, and an opportunity to practice his or her tasks. The purpose of this session ensures that each participant develops an understanding of his or her role, responsibilities and the technical knowledge to do the job.

Simulation Sessions. Simulations are designed to recreate operational tasks and situations that real airlines address on a daily basis. Upon students' arrival, flights are already enroute to their scheduled destinations. Students assess the status of the airline and assume control of its operation. Simulations typically last for 2.5 to 3 hours, allowing consequences of poor decisions to fully develop while reducing the possibility of fatigue and complacency. Simulation proctoring involves monitoring student performance and communications, as well as interacting as needed to facilitate simulation events and triggering problems. Observers assess the condition of the airline and its variables and deliver triggers that take advantage of an opportune situation to maximize the potential for disruption and thus the need for teamwork and coordination. Team response is recorded and then discussed to see if further action is needed, especially since disruptions usually cause a ripple effect of resulting problems. Teams are faced with triggers of increasing complexity and frequency as they gain experience from each session.

After-Action Reviews. Following each simulation, participants individually complete a form detailing successful and unsuccessful events and their contributing factors.

Teams then participate in a facilitated follow-up session to discuss the positive and negative events. Then the behaviors that contributed to these events are discussed and teams develop methods to anticipate and reduce negative behaviors and reinforce positive behaviors. This session typically lasts one hour and is considered a significant contribution to the educational value of the simulation experience.

5 Future Directions

The initial position training is being developed into on online module that students would complete prior to entering the simulation for initial training. Initial training will then focus on procedural rather than declarative knowledge and move more quickly into team interaction.

Additional performance measures are also in the process of development. While many subjective measures are in place, the only current objective measure is delay time, creating pressure on participants to sacrifice other important variables in order to minimize delay time. The addition of passenger disruption, cargo delivery delays, safety considerations and fuel consumption measures are all under consideration.

Further research is planned to examine the effects of training on emergent cognitive states and to examine the relations of processes and cognitive states to team performance.

Additional equipment and expanded software capabilities are needed. Objectives benefitting from additional technology include improved team observation and monitoring, increased interactivity, Excel module user interface improvements, real-time excel data sharing, expanded NexSim capabilities, procedural improvements and an expanded scenario library. Improvements in these areas will greatly enhance simulation realism and training goals.

6 Conclusion

Merging multiple technological tools has allowed the MTSU Aerospace Department to create a unique training facility that immerses students from varying aviation disciplines in a realistic airline operations control center. Students also gain a greater understanding of their interdependence, decision-making skill set, and communication patterns. Additionally, the FOCUS lab acts a research platform to faculty from both Aerospace and Psychology departments for the purpose of gaining a better understanding of team dynamics and the effects of occupational stereotypes. Since students put their specialized knowledge to work while they run their positions, faculty can also qualitatively evaluate possible knowledge holes in the training curriculum. Although some technical limitations linger, the lab has proven its effectiveness and relevance to educators, students, and employers alike.

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