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A Description of the Multi-Center Traffic Management Advisor (McTMA) Simulation Environment

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The Multi-Center Traffic Management Advisor (McTMA) tool, being developed jointly by NASA and the FAA, is being tested to aid with the coordination and management of highly congested air traffic in the "Northeast corridor" of the United States. The McTMA systems interconnect to form a data network and are being field tested in six air traffic control (ATC) facilities: Boston Air Route Traffic Control Center (ARTCC), Cleveland ARTCC, New York ARTCC, Washington ARTCC, the Philadelphia Terminal Radar Approach Control (TRACON), and the Air Traffic Control System Command Center (ATCSCC). Concept testing and validation of this highly complex system were conducted in the McTMA simulation environment at NASA Ames Research Center prior to field test. A highly innovative simulation design was employed in order to efficiently test McTMA operating in the complex Northeast Corridor. This paper presents a description of that innovative simulation architecture and its environment.

I. Introduction

The Multi-Center Traffic Management Advisor (McTMA) tool builds upon and enhances the Traffic Management Advisor (TMA) (also referred to as the single-center TMA (SC-TMA)) tool.[1,2] The TMA tools predict arrival times for traffic at a destination airport and build schedules and sequences for the orderly and efficient arrival of aircraft, according to the prescribed set of Air Traffic Control (ATC) constraints.[3,4] McTMA represents the next evolution of a traffic management decision support tool designed by NASA and the FAA, and is being tested in four Air Route Traffic Control Centers (ARTCCs or Centers) in the northeast, New York Center (ZNY), Washington Center (ZDC), Cleveland Center (ZOB), and Boston Center (ZBW). Other participants in the tests are the Philadelphia (PHL) Terminal Radar Approach Control (TRACON) and the Air Traffic Control System Command Center (ATCSCC).

The McTMA-generated scheduling and sequence advisories are presented on the displays for the traffic management coordinator (TMC) and controllers. The TMCs use the predictive capability of McTMA to make traffic flow management (TFM) plans while the controllers use the scheduling and sequencing advisories to meter or deliver aircraft over a specified location (fix) at the calculated time and sequence. This paper will specifically refer to the McTMA test sites in the description of its capabilities and the goals of the simulation environment.

The prime difference between the single and multi-center TMA systems is scalability. SC-TMA by its definition is a stand-alone system, working independently to provide an arrival traffic flow solution for a single Center/TRACON combination. The McTMA model can be viewed as a collection of SC-TMA systems working in collaboration to provide solutions for regional TFM problems. McTMA offers two major architectural differences over SC-TMA: an inter-TMA data sharing infrastructure, and the calculation of schedules and restrictions that span over multiple Centers.[5] The systems share calculated data about arrivals into a particular airport (for example, PHL) while the aircraft are well beyond the radar coverage of the primary arrival Center (ZNY in this case).

Similarly, the current simulation environment that supports the SC-TMA system has to evolve and be scalable to accommodate the complex interactions between multiple McTMA systems that represent each Center's environment. Between 40 and 50 ATC sectors and controllers are expected to participate in the control and delivery of PHL-bound aircraft throughout the four Centers. The impact of McTMA advisories on the large number of sectors and facilities needs to be explored prior to operational field evaluation. In addition, controllers at each sector and TMC from each facility have to be trained on the use of McTMA.

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The TMA simulation facility at NASA offers the researcher a high fidelity human-in-the-loop (HITL) real-time testing environment to collect engineering and human factors data on tool effectiveness. The users can interact with the system for training and testing off-nominal cases prior to any operational use. This reduces risk and provides the users an opportunity to familiarize themselves with methods to handle such situations, should they arise. The lab allows both the researchers and domain experts to exercise the system in ways not possible in a live operational environment.

II. Simulation Environment Objectives and Requirements

The objectives of conducting McTMA simulations are: to validate the various feature sets of the McTMA, to provide a training arena for the users, and to collect user-interaction data. The requirements and resources to meet the simulation objectives are considerable. Foremost, the simulation needs to operate four independent McTMA systems (each representing an ARTCC), running on the same network and sharing data. Additional hardware is also required to present the same traffic scenario to the users representing the PHL TRACON and ATCSCC facilities.

Additional computers are required to support the subsystems that sustain the simulation environment. Depending on configuration, 25 to 30 Sun Microsystems workstations are required to run a simulation. The testing of the new multi-center scheduling algorithm requires the interaction of all four systems. One cannot test this feature using a single instance of the McTMA system, as it requires trajectory calculation and user interaction from the adjacent Centers.

User participation in the simulation involves the Traffic Management Coordinators (TMCs) and sector controllers from each of the six ATC facilities. TMCs from each facility operate their corresponding McTMA system in the simulation and learn to use the various features of the system. The controllers learn how to interpret the scheduling advisories that McTMA produces and mentally convert that to ATC methodologies (e.g. issuing speed reduction or vectoring commands). In learning to use TMA (SC-TMA or McTMA), most facilities must learn to switch from controlling aircraft based on miles-in-trail separation to time-based metering (TBM). Miles-in-trail involves laterally separating aircraft based on a set distance between two aircraft. TBM is the method of delivering aircraft over a specified location or fix at the advised time (generated by TMA with lateral separation taken into account). Many facilities have not employed TBM in the past and new techniques of controlling aircraft to meet the advised time may have to be learned by each controller. The simulation environment is also used to help the users transition to the new separation paradigm.

Another requirement for the simulation environment is to allow the users from the six facilities to work together to develop a regional ATC plan. The simulation environment needs to provide the opportunity for the users to define the code of conduct, experiment with possible procedures, and fine-tune the protocol, since the use of McTMA will require the development of a new set of regional operational procedures. Part of the users' acceptance criteria of McTMA depends on how well the tool helps with improving communication between the facilities. Aiding the cadre with the development of an operational protocol is crucial in the acceptance of the tool and the simulation lab needs to advance this activity. Lastly, the researchers will need to collect system performance and user-interaction data as development of the scheduling algorithm matures and users are familiarized with the system.

The objectives of each simulation session vary widely, from evaluating system performance to promoting collaboration between the Centers. The robust design of the McTMA simulation laboratory and environment addresses all these requirements.

III. Data Collection and Analysis

The majority of the engineering analysis portion of a simulation run concentrates on analyzing the predictive and scheduling capabilities of the system (SC-TMA and McTMA simulations). The TMA scheduler uses accurate demand prediction information to provide the controllers with a traffic plan to effectively work the traffic.[4] In the case of the SC-TMA, the scheduler produces arrival times and sequences for aircraft crossing over a particular fix within a single Center's airspace and at the boundary of a TRACON's airspace. Other analyses focus on the amount of delay and the distribution of these delays between the runways, TRACON entry points (meter fixes) and outer meter fix locations. In McTMA, the analyses concentrate on the newer prediction and scheduling algorithms of the system. McTMA uses a new scheduling module, referred to as a "Rate Profiler," to generate restriction profiles to multiple metering locations within the Center and if necessary forward the restriction profile to adjacent Centers, thereby restricting the number of aircraft entering busy portions of airspace.[5]

Human factors researchers typically observe users during each simulation to collect computer-human interface (CHI) feedback and to measure and address any workload issues. Feedback on the acceptability of TMA generated sequences and schedules are also collected. In addition, questionnaires are frequently issued after each run to collect more detailed data. The data collected helps the researchers and developers to understand the users' perceptions of workload and focus on ways to reduce user workload by providing logical grouping of features, reducing level of effort to access data, and minimizing keystroke actions.[6]

The use of the McTMA tool also presents a new and unique problem that requires input from all six facilities. McTMA requires the users to work from the same instruction set or "manual," that define a concept of use (COU). The COU outlines the procedures and steps needed to make the proper TFM decisions and to synchronize their efforts to manage arrival traffic. The COU also outlines procedures for the users to collaborate and determine possible sets of operational procedures that appear equitable to all parties. Simulations are conducted to give the users an opportunity to test and fine-tune the protocol of each element of the COU which leads to developing the final COU document.[7]

This collaboration activity neither directly influences the design of the scheduling algorithm nor the human interface aspect of the tool. Nonetheless, it heavily impacts the perceived usefulness of the tool and ultimately its acceptance. The McTMA system represents the first tool to provide all parties (ZNY, ZDC, ZOB, ZBW, PHL, and the ATCSCC) a way to visualize a common picture of the arrival traffic and to devise a regional TFM plan to manage the problem.

IV. The Simulation Environment

This section details the simulation environment. Three core components characterize the simulation environment: the users, the software modules that drive the simulation, and the physical lab space.

A. The User Component

The TMA system (single or multi-center) was designed to provide ATC traffic management advisories to two groups of end users, the TMCs and controllers. In the simulation environment, other participants (researchers and pseudo-pilots) help to guide, conduct, and execute the unfolding scenarios. Figure 1 shows McTMA in the simulation environment. A four-facility simulation of the northeast corridor requires four instances of the McTMA software, to represent all four Centers (ZNY, ZDC, ZOB, ZBW) in total. The box labeled "Other TMA Processes" in Fig. 1 refers to other core software modules that make up McTMA software but do not require direct user input.[10]

The researchers define the objective of the test and create aircraft scenarios (defined by the Aircraft List file) that drive the simulations. The Aircraft List file feeds aircraft data into the Simulation Manager module of the Pseudo Aircraft System (PAS) software. PAS sends aircraft flight plans and track data to McTMA, as if McTMA were receiving the data from the Host Computer System (HCS) at the Center.

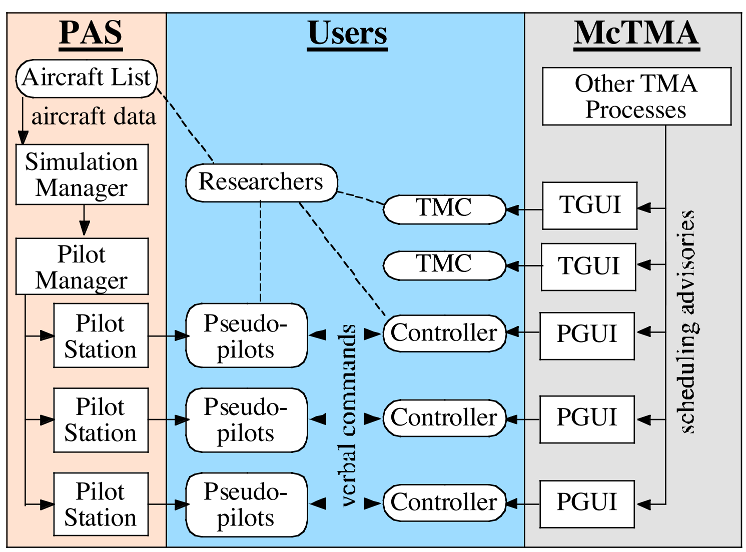

Figure 1. McTMA users and systems interaction diagram

During the collaboration exercises, the TMCs interact with each other to strategize on a TFM plan and input system constraints into McTMA via the Timeline Graphical User Interface (TGUI) software module. McTMA calculates the TFM plan and displays the scheduling advisories to the TMCs on the TGUI. The TGUI is the TMC's primary interface with the McTMA system.

McTMA also routes the scheduling advisories to the controller and displays them onto the Planview GUI (PGUI) monitor. The PGUI's function is to emulate the controllers' actual radar display. The controllers use their knowledge of the airspace and traffic situation to issue verbal commands to the aircraft via the pseudo-pilot and to meet TMA's schedule and sequence advisories. The pseudo-pilot acknowledges the controller's clearances and inputs changes to the aircraft's flight path via entries into the Pilot Station module of PAS.

B. The Software Component

TMA and PAS are the two main software systems that drive the simulation. Both suites of software are architecturally designed from various functional modules. As an example, TMA uses different software modules to calculate route segments and trajectories, generate schedules, and display advisories.[8] The PAS software consists of three major modules: the aircraft scenario processor (Simulation Manager), the system-wide aircraft management component (Pilot Manager), and the individual station that controls the aircraft (Pilot Station).[9]

The evolution of the TMA software from single-center to multi-center demands significant changes to some of the core modules (i.e. trajectory prediction and scheduling modules) and the addition of new modules (i.e. data sharing and rate restriction modules). Route generation in McTMA now includes a new algorithm to generate route segments and trajectories for aircraft destined for a metering airport outside of the current Center, but which also may need to be scheduled by the current Center.

Scheduling in McTMA now uses multiple scheduling modules that produce metering advisories for aircraft throughout the McTMA-equipped Centers and share rate restrictions amongst the various scheduling modules in the McTMA network.[5]

McTMA also employs a new Data Server (DS) software module in which TMA publishes prediction and scheduling data for other TMAs to subscribe and utilize.

Similarly, major software changes have taken place in PAS to support McTMA and its capabilities. PAS traditionally functioned as a target and flight plan generator. The Pilot Station module of PAS, with inputs from a pseudo-pilot, closes the control loop in the simulation by maneuvering the aircraft in accordance with commands issued by the controller.

New McTMA-specific features within PAS include the ability to connect and communicate with multiple instances of TMA. (See Fig. 2.) During initialization, PAS can be designated as running in either single or multi-center mode but not both simultaneously.[8]

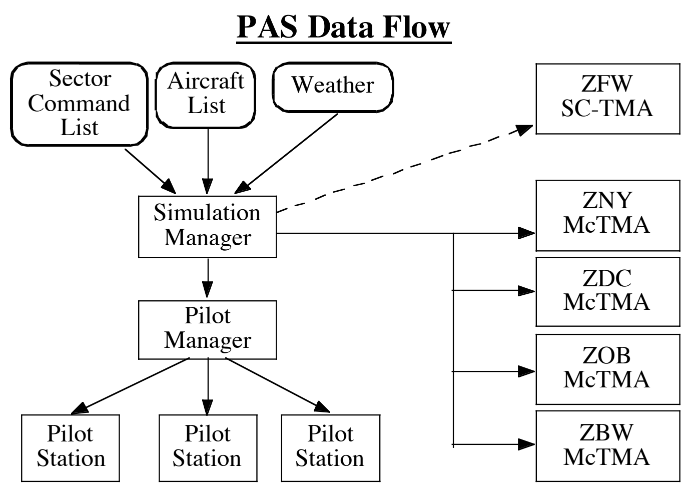

Figure 2. PAS data flow and TMA connections

Running in multi-center mode activates other multi-center specific functions, such as pseudo-Host mode and pseudo-controller mode. In pseudo-Host mode, PAS has to determine which Centers (McTMA connections) are active and send them corresponding flight plans and track data. Since PAS knows about all aircraft in the system (defined in the Aircraft List file) during initialization, it acts like a master gatekeeper. PAS takes the full flight plan data, divides it into segments that are usable and appropriate to each Center, and routes them accordingly to the respective McTMA systems. This is reflective of how the Host Computer System (HCS or Host) processes flight plans. As an example, when the aircraft nears the boundary of an adjacent Center, PAS routes the track data to both the current and adjacent Centers. In this sense, PAS acts like a Host system because of the flight plan parsing and routing capability. From TMA's perspective, it is receiving data from the Host.

The pseudo-controller mode allows PAS to issue automated controller commands to the aircraft. Basically, this feature uses the Sector Command List file, which contains a list of sectors and predefined set of instructions specific to each sector, to issue commands to aircraft under the control of the automated sector(s). This is synonymous to a script or macro that executes commands based on prescribed triggers. When a sector takes ownership (accepts a handoff) of an aircraft, it executes the instruction based on the rules defined (e.g. change altitude, change speed or heading, based on a time or distance trigger from a certain location.) The Pilot-Manager receives and carries out the commands as if a pseudo-pilot is entering them into the Pilot-Station. This capability allows multiple Centers to execute TMA commands or advisories automatically, so that a simulation can focus on key sectors or airspace and can rely on automation for the remainder of the airspace. Such a capability dramatically reduces the need for an expansive simulation environment. (See Section VI.B.)

C. The Laboratory Component

The researchers require a flexible and robust simulation laboratory to accommodate different simulations, investigate various research topics, and to collect user data and feedback. Flexibility allows the researcher to support different groups of users during different test periods, while robustness allows the researcher to conduct the simulations under different modes of operation (see Section VI).

The laboratory houses eight bays of workstations and displays. These bays can be configured to show different data to different groups of users. Figure 3 illustrates an example of one such configuration. This configuration divides the users, researchers and pseudo-pilots into their own bays. The configuration in Fig. 3 shows typical layout for a collaboration exercise in which all six facilities are working to devise an operational use procedure. Notice that all facilities are able to view the ZNY TGUI display, which shows the final traffic plan for arrivals to PHL. This is intentional and allows everyone to literally see the same picture and helps to formulate a TFM plan. All other Centers have displays showing their own traffic in addition to the remote display of the ZNY traffic. PHL TRACON and the ATCSCC only view the remote display of ZNY.

Room dividers separate each simulated ATC facility and isolate the user cadre from each facility. This forces the cadre to use more deliberate verbal communications to describe their situation to the other participants, much like a phone call in the real world. The setup also compels the cadre to develop better coordination and collaboration protocols, and to define and refine the concept of use procedures. Figures 4 and 5 are photographs of a typical Center's cadre at work during a simulation.

Running a typical collaboration exercise requires no participation from the Pilot-Station bay. In contrast, a controller training exercise may require the Pilot-Stations to expand into as many as three adjacent bays. A training session can realistically host two Centers at a time in the lab at NASA Ames but could be expanded with more available space. The lab is currently configured to allow as many as 12 sectors to be simulated simultaneously.

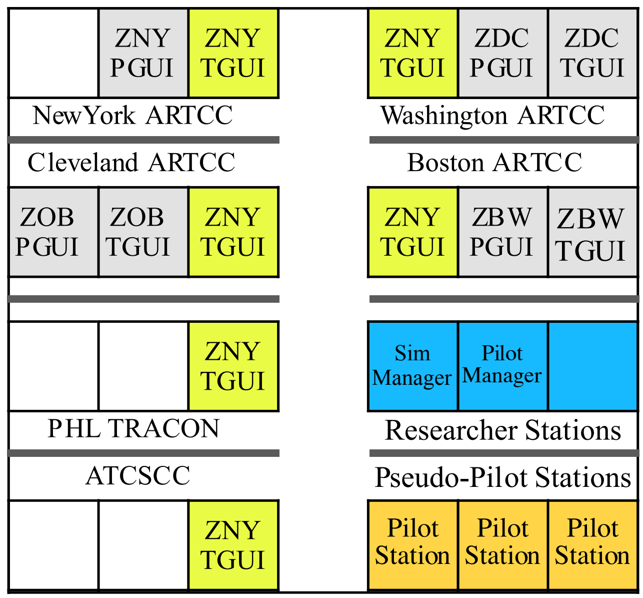

Figure 3. Example layout of the simulation lab including placement of users and equipments

Figure 4. Washington Center cadre

Figure 5. ATCSCC and PHL TRACON cadre

V. Simulation Architecture

The previous sections describe all the necessary software changes required to run McTMA and PAS to support the multi-center model. This section describes the interconnectivity architecture necessary in making the multi-center simulation environment possible. Figure 6 illustrates the basic design difference in running a single and multi-center test. Running in single-center mode prevents PAS from making connections with other McTMA systems and removes some of PAS's multi-center features.

The left side of the figure shows an example of PAS running in single-center mode, connecting to the Dallas Fort-Worth Center (ZFW) TMA system. For comparison, the right hand side shows the multiple McTMA connections with PAS running the northeast facilities. The scenario described in the Aircraft List file is read by PAS during initialization. PAS parses the data and feeds partial segments to each McTMA system. After PAS seeds the McTMA systems with aircraft data, each TMA generates its own advisories and may share that data with other TMA systems via the Data Server mechanism.

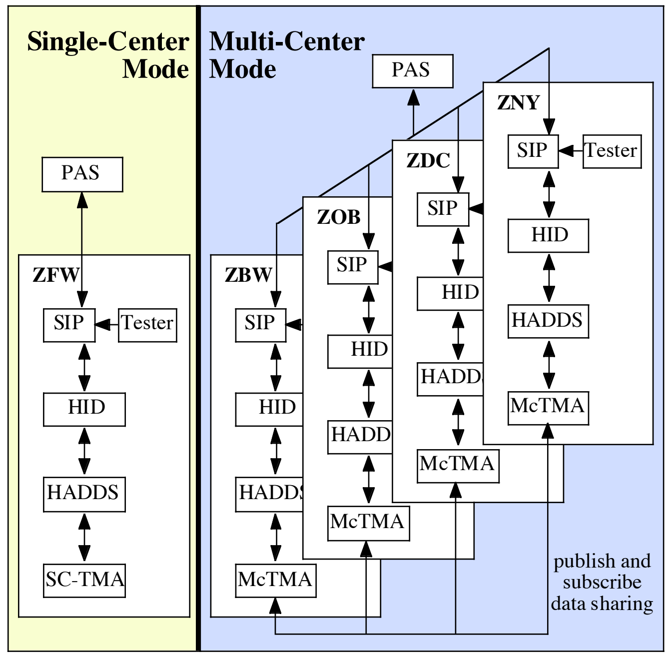

Figure 6. TMA and PAS operating in single-Center and multi-Center modes

Additional pieces of software are required to interface the PAS and McTMA systems. This simulation architecture requires the involvement of the Simulation Interface Process (SIP) and the Tester software. The SIP and Tester processes are not part of the operational environment but allow the researcher to monitor and manipulate the traffic scenario. Through the Tester's interface, the researcher can manually insert data into the communication stream between PAS and McTMA.[11] SIP converts data formats between PAS and McTMA.[11]

The McTMA software is designed and configured to be an operational piece of software. As such, it requires the presence of additional pieces of software to make the connection with PAS complete. Two such software are the Host Interface Device (HID) and the Host Acquisition Data and Distribution System (HADDS).[11] The HID and HADDS software format and route data to the appropriate Host and client applications. These software are integrated into the simulation environment without any code modifications. From McTMA's perspective, it receives PAS data as if it came from an operational Host, following the prescribed data path from Host to HID to HADDS then to McTMA.

The setup for McTMA data sharing is straightforward. These parameters are set in the Data Server adaptation file. During initialization, each McTMA system opens a listening port that corresponds to the broadcast port of the other McTMA systems. Data flows through when the Data Server communication ports are established. The system requires no further actions from the researchers.

VI. Scenario Architecture

A. Three Modes of Operation

The McTMA simulation test bed offers three modes of operation: Human-In-The-Loop (HITL), Fully Automated, and Mixed-Use. The distinguishing factor between these three modes revolves around requirements for user participation and interaction. Having a definitive research objective helps with the selection of the mode. The simulation can be used for training of TMCs and controllers, collecting user data, collecting engineering data, testing concepts and algorithms, analyzing scheduling performance, or any combination of these.

The Human-In-The-Loop mode employs TMCs and controllers. This mode also requires participation from pseudo-pilots to command aircraft in response to controller clearances. In contrast, the Fully Automated mode requires no involvement from TMCs, controllers, and pseudo-pilots. In this mode, PAS feeds aircraft data to TMA. TMA then calculates crossing time advisories and sends them to PAS. PAS then uses a simple speed reduction model to adjust aircraft flight dynamics to meet TMA's advisories. This mode relies on the automated commands (in the Sector Command List) to choreograph the vertical trajectory and horizontal profiles of each aircraft down to the runway. Lastly, the Mixed-Use mode is a combination of the two previous modes. This mode allows for human interaction within the fully automated environment. The users staff the sectors under observation and the computer controls all other aircraft in the airspace. Limited interaction exists between the user and the automated sectors, such as aircraft handoffs.

B. Mode Usage and Objective

The HITL mode satisfies several research objectives such as gathering user feedback on system performance, collecting usability data, indoctrinating new users to the system, and providing a training environment. The HITL setup offers a rich environment for researcher/domain expert interaction. All previous SC-TMA testing ran in HITL mode with TMCs, controllers, and pseudo-pilots. The new McTMA capability allows controllers from different Centers to interact with the system simultaneously. In a two-Center training exercise, controllers from both Centers can be training at the same time while running the same traffic file.

The McTMA HITL tests reveal a new utility for the simulation lab: conducting inter-facility coordination and regional TFM collaboration exercises. Most facilities have only limited exposure to the inner workings and ATC limitations of their neighbors. HITL simulation activities can foster trust and a better understanding of why certain actions were taken by the adjacent Centers. The information helps the user cadre develop a regional traffic plan that accounts for the concerns and limitations of each participant. This signifies a dramatic change in how these facilities operate because their current working environment does not promote such collaboration. Using this mode, different sites can work as one unit using the guidelines developed by the group to manage traffic.

The Fully Automated mode of operation removes the TMC, controller, and pseudo-pilots from the simulation loop. This mode of operation allows the researcher to focus on testing different permutations of the systems such as changing freeze horizons, and applying deconfliction points at multiple locations in different Centers. This capability allows for the simultaneous testing of multiple schedulers across four McTMA systems, which is reflective of the real world McTMA environment. Running in this mode does not mean that user inputs are no longer necessary. On the contrary, it usually allows the researcher to fine tune concepts before getting user feedback. This mode gives the researcher the freedom to investigate alternate procedures without the steep resource requirements (controllers and pseudo-pilot staffing, workstations and displays, etc.) in running a four-Center simulation.

During the course of the project, budgetary constraints forced the researchers to think of ways to conduct resource-intensive simulations more efficiently. This requirement helped develop the Mixed-Use mode. The objective is to use a subset of user cadres to test and verify localized concepts, validate specific designs, and provide training to a limited number of people. This mode allows the researcher to run a complex four-Center traffic scenario while concentrating only on one or two manned sectors. Cadre participation may be reduced to a third or a fourth of the original complement of users. This mode smoothly integrates the user within the automation environment. HITL sectors can be open or closed while the simulation is running, allowing greater flexibility in testing different objectives at the sectors. In short, this mode uses a combination of HITL and automation to reduce resource requirements and cost.

C. Mode Comparison and Limitations

Although the HITL mode offers an interactively rich experience, the McTMA requirements place much strain on the simulation environment. This mode limits the flexibility of the researcher to conduct a four-Center simulation, especially if participation from all four Centers is required to conduct every test. The resources required to conduct this scenario are costly but may be necessary to simulate the desired impact and to present it to the users. As an example, the congestion problem in New York Center will only materialize if there is sufficient traffic coming from the Cleveland and Boston Centers. Hence the presence of controllers and pseudo-pilots from the other Centers are required to generate traffic conditions that will be observable in New York. This situation still holds true even if the goal is to collect data from a subset of the participants. This mode requires the most resources (budget, personnel, preparation, computer hardware and lab space) to execute.

Availability of Pseudo-pilots represents an additional constraint. A typical McTMA scenario uses two to three manned sectors per Center, for up to two Centers. For a light traffic scenario, there usually is one pseudo-pilot assigned to a controller. The requirements can go up to two pseudo-pilots per controller for a heavy traffic scenario with over-crossing traffic, requiring a total of eight to twelve pilots. In short, there is a limit (twelve, due to current lab constraints) to the number of pseudo-pilots that can support the controllers.

At the other end of the spectrum, running in the Fully Automated mode requires no human interaction, except the researchers, but requires the development of a sophisticated set of Sector Command List and Aircraft List files. The development of the lists is not trivial since the files work in harmony to control the vertical and horizontal characteristics of each aircraft as they traverse multiple sectors toward the airport. The aircraft is automatically handed off from one sector to the next along its route of flight. Knowledge of airspace operations is essential to create a realistic flight profile. Good bookkeeping of flight patterns and sector configurations is necessary since the Sector Command List uses sector handoff information. Concurrently, the Aircraft List must now assign each aircraft to a unique Center during startup. PAS uses this data to create unique flight plans and track data and to route them to the appropriate ARTCCs. This mode requires the most preparatory work and knowledge about the airspace but it offers the quickest turn around time when conducting back-to-back runs. Cadre and pseudo-pilots are not essential when initially testing concepts and validating algorithms making this mode a valuable tool for the researchers.

The development and usage of the third mode represents a trade off between efforts required to create the automated command files and ability to reuse the scenarios in different test cases. To its benefit, the Mixed-Use simulations can take full advantage of the efforts invested in creating the automated command files.

VII. McTMA Simulation History

In the span of four years, the McTMA research team conducted a total of ten formal simulations to explore different aspects of the traffic problem, develop new algorithms, and evaluate potential solutions. TMCs and controllers participated in all tests. Six simulations were run with controllers in the loop, and four with TMCs in the loop. One simulation was designed specifically for users to interact with each other in order to develop the operational Concept of Use procedures.

Eight early simulations operated in the HITL mode and the two most recent tests operated in the Fully Automated mode. As stated earlier, the HITL tests were used for familiarization, training and some concept testing. As the capability of the simulation environment matured, the research objectives focused more on collaboration exercises, and the calculation and distribution of schedules throughout the four Centers.

In summary, the simulations allowed the researchers to accomplish their goals of designing and demonstrating a multi-center TMA proof of concept. Controllers and TMCs used the lab for training prior to field-testing and subsequent deployment. Just as important, the simulations allowed the users to develop and implement new protocols to manage Philadelphia-bound traffic based on the demand and capacity of the entire Northeast region.

VIII. Enhancements

The Mixed-Use mode offers researchers the greatest flexibility in investigating a variety of topics because it enables interaction with the domain experts. However, this mode requires great effort in creating the automated commands and represents the most complex mode to set up and execute. With some foresight, the commands in the Sector Command List file can be designed in a manner that allows for the insertion of a manned sector (comprised of the controller and pseudo-pilot pair). This requires the instruction set of each sector to follow a defined protocol. The protocol describes that a sector be able to accept a handoff, execute a set of commands, and issue a handoff to an adjacent sector. When the manned sector is dynamically inserted in the simulation during a simulation run, PAS disables the automated instructions for that sector and proceeds to accept inputs from the pseudo-pilot. In a fully integrated fashion, the computer hands off the aircraft to the manned sector, the users accept the handoff and issue commands to the aircraft. When finished, the users hand off the aircraft back to the computer. If the manned sector is shut down, PAS retakes control of those aircraft and reissues the commands in the Sector Command List.

The researchers achieve the process described above by manual entry today. The current process is labor intensive and error prone because of the interactions between the Aircraft List and the Sector Command List, and of the interaction between sectors. An automated way to check the logic flow (protocol) between each sector would help reduce development time. Another automated mechanism to verify commands issued to aircraft that results in a smooth and continuous trajectory profile would also greatly reduce development time. These two automated methods, if developed, will greatly improve the scenario development cycle.

Lastly, the researchers recommend validating the Mixed-Use mode with domain experts in the loop. Although the Mixed-Use mode has passed researcher scrutiny, it has yet to be validated by the users. The McTMA simulations have not formally run in this mode yet. The McTMA research team expects to use this mode in upcoming simulations.

IX. Summary

The simulation laboratory developed at NASA Ames has achieved it purpose of providing a flexible and robust testing environment for validating the capabilities of the integrated McTMA systems. The environment has allowed the researchers to conduct algorithm development, provide training to the users, and collect engineering data and user feedback. The lab also provided a unique environment for the cadre to collaborate and develop a set of Concept of Use procedures. Lastly, the different modes of operation developed for this testing environment represent its most innovative feature.

The three modes of operation create flexibility in conducting different testing scenarios and robustness of integrating various sets of users in the simulation environment. The Human-In-The-Loop mode permits interaction between researchers and users and help foster better communications between the users. The Fully Automated mode has allowed the researcher with more flexibility in the development of the scheduling algorithm. The Fully Automated mode requires the least resources of the three modes and provides the quickest simulation turn-around time. The Mixed-Use mode fits between the other two modes, providing HITL interaction as well as automation of aircraft not controlled by the subjects. This mode focuses the observation on the sector, user, or facility of interest while the computer automates the remainder of the traffic.

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