Real-Time Simulation for Air Traffic Control Research and Development

Steven R. Bussolari
Maria C. Picardi

MIT Lincoln Laboratory
Lexington, Massachusetts, USA

ABSTRACT

An approach is suggested for the incremental use of real-time ATC simulations for concept development and human factors evaluation of automation systems. Emphasis is placed on the characteristics that distinguish research simulators from those used primarily for training. Four general levels of simulator fidelity are identified for two ATC environments of interest: the radar room and the control tower. Fidelity requirements are generated by the specific needs of the particular human factors study to be conducted, ranging from part-task single-controller simulation used for concept demonstration to full-mission simulation of multiple ATC facilities to examine issues of interaction among automation systems. This approach is applicable to smaller simulations performed at an R&D contractor site as well as large-scale system integration studies conducted at a high-fidelity, centralized, simulation facility. It has been applied to the design of simulations of ATCT and TRACON environments that are being used for the evaluation of displays, controls, and procedures for the Airport Surface Traffic Automation (ASTA) and Terminal ATC Automation (TATCA) projects.*

INTRODUCTION

With recent advances in computer workstation technology, it has become possible to construct real-time Air Traffic Control simulations of high fidelity at a relatively low cost. Just as aircraft cockpit simulation has expanded from its initial role as a training tool to that of an important proving ground for new flight deck designs, ATC simulation has become an integral part of the FAA research and development process. The strength of real-time simulation with human operators in-the-loop lies in the ability to present complex scenarios under precisely controlled and repeatable conditions. Situations that are infrequent and hazardous in the actual operational environment may be studied in detail with simulation. Moreover, the flexibility of simulation lends itself well to rapid prototyping, a cost-effective method that shortens the iterative process of system design and evaluation. Control of the simulated environment is essential to a human factors evaluation of new ATC design concepts, but achieving the proper level of simulator fidelity for a particular set of evaluation goals requires careful attention to the particular tasks to be performed. The fact that it is now easier to construct a high fidelity simulation may exacerbate the problems associated with their overuse.[1] Despite these limitations, simulation is likely to be the primary means by which future ATC automation systems will be evaluated prior to initial field trials.[2]

Although commercial ATC training simulators with a wide range of capabilities are currently available, there are unique demands imposed by the research and development process that, in many cases, run orthogonal to the needs that drive the design of a training simulator. The utility of a training simulator is measured by the effectiveness of training transfer coupled with the ratio of operating costs associated with simulator and on-the-job training.[3] In fact, the achievement of a high level of operator-perceived fidelity in a particular training simulation may not be a primary design goal, for studies have shown that this is not an accurate predictor of training effectiveness.[4] Limitations of training simulator fidelity are often dealt with through the use of mediating actions by the trainee, such as manual manipulation of model aircraft on an airport mockup for tower controller training. These mediating actions are easily shed by the trainee in the ac-

* This work is sponsored by the Federal Aviation Administration.

tual environment where they are no longer needed. In some instances, the mediating action that supports a controller clearance (e.g. the manual movement of a model aircraft described above) will transform to the real-world action of verifying that a clearance has been followed. Finally, the capacity of a training simulator, as measured by the complexity of the traffic it can represent, is limited simply because they are generally designed to generate scenarios for the *ab initio* student.

By contrast, the real-time simulation used for research is primarily oriented to system evaluation where it is necessary to obtain reliable and repeatable human factors data. In this case, it is essential that controller behavior in the simulator is well matched, or at least consistently related, to behavior in the actual environment. To obtain objective performance measures, it is important that the experimental conditions be controlled for the types of repeated-measure study designs necessary for accurate statistical analysis.[5] Subjective measures such as workload ratings and opinions may be strongly influenced by the level of simulation fidelity perceived by the participating controllers. Objective performance measures selected by the investigators will, in general, be related to the type of automation being evaluated. For example, a controller using an automated planning tool to vector arrival aircraft in the terminal area may achieve near-optimum arrival rates by virtue of the automation aid, but there may be a question as to the impact, upon overall workload, of the task of monitoring the closely-spaced aircraft. The development and use of combined measures to address particular issues gives rise to the requirement that the simulation software be flexible and easily modified.

Despite the restrictions imposed by the above considerations, it is possible to construct real-time ATC research simulations with sufficient fidelity for a wide variety of human factors studies without resorting to costly full-mission simulation. In fact, it is advantageous to begin the system development process with simpler studies in order to obtain an understanding of the human factors issues prior to resorting to a complex simulation that may yield results that are difficult to interpret.[6]

The balance of this paper will be devoted to a description of four levels of real-time simulation applicable to ATC automation research. As described above, one of the primary goals of such a simulation is to collect human factors data. Therefore, it is useful to define the functional requirements for each level of simulation fidelity in terms of the particular type of human factors study to be carried out. These will be illustrated by examples of TRACON and Air Traffic Control Tower (ATCT) simulations used for work in progress at MIT Lincoln Laboratory as part of the Terminal Air Traffic Control Automation (TATCA) and Airport Surface Traffic Automation (ASTA) projects. This research is aimed at providing controllers with automation aids to assist them in the planning and safe execution of traffic movement in the terminal area and on the airport surface. More complete descriptions of TATCA and ASTA may be found elsewhere.[7,8]

CONCEPT DEMONSTRATION

When an automation system that involves a new operational concept is proposed, it is necessary to demonstrate this to the end users (in this case, controllers) and obtain initial feedback on the potential advantages and limitations of the human/system interface. This is often best accomplished through a part-task demonstration simulation. In many cases, the demonstrator will consist simply of a display prototype running on a general purpose computer workstation (e.g. the IBM RS 6000). The demonstration may be interactive, in the sense that the controller can issue clearances and make inputs to the automation by using the human/system interface. A specific example of this is a basic radar display simulation developed for TATCA and illustrated in Figure 1. A computer workstation is used to provide a representation of a terminal radar display used by a TRACON controller (Final Vector or Feeder). The TATCA planning aids (providing sequence, timing, and conformance indications) are depicted on the radar display. Arrival and departure traffic are generated automatically and

move in response to clearances automatically generated by the simulation and depicted on the radar display. In this configuration, the simulation is not interactive in the sense that controller actions are defined by the simulation, but a controller observing the operation of the TATCA planner can begin to form an opinion on the system operation. Interactive simulation is achieved with the addition of a pseudopilot at a second workstation who responds to controller commands in real time and allows the evaluator to experiment with the use of the TATCA planner. The combination of a non-interactive demonstration with an interactive part-task simulation has proved extremely valuable in refining the functional requirements and constraints of the TATCA human/system interface.

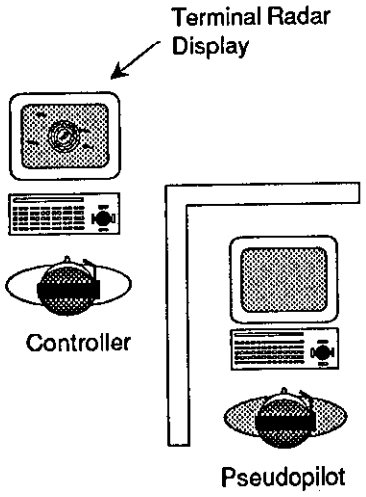

Figure 1. The basic level of research simulation, this concept demonstration was used for initial TATCA human/system interface evaluation. A computer workstation is used to depict a single terminal radar display with candidate display enhancements provided by TATCA. Addition of a pseudopilot station allows the demonstration to become interactive.

The "tabletop" concept demonstrator described above can provide a rapid and qualitative evaluation of a candidate human/system interface. However, by definition, this type of simulation operates out of the context of a full ATC task load. The effectiveness of the simulation depends on the ability of the evaluators to extrapolate performance to the "real world" and the results obtained should therefore be interpreted with caution. However, the concept demonstrator has the potential to provide valuable insight during the crucial initial stages of system development with a relatively low investment.

PART-TASK EVALUATION

As a proposed automation system design matures, the need arises for more reliable and quantitative performance data than can be obtained with a simple concept demonstration. This places much more rigorous requirements upon the simulation in terms of its capacity for interaction and control of experimental variables such as traffic generation and pseudopilot response. Controllers must be able to use some set of the automation functions envisioned for the candidate system under realistic traffic conditions. By definition, this type of simulation is part-task in nature and may consist simply of a single controller position with one or more supporting pseudopilot positions. The actions of controllers at adjacent control positions may be simulated automatically or through the use of pseudo controllers if verbal communications fidelity is desired. The operation of the automation human/system interface in this type of simulation will focus on a single mode of operation, rather than the transition among modes.

Figure 2 illustrates a part-task ATCT simulation under development for evaluation of the ASTA human/system interface. The initial evaluation will be conducted under low-IFR conditions when direct visual traffic surveillance is not possible, thus eliminating the need for an external visual system. Two tower controller positions, Ground and Local are provided. The Gate position is occupied by a pseudo controller to provide Ground with departure flight strips and coordinate aircraft push-back times. Computer workstations are used to simulate the BRITE terminal radar and the ASDE-3 (Airport Surface Detection Equipment) surface radar displays. Additional computer workstations are located in a separate

room for pseudopilots. A communication system, similar in operation to typical ATCT equipment, permits Ground and Local to issue taxi, takeoff, and landing clearances to the pseudopilots.

Actual traffic data from operations records at a particular airport are used to generate scenarios for the simulation. In a series of 1 to 2-hour simulation runs, the Ground and Local controllers will control traffic and evaluate ASTA display options depicted on the ASDE-3. Although low-IFR operations represent a small fraction (approximately 5%) of the total operations at a typical tower, these studies will provide valuable initial results, particularly because they are conducted under conditions where the controllers rely heavily on the ASDE for surface surveillance.

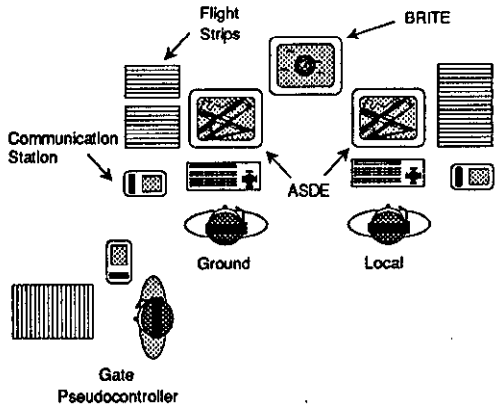

Figure 2. Part task ATCT simulation for ASTA evaluation under low-IFR conditions (no external view from the tower cab). Ground and Local controller positions are provided with radar displays and flight strip holders. Pseudopilots and a Gate pseudo controller provide communications fidelity. This type of simulation may be used for early concept development.

The simulation described above is capable of producing a reasonably high fidelity representation of an important subset of the tower controllers' tasks. The simulation is not designed for scenarios that include changes in operations mode (e.g. transition to VFR conditions) nor is it full-task in the sense that many of the controller duties such as coordination with other tower staff are not included.

MULTI-CONTROLLER EVALUATION

One of the advantages of ATC automation is the potential it holds for improved communication and coordination among controllers within a given ATC facility. In the case of traffic plans generated by TATCA and ASTA, controllers will not only refer to the plans, but will be able to interact with the plan and modify it to suit current conditions. There are important human factors issues surrounding the timing and hierarchy of such controller inputs, given that a single plan may be simultaneously viewed by a number of controllers. In order to address this, it is necessary that a simulation be capable of producing and environment in which this interaction may take place. This requires, in general, multiple controller positions and more complex traffic generation. With more controllers involved in the simulation, the experimental variables associated with objective performance measures become more difficult to control due to the effect that one controller's actions has on the traffic entering another controller's sector. Again, the experience gained in preceding studies conducted under simpler conditions (requiring less complex simulation) will prove valuable, not only in the interpretation of results, but in the design of experiments.

An example of this type of multi-controller simulation can be illustrated by one portion of the TRACON simulation developed for TATCA evaluation (see Figure 3). Both the Final Vector and Feeder Controller positions are present with radar displays simulated on computer workstations. Since this simulation is designed to examine issues of coordination within the TRACON, arrival traffic from adjacent sectors controlled by an ARTCC is generated automatically. As in previous simulations, the automated functions of TATCA are active and provide planning information to the controllers. However, in this simulation, both Feeder and Final Vector controllers are operating with the same TATCA plan and, as in the actual environment, the traffic sequence and spacing received by Final Vector will be the result of the actions of the Feeder controller. Moreover, both controllers may make inputs to

the plan. The addition of Departure controllers to this type of simulation involves the addition of computer workstations for the radar displays and the augmentation of the scenario generation routines to accommodate departure traffic.

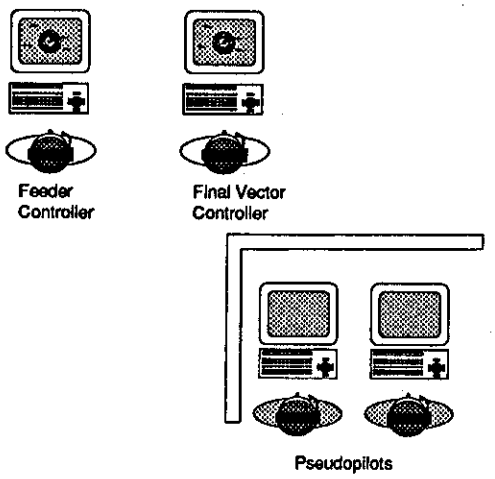

Figure 3. Portion of multi-Controller simulation developed for TATCA evaluation. Multiple positions within the TRACON are provided to assess the effect of the TATCA planner upon the coordination between adjacent sectors and the dynamics of multiple controllers interacting with the planner.

FULL-MISSION EVALUATION

At some point in the development of automation aids for controllers, it becomes necessary to evaluate their effectiveness within the complete context of the controller's tasks. The only alternative to a direct field evaluation is a full-mission simulation. Again, the issue of proper control of the experimental variables arises in the context of a field evaluation. The need for a full-mission evaluation is particularly important when one considers the implications of several individual automation systems operating in adjacent ATC facilities. For example, the traffic planning functions of ASTA and TATCA will be active and operating within the ATCT and TRACON, respectively, formulating efficient schemes for traffic movement on the airport surface and within the terminal area. Each relies on input from the other to generate these plans. At the same time, enroute automation (AERA) will be generating planning information for the adjacent enroute sectors and will require information from TATCA. Globally, flow control automation will be formulating alternative plans to accommodate system-wide factors such as weather and navigational aid problems. General parameters such as airport acceptance rate or specific information such as arrival and departure timelines will be available as an output of the TATCA and ASTA traffic plans. The effects of propagation of this type of information from the surface (ASTA) through the terminal area (TATCA) and the enroute airspace (AERA), to the Central Flow Control Facility's Enhanced Traffic Management System (ETMS) are not known. Some of these issues may be resolved in non-real-time simulation, but the effects of decision making and input by controllers at each of the ATC facilities must be addressed in a large-scale simulation that includes multiple facilities, each represented by a full-mission simulation.

One of the most challenging ATC environments to simulate in this manner is the ATCT. The primary reason for this is the requirement that controllers use direct visual surveillance of traffic on the airport surface as well as reference to displays within the tower cab. The interaction of these two tasks is an important element in any human factors evaluation of tower display systems. The development of an out-the-window visual system for full-mission ATCT simulation is a technical problem that remains to be solved. Such a system must be capable of generating a realistic visual scene that can depict approximately 50 active aircraft on the airport surface and in the immediate vicinity as well as provide for movement of the controllers within the tower cab. Servo-projector visual systems are capable of producing the high resolution required to depict distant targets, but because each aircraft requires a dedicated projector, mechanical interference limits the number of projectors that may be active in a given airport scene to approximately 10. Computer graphics imagery (CGI) systems are capable of producing a sufficient number of aircraft, but performance in the neighborhood of 150,000 polygons per second

per tower window is required to provide smooth apparent movement of aircraft of reasonable geometric fidelity (100-150 polygons) and CGI alone cannot achieve the resolution needed for distant targets. It is possible that some combination of CGI and servo-projection system may be required to achieve the level of fidelity necessary for full-mission simulation. Such a system represents a major investment in equipment, software, and maintenance. Work must be done to develop low cost alternatives, for at the present time, there is no commercial training or research ATCT simulation that has a visual system capable of full-mission simulation of operations at a busy airport.

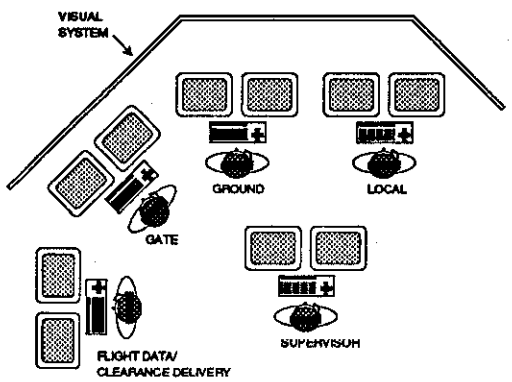

Figure 4. Level 4 full task ATCT simulation for ASTA evaluation in the TCCC environment. Five tower controller positions (Ground, Local, Gate, Flight Data / Clearance Delivery, and Supervisor) are provided with workstations that simulate TCCC functions.

A complete evaluation of the ASTA human/system interface will require the treatment of information transfer and coordination among ATCT controllers and other automation systems such as TATCA, AERA, and ETMS. Figure 4 is a schematic illustration of the type of simulation required. In this case, the controller positions are provided with the Tower Position Consoles that will be available with the Tower Computer Control Complex as part of the Advanced Automation System. The simulation depicted in Figure 4 includes five tower controllers: Flight Data/Clearance Delivery, Gate, Ground, Local, and Supervisor, but different tower staffing levels and configurations are possible. In the case of an evaluation requiring multiple facilities, the ATCT simulation would be linked with one or more additional stand-alone simulations of those facilities.

THE USE OF PSEUDOPILOTS

Information transfer by verbal communication is, and will continue to be, an important task facing the ATC controller. Providing adequate communications fidelity in simulation, therefore, is a requirement for all levels of interactive, real-time simulation described above. The results of a particular study will, in general, be sensitive to the performance of the simulated communication system, whether or not it employs human pseudopilots. At the present time, there is no substitute for the use of human operators acting as pseudopilots in research simulation. The technology of voice recognition systems has not yet reached the point where it can reliably handle the continuous speech and speed of controller communication in a typical traffic scenario. One exception to this is the simulation of data link operations where no direct verbal communication with the flight deck is employed. In any case, accurate models for the response of pilot and aircraft are still required to obtain valid results.

Central to the issue of the effectiveness of the use of pseudopilots is the design of the controls and displays they use to manipulate the simulated aircraft in response to communication with controllers. Pseudopilot interfaces for the control of airborne aircraft have been developed for both research and training simulation. Although there are refinements needed to improve the handling of airborne aircraft, the design of a proper interface to allow a pseudopilot to control an aircraft on the ground poses a somewhat more complex problem due to the fact that multiple communications channels are used and, in general, the clearances issued by ATC involve implied actions that place a heavy workload on the pseudopilot. For example, compliance with a taxi clearance that involves a series of taxiways, hold short instructions, and a frequency change is a challenging task for any pseudopilot, since that person is usually attempting to control more

than one aircraft simultaneously. The problem may be alleviated somewhat by employing a strategy that assigns pseudopilots to a particular portion of the airport surface rather than to individual aircraft. The simulated aircraft would then be "handed-off" from one pseudopilot to another as the aircraft moved from one portion of the airport to another. It is interesting to note that the same issues of communication and coordination arise for pseudopilots employing this type of strategy as do for the ATC controllers with which they interact. We are currently addressing this problem within the ASTA simulation with a graphics-based pseudopilot interface, but much work remains to be done in this area.

CONCLUSIONS

There are several low-cost alternatives to full-mission scenarios that can be applied to a research and development effort involving real-time ATC simulation. An incremental approach to the design of a simulation takes advantage of the fact that initial human factors evaluations of a new automation system are likely to be limited in scope and have goals that may be met with part-task workstation-based simulations. In many cases, the demands of a particular investigation will force development of experiment-specific software. However, common needs, such as an effective pseudopilot interface and aircraft performance models will continue to be applicable as the simulation becomes more complex.

Ultimately, there is a need for full-mission simulation capability to address the issues associated with the coordination of automated functions within and among ATC facilities, particularly when changes occur as the result of controller input or other factors. While full-mission simulations exist, or are under development for TRACON or ARTCC studies, the construction of a full-mission ATCT simulator remains as a major technical challenge, primarily due to the requirement for a high-fidelity visual system and the difficulty of designing an appropriate pseudopilot interface capable of handling the high traffic volume present at a typical large airport. One potential benefit of a national simulation facility will be that it will have the capability to support the type of full-mission simulations that will be required as automation systems mature.

REFERENCES

1. Hopkin, V.D., "Real-Time Simulation for Air Traffic Control Evaluation", Proceedings of International Conference on Simulators, University of Sussex, pp 115-120, September, 1983.
2. Air Transport Association of America, "National Plan to Enhance Aviation Safety Through Human Factors Improvements", Report of the ATA Human Factors Task Force, ATA, 1709 New York Ave, NW, Washington, DC, April 1989.
3. Rolfe, J.M., and Staples, K.J., eds., Flight Simulation, Cambridge University Press, Cambridge, England, pg. 246,1986.
4. Roscoe, S.N., Aviation Psychology, Iowa State University Press, Ames, Iowa,pg. 150, 1980.
5. Buckley, E.P.,DeBaryshe, B.D., Hitchner, N., and Kohn, P., "Methods and Measurements in Real-Time Air Traffic Control System Simulation", DOT/FAA/CT-83/26, FAA Technical Center, Atlantic City Airport, NJ, 1983.
6. Hopkin, V.D., "An Appraisal of Real-Time Simulation in Air Traffic Control", J. Educational Technology Systems, Vol 7(1), pp 91-102, 1978-79.
7. Andrews, J.W., and Welch, J.D., "The Challenge of Terminal Air Traffic Control Automation", Air Traffic Control Association Conference Proceedings, ATCA, Arlington, VA, 1989.
8. Lyon, E.F., Thompson, S.D., Kastner, M.P., Bussolari, S.R., Marquis, D., Bradford, E.R., Morin, T.J.,"The Airport Surface Traffic Automation Program (ASTA)", Air Traffic Control Association Conference Proceedings, ATCA, Arlington, VA, 1990.