Review of Controller Training Requirements for Advanced Air Traffic Control Environments
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Abstract
With current efforts to update and improve the global air navigation system, ATC training must keep pace. The purpose of this paper is to gain a better understanding of the current research on air traffic control training requirements for advanced operational environments. Based on the current literature and the development of an advanced ATC operational environment, a summary of the key themes and concepts of that research is presented. Future avenues of research are then identified and discussed.

1. Introduction
The current system updates to the global air navigation system (ANS) will cause an increase in system automation and complexity, leading to significant changes in an air traffic controller’s operational environment (Blanken, 2002; Hilburn et al., 2006). These changes to the operational environment are triggering the need for re-evaluation of the knowledge, skills and abilities (KSAs) required for successful controller performance in the modernized system. There is also a growing need to examine how best to train for the new KSAs as it is imperative that the training programs and processes evolve with the system.

Air traffic control (ATC) training programs will need to adapt to this environment and its requirements by considering the introduction of new instructional techniques. Previous work has highlighted the need for further research into future ATC training programs for the FAA as the current training program is insufficient to handle the demands of emerging issues created by the future air traffic management (ATM) system (Barr et al., 2011; USGAO, 2008). This paper summarizes the current literature on future ATC training programs and identifies areas of future research.

2. Background
A truth that has faced the aviation industry for decades is that air traffic increases every year. In 2007, the International Civil Aviation Organisation (ICAO) released a forecast of the global air traffic growth until 2025, estimating that passenger air traffic will continue to grow at approximately 4.6% annually and freight air traffic at 6.6%. In 2001 there were 3.011 trillion passenger-kilometers performed (PKPs), a number which in 2011 had grown to 5.062 trillion (ICAO, 2012). The process of upgrading to advanced global ATM systems that can handle the increased system demands safely and efficiently is currently underway.

Two of the most significant projects associated with updating the global ANS are the systematic upgrades of the ATM systems that handle the airspace over Europe and the United States. The Federal Aviation Administration (FAA) and Eurocontrol projects are entitled the Next Generation Air Transportation System (NextGen) and Single European Sky ATM Research (SESAR) respectively. The implementation plans for SESAR and NextGen offer similar approaches of using new technology and information management strategies to improve the ATM system’s ability to handle the increasing air traffic (FAA, 2012; Eurocontrol, 2012). The system updates have already begun to take place and will continue to be implemented until the final system is fully in place and activated, the estimated date of which is 2025. This model of continuous modernization is in contrast to previous system changes where they were performed in large, distinct segments rather than as a gradual transition over a long period of
time (Stillwell, 2011). These system updates can be thought of as “changing the tires on a car while it’s going 100kph (ibid, p.39)”, as the ATM system never stops controlling air traffic during the system upgrades. Some of the changes in the new ATM system include but are not limited to: Automatic Dependent Surveillance-Broadcast (ADSB), Controller-Pilot DataLink Communication (CPDLC), System Wide Information Management (SWIM), Collaborative Decision Making (CDM) and decision support tools (DSTs) for controllers (FAA, 2012; Eurocontrol, 2012). With the proposed upgrades the controller in the future ATM system will have a greater amount of information at their disposal and it is believed that the system will use this information to generate safer and more efficient air travel.

This shift in the operational environment will have a significant impact on the required KSAs for controllers. Training programs will need to adapt to meet the changes and to prepare controllers who are able to take full advantage of the new system capabilities.

3. Key Themes in Current Research on Training in Complex Systems

This section and its categories were chosen by pulling persistent themes from the amalgamated literature and arranging them under three major sections: Simulation-Based Training, Training for Automation, and Instructional Design for Training Complex Skills. A summary of the relevant literature in each subject is presented.

3.1 Approach to the Literature Review

The goal of this literature review was to gain an understanding of the current research on training for future ATC environments, highlight important considerations for those who currently design and implement ATC training programs and offer potential areas of interest for future research into the subject matter. The review relied on a combination of journal articles, conference proceedings, book chapters, and government and contractor technical reports.

Journals, conference proceedings and books were chosen based on their connection with human factors related material and included publications such as Human Factors: The Journal of the Human Factors and Ergonomics Society, The Journal of Aviation Psychology, Ergonomics in Design: The Quarterly of Human Factors Applications, Theoretical Issues in Ergonomics Science, and several others.

A key goal of this literature review was to present the most recently published research in the field of ATC training, so there was a conscious effort to use material published between 2002 and 2013 with a focus on the latter half of that time period. Search terms used to find the relevant material included: ATC, training, automation, complexity, fidelity, simulation, instructional design, and complex skills.

The relevant papers chosen for this literature review were analyzed for recurrent themes that were then aggregated into major categories to illustrate the current state of knowledge in training for future ATC environments. Finally, potential areas of interest for future research were then identified from this body of knowledge to highlight avenues for further research.

3.2 Simulation-Based Training

The use of simulation technology in ATC training has grown increasingly more as a cost efficient and effective way for trainees to learn and practice their skills. However, it is important to evaluate whether simulation based training is always effective, necessary and/or sufficient. Key themes that have been drawn out from the literature include a simulation’s level of fidelity, how best to categorise and characterize simulation scenarios and how best to structure the use of simulation in training programs.

One of the key determinants of the effectiveness of simulation-based training is the simulation’s level of fidelity, or similarity to the real-world environment, a simulation is able to recreate. Salas et al. (1998) examined the misconceptions of simulation in aviation training and how it was being used without
consideration of the relevant scientific findings on training, acquisition of KSA\textsubscript{s} and cognition. The three assumptions that the study addressed were the ideas that simulation was all that was needed for effective training, the more authentic the simulation environment the better the training would be, and if the operators, in this case pilots, liked it then it was considered a good teaching tool. These misconceptions were thoroughly debunked and a more student-centered, scientific approach to instructional design was presented. The use of simulation in training programs must be based upon research within the domain of effective instructional design, not based solely on its ability to replicate the environment (Salas et al., 1998).

The impact that the level of fidelity of a simulation has on achieving training goals has remained a key issue for debate. The use of simulations for training purposes have continued to be driven by technology and creating a hyper-realistic environment with little research into the impact those simulations have on the goals of the training (Dahlstrohm et al., 2009). It has been found that the use of lower-fidelity simulations can be more effective in terms of training skills such as generic problem solving, and that high-fidelity training simulations amplify role socialization which can actually be detrimental to the ability of handling novel situations (Dahlstrohm et al., 2009). High-fidelity simulation has been associated with the effective transfer of procedural skills, so it is not to say that high-fidelity simulation is bad altogether, but rather using it as one component of the learning process and garnering a better understanding of how best to apply its use in terms of achieving learning goals. This touches upon the idea of knowing what skills the simulation is being used to train. It is paramount that learning goals be set when using simulation as a training tool and that comprehensive performance measurements be used to ensure that learning outcomes are being met and that time spent training in simulation is not wasted (Salas et al., 2009).

Simulation fidelity can be comprised of physical fidelity and cognitive fidelity components. Physical fidelity is the authenticity of the physical environment of the simulator, whereas cognitive fidelity stresses the similarity of the cognitive activities performed in the simulation to those in real-world environments (Hochmitz & Yuviler-Gavish, 2011). The level of fidelity created by authentic simulation scenarios falls under the category of cognitive fidelity. The authenticity of the scenarios being presented to the controller is something that has improved over time, with an ability to use live traffic data to drive scenario creation (Sanchez & Celio, 2006). Scenario creators can use this traffic data to create scenarios that meet training objectives more effectively. This provides trainees with exposure to more authentic situations and is good for increasing skill transfer to the working environment. But for this to be truly effective it requires the creation of large libraries of scenarios to offer flexibility and variety to the learner, and it can be a time consuming, labour intensive and expensive process. There is work that has looked at the viability of using automatic scenario generation in order to offset these costs, in essence using information about the desired learning outcomes and the trainee to generate the appropriate scenario (Martin et al., 2009). But categorizing these scenarios so they are delivered to the trainee at the right time and responding to the right level of difficulty can be tricky.

There have been efforts in the military training domain to use complexity to inform the selection of appropriate scenarios for trainees, but no viable solutions have yet been fully realized (Dunne et al., 2010). This provides an interesting potential for ATC simulation scenario characterization, as there has been extensive research (Li & Hansman, 2009; Kopardekar et al., 2009; Histon & Hansman, 2008; Hilburn, 2004) on complexity metrics for real-time ATM applications yet no work has been applied to categorizing simulation scenarios using complexity metrics for training purposes.
Advances in other learning techniques and technologies are also emerging. Traditional classroom and computer based training techniques are often used for learning basic ATC knowledge (Nav Canada, 2009). More innovative and engaging techniques are being evaluated in later stages of an ATC training program.

Increasing use is being made of highly sophisticated computer-based training, in the form of intelligent tutoring systems (ITS). These systems are “environment[s] for a trainee to learn, practice, and receive automated feedback on ATC skills at various levels of training in a more self-paced environment that accelerates skill acquisition (Bolczak & Celio, 2006).” A key component of an ITS is the use of voice recognition and voice synthesis programs, allowing for the trainee to interact independently with the system without costly back-end support of a full fidelity simulation (Brudnicki et al. 2007, Bolczak & Celio, 2006).

Simulation has the potential for being a powerful tool in reducing time needed for on-the-job training (OJT) and improving trainees KSAs (Blanken, 2002). It should be involved in training programs, but its use should be informed by appropriate scientific research on the most effective implementation of the appropriate technology for achieving learning outcomes.

3.3 Training for Automation

The proposed changes in NextGen and SESAR will increase automation in the ATM system in order to help air traffic controllers cope with increasing air traffic. Many issues can arise from automating processes that would then have a significant impact on the successful performance of the task. Automation can have human performance consequences, specifically mental workload, situation awareness, complacency and skill degradation (Parasuraman, Sheridan & Wickens, 2000).

Studies have shown that in future ATM environments, automation is necessary to achieve the level of performance required to maintain safe and efficient traffic flow (van de Merwe et al., 2012; Rovira & Parasuraman, 2010; Metzger & Parasuraman, 2005). What is important in the process of implementing more automation systems for assisting controllers is researching the impact these system have on human performance. Examples of areas of concern include the formation of mental models (Nunes, 2003), the effects of imperfect automation on human performance (Rovira & Parasuraman, 2010), design of an effective ATC display consistent with human-centered design philosophy (Sanchez et al., 2009), and the impact of decision support tools on workload and situation awareness (van de Merwe et al., 2012). It is well known that there are potential repercussions for poorly designed automation tools in terms of the future ATM system, but the impact that these automated systems will have on the training of air traffic controllers has not been as extensively studied.

There have been several recent studies that have analyzed the impact of the proposed new automated systems on the design and implementation of training programs. Rorie et al. (2011) examined whether advanced conflict detection decision support tools should be introduced before or after traditional manual conflict detection training. Results showed that the manual controller training before NextGen tools training was significantly more effective, with participants in the NextGen tools first training reporting “that their order of training was ineffective, stating that it would have been more beneficial to receive the training on manual conflict detection and voice communications first (Rorie et al., 2011).” In Billinghamurst et al.’s (2011) study of the sequence of learning general ATM skills and NextGen tools found that “the order of introducing NextGen tools did not affect operator performance, workload, or SA [situation awareness]. Rather, performance benefitted from recent manual training regardless of order.” Finally, Vu et al. (2012) studied the effect of reliance on decision support tools during learning and how it may affect their ATM skills when those tools fail. They found that when all NextGen systems were
reliable, the type of training an operator received was inconsequential. In fact it was the amount of aircraft equipped with NextGen capabilities that influenced performance and workload. But when analyzing the same scenario where there was a failure of NextGen tools, the operators who had been trained to rely more on manual control skills earlier in training performed better than the opposite group.

Key points that should be drawn from this current research are that automation failures will generate specific training needs and that the order of training skills as well as how recent it has been performed will be significant issues moving forward.

3.4 Instructional Design for Training Complex Skills
Air traffic controllers need complex cognitive skills in order to perform their job successfully, and they will need them even more with the advanced ATC environment (Blanken, 2002). There is research that can inform instructional design in terms of learning complex skills, and it is important that this be considered when designing ATC training programs for advanced ATC environments.

Recent work has criticized decompositional approaches to instructional design for operators in complex systems. The decompositional approach, also referred to as the atomistic approach, is the process of increasingly simplifying and isolating the components that comprise complex tasks and reducing them to simple skills (van Merriënboer & Kirschner, 2013). Van Merriënboer & Kirschner (2013) suggest that this does not recognize that complex skills are more than the sum of their parts and that the relationships created by the interaction of all of the component pieces are what define complex skills. Removing those relationships can actually inhibit learning. Their proposed model for a holistic instructional design approach incorporates four inter-connected components that are needed for complex learning: learning tasks, supportive information, procedural information and part-task practice (van Merriënboer & Kirschner, 2013).

A second theme emerging from the literature on instructional design is new processes for selecting which problems a trainee will encounter as they progress through a training program. This refers to dynamic problem selection, essentially an intelligent or adaptive technique for choosing problems, providing a more personal learning experience instead of having a fixed predetermined sequence for the delivery of training problems (Camp et al., 2001). Camp et al. (2001) tested this specific approach in ATC training, basing problem selection on three learner variables: mental effort, performance and mental efficiency. Transfer of skills was measured upon completion of the training, and it was found that “dynamic problem selection would lead to more efficient training than non-dynamic problem selection…” (Camp et al., 2001). A related theme is the use of critical thinking instruction, where trainees are given in depth training on what critical thinking is and how it can be applied in real-world situations (Helsdingen et al., 2010). This training technique was shown to improve decision strategy and enhance understanding of the domain, and it was their recommendation that it be used for the training of professional decision makers (Helsdingen et al., 2010).

Key takeaways from this section are that tested instructional design models to help create more effective training programs for learning complex skills are widely accessible and that traditional methods should be compared to new learning techniques to determine their validity with regards to achieving learning goals.

4. Opportunities and Research Needs
Based on the review of emerging themes discussed above, and previous examinations of the ATC training process, a model of the training program redesign process is being developed. The model shows the training process as an integral part of overall system redesign as previous training programs are not
sufficient to meet the training requirements created by an advanced ATC environment. The developed model can be used to illustrate key factors affecting training program design and identify opportunities where additional research is needed.

In the model, which can be found in Figure 1 below, the current operational dynamic is shown on the far left side of the model. Operational tools form the basis for how operations are performed. Controllers are trained to perform the operations by the training process that is regulated by the training program. A key dynamic illustrated by this model is that the training program and process cannot merely be carried over to the future operational environment; there are steps that must be taken to ensure a smooth transition. To redesign the operational tools, a research and development process has taken place and created many new operational tools that are now being systematically deployed to the operational environment. A key component of the redesign process is the development of new training requirements based upon these new operational tools. The new requirements should then be used to inform the redesign of ATC training programs. Key issues that need to be considered when designing the training program are the issues discussed in this paper. Deployment of the updated program will then create a training process that better trains controllers for operations in the future ATC environment. It is important that development and deployment of the updated training program not lag behind the deployment of new operational tools as this could create a significant strain on an organisation’s training resources. Opportunities for further research are discussed below.

Simulation-based training is a valuable tool for effective training programs and its use will continue to rise in years to come. It is important to continue investigation into the level of fidelity of simulations and the repercussions it has on the learning of desired KSAs. As was discussed earlier in section 3.1, there is not a direct correlation between higher-fidelity simulation and effective learning for all skills. High fidelity simulation does not guarantee good training. Furthering our understanding of the optimal level of fidelity required for training specific skills is an important step in improving the use of simulation and perhaps even reducing costs due to lowering the requirements of fidelity. Developing a more comprehensive definition of the concept of fidelity of simulation in terms of training outcomes could then influence how varying degrees of fidelity would be used to improve the acquisition of desired KSAs. This process of varying the degrees of fidelity could be informed by research into whether or not complexity metrics tailored specifically to simulation scenarios could provide a better means for
effectively categorizing different simulation scenarios and thereby effecting level of fidelity. More research in this area would serve to deepen the understanding of how the level of fidelity affects training and how it is possible to positively influence the learning process through its proper application.

Human-automation interaction is an important subject when discussing the future ATC environment, as automation is a key component of the future system. The consequences of potential failure of these automated systems and how their degradation may propagate has been studied (Rigaud et al., 2012), yet there is the need for training to be able to handle these scenarios of potential failure. Some have already begun looking at the consequences of automation failure (Vu et al., 2012), yet more is needed. It is important that there is a graceful degradation to the system rather that allows for the potential of operators to recover and control the system safely without critical incident.

Another important concept is the idea of skill degradation, highlighted in Parasuraman, Sheridan and Wickens’s (2000) work on the levels of automation. With higher levels of automation, the human has less to do and is therefore more “out of the loop”. They are not using their skills on a regular basis so naturally there will be some decay in the level of their skills. There is a need for research into just how much an air traffic controller’s skill is likely to decay given the system updates and how to best mitigate that decay through more human-centered interfaces and refresher training. Being able to cope with automation failure is a key component that future controllers will need to be able to do, and in order to do that they need to keep their skills honed.

Finally, there is the impact that the automation will have on the formation of a controller’s mental model. It is been found that decision support tools and automation in general can adversely impact the formation of an effective and comprehensive mental model in air traffic controllers (Nunes, 2003), so continuing research on this subject would be beneficial to informing how best to incorporate the formation of mental models into training design. The idea of teaching how to form mental models to effectively cope with an automated environment is an avenue of research unto itself, with ATC training programs needing to incorporate this idea more and more in order to produce good controllers for their future ATC environments.

5. Conclusion

In summary, there has been significant work done in areas such as the effective use of simulation-based training, the impact of automation on training program design and delivery, and the use of proven learning theories and instructional design concepts for the formation of comprehensive training programs. This research highlights some of the requirements for training programs in advanced ATC environments but can be expanded upon. There is a need for deeper investigation into these subjects and how best to incorporate them in training program design and development to ensure that ATC training programs are offering comprehensive interventions. The goal is to efficiently train controllers who are fully capable of handling the changes to the ATC operational environment in the years to come.

References


