The Effects of Early Training with Automation Tools on the Air Traffic Management Strategies of Student ATCos

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Abstract. The present study examined whether early exposure of student air traffic controllers (ATCos) to NextGen automation technology in the form of integrated Data Comm affects the degree to which they come to rely on this tool instead of voice-based, manual tools to manage traffic. The data reported in this study comes from twenty-four students who took part in one of two semesters of an ATCo training course offered by our organization. One group received little or no early training with integrated Data Comm, managing no AC that were NextGen equipped or only 25% that were NextGen equipped in the first half of the course. A second group managed 75% AC that were NextGen equipped from the beginning of the training course. After the first half of the course, both groups received training with 75% NextGen equipped AC. Both groups were tested in a midterm and final exam that required them to manage traffic in a mixed equipage scenario. We found that proficiency of the students predicted their performance. Moreover, by the final exam, students converged on the same strategy, preferring to issue clearances using voice rather than Data Comm, regardless of early exposure to automation tools. This is likely because voice communication is faster than Data Comm, and is associated with greater efficiency of air traffic management.

Keywords: Reliance on automation, ATC communication, ATC training, NextGen

1 Introduction

The goal of the NextGen air traffic management system is to accommodate dramatic increases in air traffic density without simultaneously compromising the safety and efficiency of the National Air Space [1], [2] (NAS). In the current system, using manual tools that include radar displays and voice-based communications, Air Traffic Controllers (ATCos) can safely monitor and manage only about 15 aircraft in an en-route sector. As a result, a factor limiting the number of aircraft (AC) that can be op-

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erated in the NAS is the cognitive workload of air traffic controllers. In particular, verbal communication has been cited as a main source of ATCo workload [3-5]. To prevent significant increases in workload, NextGen will incorporate new automation tools and technologies, ones that have the potential to significantly alter the roles and responsibilities of ATCos. These will likely include, inter alia, improved traffic and weather displays, automated conflict alerting tools, conflict resolution probing tools, and Data Comm. The latter allows clearances issued by ATCos to be uplinked to an AC without the need for verbal communication. Due to high implementation costs, the technologies that will form the core of NextGen are going to be introduced gradually, with the consequence that the NAS will contain a mixture of NextGen equipped and unequipped AC. This means that student ATCos will have to be taught to use both, manual and NextGen tools. The present study examined how types of training with both types of technology affect the degree to which student ATCos come to rely on the new automation tools.

Very few studies have been conducted on how to train ATCos to use both manual and NextGen tools [6], [7]. In a study carried out with retired ATCos, for example, Kiken et al. [6] examined ATCos' performance after they were trained to manage a sector with only traditional, manual tools versus when they were trained to manage the same sector with NextGen tools. Kiken et al. found that ATCos' performance was more efficient (i.e., AC traveled less distance through the sector) when they managed all AC using manual tools, compared to when either some or all of the AC were equipped with NextGen tools. Of course, this benefit of using the manual skills could simply be due to the fact that the retired controllers were much more familiar with these traditional skills.

In Vu et al.'s [7] study, student ATCos were tested to see how best to train the use of manual and NextGen tools. In particular, they compared the benefits of using a part-whole vs. a whole-task training strategy. In the former, students learned manual skills first, receiving training on how to conduct "sweeps" of the radar scope to identify conflicts, how to generate resolutions, and how to issue verbal commands and instructions to AC using proper phraseology. Half way through the training course, (i.e., just before a midterm exam) they were introduced to NextGen tools. In contrast, the whole task group received training on both sets of tools from the very beginning of the course. They were tested for their proficiency at managing traffic in scenarios where either all AC were NextGen equipped, no AC were NextGen equipped, or where there was a mixture of the two. The results showed that more efficient traffic management occurs after practice with the whole, mixed-equipage air traffic environment. This held in particular when the student ATCos were of lower proficiency. For those that were of higher aptitude, the mode of training did not have an effect. Thus, the study supports the claim that it is important to take individual differences into account when devising training programs [8].

A central training issue is how to get ATCos to rely on technologies to a degree that accurately reflects their reliability and efficiency [9-11]. Indeed, training interventions have been developed to help encourage proper use of automation aids [12]. . In the context of ATCo operations, potential NextGen tools have advantages and disadvantages over the manual, voice-based tools. For instance, with integrated Data

Comm, where digital tools allow controllers to uplink route modifications directly into the FMS (Flight Management System) of the flight deck, the AC are automatically put on their flight path after being routed for conflicts. With manual tools, ATCos have to remember to put AC back on their flight path, and it requires additional planning and communications to do so. Important drawbacks of Data Comm, however, include the fact that it is slower relative to voice, because it requires navigating computer menus instead of simply using a push-to-talk microphone. Furthermore, the ATCo does not receive an immediate acknowledgement of the clearance from the pilots, which is standard protocol with voice communications. These readbacks allow ATCos to make sure pilots are carrying out the appropriate actions, and doing so in a timely manner. Moreover, with voice communications ATCos can communicate the urgency of the clearance by including words such as "immediate" or "expedite." In short, ATCos need to weigh these costs and benefits when deciding which tools to use to manage traffic.

The present study examined whether the amount of early experience with the automation tools affects the likelihood that they will be relied upon by student ATCos to manage traffic. In particular, we examined the degree to which student ATCos use integrated Data Comm instead of voice communication to issue altitude clearances to AC as a function of how much early exposure they get with these tools. It is possible, for example, that reliance on automation is greater when students early on receive a substantial amount of training with these tools compared to when they receive less experience with these tools. Thus, whatever tools are emphasized early in training may determine which ones students come to depend on to manage traffic. However, it is also possible that although the early exposure to automation tools will increase their use early on, all students, regardless of type of training, will converge on the same strategies for managing traffic, reflecting their assessments of the relative merits of the tools. For example, if voice-based tools are overall faster and easier to use than integrated Data Comm, it is possible that despite an initial bias to use automation tools as a result of early exposure to them, student ATCos will nonetheless come to rely more on voice to issue clearances.

We also examined whether proficiency of the student controllers interacts with the type of training (more or less early experience with automation tools) to determine whether ATCos come to rely on voice or automation tools to issue clearances. It is possible, for example, that students who are more proficient at learning ATM skills are more likely to converge on the most efficient strategy for communicating with AC, while those who are less proficient may be more dependent on whatever tools they were exposed to first. Such a finding would be consistent with Vu et al.'s [7] study that found controllers who were less proficient were more affected by type of training than those who were more proficient.

2 Method

2.1 Participants

Twenty four students enrolled in a local FAA CTI program participated in one of two semesters of a 16-week radar internship at the Center for Human Factors in Advanced Aeronautics Technologies (CHAAT) at California State University, Long Beach. Ten participated in the first semester and 14 in the second semester. They were tested at the mid-term, i.e., after 8 weeks of the internship, and again at the final, after 16 weeks of the internship.

2.2 Simulation Environment

The Multi Aircraft Control System (MACS) was used to simulate the radar display of Air Traffic Controllers (ATCos) managing Indianapolis Center (ZID) Sector 91. MACS is a medium fidelity environment that simulates traffic in ZID-91. It consists of arrivals and departures into Louisville airport, as well as overflights [13]. All aircraft were piloted by trained "pseudopilots" who provided a realistic traffic environment for the student controllers. Voice communication between controllers and pilots was provided by a voice server station via push-to-talk headsets for the unequipped AC and through Data Comm for equipped AC. The NextGen AC were equipped with:

• Integrated Controller-Pilot Data Comm. This allowed ATCo clearances and pilot requests to be delivered digitally; ATCo route modifications were integrated with the flight-deck's FMS and could be uploaded directly.

• Conflict Alerting. This tool alerted the ATCos to conflicts between two NextGen equipped aircraft within 6 minutes of a loss of separation.

• Trial Planner with Conflict probe. It allowed controllers to graphically modify AC routes while probing for potential conflicts. Once the new route was identified, the ATCos could uplink the clearance to the flight deck using Data Comm commands.

2.3 Training Procedure

The participants in each semester's class were assigned to one of two groups. The training scenarios used for both groups differed in terms of the percentage of AC that were NextGen equipped during the first 8 weeks of training. Students in the "low early automation experience" group were trained to mainly rely on their manual skills, with either 25% of the AC in their sector being NextGen equipped (in the first semester), or 0% of their AC being NextGen equipped (in the second semester), with the remaining AC being unequipped. In both semesters, students in the "high early automation experience" groups had 75% of the AC in their sector equipped with NextGen tools, and 25% of the AC unequipped, and had to be managed with manual, voice-based tools. After week 8 of the course, i.e., the week before the midterm exam, both groups in each semester were trained using scenarios in which the equipage was 50%-50% and those who had no training with NextGen tools were introduced to the tools. In terms of conflicts, half of the planned ones in each scenario were between equipped and unequipped aircraft. As a result, controllers could choose to move either the equipped aircraft (using Data Comm) or the unequipped aircraft (using voice commands).

Students were trained to detect and resolve conflicts between equipped and unequipped AC using manual and NextGen tools. Failure to resolve a conflict resulted in a loss of separation. A loss of separation (LOS) was defined as two or more AC being within 1,000 ft vertically and 5 nautical miles laterally of each other. Students were trained to use four types of methods for avoiding and resolving conflicts: vectoring aircraft through heading changes, issuing altitude clearances, issuing speed changes, and structuring traffic flows (i.e., implementing corridors to a group of AC in a manner that would result in no conflicts between AC if structured properly). A student was considered a “Lab Journeyman” when s/he mastered all four skills by managing traffic in the sector without LOS using each skill. All students achieved this Lab Journeymen status by the end of the 16 weeks, but only some of them achieved this status by the midterm exam.

2.4 Testing Procedures

For both semesters, a mid-term test was administered after the 8th week of training and a final test was run after the 16th week of training. The scenarios during the tests differed in the number of AC that were NextGen equipped, with three levels: 0%, 50%, and 100%. The order in which these scenarios were presented was counterbalanced between participants using a partial Latin square. In what follows, we present the results of the performance data during the midterm and final exam just for the 50% equipage scenarios. We limit the data to that scenario because we are interested in how the amount of early training with automation tools affects how students manage traffic in mixed equipage environments, i.e., whether this early experience increases or decreases their reliance on automation tools. The number of AC in the scenarios during each test was comparable between the two semesters, with each having between 16-18-equipped aircraft, and an equivalent number of unequipped AC.

3 Results

We recorded the number and type of clearances issued by controllers during their midterm and final exams, specifically examining the proportion of altitude clearances that they gave using voice vs. using Data Comm tools during each of these tests. We begin, however, by reporting whether behavioral measures pertaining to communication strategies can predict measures of ATCo performance.

Collapsing across midterm and final exams, we found that the total number of clearances that the student ATCos issued (regardless of type, i.e., heading or altitude, and regardless of modality, i.e., voice vs. Data Comm) was positively correlated with mean handoff accept time, $r = +.45$, $p < .001$ and with time to get aircraft through the sector, $r = +.39$, $p < .006$, two measures of sector efficiency. The more clearances they issued, the longer they took to take control over AC, and the longer it took AC to get through the sector. Greater numbers of clearances most likely extended the route taken by an AC through the sector, thus increasing time spent in the sector. Breaking down the total clearances into heading and altitude changes, we found that as the proportion of heading changes increased (relative to altitude clearances), the time it took to get aircraft through sector increased, $r = +.53$, $p < .001$, suggesting that altitude clearances led to more efficient traffic management by the student ATCos. However, the mode by which clearances were issued also predicted efficiency. Specifically, the proportion of heading changes issued by voice (as opposed to Data Comm) was negatively correlated with handoff give time, $r = -.34$, $p = .04$. For altitude clearances, as the proportion of altitude clearances issued by voice increased (and proportion of Data Comm clearances decreased), handoff give times decreased, $r = -.25$, $p = .09$. Thus, it appears as though greater numbers of clearances, especially heading changes, lengthened the time AC spent in the sector. However, managing traffic using voice-based manual tools was associated with more efficient traffic management. In what follows we examine whether amount of early training with automation tools affects the likelihood of student ATCos using voice vs. Data Comm tools.

To determine whether the communication strategy used by student ATCos was affected by type of training, a 2 x 2 x 2 x 2 mixed factors ANOVA was conducted on the proportion of altitude clearances issued by voice (vs. Data Comm), with testing session (midterm vs. final) as a repeated measures factor, and journeyman status at midterm (yes vs. no), early automation experience (high vs. low), and semester (first vs. second) as between subjects factors. Proportion of altitude clearances issued by voice was calculated by dividing the total number of altitude clearances issued by voice by the total number of altitude clearances issued regardless of modality (i.e., voice and Data Comm). This was done for the midterm and the final testing. Semester was included as a factor because, although the test scenarios had 50% equipage levels in both cases, the scenarios differed slightly in the number of aircraft at midterm and final. Furthermore, the two semesters differed in terms of the type of training participants received, with the low automation experience group in the first semester being exposed to 25% NextGen equipped aircraft for the first half of the course (and the high early automation experience group being exposed to 75% NextGen equipped aircraft from the beginning). In the second semester, those in the low automation experience group were exposed to no NextGen equipped aircraft for the first half of the course (and the high early automation experience group was exposed to 75% NextGen equipped aircraft from the beginning).

The results revealed a significant main effect of test, $F(1, 16) = 4.67$, $p < .05$, with ATCos issuing a greater proportion of altitude clearances by voice as opposed to Data Comm in the final exam ($M = .57$, $SE = .03$) than in the midterm ($M = .49$, $SE = .03$). Thus, the overall likelihood of using a communication strategy that is associated with greater efficiency increased from midterm to final testing. Importantly, however, the results revealed a significant interaction between test and early automation experience, $F(1, 16) = 5.22$, $p = .036$ (See Fig. 1). For those with little early experience with automation tools (being trained with either 0% or 25% NextGen equipped aircraft in the first half), there was no difference in the proportion of altitude clearances issued by voice at midterm ($M = .56$, $SE = .04$) and at final ($M = .55$, $SE = .04$), $F < 1$.

They tended to prefer voice over Data Comm in both tests. For those with a high amount of early experience with automation tools (being trained with 75% NextGen equipped aircraft from the beginning), the proportion of altitude clearances issued by voice increased from the midterm (M = .42, SE = .04) to the final exam (M = .59, SE = .05), F = 6.60, p = .033. Thus, they preferred Data Comm at the midterm, but arrived at a similar preference for voice by the time of the final testing.

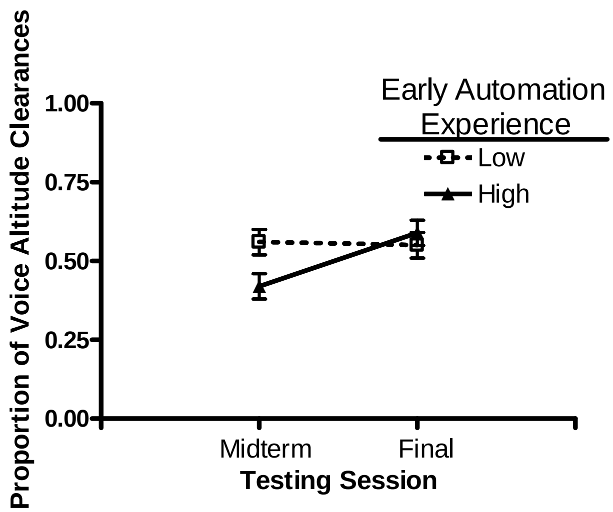

Fig. 1. Mean proportion of altitude clearances issued by voice as a function of testing session and early automation experience.

The analysis also revealed a significant main effect of semester, F (1, 16) = 9.53, p = .007, with ATCo students in the first semester (half of whom overall had more experience with Data Comm tools) being less likely to issue altitude clearances by voice (M = .46, SE = .04) than students in the second semester (half of whom overall had less experience with Data Comm tools; M = .60, SE = .03). We also found a main effect of journeyman status, F (1, 16) = 6.21, p = .024. ATCos that were categorized as journeymen by the midterm were overall more likely to issue altitude clearances by voice (M = .59, SE = .03) compared to those not categorized as journeymen at midterm (M = .48, SE = .03). Thus, ATCos that were more proficient at learning ATM tasks issued more altitude clearances by voice than Data Comm compared to those who were less proficient. No other main effects or interactions were significant at α-level of .05.

4 Discussion

We found that amount of clearances issued by student ATCos affected their workload, because as the number of clearances increased, the efficiency with which

ATCos managed traffic decreased. Furthermore, the type of clearances that they issued affected efficiency, with altitude clearances being associated with greater efficiency and heading clearances with greater inefficiency, as revealed by differences in time through sector, and handoff accept times. Furthermore, using voice communications instead of Data Comm to issue clearances was associated with greater efficiency with which student ATCos managed traffic.

The main goal of our study was to examine how type of training affected the reliance on the automated tool integrated Data Comm, instead of the more efficient, but manual, voice communications to manage traffic. We found that although there was a slight advantage in favor of Data Comm in the midterm, students came to rely on voice communications to issue altitude clearances by the final exam. One likely factor is that once it is mastered, voice is much faster than Data Comm, which would make it a more efficient strategy with which to manage traffic. It is also possible that the greater reliance on voice stems from the fact that it is seen as a more basic and essential skill by student controllers. Voice based traffic management, with its complex phraseology and rules for issuing clearances, may be more difficult to learn at first, and may be seen as requiring more practice by the student controllers, contributing to their greater reliance on it by the final exam. This interpretation is also supported by the fact that the more proficient students, those classified as journeymen by the midterm, also tended to prefer to issue altitude clearances by voice.

Importantly, we also found an interaction between amount of early experience with automation tools and test session. Those students who received very little or no early exposure to the automation tools had a consistent preference for using voice. In contrast, those with considerable early experience with the automation had a small preference for using integrated Data Comm in the midterm, likely because of the difficulty in learning voice based traffic management. However, by the final they, too, acquired a preference to use voice commands to issue altitude clearances. Therefore, in the long run, their early exposure to automated technologies did not affect the strategy with which they managed traffic. Both groups converged on the same preferences to manage traffic by using voice-issued commands.

To conclude, we found that although differences in student proficiency account for overall differences in reliance on voice vs. Data Comm, the type of early exposure to automation tools is not as important. Regardless of how much early experience students acquired with the automation tools, they converged on an overall preference to issue clearances with voice based tools.

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5 References

1. Federal Aviation Administration (FAA): FAA's NextGen: Implementation Plan 2010. NextGen Integration and Implementation Office. Washington, D.C. (2010).
2. Joint Planning and Development Office: Concept of operations for the next generation air transportation system version 3.2., http://jpe.jpdo.gov/ee/docs/conops/NextGen_ConOps_v3_2.pdf (2010).
3. Durso, F., & Manning, C.: Air traffic control. In C. M Carswell (Ed.), Reviews of human factors and ergonomics (Vol. 4, pp. 195–244). Santa Monica, CA: Human Factors and Ergonomics Society (2008).
4. Oprins, E., Burggraaff, E., & van Weerdenburg, H.: Design of a competence-based assessment system for air traffic control training. The International Journal of Aviation Psychology, 16, 297-320 (2006).
5. Prevot, T., Homola, J. R., Martin, L. H., Mercer, J. S., & Cabrall, C. D.: Toward Automated Air Traffic Control—Investigating a Fundamental Paradigm Shift in Human/Systems Interaction. International Journal of Human-Computer Interaction, 28, 77-98 (2012).
6. Kiken, A., Rorie, R. C., Bacon, L. P., Billinghurst, S., Kraut, J. M., Strybel, T. Z., Vu, K.-P. L., & Battiste, V.: Effect of ATC training with NextGen tools and online situation awareness and workload probes on operator performance. In G. Salvendy and M.J. Smith (Eds.): Human Interface, Part II, HCII 2011, Lecture Notes in Computer Science, 6772, 483-492 (2011).
7. Vu, K-P. L., Kiken, A., Chiappe, D., Strybel, T., & Battiste, V. (in press). Application of Part-Whole Training Methods to Evaluate When to Introduce NextGen Air Traffic Management Tools to Students. American Journal of Psychology.
8. Salden, R. J. C. M., Paas, F., & van Merriënboer, J. J. G.: A comparison of approaches to learning task selection in the training of complex cognitive skills. Computers in Human Behavior 22, 321-333. doi: 10.1016/j.chb.2004.06.003 (2006).
9. Lee, J. D. & See, K. A.: Trust in automation and technology: Designing for appropriate reliance. Human Factors, 46, 50-80 (2004).
10. Metzger, U. & Parasuraman, R.: Automation in future air traffic management: Effects of decision aid reliability on controller performance and mental workload. Human Factors, 47, 35-49 (2005).
11. Parasuraman, R., Sheridan, T. & Wickens, C.: Situation awareness, mental workload, and trust in automation: Viable, empirically supported cognitive engineering constructs. Journal of Cognitive Engineering and Decision Making, 2, 140-160 (2008).
12. Manzey, D., Bahner, J. E., & Hueper, A.: Misuse of automated aids in process control: Complacency, automation bias, and possible training interventions. Proceedings of the Human Factors and Ergonomics Society 50th Annual Meeting (pp. 220-224). Santa Monica, CA: Human Factors and Ergonomics Society (2006).
13. Prevot, T.: Exploring the many perspectives of distributed air traffic management: The Multi Aircraft Control System: MACS. International Conference on Human-Computer Interaction in Aeronautics, HCI-Aero 2002, 23-25 October, MIT, Cambridge, MA (2002).
14. Rantanen, E.: Development and validation of objective performance and workload measures in air traffic control (AHFD-04-19/FAA-04-07). Oklahoma City, OK: Federal Aviation Administration Civil Aeromedical Institute (2004).