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Design of an Area Controller Training System (ACTS) for Faster En Route Air Traffic Controller Certification

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Abstract: Air Route Traffic Control Centers (ARTCCs) face persistent shortages of Certified Professional Controllers (CPCs), driven in part by lengthy and resource-constrained training pipelines. This paper aims to design and evaluate a supplemental training system to improve throughput in En Route controller certification without increasing instructor workload. A stakeholder-informed, discrete-event simulation model was developed to represent the As-Is training process and identify key bottlenecks. A To-Be model incorporating the proposed Area Controller Training System (ACTS) was then evaluated. Results indicate reductions in classroom and lab waiting times and training durations, leading to an estimated decrease of approximately 4.7 months in total certification time. These findings suggest that shifting repeatable learning and practice to asynchronous environments can improve training efficiency. However, results are based on simulation and limited prototype validation and should be interpreted as exploratory.

Keywords: Air Traffic Control, Training, Simulation, Spaced Repetition

1. Introduction

In *The Air Traffic Controller Workforce Imperative*, the National Academies reports a significant shortage of Certified Professional Controllers (CPCs) across FAA facilities. En Route centers face especially severe bottlenecks because their complexity drives certification times of 3.9 to 4.3 years, which is longer than the FAA goal of 3 years, while facilities also lack enough instructors and training resources to absorb incoming trainees (National Academies, 2025; Hernandez & Rose, 2025; FAA, 2025b).

Air traffic control includes towers, Terminal Radar Approach Control facilities, and Air Route Traffic Control Centers (ARTCCs) also called En Route Centers. After applicants meet FAA qualifications, pass the Air Traffic Skills Assessment, and complete FAA Academy training, they report to a facility for on-the-job training (OJT), which includes classroom instruction, simulator training, and supervised live operations before CPC certification. Only about 3% of initial applicants become CPCs, and current staffing shortages mean that even with full FAA Academy classes, facilities still do not have enough space, time, or staff to move trainees efficiently through OJT (National Academies, 2025; B. Holguin et al., personal communication, August–November 2025; Skores & Muntean, 2025).

Prior research demonstrates that spaced repetition significantly improves learning and long-term knowledge retention, including transfer of knowledge across contexts (Price et al., 2025; Maye & Hurley, 2026). In parallel, simulation-based training is widely used in high-reliability domains such as aviation because it enables repeated, risk-free practice and supports procedural skill acquisition (Rizvi et al., 2025). Recent studies further show that combining spaced learning with simulation can improve skill retention and performance outcomes compared to traditional training approaches (Patocka et al., 2025). Together, these findings support training system designs that distribute practice over time and shift repeatable learning activities outside instructor-led environments. ACTS builds on these principles by integrating structured study tools and simulation into the ATC training pipeline.

2. Stakeholder Analysis

Twenty stakeholder interviews, including a visit to the Washington En Route Center, identified key constraints in the En Route training pipeline. Stakeholders reported delays in classroom access, long waits for simulator labs due to limited resources, and reliance on self-developed study methods. Trainees often progress unevenly, mastering classroom material faster than they can apply it in simulation, indicating a need for more structured learning and repeatable practice before lab exposure (B. Holguin et al., personal communication, August–November 2025).

The FAA operates within a complex system, balancing its roles as regulator and training provider while coordinating with Congress, the flying public, and NATCA. Within facilities, managers oversee both operations and training, while instructors must divide time between mentoring and live traffic. Trainees seek timely certification, but limited resources and inconsistent readiness create inefficiencies. These dynamics generate core tensions between cost, training quality, staffing capacity, and throughput. Addressing these tensions requires improved coordination, better use of training resources, and more consistent trainee preparation.

3. As-Is Process

Once trainees graduate from the FAA academy in Oklahoma City, they are assigned to an ATC facility. When trainees arrive at En Route centers, they must first go through Radar Associate School, or 'D-School’ to learn the Radar Associate (D-Side) position, then go through Radar School, or 'R-School' to learn the Radar (R-Side) position; both parts include classroom training, simulator training, and supervised work with live traffic. Trainees must wait for classes for D-School or R-School to become available. The order is strictly sequential; D-school and certifying in all D-Side positions must be completed before starting R-School. While they are waiting at any time during the process, trainees perform flight data duties, observe the control floor, and self-study.

Classroom learning includes memorizing maps, sectors, routes, radio frequencies, standard operating procedures (SOPs), and letters of agreement (LOAs). This information is given to trainees in the form of documents on a personal work tablet. There are no study tools provided for effective learning and memorization of the immense amount of information. The trainee must come up with their own study method. The exam at the end is pass/fail.

In the simulator lab, trainees go through scenarios with increasing difficulty over time. These include exercises to practice maintaining aircraft separation, handling different traffic volumes, managing traffic flowing into and out of adjacent airport sectors, coordinating handoffs, and sequencing aircraft for arrival, managing traffic around severe weather, and dealing with emergencies. The trainee must schedule and wait for the lab to be available based on the availability of space, a lab manager to run the machines, ghost pilots to operate the simulated aircraft, and a training instructor to oversee simulation training. Also, the radar stations in the lab are supposed to be exact replicas of the ones on the control floor, but that is not always the case at every center.

After passing classroom and simulator evaluations, trainees can start working with live traffic under the supervision of an instructor. The instructor can take over at any moment to correct mistakes. Trainees must wait for an instructor to be available to work on the control floor.

3.1 As-Is Process Simulation Results

A discrete agent based Arena model of the As-Is process for En Route training was built using the time distributions reflected in the sprint analysis. The model used triangular inputs of 3 to 4 to 6 months for classroom training, 4 to 5 to 7 months for lab training, and 10 to 14 to 18 months for OJT floor work, with monthly trainee arrivals of 0 to 1.5 to 4. However, the classroom and lab have a max capacity of 7 and 10, respectively, so if one of them is at max capacity, trainees must wait until space frees up, thus increasing the delay time. The As-Is results showed four clear bottlenecks: classroom waiting, classroom learning rate, lab waiting, and lab learning rate.

Table 1. Performance Gaps Identified in the ACTS As-Is Model

Bottleneck	**As-Is Mean**	**Target Mean**	**Standard Deviation**
Classroom waiting	2.7 mo	1.7 mo	1.2 mo
Classroom duration	4.3 mo	3.3 mo	0.62 mo
Lab waiting	1.2 mo	0.7 mo	0.37 mo
Lab duration	5.3 mo	3.8 mo	0.62 mo

The model estimated average classroom waiting at 2.7 months versus a 1.7 month target, average classroom duration at 4.3 months versus a 3.3 month target, average lab waiting at 1.2 months versus a 0.7 month target, and average lab duration at 5.3 months versus a 3.8 month target. Together, those results pointed to a simple systems insight: the En Route pipeline does not only suffer from limited resources. It also suffers from limited repetition. Trainees need more chances to rehearse procedures and retain information between formal sessions, but the current process depends heavily on instructor availability and shared lab infrastructure.

The As-Is model was parameterized using the process sequence and time ranges developed from sprint analysis, published certification timelines, and stakeholder-informed process mapping. Facility-level archival throughput data were not available for full statistical validation against a single center's historical certification record. Accordingly, validation in this study was limited to structural and face validation: the modeled sequence of classroom training, lab training, and OJT, along with the resulting order of magnitude of total certification time, were checked for consistency with published ranges and stakeholder accounts. The model should therefore be interpreted as a representative decision-support model for identifying bottlenecks and comparing alternatives, rather than as a precise predictor of throughput at any one facility.

4. Performance Gap/Problem Statement

The current En Route training pipeline does not produce R-Side CPCs at the rate ARTCCs require. Training is sequential (classroom, lab, and OJT), so delays in early stages propagate and extend total certification time. The average certification time is 27.7 months ($\sigma = 2.26$), with 14 months in OJT, which is outside the scope of intervention. Therefore, the primary opportunity lies in improving pre-OJT stages (classroom and lab).

Target values for classroom and lab performance were derived from a combination of FAA-reported certification timelines, stakeholder interview expectations, and internal benchmarking assumptions based on desired throughput improvements. Because facility-specific historical datasets were not accessible, these targets represent reasonable but approximate performance goals rather than empirically validated standards.

The As-Is simulation identifies four key pre-OJT bottlenecks. First, a classroom capacity constraint (limited instructors and seats) leads to excess waiting (2.7 months vs. 1.7 target). Second, a classroom learning bottleneck slows progress due to reliance on static materials, increasing duration (4.3 vs. 3.3 months) and variability ($\sigma = 1.2$ vs. 0.6 target).

In the lab phase, a capacity bottleneck (limited simulator access and instructors) causes additional waiting (1.2 vs. 0.7 months), while a learning bottleneck results in extended training time (5.3 vs. 3.8 months). These delays compound upstream inefficiencies and reduce overall throughput.

Overall, the performance gap is a system throughput issue driven by limited resources, inconsistent trainee preparation, and slow early-stage skill acquisition. The pre-OJT pipeline is about 4.0 months longer than target, and addressing these bottlenecks could reduce total certification time by 4.7 months. The engineering challenge is to design a supplemental training system that reduces waiting, shortens training duration, and improves readiness before OJT without increasing instructor workload or altering FAA standards.

5. Concept of Operations/To-Be Process

The To-Be process preserves the existing FAA certification sequence of classroom training, lab simulation, and OJT floor work while introducing the Area Controller Training System (ACTS) as a supplemental capability operating before and between instructor-led events. ACTS is not intended to replace instructors, OJTIs, simulator labs, or FAA qualification requirements. Instead, it functions as a pre-OJT throughput improvement that shifts memorization, knowledge reinforcement, and repeatable radar practice from constrained live resources to asynchronous trainee activity.

In the classroom portion of the To-Be process, trainees use ACTS during pre-class and between-class periods to complete structured learning modules derived from sector maps, LOAs, SOPs, procedures, and other governing material. These modules include concept maps, flashcards, quizzes, and spaced-repetition review. This changes the classroom stage in two ways: idle time before classroom entry becomes productive preparation, and trainees arrive with a stronger baseline of knowledge. As a result, instructor-led sessions can focus on clarification and application rather than initial content exposure, reducing classroom waiting and duration without increasing instructor staffing or classroom capacity.

In the lab portion of the To-Be process, ACTS provides an asynchronous radar simulation platform that supplements scheduled lab training. Trainees complete progressive scenarios outside formal sessions using software that mirrors sector maps, routes, traffic patterns, and communication tasks. The platform supports speech and text command input, automated scoring, session logging, and replay review. This extends repeatable practice opportunities without using scarce simulator bays or instructor time and allows instructors to review performance data before formal simulation. The intended effect is reduced lab waiting, shorter lab duration, and improved readiness entering OJT.

From a systems perspective, the To-Be process changes how downtime functions within the training pipeline. In the As-Is process, waiting before classroom and lab entry contributes little to readiness and increases certification time. In the To-Be process, that time is used for structured study, guided repetition, and scenario-based practice. Research indicates that combining spaced repetition with simulation-based training improves retention and skill acquisition by integrating distributed knowledge reinforcement with procedural practice (Maye & Hurley, 2026; Patocka et al., 2025; Price et al., 2025). This approach increases preparedness at stage transitions and improves the effective use of existing instructional resources.

Accordingly, the To-Be process targets the four pre-OJT bottlenecks identified in the As-Is model: classroom waiting, classroom duration, lab waiting, and lab duration. It does so without changing trainee arrival rates, removing certification stages, or altering FAA standards. The intended outcome is reduced pre-OJT delay, improved training flow, and greater trainee readiness entering OJT, ultimately shortening total time to R-Side CPC certification.

5.1 To-Be Process Simulation Results

A To-Be process simulation was constructed in Arena with reduced classroom and lab durations. By leveraging the more advanced learning methods that are less reliant on instructors, the classroom training time is expected to be reduced to a triangular distribution of 2, 3.5, 4.5. Additionally, the removed dependency on other resources in the lab is expected to reduce the lab duration to a triangular distribution of 3, 3.5, 4.5. With these new distributions, the waiting times for the classroom and the lab were also reduced.

Table 2. Performance difference between As-Is and To-Be model

Bottleneck	**As-Is Mean**	**To-Be Mean**	**Delta Mean**	**As-Is Std. dev**	**To-Be Std. dev**
Classroom waiting	2.7 mo	1.4 mo	-1.3 mo	1.2 mo	0.53
Classroom duration	4.3 mo	3.3 mo	-1.0 mo	0.62 mo	0.51
Lab waiting	1.2 mo	0.6 mo	-0.6 mo	0.37 mo	0.15
Lab duration	5.3 mo	3.7 mo	-1.6 mo	0.62 mo	0.31

The To-Be simulation reduced both training duration and queueing. Classroom duration decreased from 4.3 to 3.3 months and lab duration from 5.3 to 3.7 months, while classroom waiting decreased from 2.7 to 1.4 months and lab waiting from 1.2 to 0.6 months. Together, these changes reduced total certification time by about 4.7 months and showed that improving learning speed produces greater overall benefit than increasing capacity alone.

The reductions in classroom and lab durations in the To-Be model are based on the assumption that increased repetition, structured study, and asynchronous simulation will improve knowledge retention and procedural fluency prior to instructor-led sessions. These assumptions are supported by literature on spaced repetition and simulation-based training but are not directly validated within this study. Therefore, the modeled improvements should be interpreted as scenario-based estimates rather than predictive outcomes.

5.2 Sensitivity Analysis

Sensitivity analysis of the To-Be model examined the impact of key parameters on system performance. The parameters examined were: trainee arrival rate, classroom capacity and duration, and lab capacity and duration. Increasing trainee arrival rates raised classroom and lab waiting times and extended total certification time, reflecting current system constraints. Increasing classroom or lab capacity reduced waiting in those stages but had only minor effects on overall certification time. In contrast, reducing classroom and lab training durations produced the largest improvements, with lab duration showing a particularly strong impact. Overall, the results indicate that training duration, not capacity, is the primary driver of certification time. While adding resources yields limited gains, improving learning efficiency significantly reduces delays. This supports the conclusion that ACTS provides the most value by accelerating learning rather than increasing capacity.

6. Requirements and Design

ACTS was designed as a blended training system with three tightly connected elements. The first is a digital learning tool built around concept maps, flashcards, quizzes, interactive airspace maps, and spaced repetition. This element addresses the knowledge side of training by giving trainees a structured way to learn phraseology, geography, procedures, and local rules before and between instructor-led sessions. The second is a personal radar simulation tool that replicates the look and feel of En Route scopes and lets trainees practice asynchronously with artificial intelligence (AI) pilots through text and speech commands. The third is a progress tracking layer that records attempts, scores performance, and provides dashboards to both trainees and instructors.

At the mission level, ACTS must improve learning time, incorporate advanced learning methods, replicate lab scopes, inform trainees and instructors of progress, reduce reliance on staffing, and maintain synchronized training assets aligned with FAA standards. At the functional level, ACTS must support three user roles, digital learning content, spaced repetition, interactive airspace maps, session recording, AI pilot communication, automated grading, performance dashboards, milestone alerts, and standard synchronization features. Those requirements were intentionally written so ACTS augments the training process that already exists under FAA technical training policy rather than creating a separate unofficial pathway (FAA, 2024).

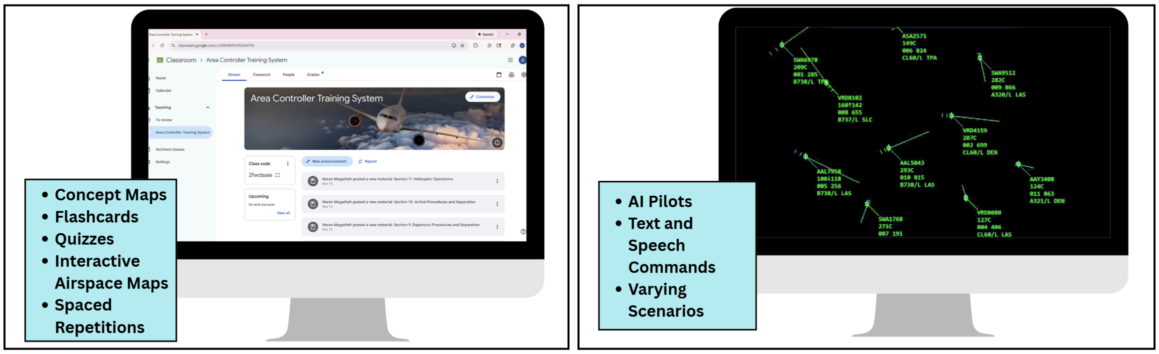
The learning content inside ACTS is built from the same material trainees are already expected to master, including FAA Order JO 7110.65, the FAA's primary manual for standard air traffic control procedures, along with SOPs, LOAs, and historical sector knowledge. That matters because controllers are not merely memorizing generic aviation facts. They are learning a specific operational language and a dense procedural rule set that must be applied correctly under time pressure (FAA, 2026). By converting that material into reusable digital assets, ACTS gives trainees more repetitions without asking facilities to create more classroom seats or more simulator bays.

7. Implementation

As a proof of concept, FAA Order JO 7110.65 served as the foundational training document for the classroom subsystem. Content from each chapter section was decomposed into structured flashcard sets using Knowt, a free AI-powered learning platform that automatically turns notes and PDFs into flashcards, summaries, and practice quizzes. Key features include unlimited flashcards, "Learn" mode, interactive review games, and active recall and spaced repetition where the system tracks difficult cards, adapting to the user's pace to improve memory retention. Concept maps for each chapter were created using the FigJam whiteboard tool to visually structure complex knowledge, improve understanding, aid memory recall, and foster critical thinking by organizing information hierarchically. Google Classroom was used as the centralized learning platform to house the learning material. For each chapter, a module was created which included a link to the FAA Order section, concept map PDF, and Knowt flashcard section links. A separate module was also created with PDFs of airspace maps obtained from a retired CPC who used them during their own training days.

The radar simulator was developed using the GameMaker engine. The simulator replicates the radar interface used in En Route Centers, a bespoke physics engine to efficiently handle aircraft movement and logic, and procedurally generated training scenarios. A secondary program processes the user's speech input, formats it to commands, and transmits validated commands to the simulator engine. The programmed tasks include identifying potential separation violations and issuing immediate instructions, managing arrivals, departures, and overflights, coordinating handoffs, handling weather deviations, and merging and spacing aircraft under varying traffic volumes.

The current prototype demonstrates both halves of the ACTS concept. On the digital learning side, we implemented structured study modules that support content review, knowledge checks, and map-based interaction. On the radar side, the prototype supports the physics of aircraft movement, the ability to alter aircraft heading, fix, speed, and altitude, and air traffic scenarios on a replicated radar display. The next development steps expand scenario selection and deepen the scenario library, which already includes representative training cases such as handoff, traffic advisory, converge-turn, and no-factor encounters.



Noran Magatheh posted a new material: Section 11. Helicopter Operations
Nov 13

Noran Magatheh posted a new material: Section 10. Arrival Procedures and Separation
Nov 13

Noran Magatheh posted a new material: Section 9. Departure Procedures and Separation
Nov 13

Fig 1. Area Controller Training System (ACTS) Classroom Platform and Radar Simulation Software

8. Validation Test Results

Validation testing assessed learning efficiency improvements. In a comparative study, six participants studied a chapter of FAA Order JO 7110.65 using different methods: half via the ACTS classroom platform and half using the source document alone. Each measured the time required to achieve 100% on a practice assessment. The ACTS users achieved mastery in an average 20 minutes, compared to 36 minutes for users using the document alone, indicating improved study efficiency. Validation of the radar subsystem evaluated whether repeated ACTS practice produces performance outcomes comparable to traditional simulator lab sessions. Results suggest that deliberate repetition and replay functionality enhance procedural fluency prior to formal lab exposure.

9. Conclusion

This paper examined the En Route air traffic controller training pipeline as a system throughput problem rather than only a staffing problem. The As-Is simulation identified four primary pre-OJT bottlenecks: classroom waiting, classroom duration, lab waiting, and lab duration. These results showed that delays before OJT are driven not only by limited instructors and simulator capacity, but also by limited opportunities for repeated practice and structured knowledge reinforcement.

In response, this paper presented ACTS as a supplemental training capability that shifts memorization, review, and repeatable radar practice into trainee-driven activity outside constrained instructor-led sessions. The To-Be simulation projected reductions in both waiting and training duration, with an estimated total reduction of about 4.7 months in time to R-Side CPC certification. A proof-of-concept implementation and initial validation results further suggested that structured digital learning and replay-supported radar practice can improve readiness before formal lab exposure.

This study also has important limitations. The As-Is model was not validated against a full archival dataset from a specific facility, the validation sample size was small, and ACTS impacts on live OJT performance were inferred rather than directly measured. Future work should validate the model with facility historical data, expand user testing across a larger trainee sample, and evaluate whether ACTS use measurably improves live OJT performance, certification rates, and time to proficiency.

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