From Concept to Implementation – Modeling and Simulation in Air Traffic Management

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Summary

This paper describes how fast-time modeling and real-time simulation were used cooperatively in the concept analysis, validation, and ultimately, the implementation of the radar and display system, called the Precision Runway Monitor (PRM).

Introduction

The William J. Hughes Technical Center (WJHTC) in New Jersey, USA, conducts research to develop, test, and validate new aviation concepts. The WJHTC has the unique opportunity to house both fast-time modeling and real-time HITL capabilities within the same organization that can be used separately or in conjunction to evaluate new National Airspace System (NAS) concepts.

PRM is a technological concept that was evaluated extensively over the years at the WJHTC. Procedural development, capacity analysis, risk analysis, level of safety, and training were all conducted using real-time HITL simulation. Cost/Benefit analysis and concept evaluation were conducted through the use of fast-time modeling. Presented in this paper are the modeling and simulation methods used at the WJHTC and the subsequent results in the evaluation of PRM.

Precision Runway Monitor

The Multiple Parallel Approach Program (MPAP), established in the 1980's, focused primarily on the capacity-enhancing benefits of PRM systems with different airport configurations. The program conducted over 20 real-time, human-in-the-loop and fast-time simulations to develop procedures for independent approaches to quadruple, triple, and closely spaced dual parallel runways in instrument meteorological conditions [1].

Extensive analysis has shown that runway spacing is one of several factors that can affect the safe execution of independent parallel approaches. Radar and display systems are also important for maintaining aircraft separation in the event of an aircraft deviation. The major features important to simultaneous parallel ILS approaches are surveillance delay, surveillance system accuracy, automation aids, and system capacity.

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During instrument meteorological conditions, airports with parallel runways spaced less than 4,300 feet apart cannot conduct independent operations due to existing equipment limitations. The PRM system allows for the conduct of independent Instrument Flight Rules (IFR) approaches to parallel runways spaced less than 4,300 feet apart because of a high update-rate phased array, an electronically scanned monopulse beacon radar, and computer predictive displays that enable controllers to more closely monitor aircraft on final approach. The update rate requirement for parallel runways down to 3,400 feet spacing is 2.4 seconds or less. All fielded PRM systems, however, include an E-Scan radar with a 1.0 second update rate. The system includes high-resolution displays with specific blunder alerts and lateral expansion capability between two approach courses to enable controllers to precisely monitor closely spaced aircraft arrivals.

Real-Time, Human-in-the-Loop Simulation

For over a decade, researchers at the WJHTC conducted numerous real-time, human-in-the-loop simulations as part of an ongoing effort to develop national standards and address site-specific airport issues for closely spaced parallel approach operations. Real-time simulation was required to prove that the proposed procedures could be safely conducted before proceeding to the operational environment.

For each simulation, WJHTC researchers developed generic airport layouts or recreated the runway configurations of specific candidate airports in Air Traffic Control (ATC) laboratories. They developed traffic scenarios reflecting anticipated levels of traffic and the traffic mixes of aircraft associated with independent approach operations. They recruited samples of Certified Professional Controllers (CPCs) with experience in parallel runway operations. In addition to the Air Traffic Controllers, the simulations also included participation from pilots to simulate flight deck operations. Where it was not necessary and/or or cost-effective, simulation operators flew computer-generated aircraft targets in simulation scenarios.

Human performance data was collected during MPAP simulations to understand exactly what the impact would be to the controllers and pilots. A major concern of operating independent approaches to closely spaced parallel runways was the ability of the ATC system to maintain adequate separation between aircraft. Therefore, critical situations, referred to as aircraft blunders, were introduced into the tests to address the safety issue. A blunder occurred when an aircraft, already established on an instrument landing system (ILS) approach, made an unexpected turn towards another aircraft on an adjacent approach. Blunders presented the controllers with worst-case situations. Blundering aircraft turned at angles of 30 degrees and, in most cases, were non-responding, simulating an inability to comply with controller instructions.

Controllers monitoring blundering aircraft and all adjacent aircraft issued commands as necessary to keep the aircraft apart. When an aircraft appeared to be heading towards an adjacent aircraft, CPCs issued 'breakout' instructions to all aircraft in potential jeopardy. If a predetermined minimum slant range miss distance was maintained, the blunder was considered resolved. If the acceptable miss distance was violated, that instance factored into an overall violation rate. Researchers calculated maximum violation rates for each simulation based on a target level of safety of no more than one fatal accident per 25 million approaches. The real-time violation rate had to be equal to or below the maximum acceptable violation rate to be considered acceptable. To ensure a more accurate measurement of this rate, researchers also conducted a fast-time, Monte Carlo simulation. The Monte Carlo simulation used data collected in the real-time simulation to model over 100 thousand at-risk blunders, thus reducing the range of the confidence interval to a very small size. Both the resulting real-time and fast-time violation rates were compared for consistency and both were considered in the overall acceptability of the proposed procedures.

The real-time simulation also investigated the impact of each proposed procedure on arrival capacity. As runways spacing decreased, Total Navigation System Error (TNSE) becomes a concern. TNSE represents the difference between the actual aircraft flight path and its intended flight path. TNSE can be caused by flight technical error, avionics error, ILS signal error, and/or weather. TNSE may contribute to the occurrence of aircraft entering prohibited airspace between such closely spaced final approach courses. If an excessive number of aircraft were broken out of the approach sequence due to unpredictable flying performance, the anticipated capacity benefits of PRM surveillance would not be realized. In addition, constant breaking out and re-sequencing of aircraft would impose a high level of communications workload on both CPCs and pilots.

The PRM researchers considered other data, including evaluations from subject participants and observers when formulating their overall operational assessment of each proposed procedure. Analyses of controller response times, pilot/aircraft response times, aircraft separation distributions, controller breakout instruction content, and controller and pilot questionnaire responses were all considered in the final recommendations.

The real-time HITL simulations provided a high fidelity environment in which reliable assessments of new procedures could be made. The MPAP simulations presented worst-case scenarios to ATC and flight deck operators to ensure that if test criteria were met, one could feel confident in the approval of a procedure.

Another benefit of the HITL simulations was that they allowed for the development and refinement of controller and pilot training associated with conducting closely spaced approaches. In fact, quality and content of training increased significantly due to the outcomes of some of the tests that were performed. Training requirements became more stringent as runway spacings decreased in both dual and triple approach operations. The FAA adopted these requirements from the simulations and implemented them in the actual operational environment [2] [3]. The simulations determined the necessary amount of controller hands-on training with PRM equipment and the appropriate breakout phraseology to be used during PRM approaches. The simulations also established the necessary pilot awareness training, which includes special notices on approach plates and required video viewing. One part of pilot training discovered during an MPAP simulation was the requirement for pilots to disconnect the autopilot and hand fly their aircraft in the event they receive breakout instructions. The simulations determined that the aircraft could execute a breakout more quickly if the autopilot was not engaged than if it was; a potential life saving maneuver.

Because human performance was so thoroughly assessed during the PRM HITL simulations, the FAA used the simulation data to approve procedures for the operational environment. They also selected airports that would benefit from conducting independent approaches to their parallel runways that were previously restricted from doing so because of existing runway configurations. Minneapolis-St. Paul International Airport (MSP) was one of those airports that could benefit from independent approach operations, and as such, was selected to receive PRM technology.

Cost/Benefit Analysis

In the 1970's Design Teams were formed to down select various capacity-increasing alternatives at airports where delays were reaching high levels. In 1992, a Design Team was formed at MSP to examine 23 capacity enhancement alternatives, including a PRM system. MSP consisted of a set of parallel primary use runways and was therefore a prime candidate for a PRM system.

Design Teams typically follow the process of data gathering, inputting the data into the model, and running the model to achieve results. Data gathering includes a site visit to obtain site specific information and an understanding of the airport operations. Traffic demands are created using airline schedules and supplementing non-scheduled aircraft. Future schedules are generated based on Terminal Area Forecasts. At MSP, 3 demand levels, baseline (420,390 operations), Future 1 (530,000 operations), and Future 2 (600,000) operations were examined. Once the data is input, the model is calibrated against field data to ensure the model is site specific. After calibration, the model is run for each runway configuration, demand level, and weather condition. The Runway Simulation Model (RDSIM), a model that simulates the effects of runways and/or procedures, was chosen to help in the analysis. RDSIM uses Monte Carlo sampling to introduce system variability. Distributions in arrival times, separation values, and exit location attribute to the variability. The processing speed of the model allows for approximately 100 iterations, producing flow rate and delay values for a given day.

To evaluate the PRM system at MSP, comparisons were made between current and PRM operations. Without PRM, MSP would have to use a 1.5nm stagger arrival approach to the parallel runways in IFR conditions. To simulate the PRM, the 1.5nm stagger was eliminated allowing the aircraft simultaneous arrival approaches.

Using annualized delay values from the RDSIM model and a conservative cost estimate based on direct operating costs, PRM would provide an annual savings at the baseline level of 3,182 hours or $4.6 million; at Future 1, 13,822 hours or $20.0 million; and, at Future 2 levels, 45,834 hours or $66.3 million [4]. Given the estimated 1992 project cost of $6 million, PRM was recommended by the Design Team.

Follow-up Evaluation

In 2003, the NAS Configuration Management and Evaluation Staff conducted an evaluation of the Operational Evolution Plan (OEP) with the focus on the National Airspace Redesign (NAR) and PRM. The results of the evaluation have been published in the Evaluation of the National Airspace Redesign and Precision Runway Monitor Programs in the Operational Evolution Plan report [5].

The team responsible for the evaluation of PRM followed a qualitative and quantitative data collection. The qualitative data collection consisted of interviews and PRM site visits (including MSP) to obtain data used in the benefits evaluation. The quantitative data collection was used to determine the benefit, if any, of using PRM. To quantify the benefits at MSP, the team used operational weather data for selected dates when PRM was in use. The team tried to compare the throughput data with similar operational days when PRM was not in use, however, this proved inconclusive. The team decided to calculate delay, based on the days selected for analysis, using a model to determine if a delay reduction could be found using PRM. To calculate the delay, the RDSIM model was selected. The model was run twice, once with PRM and once without PRM, using a 1.5 nautical mile stagger for each operational day that was selected in the quantitative data collection to identify the potential delay savings. Normally, the model is run for an entire day under one weather condition. However, for this analysis, specific days were used with specific weather conditions. During the day, conditions changed, either IFR to VFR or PRM to non-PRM use. To simulate these conditions the model was modified to handle the change in scenario conditions. It was decided that the best way to capture the benefits of PRM was to run each chosen day for 100 iterations, alternating the separation values to mimic the changing weather and associated procedures for those given days. This would provide a statistical average, which gives a better measure of the benefit of PRM for the days identified. The results of the model were presented to the evaluation team and reported in the evaluation document. The model results did show a decrease in delay and an increase in throughput when PRM was used, however the overall delay reduction was minimal. The minor decrease in delay was attributed to using schedules with traffic levels only slightly higher than those used in the 1993 study and because PRM was used in only a few hours of the chosen days. However, this concurs with the 1993 study that shows most of the benefit was during higher traffic demands (Future 1 and Future 2 operational levels).

The evaluation team concluded that; 1) Simulation data showed slightly decreased arrival delays and increased capacity, 2) The total impact of PRM, based on the simulation results, can be used as an indicator of how much delay savings PRM provides to MSP, 3) The increased throughput of four additional aircraft per hour was not reached due to the low levels operations. An MSP benefits study showed that the airport would realize the additional four aircraft per hour throughput when annual operations reached 530,000, and 4) MSP has been able to maintain an arrival acceptance rate of 60 per hour, rather than 56 per hour, using PRM. This increased capacity will become very important when operations increase. Although somewhat inconclusive, with the increase of performance measures in the future, a more thorough evaluation could be performed.

Conclusion

In the field of Modeling and Simulation, the use of fast-time modeling and real-time HITL simulation has proven invaluable. The purpose of this paper was to show that interrelationship of modeling and simulation, and how they can and have been used in many aspects of a technology's life cycle, from concept to implementation. PRM is one specific technology that has benefited from both modeling and simulation. HITL simulation was essential in the analysis of human performance, capacity gains, risk, levels of safety, and training. Fast-time modeling proved useful in cost/benefit analysis as well as analyzing the overall effectiveness of the technology following implementation.

Reference

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