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PREDICTIVE WEATHER DISPLAY IN ATC: IMPLICATIONS FOR RESEARCH AND TRAINING

Dawna L. Rhoades and Kelly Neville

Abstract

Two systems are central to the Next Generation Air Transportation System (NextGen) air traffic management program - Traffic Management Advisor (TMA) and En Route Automation Modernization (ERAM). One purpose of both systems is to reduce air traffic control (ATC) delay. The present study reports on an exploratory integration of convective weather, a major source of delay, into the ATC systems to allow early re-route around weather in order to reduce delay. Pseudo-controllers ran a series of simulation-based scenarios with screen capture and video collection to assess delay and safety performance. Results provide evidence that delay was reduced by early rerouting in response to convective weather predictions. Implications for training and research are discussed.

With air traffic for the United States projected to increase by a factor of two to three by 2025, the air traffic management system is facing a serious capacity crisis (FAA Fact Sheet, 2007). One way of addressing this crisis is through the construction of new airports and runways. While additional physical capacity will probably be necessary, a second option is to create new capacity in the National Air Space (NAS) through the application of technology. The Next Generation Air Transportation System, commonly called NextGen, is the overarching answer of the US Federal Aviation Administration (FAA) to the capacity and technology challenges facing the NAS in the 21st century. As envisioned, NextGen will not only increase the capacity of the air transportation system, it will increase safety and security as well.

At least two decision support tools (DSTs) are vital to the success of the NextGen Air Traffic Management (ATM) system - Traffic Management Advisor (TMA) and En Route Automation Modernization (ERAM). Since Because adverse weather is a major cause of accidents and a primary source of delay and disruption in air traffic flow, the prediction and integration of weather into the air traffic control system is viewed as another critical component of the NextGen system (Bureau of Transportation Statistics, 2010; Levin, 2007). As envisioned, there would be a commonly displayed weather view on both TMA and ERAM systems that could be 'moved forward' in time up to six hours from the current operating time. This forward look would help controllers to adjust traffic (amend flight plans) to minimize delays and safety hazards (FAA NextGen Fact Sheet, 2007). To understand the current project, it is necessary to briefly describe TMA, ERAM and the envisioned operation of both software systems in the NAS. Subsequently, we describe the goal of extending the capabilities of these systems to reduce weather-related disturbance of traffic flows.

Traffic Management Advisor

The purpose of TMA is to assist air management personnel in the management of arrival and departure flows, allowing them to reduce delay by maximizing capacity (number of aircraft) over specified metering fixes. A metering fix is a set point along an established route over which an aircraft is passed prior to entering the terminal airspace. At present, metering is performed for both arrival and en route points. The Terminal Radar Approach Control (TRACON) directs arriving traffic to one of the metering fixes surrounding the airport. In most cases, several streams of arriving traffic must be merged into a single line before crossing each metering fix.

The computational engine of TMA, the Dynamic Planner (DP), is responsible for computing the sequences and schedules of arriving aircraft. TMA receives a flight plan from one of the 20 traffic centers via the Host Computer System (HCS) or its replacement, the ERAM system, and calculates the route of flight, determining which flights are in the same stream at the metering fix. TMA then generates the trajectories of each aircraft and displays a timeline showing when each the aircraft should arrive at a given metering fix.

Aircraft arrival times are calculated well in advance of the actual arrival to allow for efficient coordination and delay allocation across sectors in multiple en route centers. TMA calculates an Estimated Time of Arrival (ETA) at various points along the route of flight, resulting in a four dimensional (4D) trajectory model. The Scheduled Time of Arrival (STA) at each point is calculated based on the ETA. Scheduling constraints may also be entered by the Traffic Management Coordinator (TMC) to reflect such factors as airport configuration and airport acceptance rates. The TMA system was deployed in all air route traffic control centers (ARTCCs) by March 2007.

En Route Automation Modernization

ERAM is the replacement for the old Host Computer System (HCS) that provides automated flight data processing services to support air traffic control. In addition to maintaining the current functionality of the HCS, ERAM improves information security, streamlines traffic flow, processes flight radar data, provides communication support, and generates display data. It integrates a series of new tools into the tactical (R-controller) and strategic (D-controller) air traffic control consoles.

With ERAM, the air traffic control consoles can be configured to allow a single person to access both strategic and tactical data and decision support tools. Views provide the traditional situation display, display control and status, time, aircraft lists, flight plan readouts, and trial planning. In addition, window sizing, hiding, and positioning can be used to minimize clutter on the screen. Tool bars, pull down menus, and templates minimize the amount of data the controllers must enter to access information and update flight data.

ERAM also provides support for the air traffic supervisor, flight data communication specialists, tracker position (also known as the hand-off or H-position), and traffic flow management position. The overall goal of NextGen is to provide as much common situational awareness as possible to all these personnel; thus, many of the automation tools and displays are accessible upon request (Nolan, 2004). ERAM was operationally tested at the FAAs William J. Hughes Technical Center in Atlantic City before deployment to Salt Lake City in late 2008 and is scheduled for deployment to all 20 ARTCCs in 2009-2010 (http://faa.gv/airports_airtraffic/technology/eram/).

Weather in the NAS

Hazardous weather is a major source of delay as well as accidents and reducing both of these problems is part of the FAA weather initiatives (Bureau of Transportation Statistics, 2010; Levin, 2007). If certain weather conditions could be predicted and those predictions made available to aviation decision makers in a timely manner, then early action could be taken to avoid the hazard, reducing delay and accident rates. One such adverse condition is convective weather (i.e., thunderstorms) and one means of making the information available to aviation decision makes is to integrate predictive weather into the ERAM and TMA systems, providing common situational awareness, an ability to plan avoidance trajectories, and the capability of communicating these changes between ERAM and TMA so that times of arrival can be adjusted.

The Concept of Operations for NextGen, prepared by the Joint Planning and Development Office (JPDO, 2009), defines the primary role for weather information as enabling "the identification of optimal trajectories that meet the safety, comfort, schedule, efficiency, and environmental impact requirements of the user and the system'. This information should be 'supported by a set of consistent, reliable, probabilistic forecasts, covering (three-dimensional space), timing, intensity, and the probability of all possible outcomes, each with an associated likelihood of occurrence" (p. 5-11). Further, a common weather picture that draws together multiple sources of weather information is identified as vital.

Human-Technology Integration Issues

This study involves assessing the integration of predictive weather technology with ERAM and TMA air traffic control systems. Although the focus of the data collection is on flight control efficiency effects associated with technology integration, there are human-technology integration issues that could influence the outcome. New technology often changes the nature of the work and thereby changes the ways in which co-workers interact. For example, Wiener et al. (1991) found different communications patterns between the captain and first officer in a traditional versus a glass cockpit aircraft. In the traditional cockpit, the captain was issuing commands; in the glass cockpit, the captain was more often asking questions. Organizational and social changes such as these can affect mentoring, morale, and the willingness and ability of co-workers to back each other up, ultimately negating any benefit of new technology, as described in the classic analysis of coal mine mechanization by Trist and Bamforth (1951).

Further, new technology has the potential to relieve workload in one area while increasing workload in some other place (e.g., Bainbridge, 1983; Sarter, Billings, & Woods, 1997). For example, predictive weather technology may increase controller workload by introducing uncertainty and thus greater information search or communication work into controller decision processes. Another potential unintended consequence of new technology is to benefit easy tasks while complicating more difficult tasks, as expressed by Weiner and his colleagues (1991): "...pilots of advanced technology aircraft expressed the feeling that during periods where the workload was high, the automation increased the workload, and where it was low, it tended to reduce the workload" (p. 122).

Study Goals

This paper reports on a proof-of-concept research project to integrate predictive weather into the primary decision support systems for air traffic control in the United States –TMA and ERAM. Two key research questions were the focus of this project. First, does the integration of predictive weather into the new systems contribute to a reduction in aircraft delay? Second, can this reduction in delay be accomplished without compromising the safety of the ATC system? The results of this exploratory analysis have implications for ATC training and future research and development in ATC.

Methods

Facilities and Systems

In March 2006 an agreement was signed by a aviation research and development organizations to create the Integrated Airport (IA) Initiative. This consortium included firms such as Lockheed Martin, Boeing, ENSCO, Harris, and Mosaic ATM; Daytona Beach International Airport; and Embry-Riddle Aeronautical University. The goal of the consortium and the IA is to research and promote NextGen concepts. The consortium became the catalyst for the development of the Daytona Beach NextGen Test Bed (DBNTB), located at the Daytona Beach Airport and managed by Embry-Riddle Aeronautical University. The DBNTB has evolved into a robust platform that supports a myriad of systems and technologies, allowing them to be tested in a safe, simulated environment (ERAU, 2009).

This facility was enhanced with additional hardware and software for the current project including consortium-developed versions of ERAM and TMA. Weather data for this project was recorded by ENSCO, Inc, the developer of the candidate weather decision support tool used in the current project, and the ERAU Weather Laboratory. These recordings were used to identify actual cases that met the requirement of the convective weather scenario discussed below.

Summer convective weather is a particularly troubling issue in the Southern region of the United States; therefore, the selected location (airspace) for this research was in Central Florida; specifically, a portion of the Jacksonville Center (FAA designation ZJX) area of operations including the Ocala Low Sector, Sector 15, which is adjacent to the Orlando International Airport, and high-altitude sectors 33 and 78 as shown on the map in Figure 1. Jacksonville Center (ZJX) and the Center Weather Service Unit (CWSU) were helpful in identifying cases where weather was a particular problem from their perspective. These weather recordings were collated and saved on ERAU servers for use in this project.

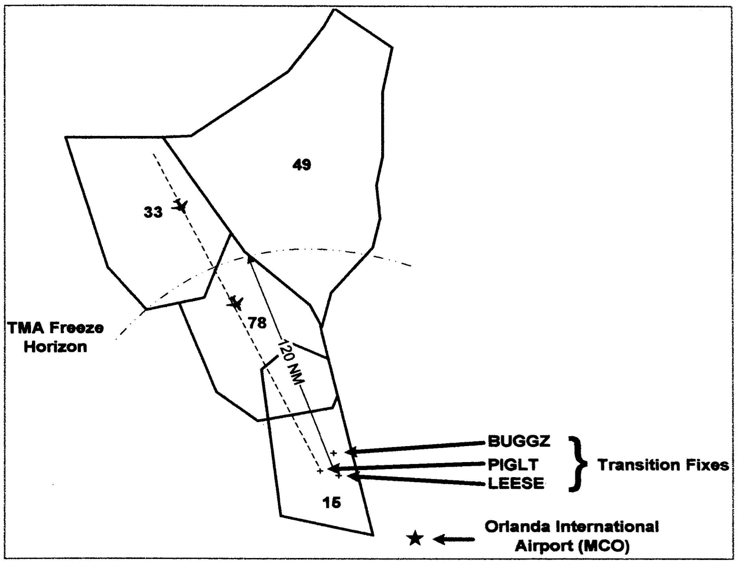

Figure 1. Sectors involved in the simulation. PIGLT is the transition, or metering, fix for arriving traffic.

For the day(s) upon which a convective weather event occurred, Next Generation Weather Radar (NEXRAD) data from a national weather product was acquired. NEXRAD is the system that provides the primary weather information input into ERAM. Upon examination of the proposed weather days, a single day (August 9, 2008) was selected for use as the weather 'event' in the simulation. Two software tools, SGET and ATCoach, were used to generate the flight scenario and ATC environment. SGET is embedded into ERAM and is used by scenario developers to create, store, retrieve, edit and preview flight scenarios. SGET provides a set of tools that assist in the generation of scenario inputs and scenario debugging, including the capability to import national NEXRAD weather data for insertion in the flight scenario. SGET used ERAM adaptation files to define metering fixes for the approach route used. ATCoach® (UAF, Inc.), a system that simulates the air traffic control environment, sent scenario NEXRAD weather to ERAM. The ERAM system carried out a trajectory assessment of each aircraft and provided a warning to the controller if an aircraft's planned trajectory penetrated a weather polygon derived from the NEXRAD data.

The D-side controller (responsible for detecting traffic conflicts and coordinating between sectors) then used the Graphical Plan Display (GPD) that shows the predictive weather and the aircraft trajectory to amend the trajectory by 'rubber banding' the trajectory around the weather. Once the D-side controller 'solved' the conflict against the predicted weather, the ERAM system created a 'clearance' (cleared to proceed) from the Amendment message function. This clearance was verbally communicated by the R-side controller (responsible for flight separation and communication with pilots) to the aircraft. The R-side controller was shown the 'current actual weather' from the NEXRAD composite and layered composite radar reflectivity displays.

Scenario Development

The scenarios were developed to meet the following requirements:

- A realistic amount of air traffic in the chosen sector based on prior traffic data.
- If a 'bad weather scenario', convective weather:
    - did not cover the entire sector,
    - did not block traffic flow through the entire sector, and
    - did cross an aircraft's trajectory prior to reaching the metering fix(es) ultimately requiring rerouting of aircraft
- A low altitude and single high altitude sector managed by ZJX (Jacksonville ARTCC).

Further, the scenarios were designed to meet the current limitations of the DBNTB systems. In particular, only a single R-controller and two D-controller positions were available. This limited the number of sectors and aircraft that could be involved in the scenarios. Aircraft in the focus sectors were to be controlled by a pseudo-pilot responding to R-controller commands. Any sectors adjacent to the sectors shown in Figure 1 were not managed by a human; the aircraft were controlled solely by simulation. High altitude sectors 78 and 33 were combined into a 'single sector' that allowed the D-controller time to probe the flight, create a re-route, submit the re-route into ERAM, communicate the re-route to the R-controller, and then communicate the re-route to the pilot. The D-controller look ahead and conflict probe capabilities were extended from 20 to 60 minutes so that the D-controller could see predictive weather conflicts in the low altitude sector containing TMA metering fixes. The TMA freeze horizon was reduced to 120nm from Orlando (typically it would be 200nm). This moved the freeze horizon to well within the sector where the D-controller was operating, which allowed the controller to provide flight plan amendments to TMA prior to the aircraft reaching that horizon, at which point the scheduled times of arrival (STAs) are frozen by TMA.

The flight plans for the selected day (August 9, 2008) were extracted by the research team from Aircraft Situation Display for Industry (ASDI) data. The extracted flight plans consisted of arrival Instrument Flight Rule (IFR) traffic that transitioned through the Ocala sector (Sector 15) going to Orlando & Tampa between 1700 to 1902 Zulu. A consultation was held with Sherrie Callon from the FAA Traffic Management Unit of the Jacksonville Center who indicated that Sector 15 is an arrival only sector and that no real west to east traffic exists. Subsequent analysis of the selected day showed no flight delays that would have caused flight cancelations during the particular time of interest. Once the flight plans were extracted, they were converted into ATCoach. In order to make the simulation become controllable at the start time of 1700Z, aircraft routes were truncated, meaning that flights were not created to start at their airport of origin but to start at waypoints that were in a much closer proximity to Orlando and Tampa. To determine the time that an aircraft would start at its truncated route, a fast-time simulation was used to generate the times aircraft would cross a fix. The times generated by the fast-time model were then inserted into the ATCoach flight plans and run to determine if there was adequate separation. To create the adequate separation, specific flights were adjusted approximately +-3 minutes to insure proper spacing when entering the sector.

It should be noted that TMA's time based metering is not currently being used in either visual or instrument metrological conditions (VMC or IMC, respectively) to manage arrivals into Orlando. It was "turned on" for this project since the purpose is to demonstrate the integration of 4D predictive weather into ERAM and TMA. The Sector 15

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position would also not use a D-controller since one is not currently employed in the sector. Based on the purpose of the demonstration and limitations of the existing system, the following scenarios were developed and utilized:

Scenario 1: Baseline, Clear Weather. Scenario 1 consisted of a clear weather day. There were no events constraining demand in the sector because of weather at the airport of destination (Orlando).

Scenario 2: Bad Weather without Flight Plan Amendments. Scenario 2 consisted of a convective weather day that was not restraining demand in the sector because of weather at the airport of destination (Orlando), nor because of mass weather fronts that blocked a portion of the route of flight. Rather, the type of weather was the kind most commonly associated with Florida. This type of weather accumulates and dissipates in a relatively short period of time. This type of weather at the arrival fixes into Orlando would require vectoring by the R-controller in the Ocala low altitude sector (Sector 15).

Scenario 3: Bad Weather with Flight Plan Amendments. Scenario 3 featured the same type of weather situation as Scenario 2. Scenario 3 differed from Scenario 2 in that predictive weather was now available and could be used to adjust flight paths proactively. A D-controller, in a sector prior to the TMA Freeze Horizon (i.e., High Altitude Sector 78), used predictive weather to determine whether aircraft in the sector would enter convective weather predicted to occur downstream in the Ocala sector (Sector 15) before the arrival fix. The D-Controller then filed a flight plan amendment that was used by TMA to calculate a new STA. The aircraft then received the re-route command from the R-controller and executed it. The R-side controller of the Ocala sector maintained separation and performed vectoring beyond the re-route instructions, if required. For Scenario 3, time based metering was turned on and required times over (RTOs) the arrival fix were issued to the pilot to demonstrate the integration of 4D predictive weather into ERAM and TMA.

Selection and Training of Study Participants

For the initial simulation, a total of four controllers were selected from a pool of students in the ERAU ATM Program based primarily on their prior experience with en-route operations, Jacksonville ARTCC and/or the Air Traffic Control System Command Center in Herndon, Virginia. For the follow-up analysis an additional 6 controllers were chosen bringing the total number of controllers used in the study to 10.

All controllers were male. The average age was 25.3, but this average was skewed by the presence of one outlier who was a retired Air Traffic Controller and current instructor in the ERAU Air Traffic Control Lab. Excluding this individual, the average age was 21. Six of the pseudo controllers were enrolled in the ATM program. One pseudo-controller was pursuing a minor in ATM. The remaining three were pursuing other areas of interest. Seven of the pseudo controllers were seniors, taking the final courses in the ATM program. Five of the pseudo-controllers were also pilots holding a private pilot's license

Initial training of the demonstration team was conducted in the ERAU College of Aviation (COA) En-Route Control Lab. Two training scenarios were adapted to the current COA lab configuration (ZME center). The first scenario had a single arrival stream that flowed north-to-south replicating the arrival flow into Orlando from the OCALA Sector. The other scenario had all the arriving and transiting flights to replicate all the traffic in the OCALA Sector. A fast time simulation of the scenario was created to generate an order of events. Once the order of events was established, a script of the events was made to map the exact communication between controllers and pilot. Upon delivery and integration of the ERAM, HCS, and TMA systems, training began on the new functionality.

Once initial training was complete, system evaluation began. Controllers were each presented with the three randomly sequenced scenarios over the course of a two week period based on their availability. No effort was made to maintain cohorts of controllers, therefore, it was possible that each controller would be assigned to work with a different group of controllers for each of the three scenarios. Controllers were not told which scenario they would participate in prior to the initial pre-briefing. The goal was to insure that each candidate had the opportunity to experience all three scenarios—Clear Weather (Scenario 1), Bad Weather without Flight Plan Amendments (Scenario 2), and Bad Weather with Flight Plan Amendments (Scenario 3).

Metrics and Data Collection

The intent of the project was to determine if the integration of predictive weather into TMA and ERAM would help controllers to maintain arrival rates and/or reduce delay while maintaining operational safety. Further, it was believed that the systems could improve route efficiency by allowing better routing around weather. Thus, the working hypothesis was that performance in the Bad Weather With Flight Plan Amendments Scenario would not differ from performance in the Clear Weather Scenario on the first three metrics listed below and would be better than in the Bad Weather Without Flight Plan Amendments Scenario on the final metric given in the list below.

The primary metric of interest was related to the ability to minimize delay at Orlando during convective weather. The full set of measures obtained consists of:

- **Arrival Rates.** Defined as a simple count of all crossing over the metering fixes. The arrival rates were measured as movements over the Orlando fix PIGLT (shown in Figure 1).

Aircraft Delay. Measured as the difference between the Scheduled Time of Arrival (STA) and the Actual Time of Arrival (ATA).

- **Aircraft Route Efficiency.** Measured as extra distance flown by each aircraft.

The unit of analysis was the individual flight. Analysis was performed on the total number of flights in all runs of the scenario (1, 2 or 3). Data was captured for the analysis in several ways. First, the TMA output was saved for each individual scenario run. The metrics of interest were identified from the output and scripts were written to extract the data.

The following recordings – screen captures, audio communication, and room video – were also collected but are not used in analyses reported in this paper:

- Virtual Network Computing (VNC) screen recordings were captured for all ATC displays
- Audio recordings for all communication between controllers and pilot and controller to controller
- A video of the positioned R-side controller

Results

Figure 2 shows the average delay (ATA minus STA) per aircraft (in seconds) for the aircraft in the two bad weather scenarios.

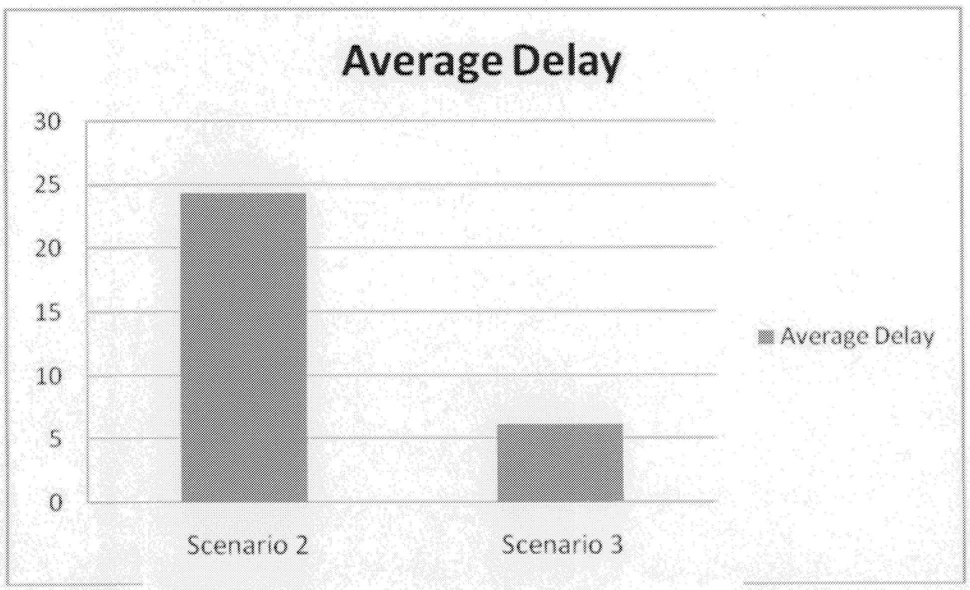

Figure 2. Average flight arrival delay (in seconds) by scenario. Scenario 2=Bad Weather without Flight Plan Amendments; Scenario 3=Bad Weather with Flight Plan Amendments; Scenario 2 sample size=192 flights; Scenario 3 sample size=180 flights.

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Overall, the data indirectly support the working hypothesis that the flight plan amendment scenario in which the flight plan was changed in response to predicted convective weather (Scenario 3 in Figure 2), did reduce the average delay for all aircraft compared to the scenario without flight plan amendments (Scenario 2 in Figure 2). Although air traffic control efficiency measures did not differ between Scenarios 2 and 3, one measure indirectly supported a benefit of predictive weather technology. As described below, the analysis of aircraft delay indicated that the use of predictive weather during bad weather benefitted performance relative to clear day performance, whereas performance in the absence of predictive weather technology was worse than clear weather performance.

Beyond the impact on flight management efficiency, the study was concerned with identifying compromises to the safety of the air space system. We did not detect any such compromises but cannot claim to have evaluated this question adequately. Pilot error rates across all scenarios were artificially high as a consequence of workload faced by the person managing the navigation and communications of multiple aircraft. This artificial error rate weakens the study, making the detection of differences across scenarios more difficult than otherwise. This should be kept in mind when interpreting the results reported below.

To analyze the results, the STA was subtracted from the ATA for each aircraft in the scenario and a mean delay and standard deviation were calculated for that scenario (see Columns 3 and 4 of Table 1). The means for each scenario were compared and a 95% confidence interval was constructed (+/- 2 standard deviations) around the difference between means. If the calculated confidence interval does not include zero, then we can be 95% confident that we have accurately detected a mean difference between delays in the two scenario conditions (i.e., a difference that would generalize to all flights in such conditions). If the interval does include zero, there is a 95% chance we have accurately assessed the absence of a difference in the means of these two scenarios.

Based on the analysis results reported in Table 2, there is a statistically significant difference in the mean delay between the Baseline, Clear Weather scenario and the Bad Weather without Flight Plan Amendments scenario (M=-24.34 s, 95% CI[-45.54,-2.14]. In other words, convective weather did produce statistically significant delay in arrivals to Orlando relative to the Clear Weather Scenario using the existing air traffic system. The analysis found no statistically significant difference in the mean delay between the Clear Weather and Bad Weather with Flight Plan Amendment scenarios; that is, the calculated confidence interval included zero.

Thus, the analysis supports our hypothesis of no difference between Clear Weather and Bad Weather With Flight Plan Amendments Scenarios. Combined with the finding of a statistically significant difference between the Bad Weather Without Flight Plan Amendments scenario and the Clear Weather scenario, we have support for the benefit of using the predictive weather technology over current ATC methods during bad weather.

Table 1

Mean Aircraft Delay (in seconds) by Scenario

Scenario*	N	M	SD
1	167	183.92	109.91
2	192	208.26	103.61
3	180	190.07	107.60

Note. Scenario 1=Baseline/Clear Weather; Scenario 2=Bad Weather without Flight Plan Amendments; Scenario 3=Bad Weather with Flight Plan Amendments.

Table 2

Confidence Intervals for Differences in Aircraft Delay (in seconds)

Scenarios Contrasted	Difference between Means	**95% Confidence Interval**	
		Lower Limit	Upper Limit
1 vs 2	-24.34	-45.54	-2.14
1 vs 3	-6.15	-29.06	16.76
2 vs 3	18.19	-3.30	39.68

Note. Scenario 1=Baseline/Clear Weather; Scenario 2=Bad Weather without Flight Plan Amendments; Scenario 3=Bad Weather with Flight Plan Amendments.

To calculate the route efficiency measurement, the total distance (nautical miles) of the optimal flight path of each aircraft was compared to actual distance flown by the aircraft to determine any extra distance that may have been flown. The optimal path was determined by summing the distances between each waypoint along the aircraft's original path reported in the flight plan. The distance was calculated along the flight path starting at the aircraft's first reported position (by the simulator) to the arrival fix. The actual path flown was determined by analyzing the aircraft track position reports in the TMA log files. Route efficiency was the difference between the actual distance flown and the optimal path distance.

Table 3 shows the results for aircraft route efficiency between the two Bad Weather scenarios. The Bad Weather without Flight Plan Amendments scenario added an average of 0.83 miles to each route while the Bad Weather with Flight Plan Amendments added only 0.58 miles. Statistical analysis revealed the difference in route efficiency is not reliable and cannot be expected to hold true beyond the specific samples measured in this study. When annualized and spread over a large number of flights, the fuel savings resulting from the implementation of flight plan amendments may prove to be substantial but cannot be counted on based on the present research. Support for a statistically significant difference may be borne out by future research conducted using experienced controllers or controllers who receive more training with use of the predictive weather capabilities.

Table 3
Route Efficiency (Additional Distance in Nautical Miles) by Scenario

Efficiency Measure	Scenario 2	Scenario 3
Total flight route distance (nm)	159	105
Average distance added to route (nm)	0.83	0.58

Note. Scenario 2 sample size=192 flights; Scenario 3 sample size = 180 flights.

An ANOVA was performed to compare scenarios in terms of the additional distance added to flight routes. The results revealed no main effects or interactions.

Discussion

This study was intended primarily as a proof-of-concept demonstration. Thus, most of the attention was placed on integrating the key systems rather than analyzing detailed operational issues. The study attempted to address two key research questions: Does the integration of predictive weather into the new systems contribute to a reduction in aircraft delay and can this reduction in delay be accomplished without compromising the safety of the ATC system?

The results of this exploratory study suggest that the integration of predictive weather technology into the ERAM and TMA systems contributes to more efficient flight management than the existing method of miles-in-trail by reducing aircraft delay during convective weather. Statistical analyses confirmed that there is no difference in the mean delay between the clear weather and bad weather simulations when integrated predictive weather with associated flight plan amendments were used. On the other hand, there was a difference between the clear weather and bad weather simulations when integrated predictive weather was not used. Results of the aircraft route efficiency analysis found that aircraft added an average of 0.58 miles to their route using the integrated predictive weather as opposed to the existing system of miles-in-trail, in which the average increase in distance traveled during convective weather was 0.83 mile. While these distances were not found to differ, a difference might emerge between scenarios that traverse a more substantial portion of the NAS and/or involve a much larger mass of convective weather.

Human-Technology Integration Issues

The focus of this study is on demonstrating the integration of TMA, ERAM, and predictive weather systems minimized attention to a number of human-technology interaction issues that deserve future investigation. These issues include the impact of the new technology on roles and responsibilities and thereby on teamwork and relationships; the implications for controller workload under both routine and off-nominal situations, differences in acceptance by and benefits for experienced versus less experienced controllers, whether new possibilities for human-human or human-technology communication breakdowns are introduced with the new technology, the usefulness of the new technology under unusually challenging circumstances and escalating stress, and the implications for training.

Based on interviews conducted with controllers following the simulation runs in this project, several specific qualitative findings were noted. First, all pseudo-controllers reported that they found the new systems (TMA and ERAM) relatively easy to learn and use. Two new features - the point-and-click re-route and the weather integration - were considered quite helpful; however, it should be noted that the controllers simply took the accuracy of the predictive weather for granted during the simulation and showed no hesitation in routing craft between areas of convective weather. In a real world scenario, the possibility that the weather phenomena were larger or more intense than predicted might cause them to take different action. Further, it is not clear that pilots would accept the re-routes if the 'way forward' was not clear to them.

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Second, the student controllers used during the study are quite familiar with the menu driven, point-and-click environment and adapted quickly. It is not clear that controllers with experience in other environments would find the new technology as easy to learn and manipulate.

Third, it was observed that the vast amount of data available via ERAM and TMA was distracting to some pseudo-controllers who had to be reminded to focus on the simulation at hand. This distraction may have accounted for several observed incidences of loss of separation during the study, a serious safety issue in air traffic control. The question is whether repeated exposure to the system would erode this novelty and allow controllers to develop their own strategies for dealing with the information.

The proposed weather technology may contribute to turning air traffic controllers into air traffic managers; that is, technology is given work with the expectation that it will be more precise and efficient than a human worker; humans are expected to be the managers of the air traffic control systems. This would represent a major shift in the roles and responsibilities of air traffic personnel and has many long-run implications for training, design, and safety. In light of the dramatic shift, human-technology interaction issues associated with cognitive workload, uncertainty, distraction, and task complexity should be explored in greater depth.

Conclusion

This study suggests that the integration of predictive weather into a system that provides common situational awareness to the key actors in the NAS holds promise for reducing aircraft delay and aviation accidents. It might also contribute to greater route efficiency and lower fuel costs, a possibility that might be borne out by additional design work and research. Further work is necessary to evaluate the usefulness and usability of the predictive weather technology. It is one thing to get computer system components to talk to each other and pass information in a form and at a speed that all units can understand, a goal that was achieved in this project. It is another thing to get the computer system components to support the efforts of the human parts of the system. This is the challenge of future research and training. Addressing this challenge may be key to improving aircraft route efficiency, a measure that did not demonstrate benefits in this study, as well as a number of other flight management efficiency measures.✈

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