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Four-Dimensional Modeling and Simulation for use in Interactive Airspace Training Materials

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Abstract

The findings from this research provide evidence that a four-dimensional flight-training program can improve flight-planning results for individual pilot and flight dispatcher students. Data collected from 22 student volunteers recruited from Sinclair Community College in Dayton, Ohio were analyzed using the Independent Group *t*-Test. These raw data were used to determine a 27% passing rate for those in the control group and a 73% passing rate for those in the experimental group. A required minimum score of 70% was used as the benchmark for passing. The results demonstrated there was a statistically significant difference for points earned on the flight-planning task for the experimental group versus the control group using a two-tailed analysis, $t(20) = -2.07$, $p < .05$. In addition to the traditional flight-planning materials and information provided to both groups, the experimental group was also supplied with the novel four-dimensional airspace presentation and interface. An examination of the mean level of difference between the students determined that the experimental group exhibited statistically significant improved performance using the novel interface compared to those in the control group. The results of the Levene's Test for Equality of Variances indicated that the two variances were approximately equal between the groups. The study addressed the research gap for Satellite Tool Kit (STK) generated four-dimensional airspace presentations and interfaces in aviation academic applications. Future researchers may expand on these findings by testing refined interfaces with larger and more diverse student and professional populations at multiple locations. This acquisition of knowledge is also applicable for operational aviation and non-aviation fields where similar visualizations and interfaces might be useful.

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Introduction

As America develops the next generation of its air traffic management network, new technologies and procedures will be leveraged to create a modern and scalable system. This system needs to include a four-dimensional (lateral, longitudinal, vertical, and time positioning) flight path visualization and projection capability. This capability represents the centerline of a path plus the positioning uncertainty, including waypoints. It was hypothesized that the use of four-dimensional visualizations would demonstrate increased performance by flight dispatchers and pilots when assigned flight-planning tasks through human performance information presentation enhancements. In addition to the benefits of advanced four-dimensional interfaces for operational professionals, it was also hypothesized that matching training and education

content to future operational systems might achieve similar benefits if they were adapted and applied to aviation education and training environments. This research used a quantitative two-group posttest only randomized experimental study to gather test subject flight-planning results from both a control group using traditional methods and an experimental group with access to a novel four-dimensional interface to aid in their flight-planning task.

Although research has been accomplished related to three and four-dimensional presentations and interface methods and how they may be applied in aviation, no prior research was discovered using Satellite Tool Kit or the novel interface developed for testing purposes. Research must be conducted to determine the aspects of the current air traffic system that should be kept, the portions that may require modernization and the procedures or tools that may need to be changed in order for the Next Generation (NextGen) system to be used effectively. Using goals of the Federal Aviation Administration (FAA) NextGen effort as a guide, this research was designed to address the foundational considerations related to how a novel four-dimensional airspace presentation and interface may affect the outcome of a flight-planning task.

Theoretical Framework

The purpose of the research was to determine if the use of a novel four-dimensional visualization and interface as a tool in aviation education and training materials for individual pilot and flight dispatcher students improves results in a flight-planning scenario assignment. The study used a quantitative design involving inferential statistics and a two-group posttest only randomized experimental study (Schumacher and Lease 2007). A graded flight-planning assignment provided requisite data for the analyses (Schumacher and Lease 2007). Student volunteers were recruited from the college aviation program operated by Sinclair Community College (SCC) in Dayton, Ohio.

The research focused on the possible applicability of a novel four-dimensional airspace visualization and interface to determine potential applications in a college aviation-training environment. Generally, the methods employed for testing the interface in comparison with the FAA approved training materials and instruments currently employed constituted a human performance or human factors study. Understanding student flight-planning performance differences that might be present between the control and experimental groups would also be important to ensure that future operational versions of similar training tools will meet design goals and improve flight-planning results by both the student and professional aviation populations (Schumacher and Lease 2007). The future of America's air traffic control (ATC) system will be shaped by the technological and systemic changes proposed as part of the NextGen programs.

Thorough academic research focused on modern interface and visualization options is imperative to ensure effective application of limited resources during NextGen development, timely implementation, and future acceptance, scalability, upgradability, and ultimate success of the final products. Understanding possible differences in performance between traditional flight-planning methods and those enhanced by the tested interface is necessary to ensure educational institutions offer resources that aid in student education and training, possibly increasing enrollment, student satisfaction, and accomplishment of educational goals (Changchit and Klaus 2008; Gordon and Buckley 2009; Kicklighter et al. 2010; Pabst et al. 2010; Schumacher and Lease 2007; Struyven et al. 2008).

Research Methodology

The employed plan asked study participants in the experimental group to use an interactive four-dimensional simulated airspace environment developed by Analytical Graphics, Inc. and Riverside Research. The interface was developed further with researcher input for research purposes at no cost beyond the commitment of time. To ensure the validity and reliability of the research design, the methodology used by Schumacher and Lease (2007) in their study of scenario based flight training was followed. Schumacher and Lease explored the introduction of a scenario based training design in a Part 141 FAA approved private pilot syllabus. Because of the restrictions of the FAA approved Part 141 curriculum, the researchers were forced to adhere to the established FAA standards while introducing the scenario based training to the experimental group as a training enhancement. This approach was also taken during this research because it sought to compare flight-planning results between a control group using a traditional and approved FAA training methods and an experimental group using the same approved procedures but with the added use of an interactive four-dimensional airspace presentation and interface.

The Schumacher and Lease (2007) study used 30 student volunteers who were randomly assigned to either the control or experimental groups to limit the potential influence of confounding variables and ensure equal distribution of student groups. Random assignment of a similar number of volunteers also occurred in this study to ensure equal distribution of students between the experimental and control groups. The enrollment in many aviation programs is limited, restricting sampling from larger populations and corresponding larger sample sizes.

Schumacher and Lease evaluated differences in performance between the control and experimental groups using standard grading and evaluation procedures for the Part 141 flight school. This study followed this approach by utilizing completed flight plans created as reference keys prior to data collection and evaluation and grading accomplished by a certified aviation professional using established FAA standards for performance to ensure that both groups were evaluated based on the same criteria. Donna Hanshew, an Associate Professor of the Aviation Technology Department at SCC, a FAA designated aircraft flight dispatch examiner, trained weather observer, and certified flight instructor, evaluated and graded participant flight plans using the developed answer keys for reference to ensure continuity and that correct procedures were followed. As in the Schumacher and Lease study, SPSS was used to evaluate the collected data using an Independent Group t-Test methodology and variations were determined to be significant if there was a 95% or greater probability that they were caused by the research treatment. Leveraging the established, validated, and reliable template established by Schumacher and Lease ensured the validity, reliability, and applicability of the research methodology and design.

Student volunteers in both the control and experimental groups were asked to complete a navigation log for a general aviation aircraft flying from Dayton, Ohio to Charlotte, North Carolina. Participants in either group had to decide if they wanted to plan a direct route from Dayton (DAY) to Charlotte (CLT), a route around the storm to CLT, or a route from DAY to the alternate airport, Chattanooga (CHA), Tennessee. All students were required to select their path after reviewing available route and weather information prior to beginning flight planning and could not plan more than one route. As in the Schumacher and Lease study, the students in both the control and experimental groups had access to traditional flight-planning information and presentations and were required to follow FAA standards. These materials were included as an attachment to the task directions for the participants that included weather, aircraft performance, and airport data matching educationally current information and the four-dimensional airspace presentation and interface. Those in the experimental group had the added use of the novel four-dimensional airspace presentation and interface. The interface included an aeronautical chart and imagery of the scenario airports overlaid on the globe, visualization and data related to all three flight path options, and the severe storm weather radar returns projected to the appropriate altitudes for analysis.

Once a flight path was selected, both groups planned their flight without altering their route selection. The students in the experimental group retained access to the four-dimensional interface throughout the planning process. The selection of route was noted and the results of the flight plan were analyzed and graded following FAA approved procedures mandated for pilot and flight dispatcher training. To ensure that the only variable was the introduction of the four-dimensional interface in the experimental group, all participants were given an equivalent period, a maximum of 90 minutes, and the same materials as they would normally receive when asked to complete a navigation log for a flight plan.

Two groups of active student volunteers were recruited from the college flight dispatcher and pilot training programs because those segments receive flight-planning training. The available eligible participant population was 30 students at the time of the study with 15 initially assigned to either the control or experimental groups to conduct a pre-research power analysis (Aczel and Sounderpandian 2006). A G-Power 3 analysis was conducted using two-tails, an effect size of .50, an error ratio of 1, and an estimated sample size of 15 for both groups. This resulted in a calculated critical *t* value of .98, Df value of 28, an error probability of .36 for both Alpha and Beta, and a power of .66. The standard deviation within each group of .05 was chosen as the benchmark for this analysis (Norusis 2008). Twenty-two students volunteered for the study with 11 randomly assigned to both the control and experimental groups. The volunteers included 21 Caucasians and 1 Asian. All volunteers were male and aged between 18 to 55 years.

The dependent variable for this study was student flight-planning results. Studies support the requirement for understanding operator or student performance and perceptional differences between varied training and education methods (Alexander et al. 2005; Guibert et al. 2009; Leonard et al. 2010; Schumacher and Lease 2007). The identified independent variable (four-dimensional airspace presentation and interface) was selected after a review of similar research efforts that compared two contrasting instructional methods or learning environments and considered student results (Schumacher and Lease 2007). Research projects often compare and contrast the performance of an experimental and a control group when both are assigned the same task (Mourant and Thattacherry 2000; Schumacher and Lease 2007). The independent variable was important to the research because the experimental group used the developed four-dimensional airspace presentation and interface during flight planning while the control group was limited to traditional and approved FAA training methods and tools.

Research Question

The research question relates to the variance between the dependent variable (student flight plan results) and the independent variable (four-dimensional airspace presentation and interface) that was identified through discoveries made in the analysis of data collected and analyzed as part of the research.

Q1. What are the comparative results for a graded flight-planning task when pilots and flight dispatchers in an experimental group are provided with an interactive four-dimensional airspace modeling and simulation interface in addition to the traditional information and materials used by the control group?

Hypotheses

The hypothesis associated with the research question used the Independent Group *t*-Test for analysis of the dependent variable (student flight plan results) and the independent variable (four-dimensional airspace presentation and interface) (Aczel and Sounderpandian 2006). To determine the tests of independence, the null and alternative hypothesis took the following forms.

$H1_0$. There are no statistically significant differences in the comparative results between the experimental and control participant populations in terms of the dependent variable (student flight plan results) and the independent variable (four-dimensional airspace presentation and interface) when the experimental group is provided with an interactive airspace four-dimensional modeling and simulation interface in addition to the traditional information and materials used by the control group.

$H1_a$. There are statistically significant differences in the comparative results between the experimental and control participant populations in terms of the dependent variable (student flight plan results) and the independent variable (four-dimensional airspace presentation and interface) when the experimental group is provided with an interactive airspace four-dimensional modeling and simulation interface in addition to the traditional information and materials used by the control group.

The hypotheses directly address the importance of determining the possible influence of an interactive four-dimensional modeling and simulation interface when groups are asked to complete the same graded exercise or provide input on a topic (Changchit and Klaus 2008; Kicklighter et al. 2010; Leonard et al. 2010; Pabst et al. 2010; Schumacher and Lease 2007; Struyven et al. 2008). The hypotheses statements are directly correlated to the research question and acknowledges the importance of the depended variable (student flight plan results) and the independent variable (four-dimensional airspace presentation and interface). The research hypotheses were developed after a review of existing research indicated the same or similar variables were commonly considered (Changchit and Klaus 2008; Kicklighter et al. 2010; Leonard et al. 2010; Pabst et al. 2010; Schumacher and Lease 2007; Struyven et al. 2008). The research justification was based on the testing of student flight-planning results when one group is provided with novel four-dimensional training interface to determine possible applicability to broader applications to address a gap in the existing literature related to the developed interface.

Flight-Planning Instrument

Participants were provided with a flight-planning instrument, a navigation log, data collection materials, and IFR Enroute Low Altitude charts, L-25, L-26, and L-27. The forms were of the same format as pilot and flight dispatcher students use throughout their training in the FAA approved SCC flight school and flight dispatch programs. The FAA has established several training guides in addition to regulations that require pilot and flight dispatcher training include navigation log and flight-planning training in approved formats to maintain the approved status that SCC enjoys (FAA 2008a; FAA 2008b; FAA 2011). Although training institutions have some degree of freedom in the design and execution of their training programs, they must adhere to the FAA generated and tested training guidance that mirrors real-world pilot and flight dispatcher tasks (FAA 2011). Therefore, as noted in their Air Agency Certificate and Aircraft Dispatch School letter of approval, the SCC approved curriculum, training processes, and grading procedures are considered valid by the FAA and are audited periodically to ensure student standards and college procedure continue to adhere to federal guidelines (FAA 2011).

After selection of one of the three possible routes, participants planned their chosen flight path and entered their calculations in the provided navigation log. The entries on the log were used to determine which route was selected and how the flight was planned for comparison to the researcher-generated and college faculty verified paths created as grading references. The SCC Aviation Technology Department Associate Professor assisted in the grading process and assignment of flight-planning task and navigation log grades. As in traditional flight training, although selection of waypoints and some flight details varied between participants and did not completely match the three master flight plans, comparison to the answer keys and SCC faculty appraisal did show whether the participants created a plan that satisfied safety and regulatory requirements.

Four-Dimensional Airspace Presentation and Interface

In addition to the traditional flight-planning information and materials already described, students in the experimental group were also provided with a four-dimensional airspace presentation and interface customized for the research task. The simulated environment was designed by the researcher and validated to match the information related to the weather conditions and generic route selection options presented to both the control and experimental groups using traditional flight-planning information and materials. Figure 1 shows a waypoint decision aid with visualized weather provided to the students in the experimental group.

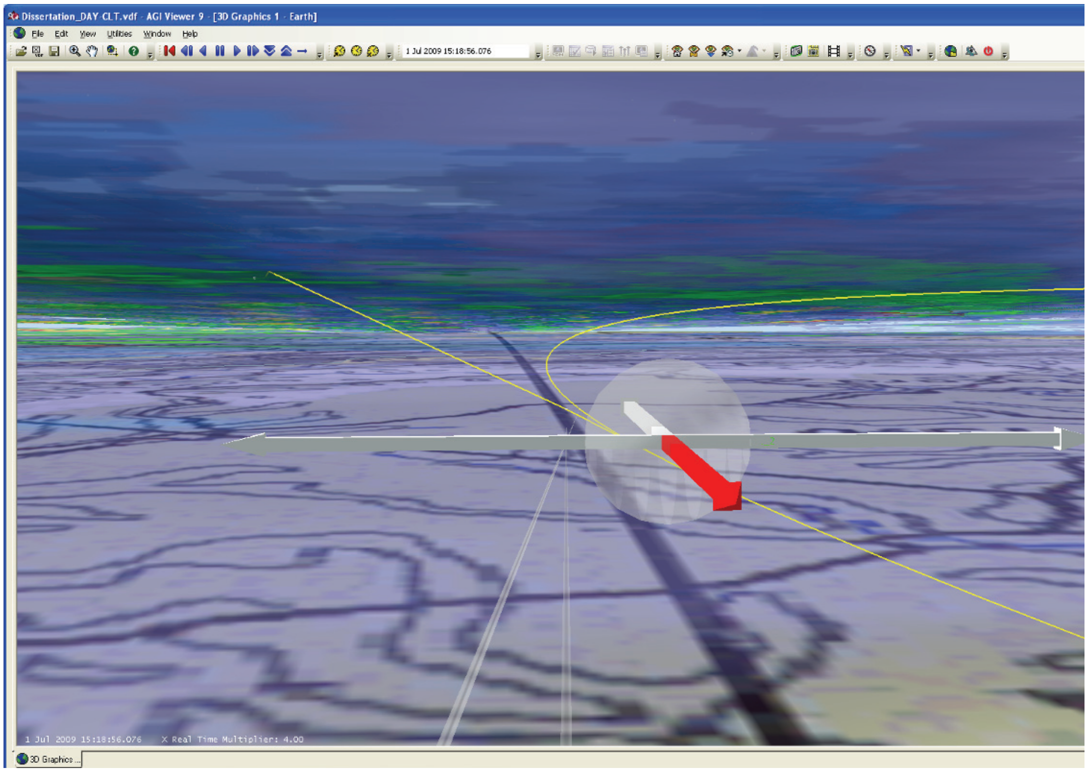

Figure 1. Initial visualized waypoint and alternate route presentation.

Participants were able to animate the flight-planning scenario from a point where small general aviation aircraft departed DAY and started on a path toward CLT. Along the route, the simulated aircraft passed through waypoints, some of which resulted in visualized decision points where the aircraft model would split into two and each aircraft would proceed on a possible flight route. In total, there were three visualized route options, a direct route from DAY to CLT through the storm, an alternate route from DAY to CLT around the storm to the south, or a diversion from DAY to CHA never passing through or navigating around the storm. The basic animation controls allowed the scenario to be played, rewound, reset, stepped forward and backward, and sped up or slowed down. Users were also able to change their perspective in the environment using the left mouse button to pan and tilt and the right mouse button to zoom in and out. The view could be changed between simulated aircraft by holding SHIFT and then double-left clicking on the desired object or route. Using these basic controls, participants were able to examine the scenario environment and possible route alternatives in four-dimensions as an added decision making tool in their flight-planning process.

Findings of the Study

From a possible population of 30 eligible pilot and flight dispatcher students, 29 students indicated they would participate and were randomly assigned to either the control or experimental groups. Initially, 15 students were assigned to the control group and 14 students were assigned to the experimental group. After assignment, 22 eligible student volunteers, 11 in each group, attended one of three data collection sessions and began the flight-planning process.

Flight plans recorded on the researcher provided navigation logs were collected from all 22 participants and graded referencing the answer keys. The scores for the flight-planning results were determined by the Associate Professor of the SCC Aviation Department in coordination with the researcher. Points were assigned based on the safety of the waypoints selected to construct the route and the final flight-plan from DAY to either a primary destination in CLT, or an alternate destination in CHA. Students received 0 points if they planned a route that went directly through the severe storm between DAY and CLT, 70 points if they planned a path around the storm to the north, 90 points if they planned a path around the storm to the south, and 100 points if they diverted to the alternate airport.

Flying through the scenario weather provided for the flight-planning exercise was too dangerous for the capabilities of the scenario aircraft, a Cirrus SR-22, and resulted in a failing flight plan grade. Planning a flight around the storm to the north to CLT was determined to be an acceptable route but one considered dangerous due to the waypoints selected and the trajectory of the storm toward the route of flight. A route planned around the storm to the south to CLT was determined to be an acceptable route that was safer than a northern route due to alternate waypoint selections and the trajectory of the storm away from the route of flight. A route planned to the alternate airport, CHA, was considered the safest option because it avoided the potential of intersecting adverse weather. Participants were not allowed to remain at DAY or to select another alternate destination. This facilitated the creation of the answer keys and assignment of scores based on predetermined grading criteria. Table 1 presents the raw student flight-planning scores with eight failing scores and three passing scores for those in the control group and four failing scores and seven passing scores for those in the experimental group.

Table 1

Raw Data – Student Flight-Planning Scores

Student	Control Group	Experimental Group
1	0	90
2	0	70
3	0	0
4	70	0
5	0	90
6	0	0
7	0	90
8	70	0
9	0	90
10	70	100
11	0	70

The scores indicate that eight students in the control group planned flights on direct routes through the storm from DAY to CLT and three students planned flights to the north around the worst portion of the storm from DAY to CLT. Four students in the experimental group planned flights on direct routes through the storm from DAY to CLT, two students planned flights to the north around the worst portion of the storm from DAY to CLT, four students planned flights to the south of the storm on a safer route from DAY to CLT, and one student planned a flight from DAY to the alternate airport, CHA. These raw data were used to determine a 27% passing rate for those in the control group and a 73% passing rate for those in the experimental group. A required minimum score of 70% was used as the benchmark passing score as is needed for FAA administered certification examinations.

The raw data were further analyzed using the Independent Group t-Test that assumes subjects are randomly assigned to one of two independent groups and the distribution of the means being compared are normal with equal variances. Volunteer study participants were randomly assigned to either the experimental or control groups using

SPSS to generate random numbers for volunteering students to achieve probability equivalency for group assignment. Analysis of the collected data resulted in a score of .11 for the Levene's Test for Equality of Variances indicating that the two variances are approximately equal between the groups. This means that the assumptions of the Independent Group t-Test were achieved.

The summary of experimental results is presented in Table 2. The control group mean was 19.09 and the experimental group mean was 52.73 resulting in a mean difference of -33.64. The standard deviation for the control and experimental groups were 32.70 and 42.92 respectively. The standard error mean for the control and experimental groups were 9.86 and 12.94 respectively. An examination of the mean level of difference between the two groups determined that there was a significant effect found for points, $t(20) = -2.07$, $p < .05$, with students in the experimental group who had access to the four-dimensional airspace presentation and interface receiving higher scores than those in the control group provided with only traditional flight-planning information.

Table 2

Summary of Experiment Results

Categories	Group Mean	Mean Difference	Std. Dev	SE Mean	*t*	*p* Value
Control	19.09		32.70	9.86		
Experimental	52.73		42.92	12.94		
t-test Equality of Means		-33.64			-2.07	.05

The *t* critical value was determined to be 2.09 for 20 degrees of freedom and the calculated *t* value was -2.07. A significance score of .05 or less was required to assure there was a 95% probability that the experimental group performance was caused by the research treatment. The calculated t value fell within the *t* critical bounds and the *p* score met the benchmark of .05.

Evaluation of Findings

The findings indicate that there was a significant improvement in flight-planning results for students in the experimental group provided with the four-dimensional airspace presentation and interface in addition to normal flight-planning information and tools compared to those in the control group that were only provided with traditional information and tools. The results of the Levene's Test for Equality of Variances indicates that the two variances were approximately equal between the experimental and control groups and the *t* and *p* scores indicate that the results were significant. The results of the study are notable because the volunteer sample sizes of the control and experimental groups were limited due to the size of the SCC Aviation Department and the available pool of students qualified to participate in the study.

Although few studies directly related to four-dimensional interfaces for NextGen existed prior to this research, and none were found that used the novel interface and airspace presentation tested in the research, a comparison of the findings to the existing literature does offer the opportunity to identify areas that may benefit from the research results. The results of this study have direct applications for human factors or performance considerations, a requirement for both academic and operational interfaces (JPDO 2007; Marakas 2006; Wickens et al. 2004). Although the results of the study showed that students in the experimental group with the aid of the interface performed better given the same information as those in the control group, thus supporting improved human performance outcomes, further study would be needed to determine specific human performance considerations benefited by the use of the tool. There is strong evidence from the current results that decision-making processes, safety considerations, and to some extent, task automation improved for the experimental group. However, other human performance principals, specifically those related to cognitive workloads, stress levels, task management, and human-computer interactions would be candidates for future study related to the developed interface (Marakas 2006). Although the results showed positive outcomes for current students of an established aviation training program, further research will be required to determine possible organizational adoption implications including potential formalized integration with existing curriculum or replacement of legacy methods (Robbins and Judge 2007; Tidd et al. 2005; Volti 2006).

Recommendations

Based on the results of the research, there are several recommendations for further exploration or development. They are grouped by academic research and operational implementation categories.

Academic Research

Because the research was conducted in a single data collection exposure with a small sample size that produced a limited demographic group, another study using a refined four-dimensional interface and visualization over longer period with a more diverse and larger group of randomly assigned volunteers would provide additional data for determining the best means of implementation. Consideration should be given to conducting possible follow-up studies at multiple training locations and host facilities to ensure the results are consistent across the pilot and flight dispatcher training communities.

Research using professional pilot, flight dispatcher, and ATC personnel as the population in operational scenarios would help determine possible applicability of the tested or improved four-dimensional interface and visualization beyond training or student applications. Similarly, research involving military personnel would help determine if the same results could be expected between those trained through civilian or military means. Additional research should also be pursued using those trained or operating in foreign aviation systems to explore application beyond the American system.

Integration of interactive learning activities directly into course materials leveraging computer-based tools can result in positive benefits including active student participation in the learning process (Struyven et al. 2008). Another area for possible academic investigation would be delivery of an enhanced four-dimensional interface through the Internet to take advantage of the benefits that distance learning and hybrid courses provide including study at times and locations convenient to the student and self-paced learning rates (Changchit and Klaus 2008). Completion of a study employing the four-dimensional interface to accomplish a flight-training task and then gathering student perceptional opinions of the tool would also provide valuable insights into the aspects the students believe are the most beneficial to accomplishing their assignments (Gordon and Buckley 2009; Kicklighter et al. 2010; Pabst et al. 2010).

A study to determine the appropriate levels of fidelity requirements for refined versions of the interface based on the costs of production and delivery should also be considered (Foster et al. 2007). Further inclusion of reporting and data recording functions in future instances of the tool could increase the value of training accomplished by including information both for student decision making and post-assignment assessment (Snow and Snow 2004). Research using the tool for interdisciplinary team projects incorporating pilot, flight dispatcher, and ATC students in comprehensive scenario-based training assignments may also be helpful in preparing students to be industry partners after completing training (Leonard et al. 2010).

Operational Implementation

The statistically significant results achieved with a small sample size in this study support the further development and refinement of a user interface with commercial potential. A comprehensive, scalable, and customizable training software should be considered as one possible outcome of future development of the tested interface and visualization method. Refined training software would potentially have broad appeal across the pilot, flight dispatcher, and ATC training disciplines because it could assist in the development of safe-decision making skills, provide a rapid means to create custom scenario-based training environments that could be accessed easily through standard personal or institutional computers, and limit training costs.

Serious consideration should be given to developing a web-based product delivery option for several reasons. First, it would allow easy and rapid access to the tool from both educational institution laboratory or library computers and from personal student devices. It would also allow deployment across multiple platforms, not just a single installation instance as was the case during this study. Web-hosting would permit dynamic program updates, user history tracking for academic reporting and personal records, trend identification of user behaviors, and a more stable revenue source because users would subscribe to a service rather than paying once for a static copy. Offering the tool as via the web would also facilitate possible incorporation or integration with other advanced training materials including interactive electronic textbooks, team activities held across broad geographic regions, and lay the groundwork for expansion into an operational planning tool.

A refined version of the expanded training software could support operational users including professional pilots, flight dispatchers, air traffic controllers, unmanned aerial systems (UAS) operators, meteorologists, and other aviation and non-aviation users. Operators could include commercial airlines, the military, general aviation pilots, various United States government agencies, and foreign corporations and government entities. Although a version of the software capable of reliable and broad daily operational use is more challenging than a training version, the potential benefits could be significant if similar gains were achieved in operational situations as those observed in a training environment.

Conclusions

The potential ramifications of these findings can be significant, especially given the current state of transition, modernization, and change taking place in America's ATC system through the NextGen initiative. This study has produced results that support continued academic research and operational implementation of refined versions of the tested four-dimensional visualization and interface. Expanded academic research examples include follow-on studies with refined interfaces to explore interdisciplinary team exercises, user perceptions, varied delivery methods, appropriate levels of fidelity, and increased integrated data recording and reporting. Potential operational implementation examples include development of a commercialized product, possibly web-hosted, which would have applications to both academic and professional users in pilot, flight dispatch, ATC, UAS, and meteorology domains. It is believed that the tested interface could significantly contribute to aviation and even non-aviation fields with proper resources, development, and implementation.

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