Collegiate Aviation Review International

Volume 36 | Issue 2
Fall 2018

UNIVERSITY AVIATION ASSOCIATION

The Peer Reviewed Journal
of the University Aviation
Association

ISSN: 1523-5955

COLLEGIATE AVIATION REVIEW INTERNATIONAL

A PEER REVIEWED JOURNAL OF THE

UNIVERSITY AVIATION ASSOCIATION

COLLEGIATE AVIATION REVIEW INTERNATIONAL
2018 VOLUME 36 ISSUE 2
Ryan J. Wallace, Editor

ISSN: 1523-5955

Correspondence and inquiries

University Aviation Association
c/o Ryan J. Wallace
600 S. Clyde Morris Blvd., COA-213
Daytona Beach, FL 32114
Tel. (386) 323-5085
E-mail: ryan.wallace@erau.edu

OBJECTIVES

The University Aviation Association publishes the Collegiate Aviation Review International throughout each calendar year. Papers published in each volume and issue are selected from submissions that were subjected to a double-blind peer review process.

The University Aviation Association is the only professional organization representing all levels of the non-engineering/technology element in collegiate aviation education and research. Working through its officers, trustees, committees, and professional staff, the University Aviation Association plays a vital role in collegiate aviation and in the aerospace industry.

The University Aviation Association accomplishes its goals through a number of objectives:

- To encourage and promote the attainment of the highest standards in aviation education at the college level
- To provide a means of developing a cadre of aviation experts who make themselves available for such activities as consultation, aviation program evaluation, speaking assignment, and other professional contributions that stimulate and develop aviation education
- To furnish an international vehicle for the dissemination of knowledge relative to aviation among institutions of higher learning and governmental and industrial organizations in the aviation/aerospace field
- To foster the interchange of information among institutions that offer non-engineering oriented aviation programs including business technology, transportation, and education
- To actively support aviation/aerospace oriented teacher education with particular emphasis on the presentation of educational workshops and the development of educational materials covering all disciplines within the aviation and aerospace field

EDITOR’S COMMENTARY & ACKNOWLEDGEMENTS

I am pleased to present the inaugural issue of the *Collegiate Aviation Review International* in its new format and look. The journal staff has made tremendous strides to advance the quality and experience of its contributors, readers, and other stakeholders. As the journal continues to evolve to meet the needs of the ever-changing field of aviation, I invite your input and participation. The journal has always been a voluntary effort of individuals committed to the advancement and communication of aviation research, practices, ideas, and knowledge. It is only with your personal commitment that we will achieve these goals.

No juried publications can excel without the tireless efforts of experts from all aerospace disciplines who volunteer their time to serve as anonymous reviewers. Indeed, the ultimate guarantors of quality and appropriateness of scholarly materials for a professional journal are the knowledge, integrity, and thoroughness of those who serve in this capacity. The thoughtful, careful, and timely work of the issue reviewers, add substantively to the quality of the journal. On behalf of University Aviation Association, we extend our thanks.

Ryan J. Wallace
Editor

TABLE OF CONTENTS

Peer-Reviewed Articles

Peer-Reviewed Practices

Literature Reviews

Collegiate Aviation Review International

Volume 36 | Issue 2 Peer-Reviewed Article #1

6-4-2018

Transformation of Air Traffic Collegiate Training Initiative (AT-CTI) Hiring Process: Institutional Perspectives

Mallory K. Casebolt
Oklahoma State University

Chad L. Depperschmidt
Oklahoma State University

Timm J. Bliss
Oklahoma State University

According to the Federal Aviation Administration (FAA) website, “The FAA has created a network of partnerships with educational institutions to prepare students to pursue their goal of a career in aviation with the FAA. This effort is known as the Collegiate Training Initiative (CTI)” (Federal Aviation Administration, 2018, p. 1). The hiring process for aspiring federal air traffic controllers from approved Air Traffic Collegiate Training Initiative (AT-CTI) institutions has undergone several revisions in recent years. Prior to 2014, graduates from AT-CTI programs were given preferential hiring from the FAA. In 2014, the FAA announced that AT-CTI graduates would equally compete with thousands of people the FAA calls “off the street hires”--anyone can literally walk in off the street without any previous training and apply for a federal air traffic control job. To apply, the FAA requires that a candidate has United States (U.S.) citizenship, a high school diploma, speaks English, and passes the FAA’s new Biographical Questionnaire (BQ). This research study examined the perceptions of Collegiate Training Initiative programs regarding the impact of the transformation of the hiring process for federal air traffic controllers. Findings indicated that changes in the federal hiring process is a major concern of CTI institutions for several reasons including: enrollment and retention rate of CTI students, CTI institutional value-added reputations, CTI students vested interest in ATC vs. off the street applicants, distrust and communication problems with the FAA, and the overall health and longevity of their AT-CTI program.

Recommended Citation:
Casebolt, M.K., Depperschmidt, C.L., & Bliss, T.J. (2018). Transformation of Air Traffic Collegiate Training Initiative (AT-CTI) Hiring Process: Institutional Perspectives. *Collegiate Aviation Review International,* 36(2), 1-17. http://dx.doi.org/10.22488/okstate.18.100487

As a recommendation of a 1988 comprehensive study commissioned by the Federal Aviation Administration (FAA) to review training for air traffic controllers one year later in 1989, the FAA began a partnership with various U.S. collegiate institutions to provide fundamental skills and knowledge related to air traffic control. This partnership become known as the Air Traffic (AT) Collegiate Training Initiative (CTI) program and initially involved only a few institutions. The program expanded and currently includes 36 institutions nationwide with the last five schools added in 2009 (Coyne, 2014). CTI programs were major incentives for students that sought employment with the federal government as an air traffic controller. Not only did students benefit from learning fundamental knowledge and skills needed to be a future federal air traffic controller, graduates from CTI programs who scored well on qualifying exams were also believed to be given preference for training at the FAA Air Traffic Control Academy in Oklahoma City. This initiative offered a pipeline for aspiring air traffic controllers, educational institutions, and the FAA. However, in 2014 the hiring process for federal air traffic controllers was significantly modified creating challenges for AT-CTI institutions and their graduates.

Literature Review

Historical Overview of Air Traffic-Collegiate Training Initiative Programs

The conception of the Air Traffic-Collegiate Training Initiative originated from studies in the late 1980s suggesting it would be beneficial to the FAA, financially and instructionally to rely on two- and four-year colleges for educational exposure for aspiring federal controllers. This suggestion was followed by FAA Order 3120.20, creating the Pre-Hire Air Traffic Control Demonstration Program (FAA, 1991). The purpose of this order was to establish procedures for implementing Pre-Hire Air Traffic Control Programs at post-secondary institutions (FAA, 1991). According to the Federal Aviation Administration (1991):

> In response to training studies conducted in 1988, FAA will test the concept of “off-loading” air traffic control screening and training into a select few accredited post-secondary educational institutions. The “proof of concept” test is a major initiative in the FAA’s Flight Plan for Training, a comprehensive design for improving recruitment and training. This initiative will involve the selection of a number of such institutions during FY 1991 through FY 1992 and will last for a 5-year period. (p. 1)

The inaugural AT-CTI institutions were Minneapolis Community and Technical College Air Traffic Control Program and Hampton University (Broach, 1998). Three additional institutions were added in 1991: Community College of Beaver County, University of North Dakota, and University of Alaska Anchorage, which brought the total to five AT-CTI programs in the U.S. The objective of these programs was to see if post-secondary educational institutions could develop adequate selection and training curriculum that encompassed the knowledge, skills, and abilities needed to be a federal air traffic controller (U.S Department of Transportation, 1991). At the five-year review period, the collegiate training initiative proved viable for the FAA and the number of AT-CTI institutions was expanded through 2009. As of March 2018, there are 36 federally-approved AT-CTI schools consisting of two- and four-year degree programs listed on the FAA's website. These institutions are (FAA, 2018):

1. Aims Community College
2. Arizona State University
3. Broward College
4. Community College of Baltimore County
5. Community College of Beaver County
6. Daniel Webster College
7. Dowling College
8. Eastern New Mexico University Roswell
9. Embry Riddle Aeronautical University — Daytona
10. Embry Riddle Aeronautical University — Prescott
11. Florida Institute of Technology
12. Florida State College at Jacksonville
13. Green River College
14. Hampton University
15. Hesston College
16. InterAmerican University of Puerto Rico
17. Jacksonville University
18. Kent State University
19. LeTourneau University
20. Lewis University
21. Metropolitan State University of Denver
22. Miami Dade College
23. Middle Georgia State University
24. Middle Tennessee State University
25. Minneapolis Community and Technical College
26. Mount San Antonio College
27. Purdue University
28. Sacramento City College
29. St. Cloud State University
30. Texas State Technical College Waco
31. Tulsa Community College
32. University of Alaska Anchorage
33. University of North Dakota
34. University of Oklahoma
35. Vaughn College of Aeronautics and Technology
36. Western Michigan University

As a result of the Professional Air Traffic Controllers Organization (PATCO) strike in 1981, the FAA forecasted a significant controller shortage due to a large number of controllers becoming eligible for retirement. The Professional Air Traffic Controllers Organization was a federal trade union that functioned from 1968-1981. After an illegal strike in 1981, President

Reagan fired more than 11,000 controllers and banned them from federal service for life. Two months later, PATCO would be declared illegal and cease to exist as a union (McCartin, 2011).

Furthermore, air traffic control is often described as a stressful career, so the FAA limits employment duration. The FAA has a mandatory retirement age of 56 and controllers are required to start at the Oklahoma City academy no later than their 31st birthday. Because of rapid retirement due to age restrictions and the lingering effects of the PATCO strike, established CTI programs could not generate the number of replacement controllers needed to maintain the federal air traffic control infrastructure. As a result, the FAA conducted a general public hiring announcement where individuals with no previous air traffic control knowledge or experience could be hired off the street for a federal air traffic control job. Off the street hires were a temporary fix for the depleting numbers of federal air traffic controllers. As a result, problems for collegiate training initiative programs and their graduates arose when the FAA was simultaneously conducting general public hiring announcements while approving more CTI programs.

Essentially, off the street hires made it more difficult for CTI graduates with previous educational concentration in air traffic control to gain employment as a federal air traffic controller. As a result, many students unified and brought a class-action lawsuit against the FAA claiming reverse discrimination (Hook, 2016). According to Brady and Stolzer (2017) in response to students' unification, the FAA's Assistant Administrator for Human Resource Management stated, "I want to assure you that the FAA's goal in implementing the interim hiring process was to ensure the agency selects applicants with the highest probability of completing our rigorous air traffic controller training program…" (p. 409). However, there is concern that the FAA achieved just the opposite--it closed the door on thousands of highly qualified college-educated applicants creating major concerns for AT-CTI institutions and its graduates (Brady & Stolzer, 2017).

History of Air Traffic Control Hiring of Collegiate Training Initiative Program Graduates

The hiring process for federal air traffic controllers has gone through significant changes throughout the years, specifically involving the collegiate training initiative programs. Historically upon graduation, AT-CTI program graduates were believed to be preferred candidates for employment in air traffic control towers and air traffic control en route centers. Yet, this changed dramatically in 2014 when the FAA abruptly revised the hiring process for federal air traffic controllers.

According to Culver (2016), prior to January 2014, the FAA recommended that students complete an approved CTI program as the preferred way to be hired as a federal air traffic controller. According to FAA (2014) the basic qualification requirements for an AT-CTI graduate to be considered for employment with the FAA were as follows:

- Graduates must successfully complete an FAA approved AT-CTI program.
- Graduates must receive a degree from the approved AT-CTI program that includes objectives required by the FAA.

- Graduates must receive an institutional recommendation for employment from an authorized school official.

After AT-CTI graduates met the basic qualification requirements for the AT-CTI program, they were required to achieve a passing score (70 or above) on the Air Traffic Selection and Training (AT-SAT) exam (FAA, 2011a), be a U.S. citizen, not have reached their 31st birthday, meet FAA medical and security requirements, and successfully complete an interview.

Recent Changes in the Air Traffic Controller Hiring Process

According to an Office of Inspector General audit published on February 15, 2017, the FAA's decision to revise its controller hiring process was based on internal and external reviews of its policies (FAA, 2017b). This review identified both equal opportunity issues and other opportunities to improve the process. As a result, the reviews triggered further analysis of the hiring process, resulting in significant changes for AT-CTI programs.

According to the Federal Aviation Administration (2017a) in fiscal year 2014, the agency instituted an interim change to the air traffic control hiring process. In the document, the FAA explains that the purpose of the changes was to allow the FAA to compare applicants more efficiently to enable them to select candidates most likely to succeed as air traffic control specialists (FAA, 2017a). The primary change in 2014 was a single vacancy announcement, which significantly reduced the role of CTI schools and opened the competition for the jobs up to the general public. A single vacancy announcement is an announcement where all applicants (CTI graduates, veterans, and off the street individuals) are grouped together regardless of their qualification or educational experience.

In January 2015, the FAA modified the interim changes again by adding a two-track announcement process. Track one targeted applicants without operational air traffic control experience, while track two targeted applicants with at least 52 weeks of certified air traffic experience either in the military or civilian environment sometimes referred to as VRA applicants.

In fiscal year 2016, H.R 636, the FAA Extension, Safety, and Security Act (FESSA), was enacted which established two separate pools for applicants. Pool one included two sub segments which included graduates from the collegiate training initiative and military veterans. Pool two were individuals who applied under a vacancy announcement recruiting from all United States citizens (Murdock, 2016). FESSA required priority considerations of applicants with previous air traffic experience. In fiscal year 2017, the FAA continued to recruit and hire air traffic control specialists to meet staffing requirements through the use of the two-track announcement process. As a result of FESSA, the Office of Inspector General criticizes these changes in hiring process by stating: "The FAA did not have an effective implementation or communication strategy when announcing the new process and has not yet implemented a tracking system to effectively track the flow of candidates through the entire hiring process" (FAA, 2017b, p. 5).

Current Hiring Process for Air Traffic Controllers

A Plan for the Future: 10-Year Strategy for the Air Traffic Control Workforce 2011-2020 states the FAA currently has two major categories of controller hiring sources which include: (1) prior ATCS experience or (2) no prior Air Traffic Control Specialist (ATCS) experience (FAA, 2011b). Individuals with prior ATCS experience have at least 52 weeks of certified air traffic control experience and individuals with no prior ATCS experience are not required to have prior air traffic control experience and may apply for vacancies announced by the FAA (FAA, 2017a).

According to the FAA's website, the current hiring process indicates that (1) entry-level applicants must complete required training courses at the FAA Academy in Oklahoma City and (2) gain on-the-job experience before becoming certified professional controllers. In addition, applicants must meet the following minimum requirements to become a federal air traffic controller (FAA, 2018):

- Be a United States citizen,
- Be age 30 or under (on the closing date of the application period),
- Pass a medical examination,
- Pass a security investigation,
- Pass the FAA air traffic pre-employment tests,
- Speak English clearly enough to be understood over communications equipment,
- Have three years of progressively responsible work experience, or a Bachelor's degree, or a combination of post-secondary education and work experience that totals three years, and
- Be willing to relocate to an FAA facility based on agency staffing needs.

Statement of the Problem

According to Brady and McGurik (2014), after decades of a working relationship between Collegiate Training Initiative institutions and the FAA, the FAA abandoned the CTI, thus creating significant problems for AT-CTI institutions and its graduates. The abandonment of the initiative affected approximately 3,500 AT-CTI graduates and current students. Furthermore, Brady and McGurik explained that in place of the CTI programs, the FAA would recruit U.S citizens with no prior background or education in air traffic control to fulfill the need for federal air traffic controllers. This change affected established CTI programs and their current and prospective students. Instead of having an educational and hiring advantage, graduates from CTI schools would be considered on the same level as other applicants with no prior background or education in air traffic control. According to Brady and Stolzer (2017):

> The result of this action by the FAA was that enrollment in air traffic education programs in all CTI schools plummeted. For example, the largest university program enrollment dropped from more than 600 students to less than 300. Students enrolled in the CTI programs felt that the FAA had abandoned them. (p. 409)

Purpose of the Study

The purpose of this national research study was to identify the institutional perspectives of CTI program administrators regarding the process changes in hiring federal air traffic controllers. This study will provide insight on institutional problems and challenges the CTI schools encountered as a result of these recent federal air traffic controller hiring changes.

Methodology

Research Question

To better understand the effects and challenges associated with changes in the hiring process of federal air traffic controllers for AT-CTI institutions, the following research question guided this study:

- What are the perspectives of collegiate CTI administrators regarding the recent changes in the hiring process of federal air traffic controllers?

Research Population and Data Collection Method

To answer this research question, this study sought perspectives from 36 federally-approved AT-CTI institutions listed on the Federal Aviation Administration's website. The authors sent the 36 identified AT-CTI individuals listed as the point of contact on the FAA's website a solicitation email inviting them to complete a voluntary research instrument with a provided electronic survey link. After approximately two weeks, a second reminder solicitation email was sent to all potential participants. After approximately one month, the survey was deactivated and the data from the submitted surveys were processed for this study. Of the 36 potential participants, 27 institutions responded to the solicitation email. Twenty-five institutions completed all of the research instrument, while two participants did not complete all the Likert-scale statements. The final response rate for this study was 27 institutions (75%) of 36 potential institutions.

Research Instrument

The research instrument was developed by the authors to solicit individual AT-CTI institutional information, perspectives, and personal comments regarding issues related to the changes in the hiring process for federal air traffic controllers. Institutional questions sought information regarding academic degree offering, program size, graduate job placement with the FAA, and enrollment trends.

Perspective questions were offered in Likert-scale statements in an ordinal measurement pattern that offered respondents the options of: Strongly Agree, Agree, Disagree, or Strongly Disagree. For this study, the authors used a 0-4, forced-response, Likert-Scale. The forced-response Likert-scale does not offer a central or neutral choice and forces the respondents to agree or disagree with the statement (Trochim & Donnelly, 2006).

The last section of the research instrument consisted of a text box and respondents were asked to include any comments or concerns they had regarding the hiring process for federal air traffic controllers for prospective AT-CTI students, current AT-CTI students, and recent AT-CTI graduates. Permission to conduct this study and solicit this research instrument was approved by the Institutional Review Board at Oklahoma State University (approval # ED-17-149).

Analysis

The Likert-scale statements were analyzed using Cronbach's alpha (α) reliability test to measure internal consistency. To measure internal consistency, Cronbach's α determines how all items on a test are related to all other items and the total test (Gay, Mills, & Airasian, 2006). George and Mallery (2003) established the following Cronbach's α acceptance scale: " ≥ .9 – Excellent; ≥ .8 – Good; ≥ .7 – Acceptable; ≥ .6 – Questionable; ≥ .5 – Poor; and ≥ .5 – Unacceptable" (p. 231). To analyze the results of this study, all data were entered into an Excel spreadsheet and then imported into SPSS statistical software. This resulted in an overall Cronbach's alpha value of .701 representing a level of acceptable based on the George and Mallery scale. This study also applied descriptive statistics. Descriptive research helps describe, show or summarize data using percentages, rates, ratios, graphs, and frequency distributions (Laerd Statistics, 2015). The benefits of using descriptive statistics are to help researchers to effectively describe and communicate patterns that might emerge from the data. The descriptive statistics in this study were summarized by using frequency distributions and percentages.

Results

Of the 36 potential participants, 27 institutions responded (75% response rate) by completing the research instrument. All institutional characteristic data resulted in 27 responses. Two respondents did not complete all Likert-Scale statements. Partial Likert-Scale data were included in the result section below.

The first section of the research instrument sought demographic information regarding the institution's characteristics including degree offering, enrollment numbers, graduate job placement, and recruitment. The second section of the research instrument explored the professional perspectives of AT-CTI administrators regarding recent changes in the federal air traffic control hiring process. The last section of the research instrument provided AT-CTI administrators an opportunity to submit professional comments, concerns, and observations regarding the changes in the federal air traffic control hiring process on prospective AT-CTI students, current AT-CTI students, and recent AT-CTI graduates.

AT-CTI Institutional Characteristics

Regarding the research instrument, the first question asked the AT-CTI administrator to identify if their institution offers a two-year air traffic control degree or four-year air traffic control degree. Table 1 states the results from this question.

Table 1

AT-CTI Degree Offering

Degree Offering	Percentage of Responses
2-year air traffic control degree	63% *n*=17
4-year air traffic control degree	37% *n*=10

The second question asked the AT-CTI administrator to identify current enrollment numbers in their AT-CTI program. Results from Table 2 are listed below.

Table 2 identified that the majority of respondents (81%) have between 0-75 students currently enrolled in their AT-CTI program at their institution, while (15%) have 76-150 students enrolled. Only one institution has more than 200 students enrolled which is only (4%).

Table 2

Current AT-CTI Institution Enrollment

How many students are currently enrolled in the AT-CTI program at your institution?	Percentage of Responses
0-25	37% *n*=10
26-50	33% *n*=9
51-75	11% *n*=3
76-100	7% *n*=2
101-125	4% *n*=1
126-150	4% *n*=1
151-175	0% *n*=0
176-200	0% *n*=0
Over 200+	4% *n*=1

In question 3, the respondents were asked to identify the percentage of graduates from their AT-CTI institution that have been offered employment as federal air traffic controllers. Table 3 represents the AT-CTI administrators' responses.

Table 3 reported that only one-third (37%) of responses indicated that 51%-100% of AT-CTI graduates have been offered employment as a federal air traffic controller, while the majority of responses (63%) indicated that less than 50% of their graduates have been offered employment as federal air traffic controllers. Before the FAA changed their hiring practices regarding federal air traffic controllers, the FAA approved a hiring preference to graduates of CTI-approved academic institutions. However, the FAA dropped the preference for CTI graduates in December 2013 in favor of a personality screening test known as the Biographical Questionnaire to review all candidates for controller positions. Many of the 3,000 candidates purged from the waiting list for employment as a federal controller were CTI graduates and had already passed the FAA's skills and aptitude exam (Smith, 2015).

Table 3

AT-CTI Graduate Employment

What percent of AT-CTI graduates from your institution have been offered employment as a federal air traffic controller?	**Percentage of Responses**
0-25%	22% *n*=6
26-50%	41% *n*=11
51-75%	33% *n*=9
75-100%	4% *n*=1

The final question on the research instrument asked the AT-CTI administrator if their institution was currently accepting new AT-CTI students. The majority of respondents (89%) indicated their institution was currently accepting new students and only 11% indicated their institution was not currently accepting new students. The results of this question are shown in Table 4.

Table 4

AT-CTI Recruitment

Is your institution currently accepting new AT-CTI students?	**Percentage of Responses**
Yes	89% *n*=24
No	11% *n*=3

Professional Perspectives of AT-CTI Administrators

To aide in answering the research question, the second section of the research instrument sought professional perspectives of each responding AT-CTI administrator by employing ten Likert-Scale statements. The Likert-scale statements requested respondents to indicate their perspective of each statement by selecting one of four options: strongly agree (SA), agree (A), disagree (D), and strongly disagree (SD).

Table 5 presents data obtained from three Likert-scale statements revealing respondents' perspectives of: (1) institutional concern of decline in placement of AT-CTI graduates, (2) prospective AT-CTI students enrolling in AT-CTI programs, and (3) continual changes in federal hiring discouraging current students to continue/complete their AT-CTI program.

The remaining seven Likert-scale statements sought the personal perspectives of AT-CTI administrators regarding the changes in the federal hiring process for federal air traffic controllers and the overall effects it will have on AT-CTI institution's enrollments/retention, graduates, current students, as well as the federal air traffic control infrastructure.

Table 5

AT-CTI Retention and Recruitment

Likert Statement	**Strongly Agree**	**Agree**	**Disagree**	**Strongly Disagree**
The decline in placement of AT-CTI graduates is a concern of AT-CTI institutions.	14 (56%)	6 (24%)	3 (12%)	2 (8%)
The decline in placement of AT-CTI graduates discourages prospective students from enrolling in AT-CTI programs.	11 (44%)	7 (28%)	3 (12%)	4 (16%)
Continual changes in the federal AT-CTI hiring process will discourage current students to continue/complete their AT-CTI program.	10 (40%)	8 (32%)	4 (16%)	3 (12%)

Table 6 demonstrates respondents' perspectives of CTI students pursuing off the street bids, students career changes (non-ATC related), as well as institutions retention rate of current students.

Table 6

AT-CTI Perspectives of Changes in Federal Hiring Process for Federal Air Traffic Controllers

Likert Statement	**Strongly Agree**	**Agree**	**Disagree**	**Strongly Disagree**
Current changes in the federal AT-CTI hiring process has encouraged AT-CTI students to pursue an off the street bid to gain employment as a federal air traffic controller.	16 (64%)	7 (28%)	0 (0%)	2 (8%)
As a result of the changes in the federal air traffic control hiring process, AT-CTI graduates are pursuing other career options (non-ATC) after completing their AT-CTI education.	10 (40%)	9 (36%)	6 (24%)	0 (0%)
The changes that have occurred in the federal air traffic control hiring process has resulted in a negative effect on the retention rate of current AT-CTI students.	10 (40%)	8 (32%)	2 (8%)	5 (20%)

Table 7 presents data obtained from the final four Likert-scale statements revealing respondents' perceptions of: (1) changes in hiring process affecting the quality of federal air traffic controllers, (2) AT-CTI production of best qualified federal air traffic controllers, (3) AT-CTI lower institutional enrollments, and (4) overall effect on air traffic control infrastructure.

Table 7

AT-CTI Perceptions of Quality and Infrastructure

Likert Statement	**Strongly Agree**	**Agree**	**Disagree**	**Strongly Disagree**
AT-CTI institutions believe that recent changes in the federal air traffic control hiring process has resulted in better qualified federal air traffic controllers.	5 (20%)	0 (0%)	7 (28%)	13 (52%)
ATI-CTI institutions produce the best qualified federal air traffic controllers.	13 (52%)	9 (36%)	3 (12%)	0 (0%)
As a result of the changes in the federal air traffic control hiring, AT-CTI institutions are experiencing lower than normal enrollments.	15 (60%)	6 (24%)	4 (16%)	0 (0%)
As a result of the changes in the federal air traffic control hiring process there has been an overall negative effect on the air traffic control infrastructure.	9 (45%)	5 (25%)	5 (25%)	1 (5%)

Conclusion

According to the results of this study, the majority of AT-CTI administrators have significant concerns regarding the changes in the hiring process for federal air traffic controllers. The data indicated that regardless of the degree offering, all institutions expressed multiple concerns. The concerns expressed by the two-year and four-year administrators include: (1) the retention and enrollment of institutions, (2) lack of value added for AT-CTI programs, (3) hiring odds against AT-CTI students, (4) and AT-CTI students' invested time and money on a degree compared to off the street hires.

The majority of respondents believed that as a result of the changes in the federal hiring process for air traffic controllers, student enrollments and student retention rates at the AT-CTI schools have been affected negatively. The majority of respondents indicated student retention problems as a direct result of the changes in hiring for air traffic controllers. The common perspectives expressed by the administrators were that current CTI students felt discouraged to continue their AT-CTI academic program and felt pressured to pursue other aviation-related educational and employment opportunities as a direct result of the changes in hiring process. One of the CTI administrators expressed their concern in the comment section stating, "Students have lost faith in the objectivity of the hiring process and have sought hire through off-the-street bids. Lack of transparency in the selection/hiring process creates lack of confidence in the FAA."

Unfortunately, because the FAA continues to revise their hiring practices for AT-CTI graduates, the AT-CTI schools are suffering the most. In Smith (2015), an AT-CTI school administrator stated that the CTIs have been hit especially hard as a result of the FAA changing the national perception of the hiring practice. In 2013, there were approximately 200 students in this college's ATC program, which had one of the highest graduating success rates at the FAA Academy at 97%; however, by 2015, the college only had 60 students in their CTI program. According to the school administrator, 60 students is still a sustainable number to provide quality; but unfortunately for other CTI schools that had smaller enrollment numbers (40-60 students) to begin with, and only had 10 or 15 students in 2015, that student count is not sustainable and they no longer can wait it out. The majority of the participating administrators also agreed that student enrollment will remain a major concern of their institution, as well as the longevity and overall financial health of their AT-CTI academic program. Eighty percent of administrators indicated their AT-CTI programs have fewer than 75 student enrollments, while some administrators indicated they have zero AT-CTI students or have placed a moratorium on additional student enrollments. One respondent stated,

> Our numbers have been devastated. As an instructor, I encourage people to apply for the ATC minor, which will give them greater options in case the ATC job does not work out. Our numbers have dropped by about 75%, which is actually good, since there was no way the majority of graduates would have gotten jobs if they remained at their historic numbers. This is due to half of all jobs being allotted to people with no education. Additionally, of the half reserved for ATC grads, any former military veterans get first priority, so even that path is questionable for non-military ATC students.

Because of financial responsibility and program completion obligation associated with the AT-CTI institutions, the lack of a competitive advantage over off the street hires has created an impossible situation for the AT-CTI institutions to promote a value added product to prospective students. An administrator said "I believe that it is more difficult to sell the merits of completing the CTI course when students could simply apply 'off the street' without spending the time or money on the CTI program." Some institutions perceive that prospective students believe there is no value to go through a CTI program for the hiring process as the system is structured today. In an effort to counter the FAA's change in the hiring practice of off the street hires, one institutional administrator stated,

> Our courses are therefore promoted as an opportunity to fast-track an 'off the street' application that would have been successful anyway, and are aimed more towards individuals passionate about Airspace Management, irrespective of whether they intend to join the FAA on graduation.

The administrator continued by saying, "This is necessary because it is difficult to justify why a student would spend money on a course that gives them no advantage unless they are just genuinely interested in studying the subject [comparable perhaps to a Minor in Psychology, which will not lead to a career as a Psychologist]."

Additionally, another concerning perspective from AT-CTI administrators is that CTI graduates are at an employment disadvantage with the new hiring initiatives. One of the responding administrators expressed concern that off the street applicants have increased odds of employment over CTI applicants because CTI students are combined in track one with Veteran's Readjustment Appointment (VRA) applicants putting CTI students second while all off the street applicants are grouped as one and have an equal opportunity for selection. The AT-CTI administrator offered the following comment, "off-the-street applicants have increased odds of getting hired over CTI applicants because CTI students are combined with VRA applicants, putting those second in Pool one while off the street applicants have an equal opportunity for selection." An additional administrator remarked,

> There is little to no value to go through the CTI program for the hiring process as the system stands today. This was not the purpose for the program. The FAA needs better educated/ability students at the Academy. This was the reason for the CTI program. I do not see this with the very high failure rate at the Academy.

Although enrollment and retention were major concerns of AT-CTI administrators, the most significant concern expressed by the responding administrators was the lack of transparency by the FAA in changing the hiring practices. The federal government's failure to communicate information about the changes in the hiring practices of FAA controllers to the AT-CTI institutions and AT-CTI graduates has created a level of frustration and untrustworthiness. As emphasized by an administrator, "No one really understands how selections are being made". In support, another administrator added, "No one really knows what is happening behind the curtain and the trust factor in the FAA has vanished." To help rebuild trust and create transparency between the FAA and CTI institutions, additional studies seeking the FAA's perspectives on the changes in the hiring process could have the potential to illustrate the FAA's perspective to aid in strengthening the relationship between the FAA and AT-CTI institutions.

According to the FAA website, *Collegiate Training Initiative (CTI) Schools,* it firmly states, "The AT-CTI program is designed to provide qualified candidates for developmental air traffic control specialist positions (FAA, 2018, p. 1)." And yet, the new FAA hiring protocol for federal air traffic controllers that was implemented in February 2014 included several significant changes. In particular, the FAA reduced the role of the CTI-approved program; therefore, the only remaining advantage for CTI graduates is that they are eligible to bypass the Air Traffic Basics Course, which is the first five weeks of qualification training at the FAA Academy in Oklahoma City (FAA, 2018).

In addition, the FAA introduced the Biographical Questionnaire which was envisioned to predict controller performance through a process of asking individuals to recall their typical and/or specific behaviors from earlier times in their lives. But due to the lengthy process of hiring and training an air traffic controller which can take several years, it is too soon to conclude whether the FAA's new hiring policies improved the ability to hire individuals who are more likely to successfully become federal controllers (FAA, 2017b).

While the intent of the FAA was to employ an additional 3,200 federal air traffic controllers in 2016 and 2017, it is not certain what the outcome of the FAA hiring process changes has had or will have on AT-CTI institutions and their highly qualified graduates (Scauzillo, 2015). But what is certain is that the AT-CTI schools will continue to question and debate whether they should or will even be able to provide the funding to maintain the financial health of their CTI programs in the coming academic years.

References

Brady, T., & McGuirk, G. (2014). *CTI white paper*. Paper on CTI changes provided to members of the House Aviation Subcommittee April 2014, Washington, DC.

Brady, T., & Stolzer, A. (2017). The evolution of air traffic controller training in the United States. *Proceedings of International Conference on Information, Communication Technologies in Education.* Retrieved from http://www.icicte.org/ICICTE_2017_Proceedings/11.3_Brady%202017.pdf

Broach, D. (1998). *Summative evaluation of the collegiate training initiative for air traffic control specialists program: Progress of Minnesota air traffic control training center graduates in en-route field training* (DOT/FAA/AM-98/22). Washington, DC: Office of Aviation Medicine

Coyne, W. (2014). A review of the history of the Air Traffic Collegiate Training Initiative program. *International Journal of Aviation Aeronautics, and Aerospace,* 1(3). Retrieved from https://commons.erau.edu/ijaaa/vol1/iss3/4

Culver, C. (2016). *Reviewing the FAA's current air traffic controller requirements*. Retrieved from https://disciplesofflight.com/faa-current-air-traffic-controller-requirements/

Federal Aviation Administration. (1991). *Pre-hire air traffic control demonstration program*. Retrieved from https://www.faa.gov/documentLibrary/media/Order/3120.26.pdf

Federal Aviation Administration. (2011a). *Air traffic selection and training (AT-SAT)*. Retrieved from http://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/acquisition/aja51/cti/AT-SAT.cfm

Federal Aviation Administration. (2011b). *A plan for the future: 10-year strategy for the air traffic control workforce 2011–2020*. Washington, DC: Federal Aviation Administration.

Federal Aviation Administration. (2014). *Air traffic controller training initiative program, program overview and FAQ's.* Retrieved from http://www.instruction.greenriver.edu/aviation/downloads/pdfs/CTI_Overview_and_%20FAQ%27s_CTI_School_Version.pdf

Federal Aviation Administration. (2017a). *Air traffic controller workforce plan 2017-2026*. Retrieved from https://www.faa.gov/air_traffic/publications/controller_staffing/media/2017_CWP.pdf

Federal Aviation Administration. (2017b). *While FAA took steps intended to improve its controller hiring process, the agency did not effectively implement its new policies*. Office of Inspector General Audit Report (Report number: AV2017028). Retrieved from https://www.oig.dot.gov/sites/default/files/ATC%20Hiring%20Report_issued%20Feb%2015.pdf

Federal Aviation Administration. (2018). *Collegiate training initiative (CTI) schools*. Retrieved from https://www.faa.gov/jobs/students/schools/

Gay, L.R., Mills, G.E., & Airasian, P. (2006). *Educational research: Competencies for analysis and applications* (8th Ed.). Upper Saddle River, NJ: Pearson Prentice Hall.

George, D., & Mallery, P. (2003). *SPSS for Windows step by step: A simple guide and reference. 11.0 update* (4th ed.). Boston, MA: Allyn & Bacon.

Hook, J. (2016). *FAA hires air traffic controllers off the street, students claim reverse discrimination.* Retrieved from http://www.fox10phoenix.com/news/arizona-news/faa-hires-air-traffic-controllers-off-the-street-students-claim-reverse-discrimination

Laerd Statistics. (2015). *Understanding descriptive and inferential statistics*. Retrieved from https://statistics.laerd.com/statistical-guides/descriptive-inferential-statistics.php

McCartin, J.A. (2011). *Collision course: Ronald Reagan, the air traffic controllers, and the strike that changed America*. New York, NY: Oxford University Press.

Murdock, S. (2016). FAA's collegiate training initiative was restored by Congress. *JDA Journal.* Retrieved from http://jdasolutions.aero/blog/faa-collegiate-training-initiative/

Scauzillo, S. (2015). Why new FAA hiring practices for air traffic controllers are being investigated. *Sangabriel Valley Tribune*. Retrieved from https://www.sgvtribune.com/2015/12/07/why-new-faa-hiring-practices-for-air-traffic-controllers-are-being-investigated/

Smith, A. A. (2015). Grounded by FAA rules. *Inside Higher Ed.* Retrieved from https://www.insidehighered.com/news/2015/09/23/collegiate-air-traffic-controller-programs-struggle-stay-relevant-after-faa-hiring

Trochim, W., & Donnelly, J.P., (2006). *The Research Methods Knowledge Base* (3rd ed.). Cincinnati, OH: Atomic Dog.

U.S Department of Transportation. (1991). *Pre-hire air traffic control demonstration program*. Retrieved from https://www.faa.gov/documentLibrary/media/Order/3120.26.pdf

Collegiate Aviation Review
International

Volume 36 | Issue 2 Peer-Reviewed Article #2

6-20-2018

Evaluation of Opportunities for Connected Aircraft Data to Identify Pavement Roughness at Airports

Wesley L. Major
Purdue University

Jijo K. Matthew
Purdue University

Sarah M. Hubbard
Purdue University

Darcy M. Bullock
Purdue University

This paper reviews the construction and maintenance guidelines for airfield pavements, as well as the current methods for assessing pavement conditions. A study is performed on an airport's taxiway to determine if acceleration data from airframe mounted accelerometers and on-board avionic systems can be used to provide an estimate of pavement roughness. A comparison of international roughness index (IRI), three-axis accelerometer data, and normal acceleration data from the G1000 unit is presented based on a field study performed at the Purdue University Airport (KLAF). The paper concludes that there is a potential for crowdsourced data obtained from an aircraft's on-board system such as the G1000 to act as an additional tool for airport managers to monitor surface conditions between routine and detailed inspections.

Recommended Citation:
Major, W.L., Matthew, J.K., Hubbard, S.M., & Bullock, D.M. (2018). Evaluation of Opportunities for Connected Aircraft Data to Identify Pavement Roughness at Airports. *Collegiate Aviation Review International,* 36(2), 18-33. http://dx.doi.org/10.22488/okstate.18.100488

Airports are an essential component of the nation's transportation system and regularly compete for federal, state and local funding. The United States Department of Transportation (USDOT) is asking all transportation systems to embrace quantitative asset management techniques (Federal Aviation Administration, 2017; U.S. Department of Transportation, 2017). Performance measures can range from usage reports, traditional asset rating systems, to emerging "crowd source" data regarding traffic delays, pothole locations, and ride quality.

The cost of collecting asset management data using traditional inspection techniques can be challenging and many transportation modes have begun to examine crowdsourced data to supplement traditional inspection techniques. Doan, Ramakrishan, and Halevy (2011) define crowdsourcing as a process that "enlists a crowd of humans to help solve a problem defined by the system owners" (p. 87). Another definition is "a sourcing model in which organizations use predominantly advanced Internet technologies to harness the efforts of a virtual crowd to perform specific organizational tasks" (Saxton, Oh, & Kishore, 2013, p. 2). In regards to transportation, crowdsourcing has been used to monitor traffic flow, ideal bike routes, and pavement surface conditions (Alessandroni et al., 2014; Belzowski & Ekstrom, 2015; Buttlar & Islam, 2014; Carrera, Guerin, & Thorp, 2013; Dennis, Hong, Wallace, Tansil, & Smith, 2014; Fox, Kumar, Chen, & Bai, 2015; Yi, Chuang, & Nian, 2013).

Many modern general aviation aircraft now have extensive sensors, including airframe accelerometers. This paper examines ground transportation trends and explores the feasibility of using existing airframe accelerometers to collect airfield pavement condition data to supplement the current asset management techniques used at airports. The objective of this exploratory study is to compare pavement condition data collected using conventional survey vehicles with two different airframe-mounted accelerometers.

Background

Fox et. al proposes crowdsourced data from multiple vehicles as an emerging solution to detect potholes on the roadway (Fox et al., 2015). Under sampled, heterogeneous and distorted signals from embedded sensors in vehicles were used to develop a system that detects potholes. Empirical experiments showed that the system was capable of detecting 88.9% of the potholes on a 38 km stretch. Another system utilized smartphones as probes in cars for mobile sensing to detect and assess anomalies on the roadways (Alessandroni et al., 2014; Yi et al, 2013).

A study conducted by the Michigan Department of Transportation and the Center for Automotive Research examined crowdsourced data from connected vehicles to monitor and assess pavement conditions (Dennis et al., 2014). The study proposes that data from embedded sensors and smartphones in a vehicle will become more prevalent for pavement monitoring in the upcoming years. The research also suggests a possible 3- to 5-year timeline for interconnected vehicle and infrastructure systems to assess pavement conditions including the acute distress events such as potholes. Surface distress such as rutting, cracking and crowd-sourced

International Roughness Index (IRI) that require advanced sensors for data collection can be collected in the next 10 or more years (Dennis et al., 2014).

A minimal level of service must be maintained for transportation pavements, and this level of service can vary across modes of transportation. Airports have particularly rigorous construction and surface monitoring requirements to ensure safe operation of aircraft. Airfield pavement roughness standards are in large part driven by concern for aircraft loss of directional control (Federal Aviation Administration, 2004). Another concern is fatigue on aircraft components (increase stress and wear) and other factors which may impair the safe operation of the aircraft (cockpit vibrations, excessive g-forces)(Federal Aviation Administration, 2009).

In contrast to road vehicle suspension systems, the primary purpose of an airplane suspension system is to absorb energy expended during landing. Airplane suspension systems have less capacity to dampen the impact of pavement surface irregularities (Federal Aviation Administration, 2015c). A study performed in 2015 regarding the feasibility of aviation rumble strips (Bullock et al., 2015) found there was considerable variation in airframe acceleration among different types of aircraft during taxiing. This paper reports on the potential to obtain pavement condition data associated with ground movements on taxiways and runways from automated aircraft data loggers such as the G1000 or low-cost airframe accelerometers. This is consistent with a broader aviation trend to move toward a *connected aircraft* environment that goes beyond traditional transponders, Aircraft Communications Addressing and Reporting System (ACARS) messages and the internet (Ros, 2016). Connected aircraft have implications not only in terms of sensors, but also the ability to collect, store, and use the data, including datalinks and systems to archive the data.

Literature Review

The Federal Aviation Administration (FAA) has released many Advisory Circulars (AC) outlining standards for the construction, monitoring, maintenance and inspection of airfield pavements (Federal Aviation Administration, 2004, 2009, 2014a, 2014b, 2015a). The National Plan of Integrated Airport Systems (NPIAS) identifies nearly 3,400 existing and proposed airports that are significant to national air transportation (Federal Aviation Administration, 2015b). Airports identified by the NPIAS are eligible to receive Federal funding under the Airport Improvement Program (AIP). The AIP provides grants to public agencies for the planning and development of public-use airports as long as they follow FAA guidelines throughout the entire pavement lifecycle (Federal Aviation Administration, 2016a).

Pavement Management Program (PMP)

A pavement's lifecycle begins with construction. FAA construction standards help protect this investment by ensuring pavements last as long as possible with the least amount of maintenance. These standards are outlined in the FAA's Standards for Specifying Construction at Airports (AC 150/5370-10G). The AC identifies materials and methods for the construction on airports, and consists of a wide range of topics; general provisions, earthwork, flexible base courses, rigid base courses, flexible surface courses, rigid pavement, fencing, drainage, turf, and lighting installation (Federal Aviation Administration, 2014a).

Pavements need to be managed, not just maintained. One of the requirements of AIP grants is for airports to develop and sustain an effective airport pavement maintenance-management program. A PMP provides a “consistent, objective, and systematic procedure for establishing facility policies, setting priorities and schedules, allocating resources, and budgeting for pavement maintenance and rehabilitation” (Federal Aviation Administration, 2014b, p. 2).

A PMP is a set of defined procedures for collecting, analyzing, maintaining, and reporting pavement data. It assists airports in finding optimum strategies for maintaining pavements in a safe serviceable condition over a given period, reducing the life cycle cost. It can also provide specific action points required to maintain a pavement network at an acceptable level of service while minimizing the cost of maintenance and rehabilitation (M&R). “A PMP not only evaluates the present condition of a pavement, but also predicts its future condition through the use of pavement condition indicators” (Federal Aviation Administration, 2014b, p. 2). Figure 1 shows a typical pavement condition life cycle. To minimize lifecycle cost, it is important to implement maintenance and rehabilitation activities before substantial deterioration begins. The FAA also encourages all airports to develop maintenance programs to preserve their facilities even if they are not required to do so. Since smaller general aviation airports have very tight budgets, crowdsourced pavement data has the potential to provide a very basic and cost effective condition assessment.

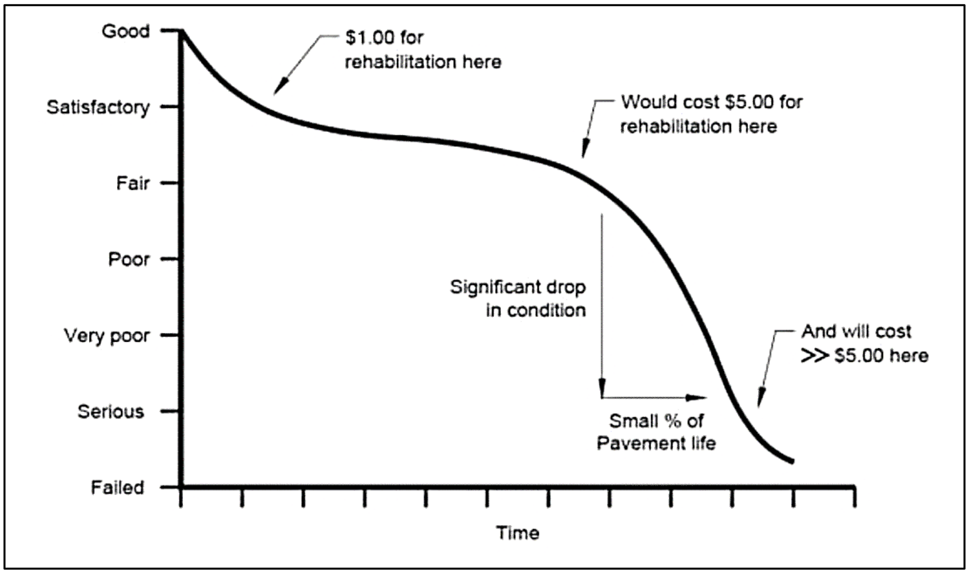


Figure 1. Pavement condition life cycle (Federal Aviation Administration, 2014b).

Early intervention of deterioration is not only important from a cost perspective, but as AC 150/5380-6C, Guidelines and Procedures for Maintenance of Airport Pavements, states, “timely maintenance and repair of pavements is essential in maintaining adequate load-carrying capacity, good ride quality necessary for the safe operation of aircraft, good friction characteristics under all weather conditions, and minimizing the potential for foreign object debris (FOD)” (Federal Aviation Administration, 2015a, p. 1).

Each airport is responsible for establishing a schedule for regular and routine pavement inspections. Routine inspections usually consist of daily visual checks to monitor surface conditions and do not require specific equipment. There are many variables that may adversely affect the pavement, such as heavy vehicle operations or severe weather, which may necessitate additional inspections. Airport personnel should also solicit reports from airport users and conduct daily drive-by inspections. These qualitative inputs are important, but very hard to normalize. Crowdsourced ride data has the potential to augment user reports with objective analytical airfield surface movement ride quality data.

Current Methods to Assess Airfield Pavement Condition

Since 1995, airports have been required to implement a pavement maintenance-management program to receive Federal funding for any construction project. An element of PMP is an annual detailed inspection of pavement conditions. The USDOT and the FAA have approved tests, and some airports have developed innovative ways to measure pavement conditions. Two methods specified by the USDOT are Pavement Condition Index (PCI) and International Roughness Index (IRI), as described below.

ASTM D5340, Standard Methods for Airport Pavement Condition Index, “provides a measure of the present condition of the pavement based on the observed distresses on the surface of the pavement which also indicates the structural integrity and surface operational condition” (American Society for Testing and Materials, 2012, p. 2). The PCI is calculated using visual assessments, rating distress type, quantity, and severity. Figure 2. Standard Pavement Condition Index (PCI) Rating Scale provides a qualitative explanation of PCI scores.

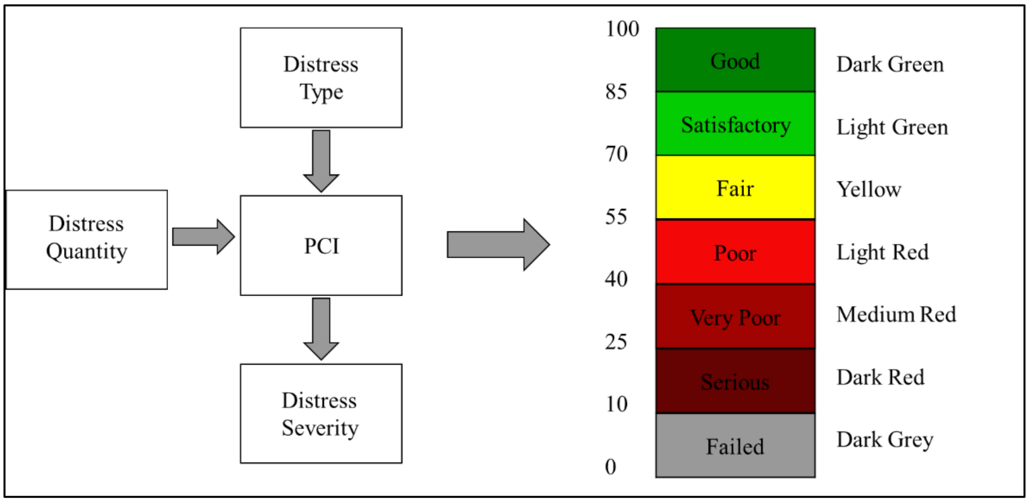


Figure 2. Standard Pavement Condition Index (PCI) rating scale (American Society for Testing and Materials, 2012).

IRI is a profile-based metric established by a study conducted by the World Bank to measure the roughness of the pavement (Sayers, Gillespie, & Paterson, 1986). The IRI defines the characteristic of the road surface along the longitudinal profiles of the travelled wheel track using high speed vans equipped with lasers and accelerometers. The commonly reported units are meters per kilometer (m/km) or millimeters per meter (mm/m), but can also be expressed as inchers per mile (in/mile). A scale of acceptable standards for different surfaces are shown in Figure 3. International Roughness Index (IRI) Scale. These examples of detailed PMP inspections are in addition to routine maintenance inspections that are conducted more frequently to ensure that the taxiways and runways are safe for operations (Federal Aviation Administration, 2014b).

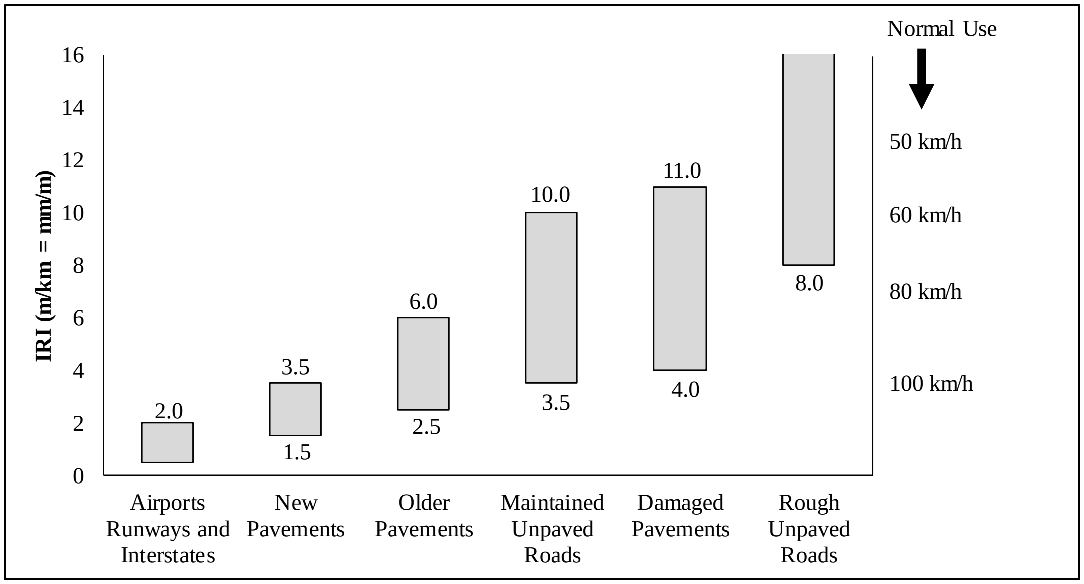


Figure 3. International Roughness Index (IRI) scale (Sayers et al., 1986).

FAA also has measurements they use to assess pavement conditions. The Boeing Bump is the FAA accepted methodology for evaluating airport runway longitudinal profiles for single event bumps; the Boeing Bump requires a minimum survey interval of 0.82 feet for evaluation (Figure 4. Boeing bump index)(Federal Aviation Administration, 2016b). Surface profiles are also captured by the FAA using a vehicle mounted with three sensors: vehicle elevation, vehicle-to pavement distance, and traveled distance (Federal Aviation Administration, 2015c).

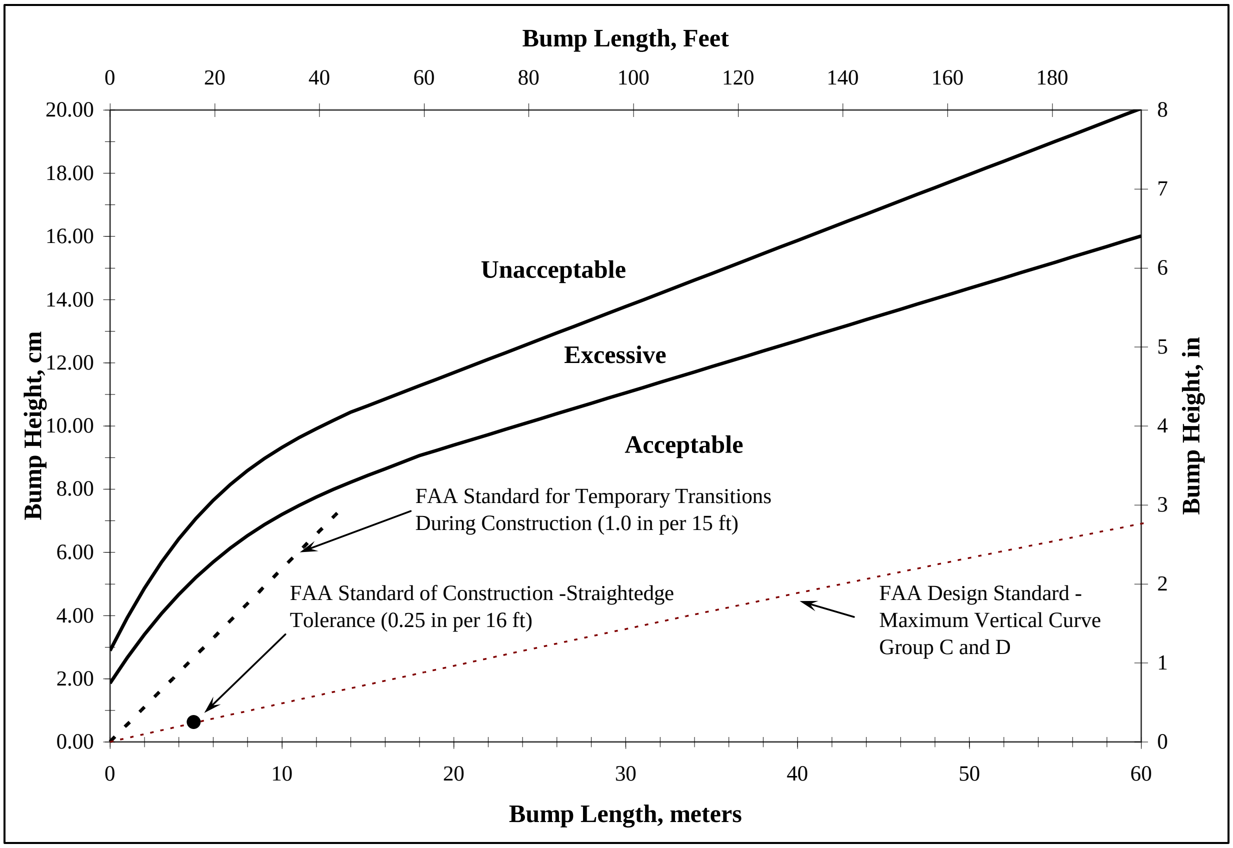


Figure 4. Boeing bump index (Federal Aviation Administration, 2009).

Other airports are taking an innovative approach to monitoring airport pavements. Shanghai Airport Pavement Management System uses geographic information system and global positioning system technologies to identify distress by type, quantity, and location. Software takes this information and computes a real-time PCI rating, aiding airport authorities in determining the most effective maintenance and rehabilitation activities (Chen, Yuan, & Li, 2012). Oakland International Airport uses laser crack measurement system (LCMS), a high speed data collection equipment that can take downward-facing images of the pavement and collect 3D imagery (Keegan, Katherine; Jung, 2014).

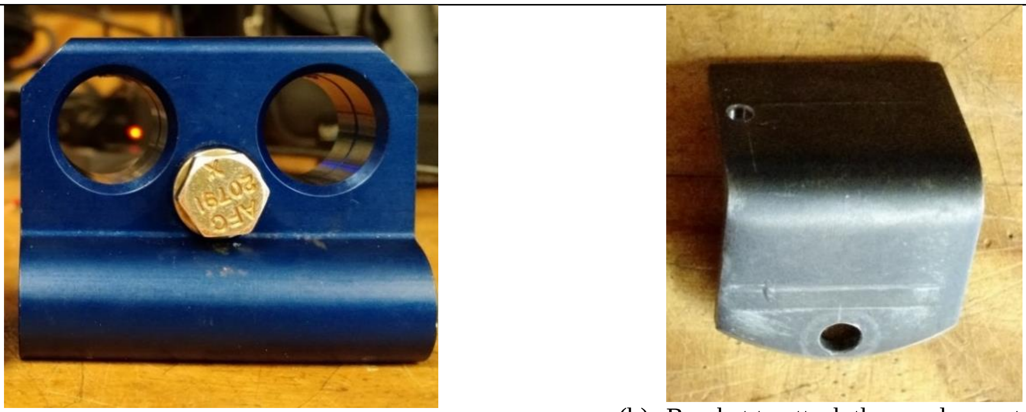
Purpose

The objective of this study is to compare IRI data collected using conventional survey vehicles with two different airframe mounted accelerometers, a custom three-axis accelerometer mounted on a Cessna 172 seat rail frame and one-axis factory installed Cirrus SR 20 accelerometer that is factory configured to log data in the G1000 avionics package.

Method

IRI data was collected using inertial profiler equipment. An Ames Engineering 8300 Survey Pro High Speed Profiler utilizing RoLine 3k line lasers, permanently mounted on a Ford panel van collected data while traveling at 20 miles per hour (Figure 5. IRI Inertial Profiler Van). Airframe acceleration data was collected from two different aircraft in two different ways. High frequency acceleration data was collected using a three-axis accelerometer mounted to a Cessna 172 seat rail with an FAA-approved cargo tie-down and a mounting bracket (Figure 6. Mount Configuration For 3-Axis Acelerometer On C172.). Acceleration data was collected while the aircraft was traveling at approximately 15 knots. Lower frequency, one-axis accelerometer data was collected from a factory installed Cirrus SR 20 accelerometer configured to log data in the G1000 avionics package. In addition to acceleration, the G1000 logs several dozen parameters such as lateral g-forces, latitude, longitude and pressure altitude (Garmin, n.d.). Acceleration data was also collected at an approximate speed of 15 knots.

Figure 5. IRI inertial profiler van.



(a) Cargo rail tie down

(b) Bracket to attach the accelerometers to the cargo rail tie down

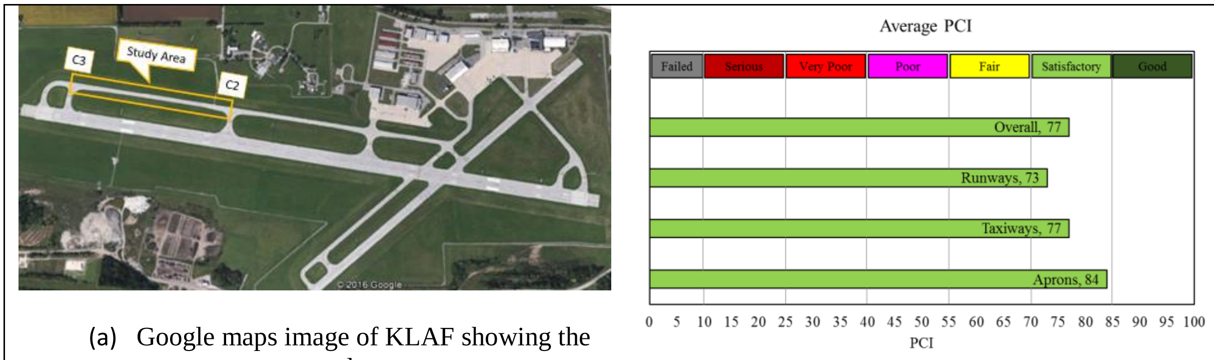
(c) Rail mount – front view

(d) Rail mount – side view

(e) Seat Rail Mounting

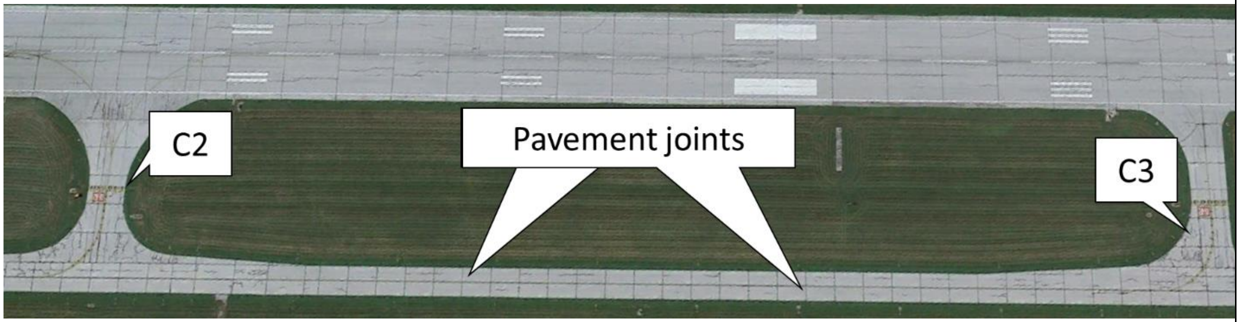
Figure 6. Mount configuration for 3-axis acelerometer on C172.

Data was collected at Purdue University (KLAF) along Taxiway C from C2 to C3, adjacent to Runway 10/28. The mean PCI for all taxiways at KLAF was 77 (Figure 7b). This taxiway section was chosen because it had regularly spaced transverse pavement joints, as shown in Figure 7c/d).



(a) Google maps image of KLAF showing the study area

(b) PCI Rating (Applied Research Associates Inc., 2015)



(c) C2 to C3 section on Taxiway C at KLAF

(d) Example of transverse joints from C2 to C3 on Taxiway C

Figure 7. Surface conditions at KLAF on Taxiway C.

Findings & Discussion

Comparison of Aircraft Accelerometer and IRI Data

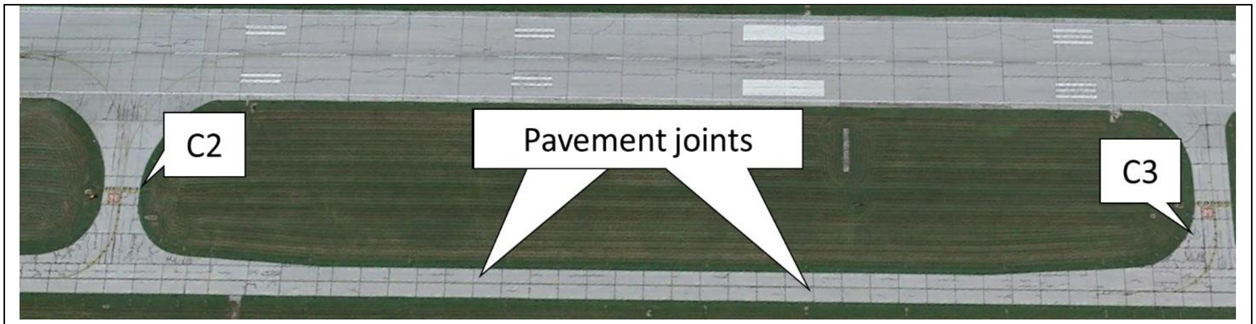
Findings are presented in Figure 8.

- Figure 8a shows photo of the studied taxiway, with three different techniques for measuring ride quality.
- Figure 8b shows a plot of the IRI obtained from a traditional truck mounted sensor (Figure 5) that has been carefully calibrated to calculate IRI.
- Figure 8c shows acceleration plots obtained from a Cessna 172 seat rail mounted 3-axis accelerometer (Figure 6) that is sampling at approximately 400Hz. Anet represents the resultant magnitude of all the three forces (A_x, A_y and A_z).
- Figure 8d shows one axis acceleration plots obtained from a factory installed SR 20 airframe accelerometer that are logged at 1 Hz in the G1000 avionics.
- Figure 8e shows areas that may warrant additional inspection, based on the amplitude of the acceleration in the G1000 data and the net acceleration from the 3-axis accelerometer).

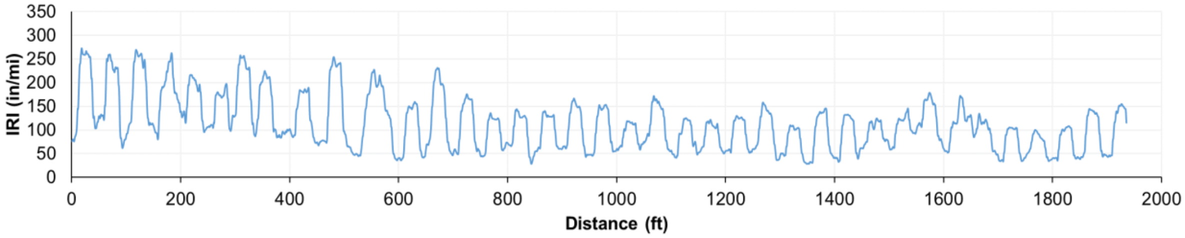
Even though the Cirrus and Cessna have quite different suspension characteristics, it can be seen that the pavement joints and irregularities highlighted in Figure 8. Comparison Of Acceleration And IRI Data For KLAF Taxiway C2 To C3. a are captured and represented by the peaks in each of the three graphs. The Cirrus data has some second-order oscillation in the data, perhaps because a Cirrus has a spring strut on the front wheel.

Previous studies have shown that accelerometer data can be used to estimate approximate IRI values. Linear predictive coding was used by a study to develop an estimate of IRI from accelerometer data collected by smartphones in vehicles (Alessandroni et al., 2014). This method predicts a particular value in the analog signal using a linear combination of the past values. The accelerometer data is passed through prediction filters and mathematical models to derive an estimated IRI value. A roughness index for every point was established based on the crowdsourced data collected from different users and this was used to identify rough areas of the pavement. Another study developed the pavement profile by double integrating the acceleration data (Buttlar & Islam, 2014). This profile was then analyzed using the ProVAL software to estimate the IRI. The study found that the IRI values estimated from acceleration data were similar to the data from inertial profilers.

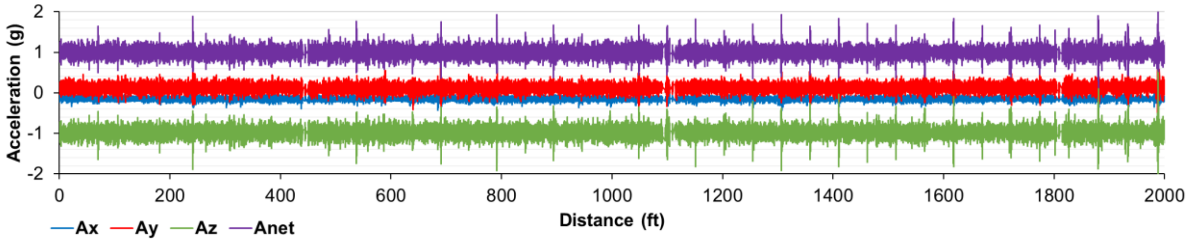
The successful estimation of IRI on roadways from vehicle acceleration data as documented in previous research lays a foundation for similar applications in aviation. In the aviation environment, the data collected from the on-board avionics systems can be used to develop a geo-coded database of the pavement roughness of taxiways, ramps, and runways. Airport managers can use this geo-coded data to identify areas of potential pavement distress that may require inspection and/or maintenance. Crowdsourced geo-coded data can be used as a supplemental tool in an airport PMP.



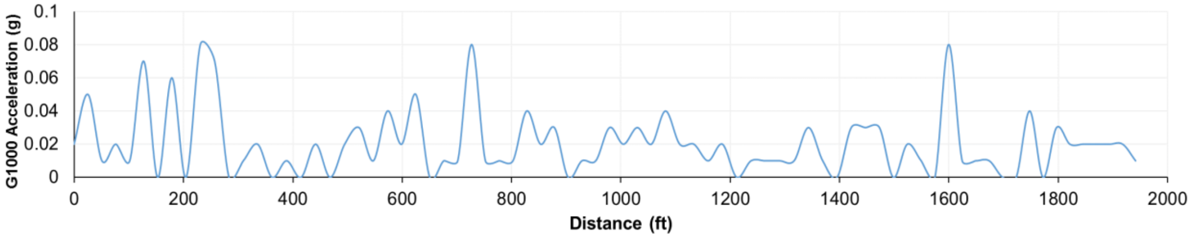
(a) C2 to C3 section on Taxiway C at KLAF



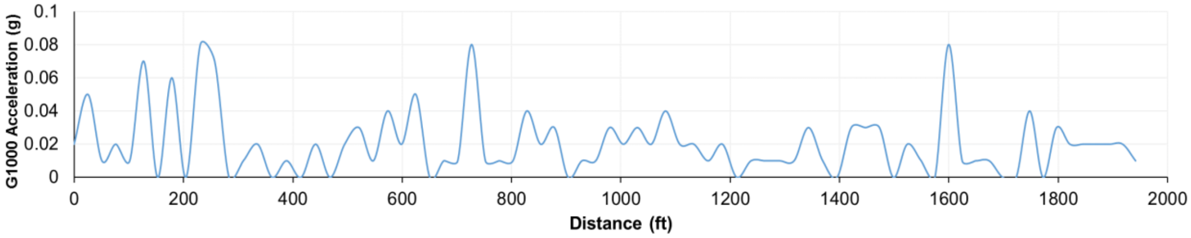
(b) IRI from inertial profiler



(c) Accelerometer data from USB accelerometer



(d) Normal acceleration data from G1000



(e) Areas that may warrant further inspection based on acceleration data

Figure 8. Comparison of acceleration and IRI data for KLAF Taxiway C2 to C3.

Conclusions

This study presents the potential use of acceleration data from airframe mounted accelerometers and on-board avionic systems to provide an estimate of pavement roughness as a low-cost tool to support of an airfield pavement management program. IRI data was obtained from an inertial profiler van, three-axis 400 Hz accelerometer data was obtained using a Cessna 152 and one-axis, 1 Hz acceleration data was obtained from a factory installed accelerometer from a G1000 on a Cirrus SR20. Both aircraft recorded data while traveling at approximately 15 knots and the instrumented van was traveling at 20 miles per hour, the minimum recommended speed for IRI data collection.

The results suggest airframe mounted accelerometers can be used to collect crowdsourced pavement condition, expanding the applicability of previous research that demonstrates the validity of using acceleration data to estimate IRI on roadways. In practice, one-axis accelerometer data, such as that collected from the G1000 might be sufficient, but it would be desirable to record data at a sampling frequency higher than the 1 Hz used in this study. A 100 Hz recording frequency would be ideal, but 10 Hz would likely be sufficient. Analysis comparing accelerometer data at a variety of frequencies with existing assessment methods would be beneficial, including correlation with the Boeing Bump Index, ProVAL software, and PCI.

Recommendations

Further research is recommended to assess the best methods for data collection, including the sampling frequency, the best methods to effectively and efficiently obtain data from aircraft accelerometers and store it, and the best methods to integrate the data from the wide range of aircraft in the GA fleet into a PMP. Future research can also be expanded to explore if accelerometer data can be used to assess the coefficient of friction. This research introduces the concept of utilizing existing technologies currently deployed as a low cost way to monitor airfield surface conditions without having to procure specialized equipment.

Acknowledgements

This work was supported by the Indiana Department of Transportation (INDOT). Thanks to Mike Buening, Dwayne Harris, and Brandon Patterson from INDOT for providing access to their IRI van. A special thanks to Andrew Quirk and Dan Winger from Purdue University Airport for providing assistance while conducting the IRI test at KLAF. Although the FAA and INDOT has sponsored this project, it neither endorses nor rejects the findings of this research. The presentation of this information is in the interest of invoking technical community comment on the results and conclusions of the research.

References

Alessandroni, G., Klopfenstein, L. C., Delpriori, S., Dromedari, M., Luchetti, G., Paolini, B. D., & Bogliolo, A. (2014). SmartRoadSense: Collaborative Road Surface Condition Monitoring. In *UBICOMM 2014: The Eight International Conference on Mobile Ubiquitous Computing, Systems, Services and Technologies*, 210–215. https://doi.org/10.13140/RG.2.2.29144.90881

American Society for Testing and Materials. (2012). Standard Test Method for Airport Pavement Condition Index Surveys (D5340-12). Reproduction, (December), 1–54. https://doi.org/10.1520/D5340-12

Applied Research Associates Inc. (2015). Pavement Condition Report: Lafayette-Purdue University Airport (Vol. 53719). Retrieved from http://www.in.gov/indot/files/Aviation_Purdue2014TechReport.pdf

Belzowski, B., & Ekstrom, A. (2015). Evaluating Roadway Surface Rating Technologies. Retrieved from https://deepblue.lib.umich.edu/bitstream/handle/2027.42/111891/103192.pdf?sequence=1&isAllowed=y

Bullock, D. M., Hubbard, S. M. L., Furr, C., Gillum, B., Gallagher, D. W., & DiPilato, M. (2015). Evaluation of Aviation Rumble Strips (DOT/FAA/TC-15/2). Retrieved from http://www.airporttech.tc.faa.gov/Download/Airport-Safety-Papers-Publications-Detail/dt/Detail/ItemID/552/Evaluation-of-Aviation-Rumble-Strips

Buttlar, W. G., & Islam, M. S. (2014). Integration of Smart-Phone-Based Pavement Roughness Data Collection Tool with Asset Management System. Retrieved from https://www.purdue.edu/discoverypark/nextrans/assets/pdfs/098IY04 Integration of Smartphone-Based-Pavement Roughness data collection tool with asset management system.pdf

Carrera, F., Guerin, S., & Thorp, J. B. (2013). By the people, for the people: The crowdsourcing of “streetbump”, an automatic pothole mapping app. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 40(4W1), 19–23. Retrieved from http://www.scopus.com/inward/record.url?eid=2-s2.0-84924338176&partnerID=tZOtx3y1

Chen, W., Yuan, J., & Li, M. (2012). Application of GIS/GPS in Shanghai airport pavement management system. *Procedia Engineering*, 29, 2322–2326. https://doi.org/10.1016/j.proeng.2012.01.308

Dennis, E. P., Hong, Q., Wallace, R., Tansil, W., & Smith, M. (2014). Pavement Condition Monitoring with Crowdsourced Connected Vehicle Data. *Transportation Research Record: Journal of the Transportation Research Board*, 2460(1), 31–38. https://doi.org/10.3141/2460-04

Doan, A., Ramakrishnan, R., & Halevy, A. Y. (2011). Crowdsourcing systems on the World-Wide Web. *Communications of the ACM*, 54(4), 86. https://doi.org/10.1145/1924421.1924442

Federal Aviation Administration. (2004). Airport Safety Self-Inspection (AC 150/5200-18C). Retrieved from http://www.faa.gov/documentLibrary/media/advisory_circular/150-5200-18C/150_5200_18C.pdf

Federal Aviation Administration. (2009). Guidelines and Procedures for Measuring Airfield Pavement Roughness (AC 150/5380-9). Retrieved from http://www.airporttech.tc.faa.gov/Portals/0/Documents/airport_pavement/150_5380_9.pdf

Federal Aviation Administration. (2014a). Standards for Specifying Construction of Airports (AC 150/5370-10G). https://doi.org/10.1177/004728757301200242

Federal Aviation Administration. (2014b). Airport Pavement Management Program (PMP)(AC 150/5380-7B). Retrieved from http://www.faa.gov/documentLibrary/media/Advisory_Circular/150-5380-7B.pdf

Federal Aviation Administration. (2015a). Guidelines and Procedures for Maintenance of Airport Pavements (AC 150/5380-6C). Retrieved from https://www.faa.gov/documentLibrary/media/Advisory_Circular/150-5380-6C.pdf

Federal Aviation Administration. (2015b). National Plan of Integrated Airport Systems (NPIAS). Retrieved from http://www.faa.gov/airports/planning_capacity/npias/

Federal Aviation Administration. (2015c). FAA Surface Roughness Study. Retrieved from http://www.airporttech.tc.faa.gov/Portals/0/download/airport_roughness/RoughnessFinal Submittal/PDF/Final Report Rev 9_08282015.pdf

Federal Aviation Administration. (2016a). Airport Improvement Program (AIP). Retrieved from http://www.faa.gov/airports/aip/

Federal Aviation Administration. (2016b). Airport Pavement Roughness Research. Retrieved from http://www.airporttech.tc.faa.gov/Airport-Pavement/Nondestructive-Pavement-Testing/AirportPavementRoughnessResearch

Federal Aviation Administration. (2017). Fact sheet - Runway safety. Retrieved from https://www.faa.gov/news/fact_sheets/news_story.cfm?newsId=14895

Fox, A., Kumar, B. V. K. V., Chen, J., & Bai, F. (2015). Crowdsourcing Undersampled Vehicular Sensor Data for Pothole Detection. In *12th Annual IEEE International Conference on Sensing, Communication, and Networking (SECON)*, 2015. https://doi.org/10.1109/SAHCN.2015.7338353

Garmin. (n.d.). G1000 Manual for Cirrus SR20 / SR22 / SR22T. Retrieved from http://data.manualslib.com/pdf3/67/6650/664986-garmin/cirrus_sr20.pdf?26270e39508f03bbdc7e73bdbf0c4770

Keegan, K. & Jung, K. (2014). Innovative Approach to Airfield Pavement Inspections and Distress Identification at Oakland International Airport. In *International Conference on Managing Pavement Assets*, 2014. Retrieved from https://vtechworks.lib.vt.edu/bitstream/handle/10919/56397/ICMPA9-000070.PDF?sequence=2&isAllowed=y

Ros, M. (2016). Inside Farnborough: Incredible aircraft that'll shake up major airshow. Retrieved from http://www.cnn.com/2016/07/07/aviation/farnborough-preview-2016/index.html

Saxton, G. D., Oh, O., & Kishore, R. (2013). Rules of Crowdsourcing: Models, Issues, and Systems of Control. Information Systems Management, 30(1), 2–20. https://doi.org/10.1080/10580530.2013.739883

Sayers, M. W., Gillespie, T. D., & Paterson, W. D. (1986). Guidelines for Conducting and Calibrating Road Roughness Measurements. World Bank [Technical Paper Number 46]. Retrieved from https://deepblue.lib.umich.edu/bitstream/handle/2027.42/3133/72764.pdf?sequence=2

U.S. Department of Transportation. (2017). Asset management overview. Retrieved from https://www.fhwa.dot.gov/asset/if08008/amo_06.cfm

Yi, C.-W., Chuang, Y.-T., & Nian, C.-S. (2013). Toward crowdsourcing-based road pavement monitoring by mobile sensing technologies. *Intelligent Transportation Systems*, 16(4), 1905–1917. Retrieved from http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=7056422

Collegiate Aviation Review
International

Volume 36 | Issue 2 Peer-Reviewed Article #3

6-29-2018

Using the Systematic Literature Review in Aviation: A Case Study for Runway Incursions

Cheng Wang
Purdue University

Sarah M. Hubbard
Purdue University

Wei Zakharov
Purdue University

This research presents the process for a systematic literature review, and demonstrates the application of this process using a case study that investigates the factors that contribute to runway incursions (RIs). Runway safety is a top priority in aviation (Federal Aviation Administration [FAA], 2012a). One factor that threatens runway safety is RIs. In the United States, an average of three RIs occurs daily. Although the reduction of RIs has been a topic of interest for many years, the number of RIs has been increasing since 2012. In this paper, a systematic literature review approach was used to synthesize the results of previous studies in a systematic way, identify contributing factors for RIs, and provide insight regarding the causes for RIs. One hundred and thirty-four articles were identified in the initial literature search from 22 databases, and 22 articles were analyzed after using filtering criteria. As a result of this analysis, six categories of contributing factors to RIs were identified: human factors, airport geometry, technical factors, airport characteristics, environmental factors, and organizational factors. Recommendations for reduction of RIs and suggestions for further studies were presented based on these factors.

Recommended Citation:
Wang, C., Hubbard, S.M., Zakharov, W. (2018). Using the Systematic Literature Review in Aviation: A Case Study for Runway Incursions. *Collegiate Aviation Review International,* 36(2), 34-57. http://dx.doi.org/10.22488/okstate.18.100489

Runway safety is a significant challenge and a top priority in aviation (Federal Aviation Administration [FAA], 2012a). One factor that threatens runway safety is runway incursions (RIs). In the United States, an average of three RIs occur daily. Every incident has the potential to cause injury or death, as well as property damage. Although the reduction of RIs has been a topic of interest of the Federal Aviation Administration (FAA) for many years, the number of RIs has been increasing since 2012 with 6,830 RIs occurring between 2012 and 2016 (FAA, 2017). Due to the important safety implication, it is valuable to analyze contributing factors in a systematic way, to assure that mitigation efforts focus scarce resources where they can have the greatest impact (Mathew, Major, Hubbard, & Bullock, 2016).

The systematic literature review approach is popular in other disciplines, such as medicine and health, and its application has a long history of improving safety in these industries. In some cases, medicine has learned from aviation, such as through the use of crew resource management in the operating room, and the application of safety management systems for a systematic approach to safety improvement. In this case, aviation can learn from medicine. This paper demonstrates the application of the systematic literature review methodology, a method that has not been commonly used in the aviation field. In contrast to the traditional literature review which is referred as narrative review, a systematic literature review uses a rigorous research methodology in an attempt to minimize bias, which means it is more objective (Bettany-Saltikov, 2010).

Although many narrative reviews have been published in aviation field, there were very few articles on the systematic literature review for the aviation. In this paper, the systematic literature review approach is used to identify the key contributing factors of RI events. Research papers that reported on the quantitative and qualitative analysis of causes of RIs were selected from a variety of databases in this study. The paper presents the synthesis and analysis of the factors contributing to RIs, based on the results of both quantitative and qualitative research as documented in peer-reviewed articles.

Background

Runway Incursions

The FAA (2015b) defines a runway incursion as, “any occurrence at an aerodrome involving the incorrect presence of an aircraft, vehicle or person on the protected area of a surface designated for the landing and take-off of aircraft” (para. 1). The FAA (2015b) further defines four categories of RI severity, with Category A being the most severe and Category D being the least:

- Category A: a serious incident in which a collision was barely avoided.
- Category B: an incident with significant potential for a collision; situation may require a time critical corrective response or evasive response to avoid a collision.
- Category C: an incident in which there is ample time and/or distance to avoid a collision.

- Category D: an incident with no immediate safety consequences although it meets the definition of RI due to the incorrect presence of a vehicle, person, or aircraft on the runway or protected area.

The FAA (2015b) also classifies RIs according to the following three major causes:

- Operational incident (OI): a RI due to the action of an air traffic controller. This includes clearing an aircraft for a closed runway or an action that results in inadequate separation between aircraft, or between aircraft and vehicles or other obstacles.
- Pilot deviation (PD): a RI due to the action of a pilot. This includes entering the runway without clearance from air traffic control (ATC) or other actions that violates any Federal Aviation Regulation.
- Vehicle/pedestrian deviation (VPD): a RI due the action of a pedestrian or vehicle. This includes a pedestrian or vehicle entering the runway or any other portion of the airport movement area without ATC authorization.

According to the FAA (2017), the number of RIs has been increasing since 2012. The most common cause for RIs is PD, which comprised 61.9% of the RIs between 2012 and 2016, followed by OI, which accounted for 20.2%, and VPD, which represented 17.5%. Table 1 shows the totals and causes of RIs from 2012 to 2016.

Table 1

U.S. RI Totals by Cause for Fiscal Years 2012-2016

Year	OI	PD	VPD	Other	Total RI per Year
2012	211 (17.9%)	765 (65.0%)	199 (16.9%)	2 (0.2%)	1,177
2013	261 (20.6%)	781 (61.7%)	216 (17.1%)	8 (0.6%)	1,266
2014	264 (20.7%)	776 (60.7%)	234 (18.3%)	4 (0.3%)	1,278
2015	326 (21.7%)	912 (60.6%)	264 (17.5%)	3 (0.2%)	1,505
2016	318 (19.8%)	993 (61.9%)	285 (17.8%)	8 (0.5%)	1,604
Total RIs per Type	1,380 (20.2%)	4,227 (61.9%)	1,198 (17.5%)	25 (0.4%)	6,830 (100%)

Note. Other includes RIs not categorized or RIs that do not meet the OI, PD, or VPD criteria.

Systematic Literature Review

A systematic literature review is an analysis of previous research using a systematic and explicit method to identify, select, and critically appraise relevant studies and to collect and analyze data from them (Siddaway, n.d.). A systematic literature review aims at addressing research questions by identifying, critically evaluating, and integrating the findings of all relevant and high-quality studies.

The main steps in conducting a systematic literature review are as follows (Siddaway, n.d.):

1. Formulating one or more research questions.
2. Searching for relevant data and identifying the publications.
3. Defining the inclusion and exclusion criteria.

4. Selecting the publications that are relevant to the question and extracting the data.
5. Critically evaluating the publications and assessing the data quality.
6. Performing data analysis and combining results.

Academic contributions must be considered within the context of previous work (Salkind, 2011); however, the number of articles published each year has been increasing dramatically (Borrego, Foster, & Froyd, 2014). Many researchers are not able to read all the published articles that are relevant to the current context for a given study area. Therefore, some research fields have developed the systematic literature review approach to synthesize the primary studies in their respective fields. In fields like education, medicine, and psychology, extensive systematic literature reviews have been conducted. By providing synthesized reviews on important topics or issues, vital contributions to evidence-based disciplines can be made (Gough, Oliver, & Thomas, 2012). For example, systematic literature reviews have demonstrated gaps in recent work and highlighted areas where a concept is accepted as true, despite little evidence to support it (Petticrew & Roberts, 2008). A systematic literature review offers a methodology that can be used by an interdisciplinary research team to design a transparent approach to selecting, analyzing, and synthesizing study to address its research question (Borrego, Foster, & Froyd, 2015). For instance, Wauben, Lange, and Goossens's (2012) research analyzed the similarities and differences of safety between the aviation industry and operation rooms in the hospital.

Systematic literature review in other disciplines. Other disciplines which have utilized systematic literature reviews include medicine, biochemistry, genetics and molecular biology, nursing, pharmacology, toxicology and pharmaceutics, neuroscience, and psychology. Numerous systematic literature reviews have been published in these areas in the past decade. A wildcard search of Scopus, the largest abstract and citation database of peer-reviewed literature, with "systematic review*" in the title, abstract or keywords, showed that the subject area produces the most systematic literature reviews is medicine, with 66,871 documents published from 2007 to 2016. The wildcard search provides results for systematic review and systematic reviews. Figure 1 shows the trend of published systematic literature reviews in subject areas such as biochemistry, genetics and molecular biology; nursing; pharmacology, toxicology and pharmaceutics; neuroscience; and psychology. These are all topic areas that are generated by Scopus. In these areas, the number of published systematic literature reviews is increasing rapidly. However, there were very few articles on the systematic literature review for the aviation field, as evidenced by the results shown, which reflect a search using "systematic review*" and "aviation" in the title, abstract or keywords.

Since systematic literature reviews are very popular in the health field, a search for systematic literature reviews in PubMed was conducted to demonstrate its potential application in aviation. PubMed is the National Library of Medicine's search interface to the MEDLINE database, which includes over 26 million references to articles, from medicine, nursing, basic sciences and related biomedical fields. The PubMed database offers a search option using "systematic reviews" as one article type and therefore has a dedicated collection. According to the search results from PubMed, a total of 80,283 systematic literature reviews were published from 2007 to 2016.

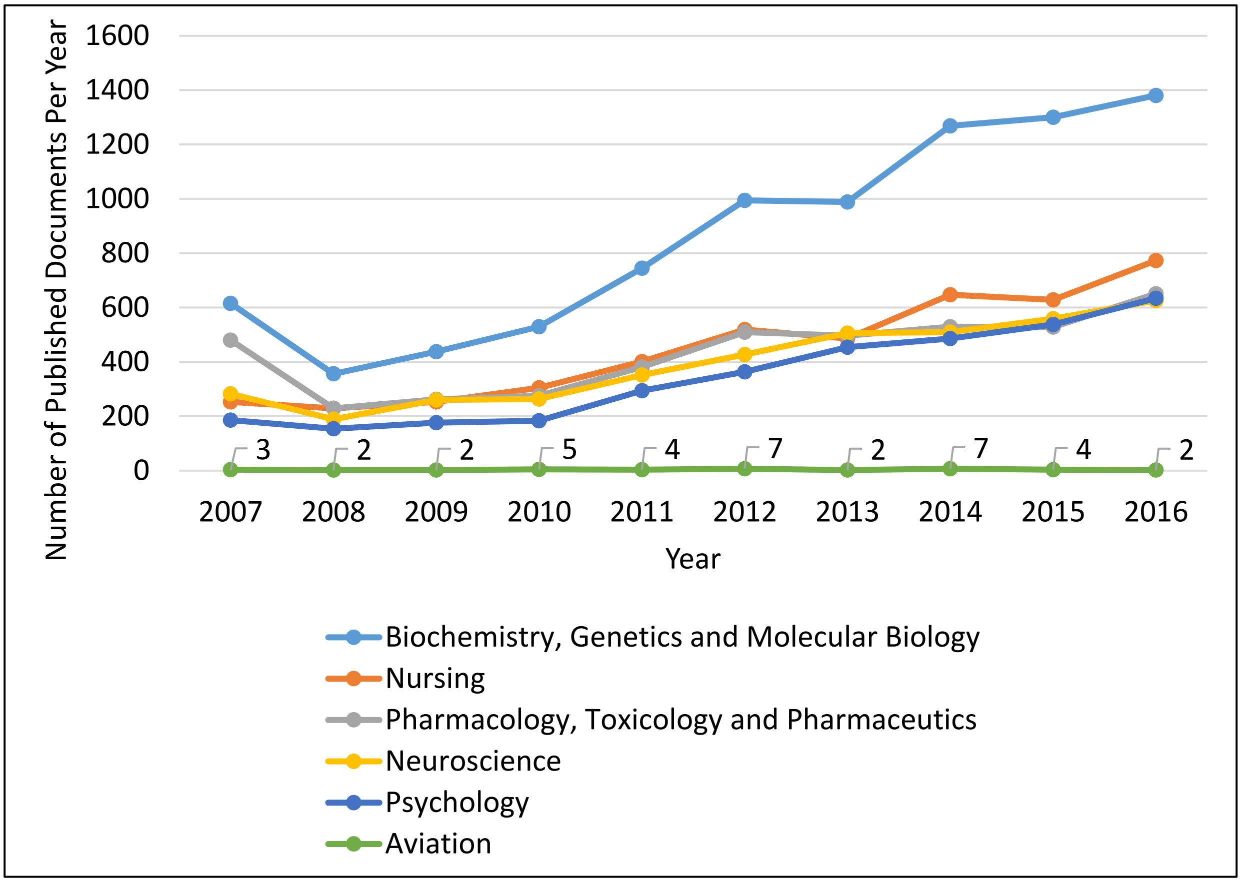


Figure 1. Number of systematic literature reviews by subject and year, 2007-2016, data source: Scopus.

In the medical field, systematic literature reviews have become highly valued evidence for clinical practices and public policies. Lessons learned from other high-risk industries are helpful for improving aviation safety, and perhaps, in this case, the aviation industry can learn from medicine, which has a long history of improving safety through clinical trials and other evidence-based approaches.

Systematic literature review in the aviation field. Although reducing the severity, number and rate of RIs was ranked as the most important goal to improve runway safety by the FAA (FAA, 2012b), the systematic literature review has not been used in aviation research to address runway safety or RIs. There were few systematic literature reviews related to aviation. A total of 38 systematic literature reviews in aviation were published during the past decade with most related to medical and health-related aviation topics, such as the examples below:

- "Learning from Aviation to Improve Safety in the Operating Room – a Systematic Literature Review," described the similarities and differences between aviation and medicine industries and discussed methods and solutions with a systematic approach to reduce errors in operating rooms (Wauben, Lange, & Goossens, 2012).
- Huster, Müller, Prohn, Nowak, & Herbig (2014) researched the medical risks faced by older pilots, and investigated whether the pilot risk of incapacitation for medical reasons increases with age.

Study Motivation and Scope

RIs are a critical concern for the safety of the air transportation system. In the worst case, a RI can result in a collision and loss of life. In 1977, the catastrophic collision of two Boeing 747 aircrafts on the runway in Tenerife, Canary Islands, resulted in the death of 583 passengers and flight crew members (Netherlands Aviation Safety Board, 1979). On October 14, 1984, Aeroflot Flight 3352, a Tupolev Tu-154B-1, hit maintenance vehicles on the runway in Omsk, Russia (Aviation Safety Network, 2017). One hundred and seventy-four people aboard the aircraft were killed, as were four people in the maintenance vehicles.

While not all RIs result in an accident, a few serious RIs challenge aviation safety each year. According to the FAA (2017), 32 Category A RIs and 43 Category B RIs occurred in the five years between 2012 and 2016. During this time period, there were more than 6,000 RIs classified as Category C or Category D. This is consistent with research conducted by Heinrich (1941), who found that for every accident that causes a major injury, there are 29 incidents that cause minor injuries and 300 incidents that cause no injuries. Identifying and reducing RIs of all categories will help reduce the likelihood of severe RIs that cause injury or death. Figure 2 illustrates the Heinrich pyramid and its application to RI severity levels.

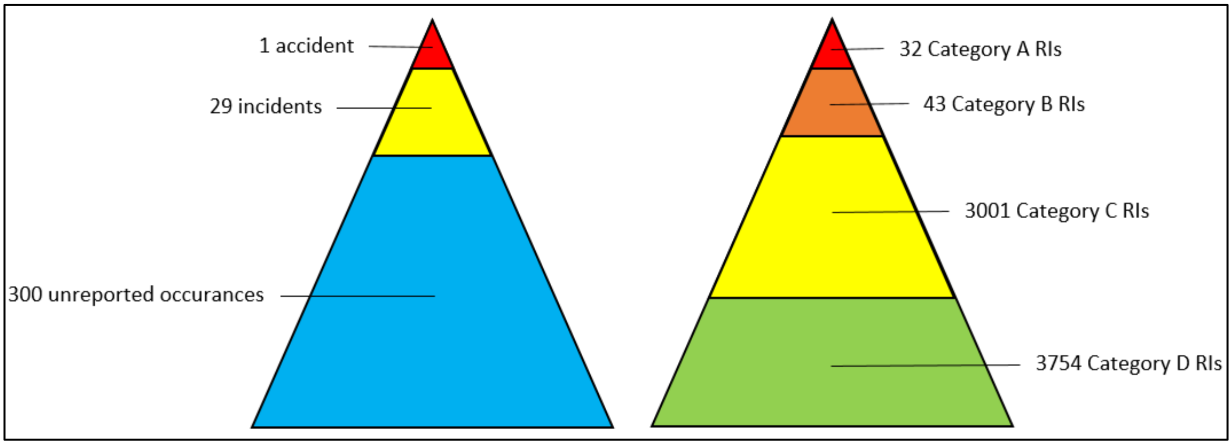


Figure 2. (Left) Heinrich (1941) pyramid and (right) its application to RIs severity (data source: FAA Runway Safety Office - Runway Incursions).

There have been numerous programs and systems put in place to reduce RIs. FAA announced the Runway Incursion Mitigation (RIM) program to identify the locations at airports where airport geometry might be a risk factor that contributes to RIs, and to develop strategies to help airport sponsors mitigate risk at these locations (2015a). Runway incursion avoidance and alerting systems are one approach to reduce RIs (Schönefeld & Möller, 2012). These systems include traffic information services, traffic information service broadcast, automatic dependency surveillance-broadcast, runway incursion prediction and detection algorithms, vehicle and airport sensors, human-machine interfaces, and airport traffic signals.

Despite the progress through RIM initiatives, the rate of RIs in the United States has steadily risen. According to the Bureau of Transportation Statistics (2017) and the General Aviation Manufacturers Association (2017), the number of flights in the United States has decreased slightly since 2012; however, the number of RIs has continued to increase during the same time period. In other words, both the number of RIs, and the rate of RIs, have increased steadily during the past five years.

However, it is still useful to closely examine the factors that have been identified to contribute to RIs. The objective of this paper is to present a methodology for systematic literature review, and apply this method to identify factors that contribute to RIs. In this research, a replicable and transparent systematic literature review approach is applied to identify, analyze, and synthesize the contributing factors to RIs. The methodology section describes the scope and procedures followed to conduct the systematic literature review. The results section presents the search and selection results, as well as the synthesis and analysis of factors that contribute to RIs. The recommendations section includes suggestions for preventing and mitigating RIs, as well as recommendations for future research studies.

Methodology

The methodology used in this study was a systematic literature review based on guidelines outlined in the “Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Statement” (Moher, Liberati, Tetzlaff, Altman, & Prisma Group, 2009). These guidelines were used to conduct a systematic literature review of correlating factors contributing to a higher incidence of RIs. This section describes the scope and procedures, including the data sources, the search strategies, inclusion and exclusion criteria, and the method of data extraction.

Data Sources and Search Strategies

The search was conducted using the 22 databases shown in Table 2. Among the databases searched were three key databases for aviation: Engineering Village, ProQuest Technology Collection, and Transportation Research Information Database (TRID) Engineering Village is an essential engineering research database which offers access to 12 engineering literature and patent databases that provide coverage from a wide range of trusted engineering sources. ProQuest Technology Collection is a major database in technology field. The Technology Collection is a full-text database which brings more value and access than other citation and abstract resources. The TRID is the world’s largest and most comprehensive bibliographic resource on transportation research information and it covers all modes and disciplines of transportation. The other databases shown in Table 2 include some aviation journals and topics, but typically have fewer results related to aviation.

The initial search was developed based on the key phrase “runway incursion.” The search criteria were customized for each database to reflect database-specific subject headings. The specifications are detailed below:

- Engineering Village: the search term was “runway incursion*” in subject/title/abstract for journal articles.
- ProQuest Technology Collection: the search term was “runway incursion*” in all fields for peer-reviewed and full-text articles.

- TRID: the search was limited to “aviation” subject area, with “runway incursion*” in all fields for articles and papers.
- Other databases: the search term was “runway incursion*” in all fields for peer-reviewed and full-text articles.

Table 2

Databases Used to Identify Sources

Citation Source
1. Aerospace Database
2. Civil Engineering Abstracts
3. Computer and Information Systems Abstracts
4. Digital Commons (Bepress)
5. Electronics and Communications Abstracts
6. Engineering Village
7. Institution of Engineering and Technology (IET) (CrossRef)
8. Materials Business File
9. Mechanical & Transportation Engineering Abstracts
10. OneFile (GALE)
11. Social Sciences Citation Index (Web of Science)
12. ProQuest Advanced Technologies & Aerospace Collection
13. ProQuest Computer Science Collection
14. ProQuest Engineering Collection
15. ProQuest Materials Science Collection
16. ProQuest Technology Collection
17. SAGE Journals
18. Science Citation Index Expanded (Web of Science)
19. ScienceDirect Journals (Elsevier)
20. Scientific.Net (Trans Tech Publications)
21. Scopus (Elsevier)
22. Transportation Research Information Database

The base search was restricted to articles written in the English language published after October 2007, which is when the FAA adopted the current definition for RI. As of October 2007, the FAA definition became the same as the definition used by the International Civil Aviation Organization (ICAO). Prior to 2007, an event that involved only vehicles or pedestrians was classified as “surface incident” by the FAA (2007). After October 2007, some events that were formerly classified as surface incidents by the FAA are now classified as Category C or D RIs. Although this change does not affect the level of safety achieved, it increases the number of reported RIs.

Inclusion criteria. For this review, the articles were original contributions published since 2008 in English that provide quantitative and/or qualitative assessment and include any of the following contents:

- Statistics of RIs.
- Severity of RIs.
- Type of RIs.
- Factors that contribute to RIs.

Exclusion criteria. For this review, articles with the following criteria were excluded from further study.

- Focus on evaluating specific methods and technologies to prevent or reduce RIs.
- Focus on validation of the new technologies about RIs.

- Focus on air traffic safety.
- Not peer reviewed (e.g., books, news articles, presentations, & government regulatory institution reports).

Results

Based on the search strategies described above, a total of 134 articles were retrieved in February 2017. This included 44 articles from Engineering Village, 43 articles from ProQuest Collection Technology, 21 articles from TRID, and 26 articles from 19 other databases. The search included 37 duplicate articles.

During the screening stage, 100 articles were initially reviewed. This included 97 articles from 22 databases and three additional articles identified through the references of primary articles. Seventy-eight of 100 articles were excluded from further study for the reasons described below.

Twenty-three articles were excluded because they focused on specific technologies to prevent or reduce RIs. These excluded articles documented studies evaluating or validating the effectiveness of specific technologies. Some technologies evaluated included incursion monitoring, detection, and alerting systems, including airport surface indications and alerts. Other technologies used logic-based reasoning to predict RIs and give explicit instructions to pilots and drivers to avoid RIs.

Thirteen articles were excluded because they focused on air traffic management and air traffic safety. These articles included analysis of air traffic incidents using event trees with fuzzy probabilities, and systematic assessment of air traffic accident risk using Monte Carlo simulation.

Forty articles were excluded because they did not address RI. Four articles of these discussed runway safety but did not specifically address RIs. For example, one included a framework for introducing and sequencing system improvements to provide greater assurances in enhancing safety, and another addressed runway excursions. Thirty-six of these articles were not relevant to RIs or runway safety. For example, one article discussed the significance of demographic characteristics in airport driver training programs and another addressed taxi route scheduling between taxiway and runway at a hub airport.

Article selection and exclusion reflected timeframe as well as subject matter. One article was excluded because it studied RIs before 2008, when FAA's definition was not the same as ICAO's.

The selection stage resulted in 22 articles, which included six articles from Engineering Village, two articles from ProQuest Collection Technology, nine articles from TRID, and five articles from other databases. The results at each stage of the searching, screening, and selection processes are illustrated in Figure 3, which is modeled after Borrego et al (Borrego, Foster, & Froyd, 2015). Of these final 22 articles selected, six used quantitative analysis, ten used qualitative analysis and six included both quantitative and qualitative methods, also referred to as mixed-methods. The results from these 22 research papers are presented in Table 3 and Table 4, with the author, year of publication, title, and analysis method used.

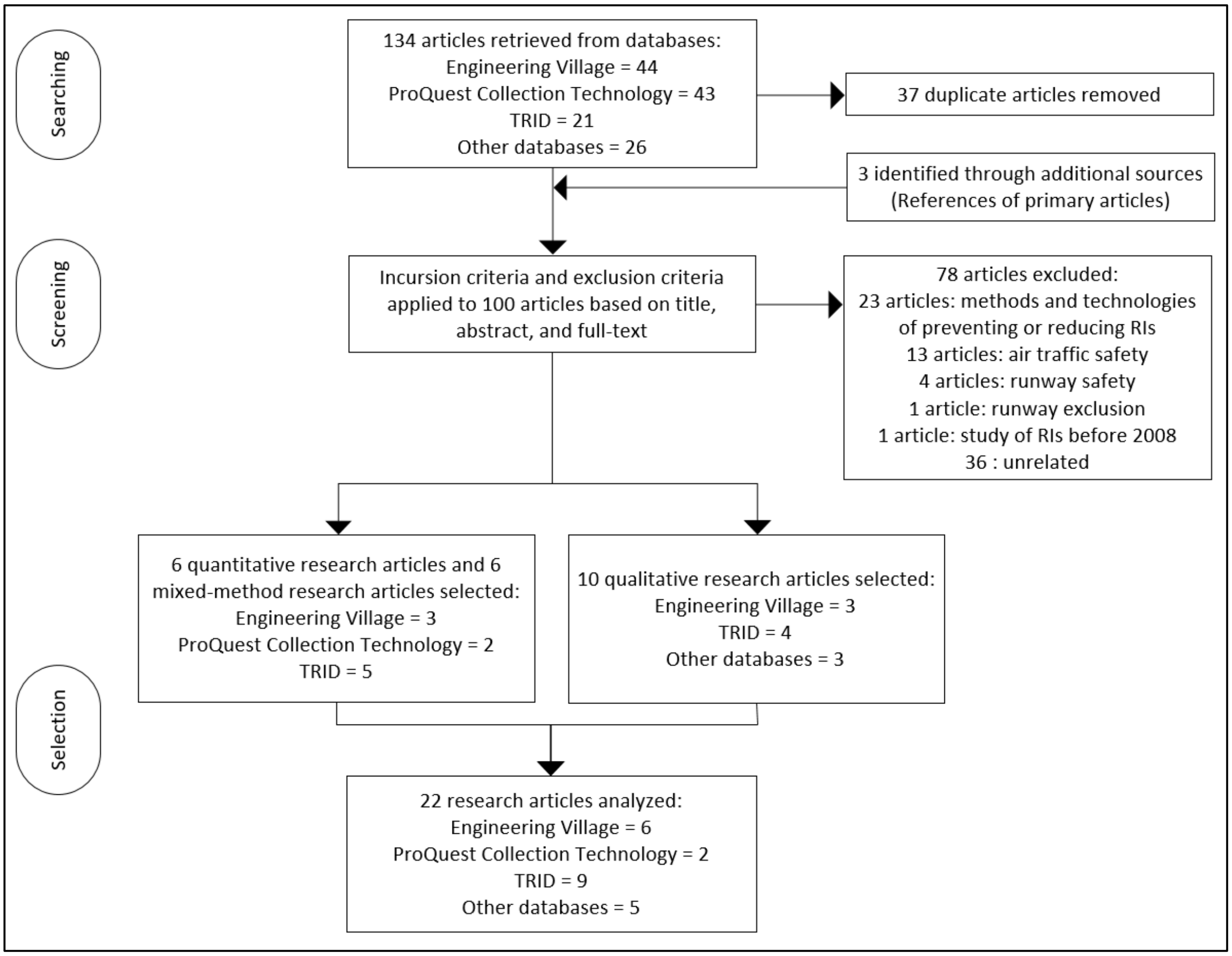


Figure 3. Number of articles searched, screened and selected at each stage.

Table 3

Articles with Quantitative Research of RI Contributing Factors

Author (Year)	Title	Statistical Method
Chang & Wong (2012)	Human risk factors associated with runway incursions	Fuzzy Delphi method Likert scale Analytic hierarchy process Improvement-achievability assessment
De Reuck, Donald, & Siemers (2014)	Factors associated with safety events in air traffic control	Multivariate logistic regression
Goodheart (2013)	Identification of causal paths and prediction of runway incursion risk by means of Bayesian Belief Networks	Bayesian Belief Network model
Johnson, Zhao, Faulkner, & Young (2016)	Statistical models of runway incursions based on runway intersections and taxiways	One-sided test Multiple regression model
Joslin, Goodheart, & Tuccio (2011)	A mixed method approach to runway incursion rating	Cronbach's Alpha *t*-test
Ju (2011)	Reason analysis of runway incursions based on Grey Theory	Grey Theory
Kim & Yang (2012)	Evaluation of the risk frequency for hazards of runway incursion in Korea	Preliminary hazard analysis Analytic hierarchy process Fault tree
Mathew, Major, Hubbard, & Bullock (2016)	Statistical modelling of runway incursions	Multinomial logit model
Mrazova (2014)	Runway Incursions - clear and constant danger	Descriptive statistics
Stroeve, Blom, & Bakker (2013)	Contrasting safety assessments of a runway incursion scenario: event sequence analysis versus multi-agent dynamic risk modelling	Event tree Multi-agent dynamics risk model
Wilke, Majumdar, & Ochieng (2015a)	Modelling runway incursion severity	Kolmogorov-Smirnov test Shapiro-Wilk test Kruskal-Wallis test Mann-Whitney U test Pearson Chi-Square test Logistic regression Maximum likelihood estimation
Wilke, Majumdar, & Ochieng (2015b)	The impact of airport characteristics on airport surface accidents and incidents	Kolmogorov-Smirnov test Kruskal-Wallis test Pearson Chi-Square test Logistic regression

Table 4

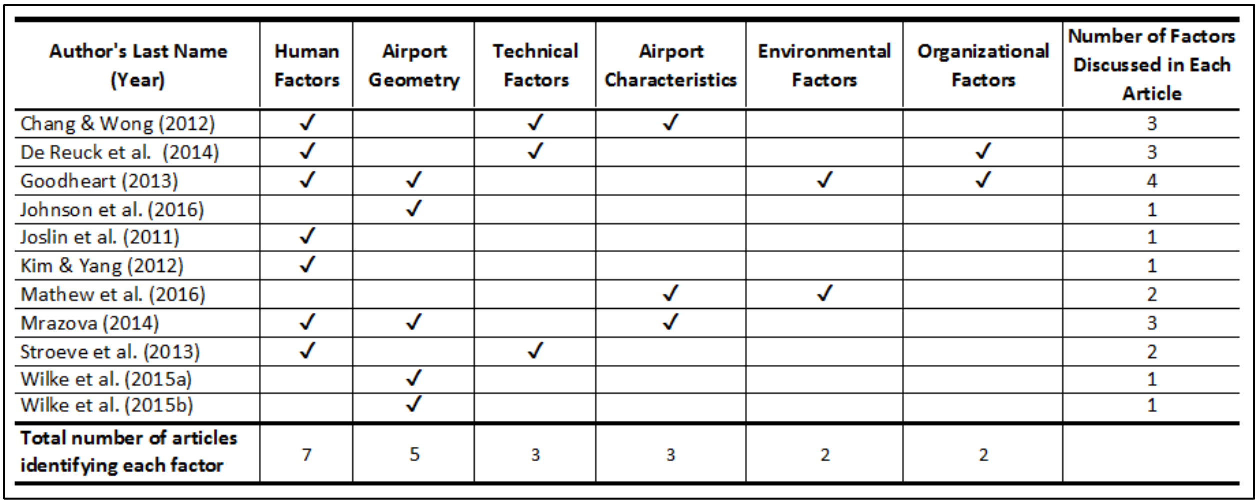
Articles with Qualitative Research of RI Contributing Factors

Author (Year)	Title	Qualitative Method
Asare & Ford (2008)	Reducing runway incursions - A simple, yet effective next step	Thick descriptions
Cardosi, Chase, & Eon (2010)	Runway safety	Historical research
Leon (2009)	Combating runway incursions	Thick descriptions
Oetzell (2008)	Avoiding runway incursions	Thick descriptions
Redzepovic (2009)	Prevention of runway incursions at joint use aerodromes	Narrative
Rogerson & Lambert (2012)	Prioritizing risks via several expert perspectives with application to runway safety	Hierarchical Holographic Modeling (HHM) Risk Filtering, Ranking, and Management (RFRM)
Rogerson, Lambert, & Johns (2013)	Runway safety program evaluation with uncertainties of benefits and costs	Hierarchical Holographic Modeling (HHM) Risk Filtering, Ranking, and Management (RFRM)
Stroeve, Som, van Doorn, & Bakker (2016)	Strengthening air traffic safety management by moving from outcome-based towards risk-based evaluation of runway incursions	Severity-based assessment
Wilke, Majumdar, & Ochieng (2012)	Holistic approach to airport surface safety	Survey Semi-structured interview Structured communication
Wilke, Majumdar, & Ochieng (2013)	Airport surface operations: A holistic framework for operations modeling and risk management	Business Process Model (BPM)

In quantitative studies, a variety of statistical and mixed-methods are used. Quantitative methods include *t*-tests, multiple regression models, Pearson Chi-Square tests, and multinomial logit models, all of which are used extensively in many aviation-related research studies. Qualitative methods which are incorporated into mixed-method research studies include the Likert scale, analytic hierarchy process, preliminary hazard analysis, and fault tree analysis. These methods are not only used in aviation and runway incursion studies, but are also commonly used in other disciplines. The qualitative methods used in aviation research are more generalized and include narrative research, surveys, and semi-structured interviews.

Quantitative Research Results

Six main categories of contributing factors were identified based on the 12 quantitative research papers. These six main categories are shown in Figure 4 and include *human factors*, *airport geometry*, *technical factors*, *airport characteristics*, *environmental factors*, and *organizational factors*.



Author's Last Name (Year)	Human Factors	Airport Geometry	Technical Factors	Airport Characteristics	Environmental Factors	Organizational Factors	Number of Factors Discussed in Each Article
Chang & Wong (2012)	✓		✓	✓			3
De Reuck et al. (2014)	✓		✓			✓	3
Goodheart (2013)	✓	✓			✓	✓	4
Johnson et al. (2016)		✓					1
Joslin et al. (2011)	✓						1
Kim & Yang (2012)	✓						1
Mathew et al. (2016)				✓	✓		2
Mrazova (2014)	✓	✓		✓			3
Stroeve et al. (2013)	✓		✓				2
Wilke et al. (2015a)		✓					1
Wilke et al. (2015b)		✓					1
Total number of articles identifying each factor	7	5	3	3	2	2	

Figure 4. Factors contributing to RI identified in quantitative analysis.

Human factors. Human factors are the most often cited contributors to RIs, and were identified as a contributing factor in seven of the 12 quantitative articles. Human factors can affect pilots, air traffic controllers, pedestrians, and ground vehicle drivers. For pilots, failure to hold short is the most frequently cited cause of RIs, followed by: crew coordination, situational awareness, misunderstanding of air traffic control (ATC) instructions, the cross-checking of instructions, lack of familiarity with airport layout, conducting checklist while taxiing, and reading back instructions. Task saturation, momentarily forgetting or confusing of an issued clearance, issuing incomplete clearances, and misidentification of an aircraft/vehicle or its location are four major causes of RIs for controllers. The communication between pilots and controllers and their attitude toward safe flight operations or air traffic management are also important human factor considerations that play important roles in runway safety.

Airport geometry. Airport geometry is the second most often identified contributor to RIs. Five of the 12 quantitative studies identified factors related to airport geometry as contributors to RIs. Generally, as the complexity of airport geometry increases, RIs increase.

Intersecting runways, intersections of runways and taxiways, the number of conflict points, complex intersections or airport layouts all increase airfield complexity and all contribute to a higher incidence of RIs.

Technical factors. Technical factors refer to the use of standard technologies which have been widely used, such as runway incursion prevention systems (RIPS), flight dynamics and surface guidance systems (SGS), radar and visual monitoring systems, and ATC alert systems. The effective use of these systems or combinations of these systems is crucial to the prevention of RIs. This is substantiated by the research findings that demonstrate risk is reduced significantly through the combined actions of pilots, controllers and alert systems (Stroeve, Blom, & Bakker, 2013). Furthermore, RIPS and SGS were identified as risk factors which have small influences on RIs (Chang & Wong, 2012).

Airport characteristics. Airport characteristics include inadequate lights, inadequate or ambiguous signs and markings, traffic volume, construction, and airport size. Numerous studies have been conducted on runway lighting systems, since they are powerful tools in the prevention of RIs. The FAA has developed Runway Status Lights, which provide direct warnings to pilots and drivers of ground vehicles of a potential runway incursion or collision. Mathew et al. (2016) found that RIs' severity depends on the size of the airport, with OI more likely at large airports, and PD more likely for less severe (C and D) incursions at GA and non-hub airports.

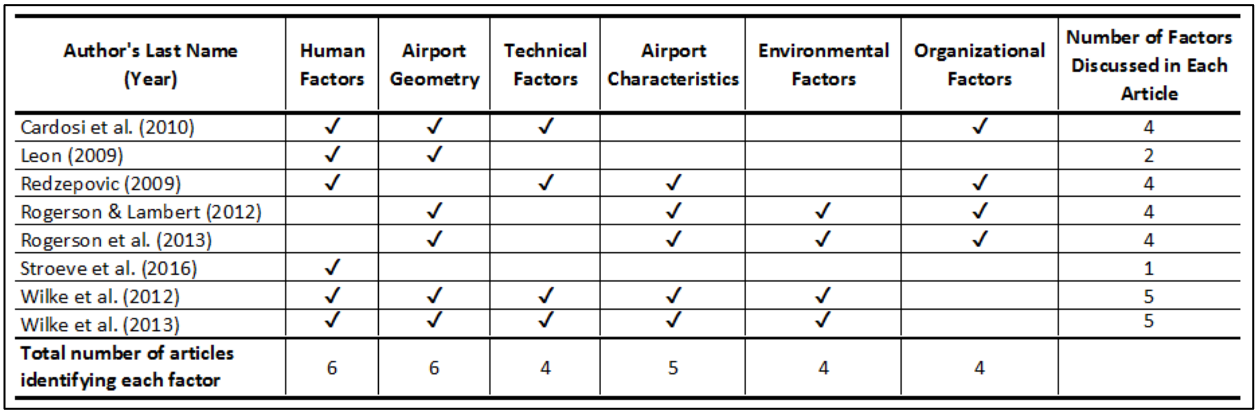
Environmental factors. Environmental factors include weather, daylight and glare, and were identified as a contributing factor for RIs in two quantitative articles. Mathew et al. (2016) noted that the probability of category D incursions is higher at most GA airports during the winter. Since GA operations are lower in winter, the probability of a severe incursion with another aircraft decreases. This research modeled RI as a random parameter; a small number of general aviation (GA) airports had a higher probability of category A incursions and a lower probability of less severe incursions. This was attributed to the fact that GA airports in Florida and California do not have harsh winter weather and operations may even increase during winter months.

Organizational factors. Organizational factors include poor standards and inadequate supervision, both of which have a negative impact on RIs. In De Reuck's et al. (2014) study, poor coordination standards resulted in ineffective coordination and communication among controllers, between controllers and pilots, and between pilots in the cockpit. In some cases, communications are considered a human factor, as noted previously. In this case, communications are considered an organizational factor and research indicates that a well-designed standard for coordination and communication is the first step in improving safe operations. The effect of inadequate supervision and safety climate also influenced RI events (Goodheart, 2013).

Some of the research also included analysis of the causation factors for RIs, specifically the designation OI, PD, and VPD. According to Ju (2011), VPDs are the key factor influencing Category A and B incursions, and PDs are the key factor influencing Category C and D incursions. Using different analysis methods, Wilke, Majumdar and Ochieng (2015a) also found that PDs are more likely to contribute to lower severity incursions, but found that ATC (OI) is often a contributor for more severe (A and B) incursions.

Qualitative Research Results

These same six main categories that were identified by the quantitative research were also applicable to the qualitative research. The results are shown in Figure 5 and discussed below.



Author's Last Name (Year)	Human Factors	Airport Geometry	Technical Factors	Airport Characteristics	Environmental Factors	Organizational Factors	Number of Factors Discussed in Each Article
Cardosi et al. (2010)	✓	✓	✓			✓	4
Leon (2009)	✓	✓					2
Redzepovic (2009)	✓		✓	✓		✓	4
Rogerson & Lambert (2012)		✓		✓	✓	✓	4
Rogerson et al. (2013)		✓		✓	✓	✓	4
Stroeve et al. (2016)	✓						1
Wilke et al. (2012)	✓	✓	✓	✓	✓		5
Wilke et al. (2013)	✓	✓	✓	✓	✓		5
Total number of articles identifying each factor	6	6	4	5	4	4	

Figure 5. Factors contributing to RI identified in qualitative analysis.

Human factors. Human factors are one of the most often identified contributing factors of RIs, and were identified in six qualitative studies. For pilots, crossing the hold short line without authorization and loss of situational awareness are the two most frequent causes of RIs. Other causes include missing a turn or taking a wrong turn, accepting another aircraft's clearance, and distraction due to unnecessary flight deck conversations or the performance of head-down tasks. Inadequate coordination, forgetting about an aircraft or a closed runway are common causes of RIs that resulted from controllers (OI). Fatigue, read-back and hear-back errors, as well as communication problems are contributors to RIs caused by either pilots (PD) or controllers (OI). Redzepovic's (2009) research at joint-use airports suggests that RI may have different contributing factors for military and civilian operations. For civilian pilots, RIs may result because civilian pilots may not be familiar with the operational performance of military aircrafts. For military pilots, RIs may result because military pilots may not be familiar with ICAO standards for airport signs, lights and markings.

Airport geometry. Airport geometry is another contributor often identified in qualitative articles. It was identified in six articles, and includes complex and confusing airport layouts. Crossing runways, T-intersecting runways, closely- aligned runways, parallel runways, taxiways crossing many runways, short taxi routes and close thresholds are all more likely to increase the likelihood of RI occurrence.

Technical factors. Technical factors were studied in four qualitative articles, and results are divided into two categories: communication-related technical factors and aircraft-related technical factors. In Cardosi et al. (2010), three communication-related technical factors were studied: frequency congestion, blocked or partially blocked voice communications, and a high rate of false alarms from Airport Movement Area Safety System (AMASS). According to this research, the rate of false alarm from AMASS was so high that controllers ended up ignoring valid alerts. Other research found that aircraft malfunction contributed to RIs; this would be considered as an aircraft-related technical factor (Wilke, Majumdar, & Ochieng, 2012; Wilke, Majumdar, & Ochieng, 2013).

Airport characteristics. Airport characteristics were identified as a contributor to RI in five qualitative research studies. Airport infrastructure components such as inadequate lightning and ambiguous markings or signals contributed to RIs, findings that were consistent with the results of quantitative research. Characteristics such as flight school near the airport, federal contract tower, and number of flights at the airport were also factors that contributed to RIs and reflect airport characteristics.

Environmental factors. Environmental factors were identified in four qualitative articles. According to Rogerson and Lambert (2012), yearly snowfall, rainfall, freezing conditions, heat, and variation in day length are all influential causes of RIs. Three other studies also found that the weather plays an important role in RIs (Rogerson, Lambert, & Johns, 2013; Wilke, Majumdar, & Ochieng, 2015a; Wilke, Majumdar, & Ochieng, 2015b).

Organizational factors. Organizational factors appeared in four qualitative articles. Redzepovic (2009) noted that organizational factors are the most important factor at joint-use airports, since many military operations differ from purely civil operations, and reflect different standards and procedures. At joint-use airports, military pilots and controllers use non-standard International Civil Aviation Organization (ICAO) phraseology or local language, and military operational procedures for ground lighting may deviate from ICAO standards. The application of different rules and procedures can create confusion during operations. Deviation from standard operating procedure (SOP) is a cause of RIs, because the successful adoption of a non-obligatory procedure depends on the operator, and confusion may be created when some operators follow the SOP but others do not (Cardosi, Chase, & Eon, 2010).

Comparison of Quantitative Research and Qualitative Research

There were numerous similarities between the findings of the quantitative research and qualitative research. Not surprising, the six contributing factors of human factors, airport geometry, technical factors, airport characteristics, environmental factors, and organizational factors were adequate to describe the research findings for both quantitative and qualitative research. There were some notable differences between the quantitative and qualitative findings, however, as described below.

The qualitative research tends to identify more contributing factors for RIs than the quantitative research. Six of eight qualitative research studies identified at least four contributing factors for RIs, whereas only one of 12 quantitative research study identified four contributing factors. One possible explanation for the difference is that the qualitative research utilized a systematic and holistic approach, and focused on a higher level of analysis. Numerous quantitative research papers focused only on one or two specific contributing factors. This reflects the fact that it may be challenging to study some categories of factors with statistical methods. For example, analysis of environmental factors and organizational factors may be challenging with existing databases. It is also notable that all of the quantitative research studies were published after 2011, whereas most of the qualitative research studies were conducted before 2013. Perhaps researchers used qualitative methods to study RIs and identify contributing factors, and then subsequent research used statistical methods to analyze the contributing factors originally identified by qualitative research. It is also likely that internet databases have made quantitative analysis possible for more researchers. Similarities and differences between the findings for each category of factor for the qualitative and quantitative research are discussed below.

Human factors. Human factors are studied frequently in both quantitative research and qualitative research, which is logical since human factors accounted for the majority of RIs. The causes of human factors resulting in RIs were basically the same for quantitative and qualitative research and included failure to hold short, loss of situational awareness, miscommunication, and crew coordination.

Airport geometry. Airport geometry is frequently included in both quantitative and qualitative research studies, and include complexity correlates with more RIs. Airport geometry was cited as a factor in qualitative research as early as 2008, and it is included in quantitative research with increasing frequency after 2012.

Airport characteristics. Airport characteristics studied in qualitative research articles encompassed more components than those identified by quantitative research. Quantitative research addressed inadequate lights, inadequate or ambiguous signs and markings, aircraft traffic volume, construction and airport size. Qualitative research addressed these components as well as the mix of air traffic (e.g., nearby flight schools) and ATC factors. Statistical methods may be able to quantify and document the impact of specific airport characteristics, but qualitative assessment methods may be able to identify a broader range of airport characteristics that may not be included in standard aviation databases.

Environmental factors. Environmental factors were identified in four qualitative research articles, but only one quantitative research article. This may be because environmental factors are not included as an explicit field in the FAA runway incursion database, making it more difficult to analyze using quantitative research methods. In some cases, quantitative research that included environmental factors was based on inferences using the month of the year (season), the time of day (light), and the weather conditions (airspeed, wind direction, temperature, and visibility); seasonal effects and sun glare were most frequently addressed by quantitative research. Environmental factors are much more likely to be included in qualitative analysis, and the qualitative approach may be more comprehensive, addressing a wider range of factors including variation in day length, snowfall, rainfall, and temperature.

Organizational factors and technical factors. Organizational and technical factors are also more likely to be addressed by qualitative articles than quantitative articles. The reason organizational factors are hard to analyze using quantitative research methods is that the enforceability of procedures, the ability to execute standards, and the effectiveness of supervision may be difficult to measure in quantitative ways, and are not reported in any public database. Technical factors in qualitative research articles analyzed the causes resulting from communication equipment problems and aircraft malfunctions. Technical factors addressed by quantitative research but not qualitative research include the effectiveness of widely-used technologies such as radar and visual monitoring systems and ATC alert systems.

Conclusions and Recommendations

Systematic literature reviews provide an evidence-based approach to facilitate reliable and accurate conclusions from multiple studies, and a strong basis for decision making. This paper introduces the concept of the systematic literature review to the aviation sector, and provides an example application to the study of RIs, an important factor for runway safety and a priority for the FAA.

The findings of this systematic literature review suggest that human factors and airfield geometry are the most influential factors affecting RIs, based on the findings of both quantitative and qualitative research. Other factors that affect RIs include airport characteristics and technical factors, followed by organizational factors and environmental factors. Environmental and organizational factors are important, but have not been addressed as often by quantitative research, perhaps because these factors are not explicitly included in many aviation databases. Qualitative research was much more likely to identify contributing factors from multiple topic areas, and often provided a higher level perspective on RIs.

The quantitative, qualitative and mixed-methods literature provide a number of recommendations to reduce RIs. These recommendations reflect the factors identified, including human factors, organizational factors and airport factors, such as airport geometry and airport characteristics, as well as technical factors related to both airports and aircraft. There were limited recommendations related to environmental factors.

One way to address human factors is to conduct initial and continuous training for pilots, air traffic controllers and ground operators. This training would address all causes of RI, including PD, IO and VPD incursions. Training may focus on both technical and non-technical skills. Technical skills include decision-making and the ability to deal with rapidly changing situations. Non-technical skills include communication skills, one of the most important components for safe ground operations. This training would mitigate errors made by controllers such as forgetting about an aircraft or a closed runway (Cardosi, Chase, & Eon, 2010). Training can also provide information regarding practices that help memory, such as writing instructions down or repeating them, as well as conditions that impair memory, such as environmental distractions and temporary or abnormal situations (Cardosi, Chase, & Eon, 2010). Training can also reinforce the importance of using standard aviation phraseology, including proper call signs and read back protocol and simple and short messages in communication, and the importance of requesting clarification when instructions are confusing (Leon, 2009; ICAO, 2007; Eurocontrol, 2011). Training should also include the development of organizational factors that support a systemic approach for human factors. This recognizes the importance of solutions that address both human factors and organizational factors that may affect human factors.

Organizational factors may best be addressed with support from the FAA and ICAO. These entities can support the reduction of RIs through the identification of best practices, standards and procedures. The airport ATC tower and ground control are responsible for different areas of the airport. As aircrafts and vehicles pass through different areas, responsibility passes from ATC controllers to the ground control operators responsible for that area (and vice versa). It is important that controllers and ground control operators remain in constant communication with each other throughout these transitions (De Reuck, Donald, & Siemers, 2014). It is also important that operational procedures and standards be consistent for everyone at joint-used airports, particularly where civil and military aircraft share a maneuvering area (Redzepovic, 2009).

Recommendations also address airport facilities, including airport geometry, airport characteristics, and airport technical factors. In some cases, RI can be addressed by reducing airfield complexity, including the number of intersections and conflict points. Airports with airside intersections (runway/runway, runway/taxiway or taxiway/taxiway) should have a long-term goal to revise the airport layout and reduce intersections. Modifying airport layout is an effective but an expensive way to reduce RIs and improve runway safety, and is consistent with the FAA (2015a) RIM program activities. Short term recommendations to address complex airport geometry include pilot review of the likely path for taxiing to the departure runway well before the aircraft leaves the gate or ramp. Similarly, pilots should also review the likely path for taxiing to the ramp or the gate before leaving cruise altitude (Oetzell, 2008).

Airport characteristics include airport construction, as well as inadequate lights, signs and markings. To address airport construction, controllers should notify pilots about construction before landing, and pilots should determine the location of construction areas at the origin and destination airports before they even start the engines (Torres, Metscher, & Smith, 2011). Inadequate airport lights, signs and markings can be addressed by enhanced airport surface markings, which make the hold short lines more distinct and highlight the centerline leading up to the hold short lines, providing an additional cue that there is an approaching runway (Cardosi, Chase, & Eon, 2010). Enhanced markings can reduce the likelihood that pilots and ground vehicle operators will cross the runway threshold when they intend to hold short.

Technology can also be used to reduce RIs, and may include technical enhancements for airports and in aircrafts. Airport technology includes airport surface detection equipment (e.g., ASDE-X) to provide robust information about aircraft and movement on the ground at airports. In the aircraft, technologies include enhanced displays for the commercial flight deck, which reduce the chance of being “head-down” and ensure continuous watch while taxiing (Leon, 2009). Enhanced displays in the cockpit may be particularly helpful for airline pilots taxiing at airports with unfamiliar or complex airport layouts. The wide range of recommendations reflect the complex operating environments of airports, and the variety of factors that contribute to RIs.

Future research in this area is recommended, including the use of the systematic literature review methodology to investigate other topics in aviation, as well as an expanded investigation of RIs. Expansion of the systematic literature review for RIs could include research conducted in other languages, and the inclusion of reports that have not been peer-reviewed. While the inclusion of only peer-reviewed research assured that all research included reflected quality publication standards, it also meant that publications from regulatory institutions such as the FAA and the European Aviation Safety Agency (EASA) were not included. Often significant findings from FAA and EASA research is documented not only in agency reports, but also in peer-reviewed conference proceedings and journal articles, however, this may not always be the case. Expansion of the study to include agency reports could encompass the findings of the FAA Runway Safety Reports between 2008 and 2014, the FAA National Runway Safety Plan for 2015 to 2017, and The European Action Plan for the Prevention of Runway Incursions published by the Eurocontrol.

The reduction of RIs is a top priority for FAA and an important activity to ensure aviation safety. In order to reduce the incidence of RIs, it is valuable to systematically investigate the research that has been conducted regarding contributing factors of RIs. This paper presents the process for a systematic literature review, and demonstrates the application of this method to synthesize the factors that correlate with RIs for quantitative, mixed-method and qualitative analysis published in peer-reviewed journal and conference papers. Six contributing factors to RIs were identified; these include human factors, airport geometry, technical factors, airport characteristics, environmental factors, and organizational factors. This research demonstrates the value of this systematic approach, which provides a useful tool to synthesize research findings from multiple studies, and is one way to advance research, increase safety, and optimize efficiency in the aviation sector.

References

Asare, B., & Ford, D. W. (2008). Reducing runway incursions: A simple, yet effective, next step. *Journal of Air Traffic Control*, 50(3), 22-28.

Aviation Safety Network. (2017). *Accident description.* Retrieved from http://aviation-safety.net/database/record.php?id=19841011-0

Bettany-Saltikov, J. (2010). Learning how to undertake a systematic review: Part 2. *Nursing Standard,* 24(51), 47-56.

Borrego, M., Foster, M. J., & Froyd, J. E. (2014). Systematic literature reviews in engineering education and other developing interdisciplinary fields. *Journal of Engineering Education*, 103(1), 45-76.

Borrego, M., Foster, M. J., & Froyd, J. E. (2015). What is the state of the art of systematic review in engineering education?. *Journal of Engineering Education*, 104(2), 212-242.

Bureau of Transportation Statistics. (2017). *U.S. air carrier traffic statistics through April 2017* [Data set]. Retrieved from https://www.transtats.bts.gov/TRAFFIC/

Cardosi, K., Chase, S., & Eon, D. (2010). Runway safety. *Air Traffic Control Quarterly*, 18(3), 303-328.

Chang, Y. H., & Wong, K. M. (2012). Human risk factors associated with runway incursions. *Journal of Air Transport Management*, 24, 25-30.

De Reuck, S., Donald, F., & Siemers, I. (2014). Factors associated with safety events in air traffic control. *Ergonomics SA: Journal of the Ergonomics Society of South Africa*, *26*(1), 2-18.

Eurocontrol. (2011). *European action plan for the prevention of runway incursions edition 2.0*. Retrieved from www.skybrary.aero/bookshelf/books/151.pdf

Federal Aviation Administration. (2010). *Runway safety program* (Order 7050.1A). Retrieved from https://www.faa.gov/documentLibrary/media/Order/7050.1A.pdf

Federal Aviation Administration. (2012a). *Pilot's handbook of aeronautical knowledge, Appendix 1*. Retrieved from https://www.faa.gov/airports/runway_safety/media/pdf/PHAK%20-%20Appendix%201%20-%20April%202012.pdf

Federal Aviation Administration. (2012b). *The strategic runway safety plan* (Publication No. 112-95). Retrieved from https://www.faa.gov/airports/runway_safety/news/congressional_reports/media/The%20Strategic%20Runway%20Safety%20Plan.pdf

Federal Aviation Administration. (2015a). *FAA implements new airport safety program*. Retrieved from https://www.faa.gov/news/updates/?newsId=83046

Federal Aviation Administration. (2015b). *Runway incursion*. Retrieved from https://www.faa.gov/airports/runway_safety/news/runway_incursions/

Federal Aviation Administration. (2017). *FAA runway safety office - runway incursions (RWS)* [Data base]. Retrieved from https://www.asias.faa.gov/apex/f?p=100:28::::::

General Aviation Manufactures Association. (2017). *2016 general aviation statistics databook & 2017 industry outlook*. Retrieved from https://gama.aero/wp-content/uploads/2016-GAMA-Databook_forWeb.pdf

Goodheart, B. (2013). Identification of causal paths and prediction of runway incursion risk by means of Bayesian belief networks. *Transportation Research Record: Journal of the Transportation Research Board*, (2400), 9-20.

Gough, D., Oliver, S., & Thomas, J. (2012). *An introduction to systematic reviews* (1st edition). Thousand Oaks, California: Sage Publications.

Heinrich, H. W. (1941). *Industrial accident prevention: A scientific approach.* New York City, New York: McGraw-Hill.

Huster, K. M., Müller, A., Prohn, M. J., Nowak, D., & Herbig, B. (2014). Medical risks in older pilots: A systematic review on incapacitation and age. *International Archives of Occupational and Environmental Health*, 87(6), 567-578.

International Civil Aviation Organization (ICAO). (2007). *Manual on the prevention of runway incursions* (Doc 9870 AN/463). Retrieved from https://www.icao.int/safety/RunwaySafety/Documents%20and%20Toolkits/ICAO_manual_prev_RI.pdf

Johnson, M. E., Zhao, X., Faulkner, B., & Young, J. P. (2016). Statistical models of runway incursions based on runway intersections and taxiways. *Journal of Aviation Technology and Engineering*, 5(2), 3.

Joslin, R. E., Goodheart, B. J., & Tuccio, W. A. (2011). A mixed method approach to runway incursion rating. *International Journal of Applied Aviation Studies*, 11(2), 13-36.

Ju, Z. (2011). Reason analysis of runway incursions based on grey theory. *Advanced Materials Research*, 328, 2400-2404.

Kim, D., & Yang, H. (2012). Evaluation of the risk frequency for hazards of runway incursion in Korea. *Journal of Air Transport Management*, 23, 31-35.

Leon, S. (2009). Combating runway incursions. *Professional Pilot*, 43(10), 110-114.

Mathew, J. K., Major, W. L., Hubbard, S. M., & Bullock, D. M. (2016). Statistical modelling of runway incursions. *Proceedings of the Transportation Research Board 95th Annual Meeting*.

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & Prisma Group. (2009). Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS Med, 6*(7). doi: 10.1371/journal.pmed.1000097

Mrazova, M. (2014). Runway incursions-clear and constant danger. *Incas Bulletin*, 6(3), 71.

Netherlands Aviation Safety Board. (1979). *Final report and comments of the Netherlands aviation safety board of the investigation into the accident with the collision of KLM flight 4805, Boeing 747-206B, PH-BUF, and Pan American flight 1736, Boeing 747-121, N736PA at Tenerife airport, Spain on 27 March 1977.* Retrieved from http://www.project-tenerife.com/nederlands/PDF/ finaldutchreport.pdf

Oetzell, S. (2008). Avoiding runway incursions. *Professional Pilot*, 42(1), 90-94.

Petticrew, M., & Roberts, H. (2008). *Systematic reviews in the social sciences: A practical guide*. Hoboken, New Jersey: John Wiley & Sons.

Redzepovic, G. (2009). Prevention of runway incursions at joint use aerodromes. *International Airport Review*, 13(4).

Rogerson, E. C., & Lambert, J. H. (2012). Prioritizing risks via several expert perspectives with application to runway safety. *Reliability Engineering & System Safety*, 103, 22-34.

Rogerson, E. C., Lambert, J. H., & Johns, A. F. (2013). Runway safety program evaluation with uncertainties of benefits and costs. *Journal of Risk Research*, 16(5), 523-539.

Salkind, N. J. (2011). Exploring research. *Selecting a problem and reviewing the research* (pp. 39-82). London, United Kingdom: Pearson Education Inc.

Schönefeld, J., & Möller, D. P. F. (2012). Runway incursion prevention systems: A review of runway incursion avoidance and alerting system approaches. *Progress in Aerospace Sciences*, 51, 31-49.

Siddaway, A. (n.d.). *What is a systematic literature review and how do I do one* [PDF document]. Retrieved from https://pdfs.semanticscholar.org/2214/2c9cb17b4baab118767e497c93806d741461.pdf

Stroeve, S. H., Blom, H. A., & Bakker, G. B. (2013). Contrasting safety assessments of a runway incursion scenario: Event sequence analysis versus multi-agent dynamic risk modelling. *Reliability Engineering & System Safety*, 109, 133-149.

Stroeve, S. H., Som, P., van Doorn, B. A., & Bakker, G. B. (2016). Strengthening air traffic safety management by moving from outcome-based towards risk-based evaluation of runway incursions. *Reliability Engineering & System Safety*, 147, 93-108.

Torres, K. R., Metscher, D. S., & Smith, M. (2011). A correlation study of the relationship between human factor errors and the occurrence of runway incursions. *International Journal of Professional Aviation Training & Testing Research*, 5(1).

Wauben, L. S., Lange, J. F., & Goossens, R. H. (2012). Learning from aviation to improve safety in the operating room-a systematic literature review. *Journal of Healthcare Engineering*, 3(3), 373-390.

Wilke, S., Majumdar, A., & Ochieng, W. (2012). Holistic approach to airport surface safety. *Transportation Research Record: Journal of the Transportation Research Board*, 2300, 1-12.

Wilke, S., Majumdar, A., & Ochieng, W. Y. (2013). Airport surface operations: A holistic framework for operations modeling and risk management. *Safety Science*, 63, 18-33.

Wilke, S., Majumdar, A., & Ochieng, W. Y. (2015a). Modelling runway incursion severity. *Accident Analysis & Prevention*, 79, 88-99.

Wilke, S., Majumdar, A., & Ochieng, W. Y. (2015b). The impact of airport characteristics on airport surface accidents and incidents. *Journal of safety research*, 53, 63-75.

Collegiate Aviation Review
International

Volume 36 | Issue 2

Peer-Reviewed Article #4

7-25-2018

The Relationship Between Pilot Attitudes and the Execution of Flight Safety Checklists

Barry H. Hyde
Federal Aviation Administration

David S. Cross
Embry-Riddle Aeronautical University

A foundation of safe aircraft operation is correct checklist usage by the pilot. Correct checklist usage increases safe operations, which, in turn, creates a more efficient and economically-stable air transportation system. Pilots do not always properly execute their flight safety checklists before takeoff, during flight, and before landing airplanes, resulting in aviation accidents. The resultant business and social costs merit examination of the factors, attitudes, and training needed to minimize or eliminate accidents due to improper checklist execution. This quantitative research identified and evaluated the factors related to the improper execution of flight safety checklists with a survey of 109 certificated pilots regarding their usage and attitudes with respect to flight safety checklists. An important finding was that although no statistical difference was found, pilots with greater self-confidence and less risk orientation tended to place greater importance on the execution of flight safety checklists.

Recommended Citation:
Hyde, B.H., & Cross, D.S. (2018). The Relationship Between Pilot Attitudes and the Execution of Flight Safety Checklists. *Collegiate Aviation Review International*, 36(2), 58-73. http://dx.doi.org/10.22488/okstate.18.100490

Overall accident rates in the aviation industry have declined since 1990 and changes in flight safety operations, combined with important advances in technology, have led to significant improvements in flight safety. The Federal Aviation Administration (FAA) has for more than two decades focused its training on pilot attitudes regarding aviation safety as a mechanism to prevent aviation accidents. However, little research has been done to assess the impact of pilot attitudes on behaviors cited as causal or contributing factors in aviation accidents. Pilots have trained to perform cockpit tasks by using checklist procedures during normal and abnormal operations. A checklist is a visual or oral aid used to identify and verify that items or steps were completed for a particular task, however, the improper performance of a flight safety checklist is a potential safety hazard. The improper performance of flight safety checklists for the purpose of this study includes skipping items on a checklist either intentionally or in error, or not executing a required checklist in its entirety. Improper checklist execution can occur due to pilot time constraints and because pilots forget to execute a checklist associated task after postponing it. Pilot performance of flight safety checklists is an integral part of flight safety as the checklists aid a pilot in completing tasks before takeoff, during flight, and before landing an airplane. Although the importance of flight safety checklists to safe flight has been well established, some pilots continue to take risks by not completely executing flight safety checklists. Risk is inherent to every flight, but how risk is perceived and influenced by pilot attitudes has implications for aviation safety.

Background

Flight safety checklists date back to the 1930s, predating the post-war interest and development of the human factors profession (Forsyth, 2007). During this time, checklists were developed because pilots were being injured and killed as a result of neglecting important tasks thought to be a result of relying solely on memory.

The complete execution of a flight safety checklist decreases the likelihood of an accident by removing the human factor of memory reliance. Rather, improper execution of a checklist occurs due to an improper attitude toward completion, pilot time constraints, and pilot failure to execute a checklist associated task after postponing it. Thus, any opportunity to improve checklist usage, such as through training, flight reviews, and pilot recertification should be considered to improve flight safety.

Literature Review

Previous research that examined the flight safety attitudes of pilots led Berlin et al. (1982) to develop a self-assessment instrument that was used to help identify hazardous pilot attitudes. The attitudes that were identified included the following: *macho* (characterized as a belief that one was better than others and risky behaviors that serve to justify this belief), *antiauthoritarianism* (characterized as a resentment of control by outside authority figures), *impulsivity* (characterized as a need to react quickly without thinking a situation through), *resignation* (characterized by a belief that one has no control over a situation), and *invulnerability* (characterized by a belief that one is immune to harm).

In later research, the Aviation Safety Attitude Scale (ASAS) was developed to assess pilot attitudes regarding aviation safety issues with items reflecting the five hazardous attitudes in addition to items reflective of self-perceived skill and risk perception during flight. The ASAS included three pilot attitude subscales: *self-confidence*, or a pilot's confidence in his or her abilities related to operating an aircraft; *risk orientation*, the extent to which a pilot exhibited risky behavior; and *safety orientation*, the extent to which a pilot makes more cautious decisions. Research using ASAS suggested that risk perception was a key predictor of pilot behavior and was positively correlated with accident involvement (Hunter, 2005).

According to Parson (2008), aviation accidents associated with the improper execution of flight safety checklists occur because pilots do not completely execute their flight safety checklists before takeoff, during flight, or before landing. In this study the authors created a simple plan for dealing with emergency approaches. The plan included use of the ABCs (airspeed, best field for landing, checklist, etc.). This system, although generic, helped reinforce the criticality of checklists.

The Aircraft Owners and Pilots Association Air Safety Foundation (AOPAASF), the FAA, and the National Transportation Safety Board (NTSB) have identified a number of reasons for the improper execution of checklists. Some of these reasons include pilots unintentionally missing items or becoming complacent while checking important items on a flight safety checklist (AOPAASF, 2011; FAA, 2010; NTSB, 2012). Greater pilot compliance regarding checklist completion could lead to a reduction in aviation accidents and decreases in property damage and loss of life.

Risk tolerance is particularly important in safety-related professions, as workers are often exposed to workplace risks. The opportunity for pilots to engage in risky behavior is present daily. A pilot's risk tolerance can have a direct impact on safety (Ji, You, Lan, & Yang, 2011). Pilots with high risk tolerance make decisions that expose them to unnecessary dangers, leading to increased chances of an accident. However, a more experienced pilot may consider a situation to be low risk; whereas, a less experienced pilot may consider this same situation to be high risk. For example, a pilot that is qualified to fly in instrument meteorological conditions may perceive less of a risk when encountering clouds and low visibility than a pilot who is only qualified to fly in visual meteorological conditions (Joseph & Reddy, 2013). Underestimating the risk inherent in a particular situation and overestimating personal ability leads to a misperception of risk and these decision-making errors have been frequently found to contribute to aircraft accidents (Joseph & Reddy, 2013).

Research has shown that hazardous pilot attitudes are important with respect to the relationships between risk perception, risk tolerance, and safety. These relationships are important because risk tolerance directly influences hazardous attitudes, which then directly influences safety (Ji et al., 2011). A pilot who does not execute a flight safety checklist exemplifies behavior directly related to a hazardous attitude associated with their risk perception. Pilots were trained to perform all checklist items and they know how important they are to safety. In some cases, however, pilots do not perceive that a flight safety checklist is necessary, thereby placing the flight at risk. A pilot's hazardous attitudes regarding safety increases their risk tolerance due to a number of factors, such as skipping items on a checklist due to time constraints, being interrupted and not returning to the stopping point on the checklist, and taking short cuts on the flight safety checklist because of fatigue.

Joseph and Reddy (2013) administered four questionnaires to a sample of 275 Indian Army helicopter pilots in order to study risk perception and safety attitudes regarding risky behavior and hazardous events. The four questionnaires consisted of: (1) the ASAS; (2) the Army Hazardous Event Scale (AHES), a 36-item scale used to assess a participant's involvement in hazardous aviation events; (3) the Risk Perception (Other) scale (RPO), a 17-item measure of a participant's perception of risk present in an aviation situation; and (4) the Risk Taking Tendency (RTT) scale, a five-item measure of a participant's risk-taking tendencies (Joseph & Reddy, 2013). Results from the research revealed that high scores on risk-orientation, the extent to which a pilot exhibited risky behavior, and low scores on safety-orientation, the extent to which a pilot makes more cautious decisions, were related to a higher risk-taking tendency. The high risk-orientation and low safety-orientation scores were significantly associated with increased involvement in hazardous aviation events as measured by the ASAS (Joseph & Reddy, 2013). Demonstration of the relationship between pilot attitudes, risk-taking tendency, and involvement in hazardous aviation events supported the use of the ASAS for aviation research studies pertaining to hazardous attitudes and safety related behaviors, such as the execution of flight safety checklists. The measures of safety attitudes, risk-perception, risk-taking, and involvement in hazardous aviation events could serve to assess precursors of accident risk among pilots (Joseph & Reddy, 2013).

Several factors contributing to deviations in proper checklist execution have been identified. For example, pilots may rush through the execution of a flight safety checklist, thereby skipping items or become complacent with the execution of a flight safety checklist (FAA, 2010; NTSB, 2012). The National Aeronautics and Space Administration (NASA) analyzed human errors associated with the improper execution of flight safety checklists. NASA's project revealed five different patterns of human error associated with the improper execution of flight safety checklists, including: (1) reciting a flight safety checklist from memory and not actually executing the flight safety checklist; (2) the failure of a pilot to read a flight safety checklist to verify and crosscheck another pilot's actions, in cases where there was more than one pilot; (3) performing multiple checklist items together instead of individually; (4) early termination of or incomplete execution of a flight safety checklist; and (5) distractions leading to missed checklist items (Frakes & Van Voorhis, 2007). In addition to different patterns of human error, errors related to the execution of flight safety checklists were generally classified into one of the following five categories: (1) checklist interruptions; (2) overlooking a checklist item; (3) using the wrong checklist; (4) checklist omission; and (5) checklist confusion (National Aeronautics and Space Administration, 2014). Checklist interruptions and distractions was the human error category that was most prevalent in ASRS reports involving checklist errors.

Problem

A pilot's attitudes affect his or her decision-making ability, thought patterns, and risk perceptions during all aspects of flight, which affects how he or she will respond to a given situation. Researchers have identified several specific hazardous pilot attitudes that are related to their willingness to violate regulations, exceed safety limits, or operate an aircraft in conditions beyond their capabilities (Berlin et al., 1982). The problem investigated was the potential devastating effects of not correctly completing flight safety checklists. Previous research suggests that improper execution of checklists has had devastating effects on pilots, property, and the air transportation system itself throughout aviation history.

Purpose

The purpose of this quantitative, correlational survey study was to examine whether a relationship exists between pilot attitudes and the execution of flight safety checklists. To examine the relationship between these variables, the ASAS was administered to pilots to assess their attitudes toward flight safety as well as the extent to which they properly executed all flight safety checklists. The theoretical perspective for this study is derived from the literature review, specifically, Berlin et. al. (1982) and Hunter (2005) whose research suggest that pilot attitudes and risky behavior influence safety behaviors. A better understanding of the effects of pilot attitudes will provide managers options for better processes and planning of aviation systems throughout the aviation industry.

Research Question

The research addressed the following research question:

Q: To what extent, if any, do the pilot attitudes self-confidence and risk orientation, as measured by the self-confidence and risk orientation subscales of the ASAS, respectively, predict the self-reported complete execution of all flight safety checklists for every flight, among participating pilots?

Hypotheses

$H1_0$: The pilot attitudes self-confidence and risk orientation, as measured by the self-confidence and risk orientation subscales of the ASAS, respectively, do not significantly predict the self-reported complete execution of all flight safety checklists for every flight, among participating pilots.

$H1_a$: The pilot attitudes self-confidence and risk orientation, as measured by the self-confidence and risk orientation subscales of the ASAS, respectively, do significantly predict the self-reported complete execution of all flight safety checklists for every flight, among participating pilots.

Research Method

Research Method and Design

The research was conducted using a quantitative, correlational survey design to examine the relationship between hazardous pilot attitudes and the usage of flight safety checklists. A survey design was selected because the use of personal interviews did not allow for pilot anonymity. Participant anonymity was critical because it increased the likelihood of truthful participant responses. Pilots may be reluctant to report not executing a flight safety checklist without an assurance of anonymity.

The ASAS was selected for this study because it was developed to assess pilot attitudes regarding aviation safety issues with items reflecting the five hazardous attitudes in addition to items regarding the weather, risk perception, and self-perceived skill. The ASAS consists of 27 items, 10 of which reflect the five hazardous attitudes that were identified in previous research, including macho, antiauthoritarianism, impulsivity, resignation, and invulnerability (Hunter, 2005). The remaining 17 items assess pilot attitudes regarding the weather, risks encountered in aviation, the likelihood of experiencing an accident, and self-perceived skill. Exploratory principle component analysis of the ASAS identified three subscales representing self-confidence, risk orientation, and safety orientation. For example, an item representing self-confidence is “I am a very capable pilot.” An example of a risk orientation item is “I would duck below minimums to get home.” An example of a safety orientation item is “I am a very cautious pilot.”

Sample

Pilots were recruited using the email newsletter distributed by the consulting firm Curt Lewis and Associates. The sample was one of convenience. A description of the proposed study and an invitation to participate in the research was provided within the email newsletter, which also included a link to the survey.

A power analysis was conducted using G*Power (Faul, Erdfelder, Buchner, & Lang, 2009) to determine the appropriate sample size for the multiple regression analysis using the following parameters: two predictor variables (self-confidence attitude and risk orientation attitude), a small effect size of .15, and an alpha and beta of .05 and .80, respectively, resulting in a required sample size of 87. A link to the survey was included as part of the newsletter.

Materials and Instruments

The ASAS consisted of 27 items that assessed pilot attitudes regarding aviation safety issues. Sample items from the scale included: *I am a very careful pilot*; *I know aviation procedures very well*; and, *I deal with stress very well*. A second section was included consisting of two items that assessed pilot attitudes regarding flight safety checklist usage: *I believe flight safety checklists are necessary for every flight*, and *I completely execute all flight safety checklists for every flight.* The sections utilized a Likert-type response scale that ranged from 5, *strongly agree*, to 1, *strongly disagree*. A third section included demographic questions assessing age, gender, and flight experience.

Limitations

One possible limitation to the proposed research is the use of participant self-reported data. Participants may be reluctant to respond honestly regarding whether they executed all flight safety checklists for all flights, given that the execution of all flight safety checklists was a requirement for every flight. One measure taken to mitigate this limitation was the assurance of participant anonymity.

Findings

This study included a survey of 109 pilots to examine the extent to which pilot attitudes of pilot self-confidence and risk orientation as measured by the self-confidence and risk orientation subscales of the Aviation Safety Attitude Scale (Hunter, 2005) predict the self-reported completion of all flight safety checklists for every flight among participating pilots.

A total of 109 responses were received from the study invitation. Of the 109 responses, 97 (88.9%) study participants were male, and 12 (11.1%) were female. The age distribution of participants included 3 (2.8%) 18-25 years, 14 (12.8%) 26-40 years, 57 (52.3%) 41-59 years, 35 (32.1%) 60 years or older. The majority, 70 (64.2%) had more than 5,000 hours of total flight time. The most common type of pilot was airline transport 79 (72.5%).

The ASAS scale measures three variables, self-confidence, risk orientation, and safety orientation. The researchers included three questionnaire items to measure pilot's execution of flight safety checklists.

Table 1 shows descriptive statistics for the independent variables, self-confidence and risk orientation regarding aviation safety. The self-confidence score had a possible range of 14 to 70. The mean, 52.9, was well above the midpoint of 42, indicating that on average, the study participants had a relatively high level of self-confidence regarding aviation safety. The risk orientation score had a possible range of 8 to 40. The mean, 16.7, was well below the midpoint of 24, indicating that on average, the study participants had a relatively low level of risk orientation (risk averse) regarding aviation safety.

Table 1

Descriptive Statistics for Aviation Safety Attitude Scores

	N				
	Valid	*M*	*SD*	Min	Max
Self-confidence	109	52.93	6.34	34.00	66.00
Risk Orientation	109	16.73	4.15	10.00	29.00

Table 2 provides the frequency distributions for the two-flight safety checklist questionnaire items (dependent variables). Although every study participant answered either s*omewhat agree* or s*trongly agree*, these two responses are very different. That is, for maximum safety, all pilots should *strongly agree* to both questions. It could also be argued that those who only *somewhat agreed* have a less safe attitude regarding the use of flight safety checklists. Therefore, it is reasonable to compare the independent variables with these two dependent variables.

Table 2

Frequency table for "I Believe Flight Safety Checklists are Necessary for Every Flight"

	Frequency	Percent
Somewhat Agree	9	8.3
Strongly Agree	100	91.7
Total	109	100.0

Frequency table for "I Completely Execute all Flight Safety Checklists for Every Flight"

	Frequency	Percent
Somewhat Agree	22	27.2
Strongly Agree	59	72.8
Total	81	100.0

The research question was analyzed in four areas:

$H1_0$: There is not a significant difference in the level of self-confidence regarding aviation safety between those who *somewhat agreed* and those who *strongly agreed* that flight safety checklists are necessary for every flight.

$H2_0$: There is not a significant difference in the level of risk orientation regarding aviation safety between those who *somewhat agreed* and those who *strongly agreed* that flight safety checklists are necessary for every flight.

$H3_0$: There is not a significant difference in the level of self-confidence regarding aviation safety between those who *somewhat agreed* and those who *strongly agreed* with the statement "I completely execute all flight safety checklists for every flight."

$H4_0$: There is not a significant difference in the level of risk orientation regarding aviation safety between those who *somewhat agreed* and those who *strongly agreed* with the statement "I completely execute all flight safety checklists for every flight."

Dependent Variable 1: Flight safety checklists are necessary for every flight (Labeled "RSQ1").

Dependent Variable 2: I completely execute all flight safety checklists for every flight (Labeled "RSQ2").

Both questions were asked as Strong Agree (coded as "5") to Strongly Disagree (coded as "1"). Because the distribution of the both dependent variables was binary, logistic regression was determined appropriate for the analysis. Below, "5" = Strongly Agree and "4" = Agree" for both dependent variables.

Frequencies and Percentages

The most frequently observed category of RSQ1 was 5 (*n* = 100, 92%). The most frequently observed category of RSQ2 was 5 (*n* = 82, 75%). Frequencies and percentages are presented in Table 3.

Table 3

Frequency Table for Nominal Variables

Variable	*n*	%
RSQ1		
4	9	8.26
5	100	91.74
Missing	0	0.00
RSQ2		
4	27	24.77
5	82	75.23
Missing	0	0.00

It is important to note that the dependent variable for RSQ1 is less than 10, which means the regression analysis should be interpreted with caution given the rare-event data. However, given that there are two dependent variables, the overall results may be interpreted holistically.

Next, descriptive statistics were examined for the independent variables or predictors (Pilot Self Confidence and Pilot Risk Orientation). Both predictors are scales based on the Aviation Safety Attitude Scale (Hunter, 2005). Pilot Self Confidence were asked on Likert scale as Strong Agree (coded as “5”) to Strongly Disagree (coded as “1”).

Summary Statistics

The observations for Pilot_Self_Confidence had an average of 3.80 (*SD* = 0.32, SE_M = 0.03, Min = 2.94, Max = 4.44). The observations for Pilot_Risk_Orientation had an average of 2.23 (*SD* = 0.56, SE_M = 0.05, Min = 1.14, Max = 4.14). Skewness and kurtosis were also calculated in Table 4. When the skewness is greater than or equal to 2 or less than or equal to -2, then the variable is considered to be asymmetrical about its mean. When the kurtosis is greater than or equal to 3, then the variable's distribution is markedly different than a normal distribution in its tendency to produce outliers (Westfall & Henning, 2013). Both skewness and kurtosis fell in the normal range.

Table 4

Summary Statistics Table for Interval and Ratio Variables

Variable	*M*	*SD*	*n*	SE_M	Skewness	Kurtosis
Pilot_Self_Confidence	3.80	0.32	109	0.03	-0.41	0.08
Pilot_Risk_Orientation	2.23	0.56	109	0.05	0.91	1.03

Binary Logistic Regression

Research Question 1 (RSQ1). A binary logistic regression was conducted to examine whether Pilot_Self_Confidence and Pilot_Risk_Orientation had a significant effect on the odds of observing the “5” category of RSQ1. The reference category for RSQ1 was a score of 4.

Assumptions. Variance Inflation Factors (VIFs) were calculated to detect the presence of multicollinearity between predictors. High VIFs indicate increased effects of multicollinearity in the model. Variance Inflation Factors greater than five are cause for concern, whereas VIFs of 10 should be considered the maximum upper limit (Menard, 2009). All predictors in the regression model have VIFs less than 10. Table 5 presents the VIF for each predictor in the model.

Table 5

Variance Inflation Factors for Pilot_Self_Confidence and Pilot_Risk_Orientation

Variable	*VIF*
Pilot_Self_Confidence	1.00
Pilot_Risk_Orientation	1.00

Results. The overall model, $\chi^2(2) = 0.49$, $p = .781$ was not significant, suggesting that Pilot_Self_Confidence and Pilot_Risk_Orientation did not have a significant effect on the odds of observing the 5 category of RSQ1. McFadden's R-squared was calculated to examine the model's fit, where values greater than .2 are indicative of models with excellent fit (Louviere, Hensher, & Swait, 2000). The McFadden R-squared value calculated for this model was .01. Since the overall model was not significant, the individual predictors were not examined further. Table 6 summarizes the results of the regression model.

Table 6

Logistic Regression Results with Pilot_Self_Confidence and Pilot_Risk_Orientation Predicting RSQ1

Variable	*B*	*SE*	χ^2	*p*	*OR*
(Intercept)	4.22	4.37	0.94	.333	
Pilot_Self_Confidence	(-0.24)	1.08	0.05	.826	0.79
Pilot_Risk_Orientation	(-0.40)	0.58	0.48	.487	0.67

Note. $X^2(2) = 0.49$, $p = .781$, McFadden $R^2 = 0.01$.

Research Question 2 (RSQ2). Next, a binary logistic regression was conducted to examine whether Pilot_Self_Confidence and Pilot_Risk_Orientation had a significant effect on the odds of observing the “5” category of RSQ2. The reference category for RSQ2 was 4.

Assumptions. Variance Inflation Factors (VIFs) were calculated to detect the presence of multicollinearity between predictors. High VIFs indicate increased effects of multicollinearity in the model. Variance Inflation Factors greater than 5 are cause for concern, whereas VIFs of 10 should be considered the maximum upper limit (Menard, 2009). All predictors in the regression model have VIFs less than 10. Table 7 presents the VIF for each predictor in the model.

Table 7

Variance Inflation Factors for Pilot_Self_Confidence and Pilot_Risk_Orientation

Variable	*VIF*
Pilot_Self_Confidence	1.00
Pilot_Risk_Orientation	1.00

Results. The overall model was not significant, $\chi^2(2) = 0.09$, $p = .956$, suggesting that Pilot_Self_Confidence and Pilot_Risk_Orientation did not have a significant effect on the odds of observing the 5 category of RSQ2. McFadden's R-squared was calculated to examine the model's fit, where values greater than .2 are indicative of models with excellent fit (Louviere et al., 2000). The McFadden R-squared value calculated for this model was 0.00. Since the overall model was not significant, the individual predictors were not examined further. Table 8 summarizes the results of the regression model.

Table 8

Logistic Regression Results with Pilot_Self_Confidence and Pilot_Risk_Orientation Predicting RSQ2

Variable	*B*	*SE*	χ^2	*p*	*OR*
(Intercept)	1.74	2.87	0.37	.543	
Pilot_Self_Confidence	(-0.19)	0.70	0.07	.785	0.83
Pilot_Risk_Orientation	0.04	0.40	0.01	.920	1.04

Note. $X^2(2) = 0.09$, $p = .956$, McFadden $R^2 = 0.00$.

Discussion

The intent of this research was to examine to what extent, if any, do the pilot attitudes self-confidence and risk orientation, as measured by the self-confidence and risk orientation subscales of the ASAS, respectively, predict the self-reported complete execution of all flight safety checklists for every flight, among participating pilots.

$H1_0$: There is not a significant difference in the level of self-confidence regarding aviation safety between those who *somewhat agreed* and those who *strongly agreed* that flight safety checklists are necessary for every flight.

The results indicated some evidence to suggest that pilots who *strongly agreed* that flight safety checklists are necessary for every flight tend to have more self-confidence regarding aviation safety compared to those who only *somewhat agreed* that flight safety checklists are necessary for every flight. However, there was not a statistically significant difference between the two groups. The null hypothesis was not rejected and it was concluded that there is insufficient evidence to suggest there is a difference in the level of self-confidence in aviation safety between those who *somewhat agreed* and those who *strongly agreed* with the statement.

H2$_0$: There is not a significant difference in the level of risk orientation regarding aviation safety between those who *somewhat agreed* and those who *strongly agreed* that flight safety checklists are necessary for every flight.

The results indicated some evidence to suggest that pilots who *strongly agreed* that flight safety checklists are necessary for every flight tend to have less risk orientation regarding aviation safety compared to those who only *somewhat agreed* that flight safety checklists are necessary for every flight. However, there was not a statistically significant difference between the two groups. The null hypothesis was not rejected and it was concluded that there is insufficient evidence to suggest that pilots who *strongly agreed* that flight safety checklists are necessary for every flight tend to have less risk orientation regarding aviation safety compared to pilots who only *somewhat agreed* with the statement.

H3$_0$: There is not a significant difference in the level of self-confidence regarding aviation safety between those who *somewhat agreed* and those who *strongly agreed* with the statement "I completely execute all flight safety checklists for every flight."

The results indicated some evidence to suggest that pilots who *strongly agreed* with the statement "I completely execute all flight safety checklists for every flight" tend to have greater self-confidence regarding aviation safety compared to those who only *somewhat agreed* with the statement. However, there was not a statistically significant difference between the two groups. The null hypothesis was not rejected and it was concluded that there is insufficient evidence to suggest that pilots who *strongly agreed* with the statement "I completely execute all flight safety checklists for every flight" tend to have greater self-confidence regarding aviation safety compared to those who only *somewhat agreed* with the statement.

H4$_0$: There is not a significant difference in the level of risk orientation regarding aviation safety between those who *somewhat agreed* and those who *strongly agreed* with the statement "I completely execute all flight safety checklists for every flight."

The results indicated some evidence to suggest that pilots who *strongly agreed* with the statement "I completely execute all flight safety checklists for every flight" tend to have a lower level of risk orientation regarding aviation safety compared to those who only *somewhat agreed* with the statement. However, there was not a statistically significant difference between the two groups. The null hypothesis was not rejected and it was concluded that there is insufficient evidence to suggest that pilots who *strongly agreed* with the statement "I completely execute all flight safety checklists for every flight" tend to have less risk orientation regarding aviation safety compared to those who only *somewhat agreed* with the statement.

The findings indicated that a study with a larger number of participants and more discriminatory questions is needed to determine whether there is a relationship between pilot attitudes and their self-reported use of flight safety checklists. Analysis of the demographic data revealed that the sample was not representative of the entire pilot population because of the high number of pilots with airline transport pilot qualifications and flight instructor certificates. It is likely that these more experienced pilots would have more positive habits and attitudes associated with flight safety checklists. A solution may be to exclude airline transport pilots from a future study, thereby focusing on general aviation pilots exclusively. Another solution would be to solicit feedback from private pilots that fly for pleasure and eliminate any commercial pilots. It would also be important in future research to provide the questionnaire to a wider variety of pilots as this questionnaire was available only to pilots who used this one website and may not be representative of the total pilot population. Additional items should also be added to gather more specific information on the quality of checklist usage versus whether or not a checklist was completed. These items could include whether checklists are read out loud, whether they are restarted when interrupted, and whether their initiation is associated with salient events. This study is a first step in evaluating whether an emphasis on pilot attitudes in flight training is a meaningful way to affect pilot behavior with respect to issues of flight safety, such as the use of checklists.

Conclusions

In conclusion, these research findings may not be generalizable to the entire population of general aviation pilots because of limited sample size and the convenience sampling method used. Even with these limitations, an important finding was that pilots vary in the extent to which they regard the necessity and importance of flight safety checklists. The data suggest that checklist usage, which is a fundamental part of aviation safety practices from the very first flight lesson, may not be considered at the critical level of importance that it needs to be to achieve the greatest safety benefits. If flight safety checklists are not always regarded at the highest level of importance by a pilot for every flight, this may be an indication that there is a need to reemphasize training on this particular skill more effectively.

Recommendations

Based on the findings from this study, one recommendation is that pilot training should continue to focus on the importance of executing all flight safety checklists for every flight. Pilots in this study all agreed that checklists are necessary for every flight, however, some of the pilots only *somewhat agreed* with this statement indicating there is opportunity for improvement.

Although there were indications that self-confidence and risk orientation affected how strongly pilots regarded checklist usage, no strong conclusions could be made that the focus of training on pilot attitudes would affect checklist usage. To ensure the proper execution of checklists, pilot training needs to focus on the proper and consistent execution of checklists and not solely focus on attitudes which affect behavior. Training should focus on those factors that have been shown to affect the proper deliberate execution of checklists rather than performing checklists in a mechanical fashion that is vulnerable to errors. If pilots do not strongly regard the execution of checklists, then it may be that the pilots are not performing the checklists properly or as consistently as they should be, indicating that more training on this behavior is warranted by the findings.

Future Research

Significant value can be derived from this research for the additional future research that can build upon these initial findings. Future research needs to focus on private pilots from a wider demographic area by soliciting through multiple means. A larger sample would broaden the scope of future research. More research should also focus more on the quality of the checklist execution process versus the importance of checklist execution completion. It is important that future research recognizes the trends in checklist usage that is redirecting general aviation away from the use of manual checklists and toward the use of electronic checklists. Flight safety attitudes identified in previous research by Berlin et al. (1982) could also be used comparatively with checklist usage in future research. In addition, future research should take into account a larger level of detail related to Hunter (2005) including pilot experience, aircraft complexity, phase of flight, and other key variables that may influence both human factors and checklist significance.

References

Aircraft Owners and Pilots Association Air Safety Foundation. (2011). Joseph T. Nall report, accident trends and factors for 2010. Retrieved from https://www.aopa.org/-/media/files/aopa/home/training-and-safety/nall-report/11nall.pdf

Berlin, J. I., Gruber, E. V., Holmes, C. W., Jensen, P. K., Lau, J. R., Mills, J. W., & O'Kane, J. M. (1982). Pilot judgment training and evaluation (Volume I) (DOT/FAA/CT-82/56-I). Retrieved from http://www.tc.faa.gov/ its/worldpac/techrpt/ct82-56-1.pdf

Faul, F., Erdfelder, E., Buchner, A., & Lang, A. G. (2009). Statistical power analyses using G*Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods*, 41, 1149-1160.

Federal Aviation Administration. (2010). Abbreviations, acronyms and definitions. Retrieved from https://www.faa.gov/jobs/abbreviations/

Forsyth, E. (2007). *Human factors in aviation/aerospace industry*. Daytona Beach, FL: Embry-Riddle Aeronautical University.

Frakes, M., & Van Voorhis, S. (2007). Effectiveness of a challenge-and-respond checklist in ensuring safety behavior compliance by medical team members at a rotor-wing air medical program. *Air Medical Journal*, 26(5), 248-251. doi:10.1016/j.amj.2007.05.009

Hunter, D. (2005). Measurement of hazardous attitudes among pilots. *International Journal of Aviation Psychology*, 15(1), 23-43. https://doi.org/10.1207/s15327108ijap1501_2

Ji, M., You, X., Lan, J., & Yang, S. (2011). The impact of risk tolerance, risk perception and hazardous attitude on safety operation among airline pilots in China. *Safety Science*, 49, 1412-1420. https://doi.org/10.1016/j.ssci.2011.06.007

Joseph, C., & Reddy, S. (2013). Risk perception and safety attitudes in Indian army aviators. *International Journal of Aviation Psychology*, 23(1), 49-62. https://doi.org/10.1080/10508414.2013.746531

Louviere, J. J., Hensher, D. A., & Swait, J. D. (2000). *Stated choice methods: Analysis and applications*. Cambridge University Press. Cambridge, UK.

Menard, S. (2009). *Logistic regression: From introductory to advanced concepts and applications*. Sage Publications. Thousand Oaks, CA.

National Aeronautics and Space Administration. (2014). Aviation safety reporting system: Callback. Retrieved from http://asrs.arc.nasa.gov

National Transportation Safety Board. (2012). Improve general aviation safety. NTSB most wanted list. Retrieved from www.ntsb.gov/safety/mwl5_2012.html

Parson, S. (2008). ABCDE emergencies step by step: Teach emergencies with the ABCs. *FAA Safety Briefing*. Retrieved from www.faa.gov/news/safety_briefing/2008/media/mayjun2008.pdf

Westfall, P. H., & Henning, K. S. S. (2013). *Texts in statistical science: Understanding advanced statistical methods*. Boca Raton, FL: Taylor & Francis.

Collegiate Aviation Review International

Volume 36 | Issue 2 Peer-Reviewed Article #5

9-6-2018

Commercial Airline Pilots’ Attitudinal Data on Controlled Rest in Position: A Qualitative Inquiry

Stephen Rice
Embry-Riddle Aeronautical University

Scott R. Winter
Embry-Riddle Aeronautical University

Emily C. Anania
Embry-Riddle Aeronautical University

Gajapriya Tamilselvan
Hampton University

Shawn Doherty
Embry-Riddle Aeronautical University

The purpose of this study was to assess the attitudinal data of commercial pilots on the possible implementation of controlled rest in position (CRIP). Prior research indicated that pilot napping could be beneficial to reduce fatigue. While CRIP has been implemented by some international regulatory agencies, it remains prohibited in the United States. Through a qualitative methodology and a phenomenological approach, 30 commercial pilots from the United States presented their thoughts on an open-ended research instrument as to the possible advantages, disadvantages, and implementation aspects of CRIP. The findings indicated that 70% of participants were in favor of CRIP implementation. However, participants expressed concerns over ensuring that proper CRIP policies and procedures were implemented to ensure safety was not compromised.

Recommended Citation:
Rice, S., Winter, S.R., Anania, E.C., Tamilselvan, G., & Doherty, S. (2018). Commercial Airline Pilots’ Attitudinal Data on Controlled Rest in Position: A Qualitative Inquiry. *Collegiate Aviation Review International,* 36(2), 74-94. http://dx.doi.org/10.22488/okstate.18.100491

Fatigue is a significant contributor to accidents in aviation, in commercial, private, and military aircraft, and is defined as “extreme tiredness resulting from mental or physical exertion or illness” (Oxford Dictionary, 2017, n.p.). Typical fatigue mitigation techniques include work and rest scheduling, obtaining required minimum rest before a flight, and pharmacological countermeasures (Caldwell & Caldwell, 2005; Caldwell, Mallis, Caldwell, Paul, Miller, & Neri, 2009). However, Controlled Rest in Position (CRIP), or in-flight sleep, may be another potential way to mitigate pilot fatigue. Prior research has investigated consumer perceptions relating to CRIP, revealing unfavorable perceptions (Winter, Carryl, & Rice, 2015). However, it is likely that pilots feel differently about CRIP owing to their experience with fatigue in the cockpit and their knowledge of standard aviation practices. The purpose of this study is to understand commercial airline pilots’ attitudes regarding controlled rest in position using a qualitative method and a phenomenological approach.

Literature Review

Causes and Outcomes of Pilot Fatigue

Pilot fatigue is a known hazard to pilots (Jackson & Earl, 2006; Rosekind et al., 1994). Pilots have reported fatigue emerging from poor work schedules, jet lag, night flights, and general time pressure (Bourgeois-Bougrine, Carbon, Gounelle, Mollard, & Coblentz, 2003). Fatigue effects can also emerge from changing flight times and inconsistent sleep schedules (Goode, 2003; Powell, Spencer, Holland, Broadbent, & Petrie, 2007).

Flight Rules. The first update to pilot rest rules and duty limitations in more than 60 years occurred with the release of 14 CFR Part 117 (Federal Register, 2012). This regulation is a data-based approach to pilot flight time limitations and required rest and was applied to commercial pilots operating under 14 CFR Part 121. This new regulation uses multiple factors to identify the amount of crew rest required such as time of reporting, time zones crossed, and flight duty time. Fatigue Risk Management Systems (FRMS) are included in the regulation as a way for carriers to collect data and provide a source of continuous monitoring to assess fatigue. While the release of this rule was considered a notable change in targeting pilot fatigue, pilots have continued to express concerns over fatigue, and 14 CFR Part 117 does not apply to all commercial pilots. For example, most pilots that fly commercially in the United States operate under the rules and guidance for airlines (14 CFR Part 121) or commercial on-demand operators, commonly called charter flights (14 CFR Part 135). Fractional aircraft ownership is covered by a different section of regulations (14 CFR Part 91 Subpart K), and another category includes personal aircraft operation, which may be for private business use (14 CFR Part 91). This suggests that existing regulation may be insufficient to combat fatigue effects and additional approaches are needed.

Empirical Research on Controlled Rest in Position

While recent regulatory changes may provide some help to reduce fatigue levels in aviation, other solutions should still be considered. One potential solution is controlled rest in position (CRIP). Controlled rest in position refers to in-flight sleep or napping in place. Napping has a myriad of benefits, including increasing alertness and combating sleep deprivation, as well as augmenting physical and mental health (Takahashi, 2003). Indeed, some foreign air carriers (e.g., Air Canada) currently allow CRIP naps as a fatigue mitigation technique for their pilots (Transportation Safety Board of Canada (TSB), 2011). However, CRIP is still currently prohibited by the Federal Aviation Administration (FAA). One study found that pilots who take a short nap (40 minutes, compared to a no-sleep control group) had shorter reaction times and higher subjective alertness ratings than those who did not nap (NASA, 1994). Also, long-haul pilots can benefit from in-flight napping to increase alertness during later, more critical portions of flight (Rosekind et al., 1995).

It is important to note that minimal research has been done as to the quality of sleep obtained while in-flight. Even in situations with cruise relief pilots, where one pilot can sleep in a crew rest compartment, little research has been completed on the quality of sleep obtained by the pilot in this situation. Some research suggests that in-flight sleep is of a lower quality than sleep experienced on the ground (e.g., in a hotel) and less time is spent in the REM stage when sleeping in-flight (Signal, Gander, van der Berg, & Graeber, 2013). Also, there may be severe decrements in functioning upon awakening from in-flight sleep. This *sleep inertia* is defined by Hartzler (2014) as a period immediately after awakening in which individuals can suffer from cognitive impairments, mood impairments, and over-reaction to stimuli.

Prior Consumer Perceptions Research on CRIP

The FAA is not the only agency impacted by regulation on CRIP. Another group that would be impacted is the traveling public. Some research has been done on the consumer perception facet of CRIP. Winter et al. (2015) performed a preliminary investigation into consumer perceptions of CRIP, including the emotionality associated with those flights. In this study, consumers were significantly less willing to fly when controlled rest was being utilized in the cockpit than when it was not (Winter et al., 2015). Females were also significantly less willing to fly in the controlled rest condition than males were (Winter et al., 2015). Furthermore, affect was shown to fully mediate the relationship between the condition and willingness to fly; showing that the decision not to fly when CRIP is in use is largely influenced by emotionality (Winter et al., 2015).

Need for a Phenomenological Approach to CRIP

This study utilizes a qualitative phenomenological approach to understand pilot perceptions. The phenomenological approach centers on individual lived and shared experiences within a particular phenomenon and are primarily assessed through qualitative methods (Lester, 1999). Though a phenomenological approach does not always lend itself well to generalization, it can be a useful tool for gauging a specific sample or population's views on a phenomenon (e.g., CRIP). This study investigates CRIP through the lens of commercial pilots. Prior research on CRIP focuses on quantitative issues such as pilot reaction times and subjective ratings of tiredness or alertness. Pilot opinions on CRIP, in general, are essentially unassessed. There is a significant gap in the literature where attitudinal data of pilots are not discussed, nor a qualitative methodology utilized.

Whether or not CRIP is shown to be empirically valuable, pilots may refrain from using the process if they find it dangerous or unhelpful, and their attitudes toward it could have a significant impact on their behaviors. Similarly, some pilots may take advantage of it whether or not it is explicitly allowed. In addition, pilots have a unique insight into aviation culture implications, as well as any possible ways their superiors may take advantage of CRIP regarding scheduling. Prior research has shown a strong connection between attitudes and behavior (Ajzen, 1991; Ajzen & Fishbein, 1980; Fishbein & Ajzen, 1975).

Methods

Design and Research Questions

The study uses a qualitative design with additional descriptive statistics to identify the various research questions. This research followed ethical protocol for human participant research with oversight from the Institutional Review Board at the research university. The overall research questions under investigation in this study were: a) what will be pilot’s general perceptions on the implementation of controlled rest in position in the United States, and b) what will pilots perceive as the advantages and disadvantages of the possible implementation of controlled rest in position?

Participants

The study was posted on Curt Lewis’ Flight Safety Info daily newsletter (www.fsinfo.org) for two weeks. The newsletter gets emailed to subscribers each weekday, and the link to the online survey was placed within this email. There were 30 (5 female) licensed commercial pilots from the United States who voluntarily took part in the study. The mean age was 52.97 (*SD* = 9.06) years. In order to participate, participants must have been current commercial airline pilots.

Procedure and Materials

Participants were first provided with an informed consent form as part of the online survey, which they signed before beginning the study. They were then presented with the following description of CRIP:

> *“Controlled Rest in Position (CRIP) allows pilots to nap while remaining in the cockpit seat during the non-critical stages of flight. Take-off, climb, approach, and landing are considered the critical phases of flight, whereas when the aircraft is at cruise altitude, it is considered non-critical. Controlled rest in position (CRIP) has been suggested as a viable countermeasure to the Federal Aviation Administration (FAA) in the ongoing efforts to combat in-flight pilot fatigue. It is already in use in other parts of the world;*

> *however, it is not currently permitted in the United States. In some countries where CRIP is used, they have a strict policy on how it is implemented. For example, when the pilot wants to take a nap, s/he has to inform the co-pilot and flight attendants. When the pilot wakes, s/he cannot perform any essential tasks until s/he is fully awake (e.g., 20 minutes). However, this does not apply to emergency situations, where the pilot might be expected to operate the aircraft immediately."*

Following this, participants were asked for basic pilot demographics such as flight hours and ratings. A full list of questions can be found in Appendix A. Then participants were asked to fill out the CRIP questions also found in Appendix A. Participants were allowed to opt out of any questions, however, an initial data screening found no missing data. Participants were then asked to provide some feedback on the strengths and weaknesses of CRIP followed by any last thoughts they had on the topic. Participants were asked to provide basic demographics including age, ethnicity, gender, and nationality. Lastly, participants were debriefed and dismissed. There was no monetary compensation for this study. All participants volunteered willingly.

Results and Discussion of Themes

Descriptive Statistics

Participants reported a mean total number of flight hours as 13,469 (*SD* = 7,692) with 11,411 (*SD* = 7,480) hours of commercial flying. Twenty-four of the participants reported flying for a Part 121 air carrier, four flew Part 91 business/corporate, and the remaining participants flew Part 91K or Part 135. All but one participant reported holding an Airline Transport Pilot (ATP) certificate.

Regarding the type of flying completed by participants, 63% flew "narrowbody" aircraft and 37% flew "widebody" aircraft. Figure 1 depicts the types of routes flown. When asked what percentage of their flights were "red-eye" or overnight flights the mean response was 32.41% (*SD* = 30.90%). The range of responses to this question was from 0% to 100%, which resulted in a large standard deviation. Therefore, the median value of 20% was also calculated.

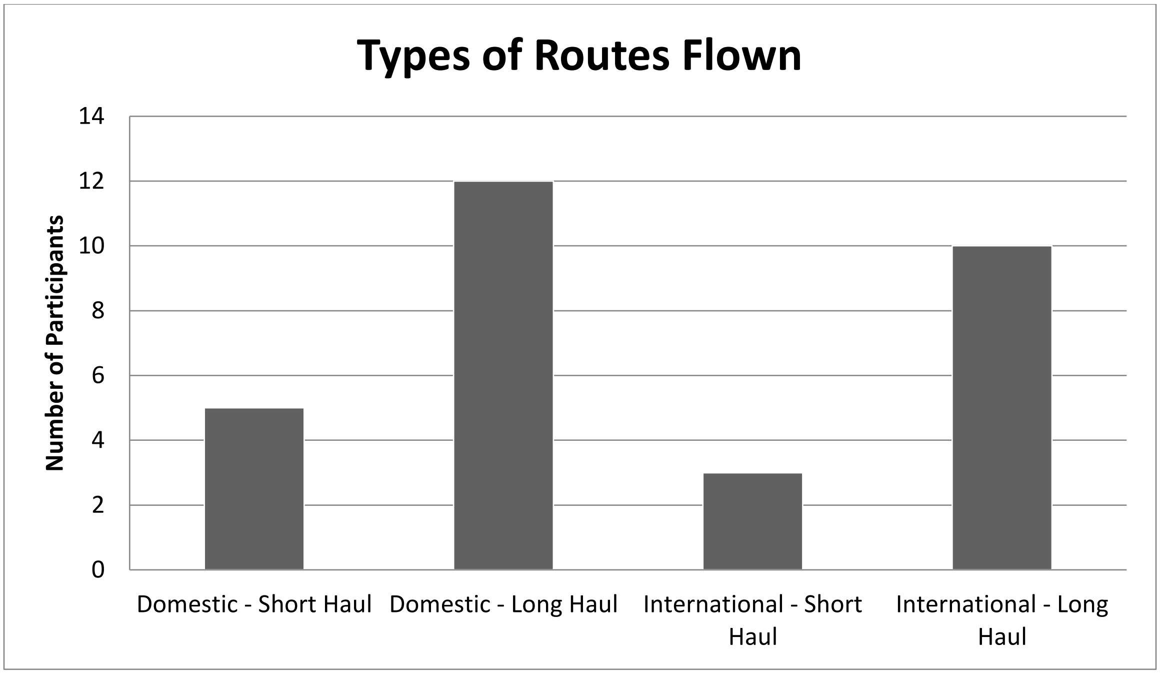


Figure 1. Types of routes flown by participants.

Participants were asked to identify how strongly they would disapprove or approve of controlled rest in position being implemented in the United States. Figure 2 identified the responses from participants and 70% either would approve or strongly approve.

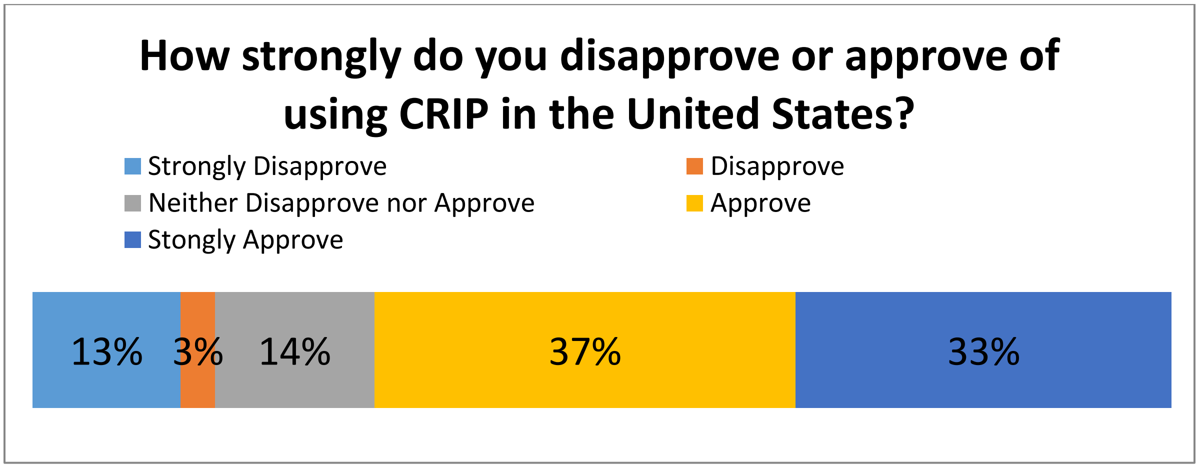


Figure 2. Participants disapproval or approval on the hypothetical implementation of CRIP.

Participants were then asked a series of questions as shown in Table 1 to gather their insights into how they felt CRIP should be applied if implemented in the United States. Participants, on average, felt 1-2 naps should be completed per four-hour block, with the length of each nap just less than 45 minutes. Participants indicated that they felt the napping pilot should be awake for just over 15 minutes to get over sleep inertia before re-engaging in-flight responsibilities (assuming a non-emergency scenario). When multiple CRIPs would be allowed within a single flight, participants felt there should be just under 70 minutes between naps. Participants were somewhat divided on their views of whether CRIP could be used differentially dependent upon pilot flight hours. While some expressed the need for experience, others stated that fatigue effects all pilots regardless of experience. Lastly, participants were asked how long from takeoff and how long before landing should CRIP be allowed. On takeoff, many expressed CRIP should not be used any sooner than the top of climb plus 15 minutes, or around 45 minutes, on average. Before landing, many participants stated CRIP should be used no later than 30 minutes before the top of descent or just over one hour before landing.

Lastly, participants were asked whom the flight crew should notify before CRIP and who should wake the pilot. Many participants indicated multiple individuals should be notified before CRIP; most commonly the other pilot and lead flight attendant. Most participants felt the other pilot should be the one to wake the napping pilot, but many also indicated any flight crewmember.

Table 1

Participant feedback on the application of CRIP

Questions on hypothetical CRIP Application in the U.S.	*Mean* (*SD*)
What should be the **maximum number** of CRIPs allowed per pilot per four-hour block during a flight?	1.44 (0.63)
What should be the maximum time (**in minutes**) allowed per CRIP?	42.41 (28.30)
How long (**in minutes**) should the pilot be required to be awake after a CRIP before continuing flight operations (assuming a non-emergency scenario)?	16.64 (13.40)
If multiple CRIPs were allowed per flight, how long a duration (**in minutes**) should there be between each CRIP for a single pilot?	68.50 (54.87)
What should be the minimum flight length (**in minutes**) before allowing CRIP?	120.92 (94.58)
What should be (if any) the minimum type specific **flight hours** (in model) a pilot has before being allowed to use CRIP? (For example, if a pilot is on IOE or a high minimums captain).	118.40 (175.97)
How far from to takeoff (**in minutes**) should CRIP be allowed?	45.89 (34.51)
How close to landing (**in minutes**) should CRIP be allowed?	66.12 (34.82)

Qualitative Analyses

The primary goal of this study was to examine the pilot's responses to the potential use of CRIP in the United States and what regulations should be in place if CRIP were to be implemented. In order to gather this information, participants were asked to provide information on the following topics: a) What should the non-CRIP pilot be required to do during CRIP; b) What conditions should preclude CRIP; c) What are the strengths of CRIP; d) What are the weaknesses of CRIP; e) If CRIP were implemented, what recommendations did they have to offer about CRIP; and f) What additional feedback did participants have? The results of each question are presented in order below.

The data from these six questions were analyzed with NVivo; a software program designed specifically to organize, analyze and code qualitative responses from participants. NVivo provided word clouds that revealed the most common phrases and terms that participants used in their responses. It also helped collate the data regarding participants' attitudes and perceptions about CRIP. Figure 3 presents a visualization of the process used to complete the qualitative analysis portion of the study. In summary, the first four questions of interest were collated and summarized on the basis of the linguistic answers provided. The first question on the actions of the non-CRIP pilot was condensed into a word count of suggested actions. The second question regarding preconditions leading to CRIP was summarized as a table identifying the most common responses of conditions that prohibited the use of CRIP. The third question about the strengths of CRIP was summarized into a set of common themes through a group map. The fourth question involving weaknesses of CRIP was analyzed via a hierarchy chart. In each of the following analyzes representative qualitative responses are provided in support of the key ideas and the comments are preserved verbatim. Questions five and six were coded manually for common themes. Recommendations for CRIP implementation is discussed in its own section while responses to question six are included throughout the results where appropriate.

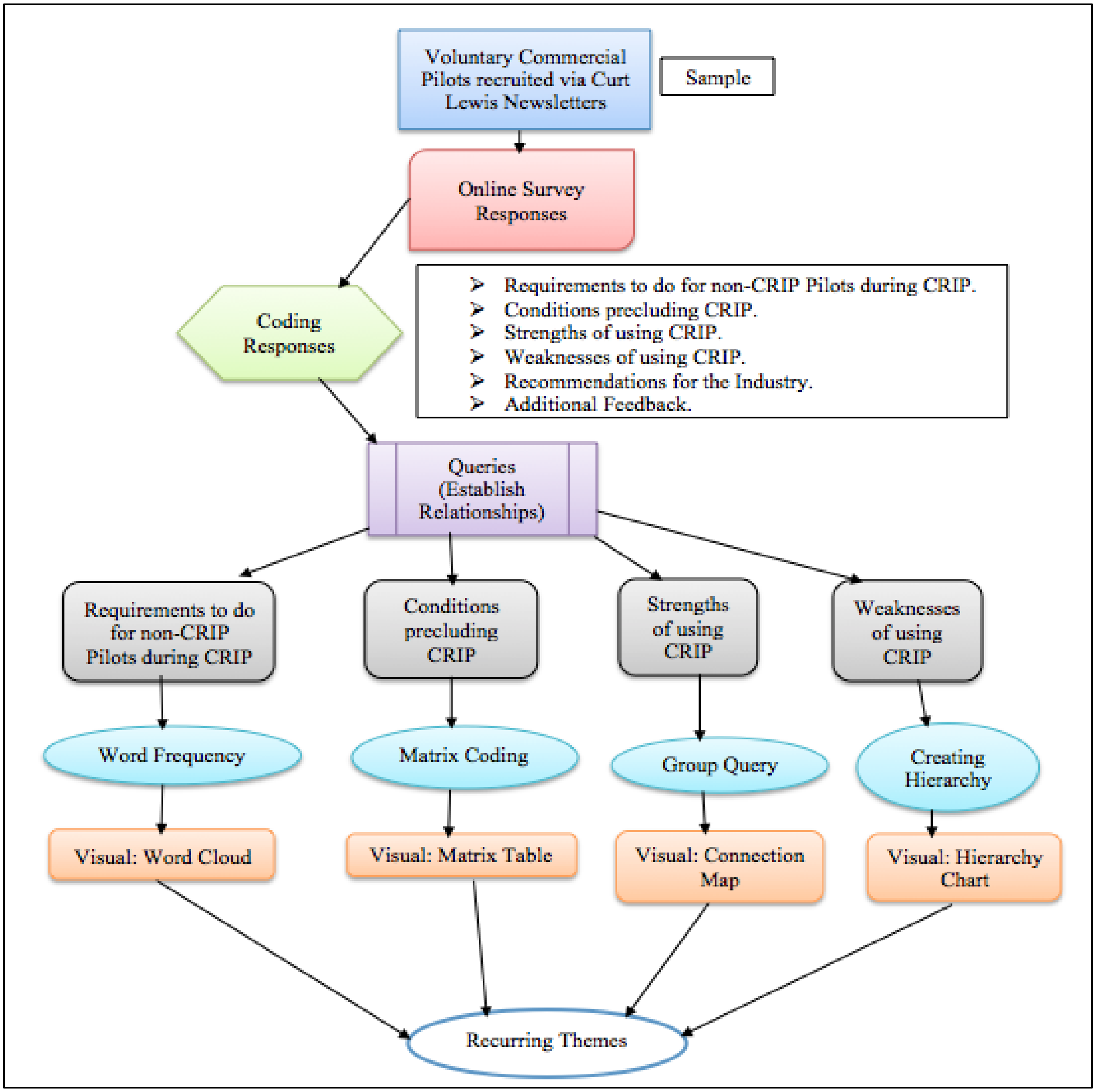


Figure 3. NVivo - Qualitative Data Analysis Software – Data Visualization

Non-Pilot Activity. The first qualitative question asked, "what should, if anything, the non-CRIP pilot be required to do during the CRIP"? NVivo provided a word frequency count for these data identifying which terms were most commonly associated with actions for the non-CRIP pilot. These data are also visualized in Figure 4 that demonstrates not only the frequency of the word responses but the thematic distance between terms, such as "stay" and "awake" being terms that appear frequently in tandem as identified by how proximal each word is to the other. These data revealed that staying awake was the most important topic in the participants' minds. A majority of participants responded to this question with the answer of "stay awake," with one participant highlighting that this can be a real concern in the cockpit by stating "remain awake-have seen both pilots asleep before."

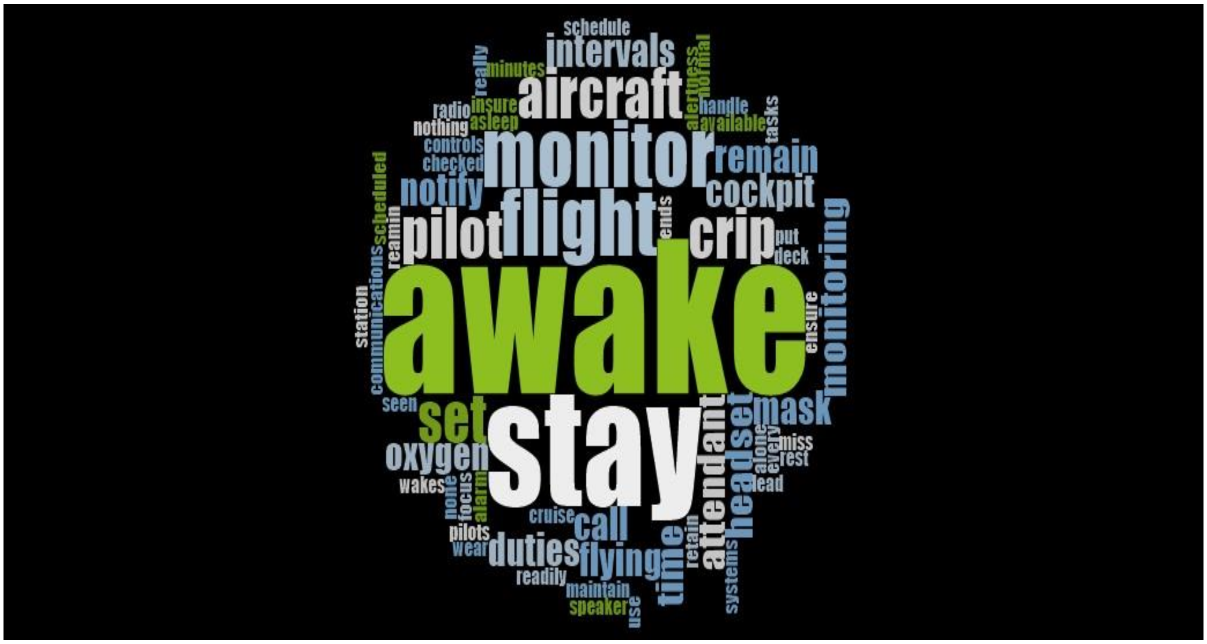


Figure 4. Requirements to do for non-CRIP Pilots during CRIP.

Along with this advice, pilots mentioned several other things that the non-CRIP pilot should do during a CRIP period, including monitoring tasks in the cockpit and notifying the flight attendant at scheduled times as identified by quotes such as “monitor flight controls and communications,” “cockpit monitoring tasks on set schedule,” “flying the aircraft, monitoring systems,” “monitor aircraft and ensure CRIP pilot wakes on time,” and “monitor rest time for CRIP pilot. Lastly, participants suggested to notify flight attendant[s] at scheduled intervals (or be checked by a flight attendant at set intervals (about every 10 minutes).”

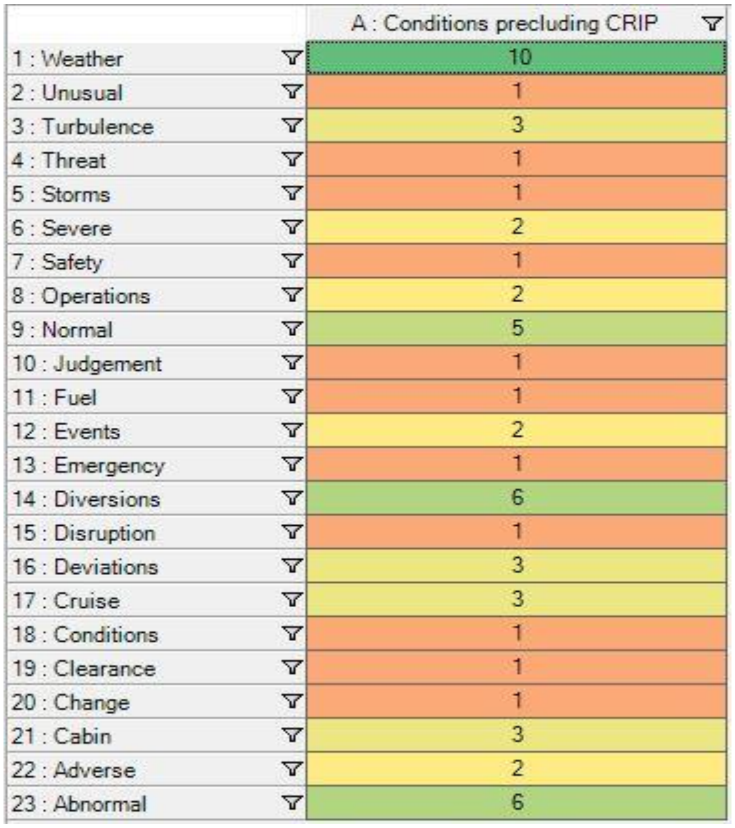
Another common theme was to either don an oxygen mask or have it at the ready; this follows compliance with Federal regulations in the United States that requires, one pilot to don an oxygen mask when the other pilot leaves the flight deck if the aircraft is above FL 350. Comments from pilots in this theme included “stay in flight deck, only in cruise. Put on O2 mask,” “remain on oxygen mask,” and “have Oxygen readily available.”

A fourth theme revolved around maintaining position at the station and avoiding distracting activities, presumably so that the non-CRIP pilot does not lose track of time or situation awareness. Quotes in this category included “remain at their station,” “wear headset. To retain focus and not miss a radio call,” “maintain alertness and SA,” and “use headset – not speaker.”

These four themes of staying awake, monitoring the cockpit, donning an oxygen mask, and maintaining awareness demonstrate that pilots feel there are activities required by the non-CRIP pilot to be performing in order to maintain safety under the conditions of the other pilot pursuing CRIP.

Conditions Preventing CRIP. Figure 5 is a matrix frequency table that reveals that weather and diversions were significant themes for the question regarding which conditions should prevent the use of CRIP. A particular type of query within NVivo software is the matrix coding query, where different nodes such as weather conditions and deviations were defined as rows and conditions precluding CRIP was as a column, respectively. The matrix table presents the coded qualitative data in numerical form, where each unit represents the number of times the information was coded in each node. The entities of matrix frequency table were presented in descending alphabetical fashion. The analysis of results from matrix coding query indicated that many of the respondents focused on weather issues, indicating that they did not feel it was safe to use CRIP during poor weather conditions, abnormal situations or time requiring diversions. Typical quotes supporting this theme include statements such as "severe weather…any other condition that is not normal cruise operations," "turbulence, storms, anything that would disrupt a normal cruise," "absolutely – adverse weather, mechanical, diversion, reroute…," "deviating through weather," and "severe WX, if diversion necessary, cabin disruption."

A second common theme for conditions preventing the use of CRIP included course deviations not related to weather, including traffic and complicated airspaces. Respondents clearly felt that pilots should stay awake during any period of time that was outside of normal cruise operation such as "diversions, abnormal systems operation," "any deviation from course, alt chg, clearance modification, etc.," "poor weather, diversions, abnormal procedures," "weather requiring deviations, abnormal operations," and "any conditions that would require a change of course."



	A : Conditions precluding CRIP
1 : Weather	10
2 : Unusual	1
3 : Turbulence	3
4 : Threat	1
5 : Storms	1
6 : Severe	2
7 : Safety	1
8 : Operations	2
9 : Normal	5
10 : Judgement	1
11 : Fuel	1
12 : Events	2
13 : Emergency	1
14 : Diversions	6
15 : Disruption	1
16 : Deviations	3
17 : Cruise	3
18 : Conditions	1
19 : Clearance	1
20 : Change	1
21 : Cabin	3
22 : Adverse	2
23 : Abnormal	6

Figure 5. Conditions when CRIP should be precluded depicted as a matrix table.

The last big theme in the responses to this question involved unusual cabin activities and other non-normal situations, including emergencies. Qualitative statements in this category included "non-normal passenger cabin situations," "if disagreeable customers were identified in the cabin previously," "CRM applies," "WX, non-normal events, any event that require crew coordination," "emergency situations," and "any non-normal or abnormal situation, including non-routine routings and crew pairings."

When questioned about conditions that preclude the use of CRIP pilots provided responses that suggested that three key themes are of concern: weather and environmental factors, course deviations, and abnormal situations. These responses from pilots identify that pilots are sensitive to factors that influence the use of CRIP in the cockpit.

Strengths of CRIP. Figure 6 displays a group query that gives some clues about what participants were thinking when they responded to the question about the benefits of using CRIP during flights. Group query is a technique that helps to find the associations between concepts discussed under strengths of using CRIP. The corresponding visual for the group query was a connection map, where the nodes show associations between strengths of using CRIP (scope item) and different concepts like tool, tired, or staffing. The scope item is defined as the primary theme, in this case, the strength of CRIP, which is then associated with other second level items (range items). The range items are defined as the items grouped under the scope item. In context of this study, various range items grouped under strengths of using CRIP (scope item) were tool, tired, staffing, schedule, safer, rules, rested, recovery, nap, mitigation, mistakes, landing, immediate, hours, haul, fatigue, critical, crews, blame, awake, approach, alertness, and ability. In Figure 6, the branches of the connection map were presented with a hierarchy of nodes (for example, Strengths of CRIP\Tool or Strengths of CRIP\Tired), and this redundancy of items cannot be eliminated, which was considered as a limitation of NVivo software. From Figure 6a and 6b, fatigue and alertness are critical issues for maintaining safe conditions during flight, and most participants felt that CRIP would help to relieve these issues as evidenced by responses such as "fatigue is real and affects performance," "small controlled naps following prescribed rules allow recovery from fatigue for 3-4 hours," "improve crew alertness," "the ability to regain full capability during a long flight/back side of the clock operation," "it 'does' help with fatigue if managed properly," and "helps pilots recharge and be more alert."

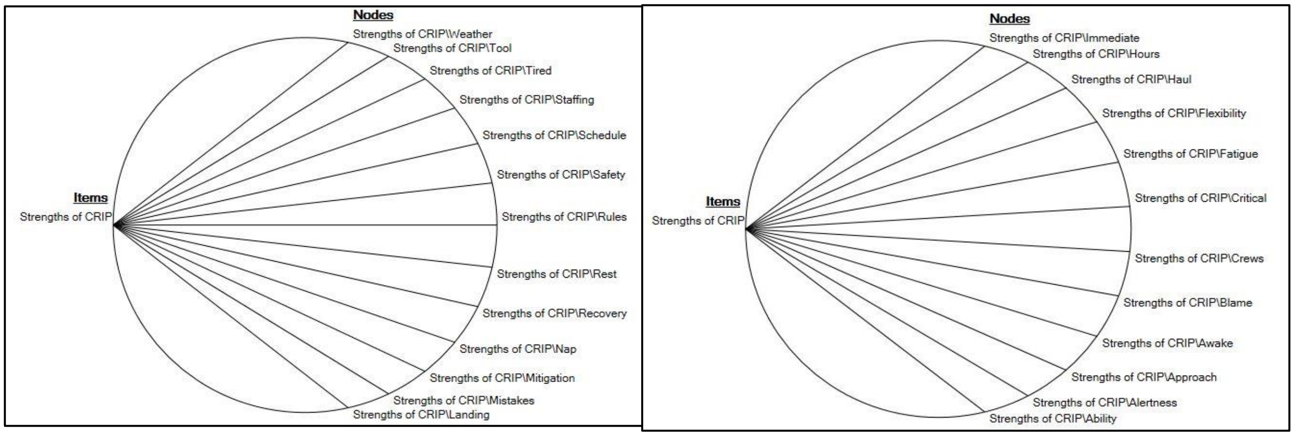


Figure 6a (left) and 6b (right). Strengths of CRIP depicted in a group query analysis. The branches depict the common themes in response to the question.

Participants also felt that CRIP would legitimize the rest periods as demonstrated by comments such as "legitimize tool to combat inflight fatigue," "20-minute power nap," and "it's much better to nap than nod." These data demonstrate that pilots do feel that CRIP has multiple benefits to its use even to the point of legitimizing unsanctioned behavior that is already occurring.

Weaknesses of CRIP. Participants were not all positive about CRIP and the opportunity to point out any weaknesses associated with CRIP was provided to respondents. Figure 7 is a hierarchy chart that serves as a visualization tool for nodes. The hierarchy chart was presented as a collection of nested rectangles of different sizes. Size is an important parameter of the hierarchy chart where bigger sized rectangles indicate a node with a significant amount of information coded. The algorithm behind the hierarchy chart was designed to place the larger rectangles at the top left of the chart, and smaller ones were displayed towards the bottom right of the chart. The aggregate data on weaknesses of using CRIP was presented as various themes in the hierarchy chart, such as pilots, tiredness, or policies. Additionally, major themes like pilots, no weaknesses, or asleep have more coded information when compared to other themes like dozing, cockpit, or alarms that are placed at the bottom right of the chart.

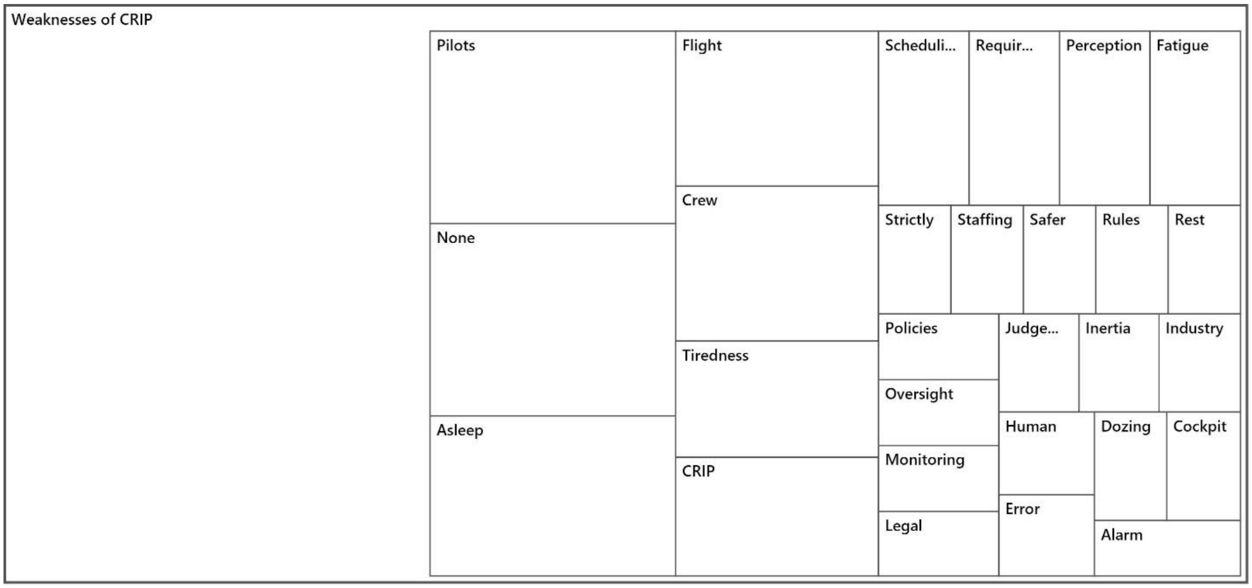


Figure 7. Weaknesses of CRIP shown in a hierarchy chart. Word position and size of the box indicates how commonly terms appeared in participants' answers.

This hierarchy chart reveals that many of the participants were of the opinion that there were no weaknesses to CRIP as long as it was implemented properly. Quotes illustrating this point include "none !! its definitely needed to be legal. Its being done anyway," "none provided there is external monitoring of crew to avoid non-CRIP pilot from dozing off," and "none – a safer way to fly."

However, some participants suggested possible weaknesses to CRIP. One common theme that seemed to arise was the fear that airlines would take advantage of CRIP in various ways that could only be implemented if CRIP were legal. These included comments such as "the industry will try to use this to weaken augmented flight crew requirements," "a patch for a failed scheduling and crew pairing vice a viable solution of better crewing and staffing," and "that crews would not strictly adhere to the polices, or that some pilots would scoff at or not allow CRIP on their flight. All of the crew must be in agreement to employ CRIP."

Another concern to pilots was whether or not the non-CRIP pilot could stay awake during a CRIP. Several participants were concerned that implementing CRIP could more easily result in both pilots falling asleep. Another related concern was that the non-CRIP pilot would wake up the CRIP pilot and then go to sleep herself/himself immediately afterward. For example, comments were provided like "what happen[s] when both pilots fall asleep due to a Fatigued schedule. Who is flying the aircraft then," "how to make sure other pilot doesn't go to sleep," and "both pilots falling asleep. Need loud alarm like B777 has."

Finally, two participants pointed out that using CRIP may not be conducive to public perception. These two comments were "would American passengers be willing to fly in an airplane when they know the pilots are allowed to sleep during cruise" and "public perception [will be negative]."

The responses to the question of weaknesses of CRIP were mostly uniform in the lack of weakness save for some concerns about the format of implementation and its impact on the pilots in the cockpit depending on that implementation. These comments suggest a generally positive view of CRIP with some caveats.

Pilot Recommendations for CRIP. There were quite a few responses to this question as participants highlighted several themes here. The first theme revolved around making sure that CRIP was used as a fatigue management tool, and not a substitute for getting good rest as reflected in the comment "use CRIP as a fatigue management tool, not a substitution for crew rest."

Another theme revolved around making sure that CRIP was correctly implemented, with safety taking the forefront in its implementation. This theme was seen in the following examples: "implement it but with training and safety guards in place," "during CRIP, crew should be checked every ten minutes by a non cockpit crew member. CRIP should not be allowed without external monitoring of crew," "have a defined and explicit plan, and the ability to CRIP should be part of the crew brief," and "industry wide data collection from multiple airlines and combined effort from scientific consultants would be needed for FAA approval. Each airline would have to adopt the same procedures." Two other comments included "minimize the required parameters. Professionals know how to operate have the ability to operate in the safest way," and "strictly monitor results and modify procedures, staffing, crew pairings via the FRMS."

Lastly, many participants indicated that they would want post-implementation data to ensure that CRIP is working and is being used properly. This should be supported by both the FAA and the pilot unions as seen in statements such as "strictly monitor results and modify procedures, staffing, crew pairings via the FRMS," "some confidential way to keep track of how much it is being used," "qualified pilots would have to ride in jumpseat to protect the flying public from data collection phase with one pilot sleeping until FAA approves practice under FRMS," and "include it in CRM [Crew Resource Management] training."

A typical series of suggestions regarding the implementation of CRIP from pilots included concerns about CRIP being used as a replacement for getting solid rest, proper implementation, and a need for proper assessment once CRIP was implemented to make sure this regulation did not generate a detriment to pilot performance.

Feedback from Current CRIP Implementation. There were some comments provided in the section of the survey that provided additional feedback. Many of these comments repeated what was reported already; however, some additional comments were not captured in the previous analyses. Twelve additional participants who identified as flying for international airlines and who may already use CRIP also participated in the data collection. Since these individuals were outside of the scope of the current study, their responses were removed from the dataset before the reported analysis of the data because there were outside of the United States and may already be using CRIP. However, their comments are valuable as a lens for understanding ideas from those who are already experienced with CRIP. Their comments are included for this section only in combination with the other participants. Many of these twelve international participants saw that CRIP does work for them and should be implemented with a minimal rule set. Other participants noted that it is already being used elsewhere and should be used in the United States as well. Quotes from pilots in this area were numerous and included statements such as "CRIP works best with a general common-sense minimal rule set. I have been flying with it for over 20 years," and:

> I've been using CRIP for almost 12 years now. It works well. Our procedures says to turn the loudspeakers down but I keep it up. There are times when I am in a light sleep and can still hear the radio calls and can help the other pilot. If it is too quiet in the cockpit, the tendency is to oversleep. Worse is to extend your sleep to find the other pilot micro-sleeping. CRIP is better than micro-sleeping on descent and approach.

Other comments include "we CRIP in QUANTAS and under a FRMS it will become another fatigue mitigator PS," "CRIP works VERY well," "pilots have always used and are currently using crip to manage alertness," and "ICAO has adopted CRIP, the US Military has adopted CRIP and several foreign carriers are as well. NZ, and Air Canada being two."

It is clear from comments like this that CRIP is already implemented in other countries and is viewed in a favorable light.

General Discussion

The purpose of this study was to assess the attitudinal data of commercial airline pilots regarding the possible implementation of controlled rest in position. Prior research has studied and demonstrated the benefits of CRIP (NASA, 1994; Rosekind et al., 1995) and the perspectives of consumers (Winter et al., 2015), but a gap existed in the literature on how commercial airline pilots viewed CRIP.

The majority of participants approved or strongly approved the use of CRIP in the United States. The suggested time lengths of naps seemed to parallel that suggested in the scientific research. Therefore, it is possible that participants may be familiar with existing information on controlled rest in position or their practical experiences match what was found in the scientific research. Regardless of the reason (which is impossible to determine from this study), the data indicates that the attitudinal data of participants is similar to that recommend through scientific investigation. This commonality may be useful if regulators ever attempt to implement policies and procedures that would allow CRIP in the United States.

Participants identified the importance of the second pilot remaining awake when the other pilot was resting. Maintaining a set schedule of tasks, oxygen usage, and headset usage were all items suggested by participants to maintain the awareness and alertness of the non-resting pilot. However, participants also recognized that there were conditions in which CRIP should not be used such as during periods of severe weather en route or if a disruptive passenger was identified in the cabin. These conditions could undoubtedly increase the workload of pilots, and therefore, may require more attention of both pilots, suggesting CRIP would not be appropriate in those situations.

Participants seemed to acknowledge the effect fatigue has on performance. A common theme identified by participants was how the use of a short nap (20-30 minutes) could improve alertness for 2-4 hours. However, participants also indicated that implementation of CRIP might affect (perhaps unintended) on the overall scheduling of crews that could result in increased fatigue due to shorter rests between shifts due to the assumption that the pilots would nap during the flight and rest via CRIP. If CRIP is pursued, there should be a balanced approach between CRIP implementation and the legal flight duty limitations.

Finally, pilots stressed the importance of adequately implementing CRIP. Pilots indicated that passengers might not like the idea and pilots emphasized the need for training and safeguards to prevent a reduction in safety. Suggestions included the airlines working together with government to obtain the needed approvals and adoption of the same procedures.

Practical Applications and Recommendations

This study offers valuable information from the group of individuals that would be most affected by CRIP implementation: the pilots. The data from this study offers some valuable insight into the attitudinal data of current commercial airline pilots. While the majority of participants favored the use of controlled rest in position, there were still concerns over how CRIP, if adopted by the FAA, could impact crew scheduling. Participants also expressed an interest in follow-up studies to verify any implementation of CRIP had the desired outcomes. If CRIP is considered for implementation in the United States, regulators should consider the end users, pilots, as they draft legislation to help ensure the rule change would have the desired outcome of reducing pilot fatigue.

Industry representatives, members of the government, and regulators may be interested in the findings of these studies. While prior research (Rice, Winter, Tamilselvan, & Milner, 2017; Winter, Carryl, & Rice, 2015) has demonstrated consumers may be less willing to fly if CRIP was used, pilots have expressed a strong desire for its implementation. The data presented by participants in this study provides valuable thoughts and insights that could be utilized by those who would be in charge of proposing, implementing, and monitoring CRIP in the United States. While participants tended to favor CRIP implementation, they still identified areas of concerns related to government and regulation such as proper policies and procedures and ensuring safety. If CRIP would be implemented, continued research should be conducted to measure the effect of the new rules and its implementation.

Limitations

Certain limitations were present in the current study. The participants that were used in this study only consisted of those that received the Flight Safety Newsletter, and therefore, their attitudes may not match the attitudes of the greater population of commercial airline pilots. The study also only collected data at one point in time over a two-week period and therefore a longitudinal study may reveal differing attitudes of participants toward CRIP. Lastly, the researchers developed the instrument used in the data collection. Further validation of the instrument and findings is recommended.

Conclusions

The purpose of this study was to fulfill a gap in the research on controlled rest in position; that being the attitudinal data from commercial airline pilots. While a few countries have implemented the used of CRIP the United States has not. This study sought the input from commercial airline pilots on the advantages, disadvantages, and implementation aspects of CRIP. The findings indicate that the majority of participants favor the use of CRIP, but many expressed the need to have proper policies and procedures in place to ensure safety was not compromised. There were specific issues in which participants indicated that CRIP should not be used, such as thunderstorms or a disruptive passenger in the cabin. Concerns were expressed that implementation of CRIP may have unintended consequences of harsher crew scheduling, and procedures should be in place to prevent both flight crew members from falling asleep. Participants provided their recommendations on how often, how long, and how they thought CRIP could be successfully implemented in commercial aviation.

References

Ajzen, I. (1991). The theory of planned behavior. *Organizational Behavior and Human Decision Processes, 50*, 179–211. doi: 10.1016/0749-5978(91)90020-T

Ajzen, I., & Fishbein, M. (1980). *Understanding attitudes and predicting social behavior*. Englewood-Cliffs, NJ: Prentice-Hall.

Bourgeois-Bougrine, S., Carbon, P., Counelle, C., Molland, R., & Coblentz, A. (2003). Perceived fatigue for short- and long-haul flights: A survey of 739 airline pilots. *Aviation, Space, and Environmental Medicine, 74,* 1072-1077.

Caldwell, J. A., & Caldwell, J. L. (2005). Fatigue in military aviation: an overview of US military-approved pharmacological countermeasures. *Aviation, Space, and Environmental Medicine*, *76*(7, Suppl.), C39-C51.

Caldwell, J. A., Mallis, M. M., Caldwell, J. L., Paul, M. A., Miller, J. C., & Neri, D. F. (2009). Fatigue countermeasures in aviation. *Aviation, Space, and Environmental Medicine, 80*(1), 29-59. doi: 10.3357/ASEM.2435.2009

Federal Register. (2012). Flightcrew member duty and rest requirements. *U.S. Department of Transportation, Federal Aviation Association, Rules and Regulations, 7*(2), 330-403. Retrieved from https://www.gpo.gov/fdsys/pkg/FR-2012-01-04/pdf/2011-33078.pdf

Fishbein, M., & Ajzen, I. (1975). *Belief, attitude, intention, and behavior: An introduction to theory and research.* Reading, MA: Addison-Wesley.

Goode, J. H. (2003). Are pilots at risk of accidents due to fatigue? *Journal of Safety Research, 34*(3), 309-313. doi: 10.1016/S0022-4375(03)00033-1

Hartzler, B. M. (2014). Fatigue on the flight deck: the consequences of sleep loss and the benefits of napping. *Accident Analysis & Prevention, 62*, 309-318. doi: 10.1016/j.aap.2013.10.010

Jackson, C. A. & Earl, L. (2006). Prevalence of fatigue among commercial pilots. *Occupational Medicine, 56*(4), 263-268. doi: 10.1093/occmed/kql021

Lester, S. (1999). An introduction to phenomenological research. Available online at https://www.researchgate.net/profile/Stan_Lester/publication/255647619_An_introduction_to_phenomenological_research/links/545a05e30cf2cf5164840df6/An-introduction-to-phenomenological-research.pdf?origin=publication_detail

NASA. (1994). Crew Factors in Flight Operations IX: Effects of Planned Cockpit Rest on Crew Performance and Alertness in Long- Haul Operations. (*NASA Technical Memorandum 108839*). Moffett Field, California: Ames Research Center.

Oxford Dictionary. (2017). Definition of fatigue. Retrieved from: https://en.oxforddictionaries.com/definition/fatigue

Powell, D. M. C., Spencer, M. B., Holland, D., Broadbent, E., & Petrie, K. J. (2007). Pilot fatigue in short-haul operations: Effects of number of sectors, duty length, and time of day. *Aviation, Space, and Environmental Medicine, 78*(7), 698-701. doi: 10.1080/13669877.2016.1235603

Rice, S., Winter, S. R., Tamilselvan, G., & Milner, M. N. (2017). Attitudes toward controlled rest in position (CRIP): A gender comparison between pilots and non-pilots. *International Journal of Aviation, Aeronautics, and Aerospace, 4*(3), 1-33. doi: 10.15394/ijaaa.2017.1181

Rosekind, M. R., Gander, P. H., Miller, D. L., Gregory, K. B., Smith, R. M., Weldon, K. J., Co, E. L., McNally, K. L., & Lebacqz, J. V. (1994). Fatigue in operational settings: Examples from the aviation environment. *Human Factors, 36*(2), 327-338. doi: 10.1177/001872089403600212

Rosekind, M. R., Smith, R. M., Miller, D. L., Co, E. L., Gregory, K. B., Webbon, L. L., ... & Lebacqz, J. V. (1995). Alertness management: strategic naps in operational settings. *Journal of Sleep Research*, *4*(s2), 62-66. doi: 10.1111/j.1365-2869.1995.tb00229.x

Signal, T. L., Gander, P. H., van der Berg, M. J., & Graeber, R. C. (2013). In-flight sleep of flight crew during a 7-hour rest break: Implications for research and flight safety. *Sleep, 36*(1), 106-115. doi: 10.5665/sleep.2312

Transportation Safety Board of Canada (TSB). (2011). Aviation investigation report. Pitch excursion: Air Canada Boeing 767-333, C-GHLQ North Atlantic Ocean, 55°00'N 029°00'W 14 January 2011. Retrieved from: http://www.tsb.gc.ca/eng/rapports-reports/aviation/2011/a11f0012/a11f0012.pdf

Takahashi, M. (2003). The role of prescribed napping in sleep medicine. *Sleep Medicine Reviews*, *7*(3), 227-235. doi: 10.1053/smrv.2002.0241

Winter, S. R., Carryl, J., & Rice, S. (2015). Controlled rest in position (CRIP): Consumer perceptions in the United States. *Collegiate Aviation Review*, *33*(1), 14-28. Retrieved from http://ojs.library.okstate.edu/osu/index.php/CARI/article/view/7456

Appendix A: Instrument

Pilot Demographics

How many commercial flight hours do you have?

Please indicate the highest pilot certificate and ratings that you have (check all that apply):

How many total flight hours do you have?

Do you primarily fly (please select one)?

CRIP Questions

If CRIP were used in the United States, what should be the maximum number of CRIPs allowed per pilot per four-hour block during a flight?

In general, how strongly do you approve or disapprove of using CRIP in the United States?

If CRIP were used in the United States, what should be the maximum time (in minutes) allowed per CRIP?

If CRIP were used in the United States, how long (in minutes) should the pilot be required to be awake after a CRIP before continuing flight operations (assuming a non-emergency scenario)?

If CRIP were used in the United States, who should the pilot be required to notify before using CRIP? (Check all the may apply).

If CRIP were used in the United States, who should be allowed to wake up the pilot from a CRIP?

If multiple CRIPs were allowed per flight, how long a duration (in minutes) should there be between each CRIP for a single pilot?

How close to landing (in minutes) should CRIP be allowed?

How far from to takeoff (in minutes) should CRIP be allowed?

What should be the minimum flight length (in minutes) before allowing CRIP?

What should, if anything, the non-CRIP pilot be required to do during the CRIP?

What should be (if any) the minimum type specific flight hours (in model) a pilot has before being allowed to use CRIP? (For example, if a pilot is on IOE or a high minimums captain).

Are there any type of environmental/weather conditions that should preclude CRIP? If yes, what environmental/weather conditions?

Additional Feedback

What do you view as the strengths offered by using CRIP (if any)?

What do you view as the weaknesses offered by using CRIP (if any)?

What recommendations would you offer to the industry if CRIP was implemented?

Please provide any additional feedback that you wish to share. Again, your responses are completely confidential.

Demographics

What is your Age?

What is your ethnicity?

Are you male or female?

What country are you from?

Collegiate Aviation Review
International

Volume 36 | Issue 2 Peer Reviewed Article #6

10-3-2018

Understanding Determinants of Making Airline Route Entry and Exit Decisions: An Application of Logit Models

Canh Nguyen
Florida Institute of Technology

Cuong Nguyen
Ho Chi Minh City University of Technology

Understanding patterns of entry and exit decisions and determinants shaping the patterns are necessary for airline planners in drawing a robust route map and gaining their own competitive advantages. The study used logit models to exam the relationship between two separate binary dependent variables: entry versus no-entry, exit versus no-exit, and multiple independent variables. Dataset was extracted from the Bureau of Transportation Statistics DB1B for Quarter 1 of 2018, then was reconstructed based on original and destination (O&D) airport pairs to gain insights. The entry decision pattern model yielded seven significant factors: total passengers, average market fare, number of carriers, distance, low-cost carriers (LCC) existence, origin hub, and destination hub. In the meantime, the exit decision pattern model yielded all the seven aforementioned factors and two other significant factors: route type and the business model of the largest share airline. The findings made a practical implication to airline network planners in considering determinants affecting entry and exit decisions to build a more efficient and profitable network.

Recommended Citation:
Nguyen, C. & Nguyen, C. (2018). Understanding Determinants of Making Airline Route Entry and Exit Decisions: An Application of Logit Models. *Collegiate Aviation Review International*, 36(2), 95-119. http://dx.doi.org/10.22488/okstate.18.101001

As a result of the Airline Deregulation Act in 1978, the U.S. airline industry has changed radically. Since then, airlines are able to freely make their own decisions as to where they should fly, what route market they should enter or increase frequencies, and what route market they should reduce or completely remove from the network. The newly deregulated industry witnessed an influx of new entrants with new business models such as low-cost carriers; Southwest Airlines is a typical and successful example thus far. Besides that, innovations in aircraft manufacturing has helped airlines operate flights more efficiently with lower costs, but higher capacity and longer range. Under all these conditions, the airline industry has been characterized as a free market economy, bringing out many flying opportunities for passengers; however, the competition among commercial airlines has become more intensive than ever. In order to survive in such a stiff competition, airlines are attempting to gain their own competitive advantages by building an efficient and profitable network. Understanding patterns of entry and exit decisions and determinants shaping these patterns are necessary for airline planners in drawing a robust route map.

The literature is replete with studies exploring key drivers and barriers to entering and exiting a given route. Baran (2018) examines the survival strategies of U.S. domestic airlines, which corresponded to route entry and exit decision and airfare competition. The dataset was a combination of Airline Origin and Destination (DB1B) and the U.S. Census Bureau in the period of 2011-2015. Baran restricted all entry and exit data associated with eight U.S. major airlines, and thus the dataset was $N = 2{,}111$ routes; however, there was no information about defining and measuring entry and exit decisions. Utilizing a logistic regression for a binary response, either entry or exit, the result showed a significant model with $\chi^2(10) = 120.59$, $p < .0001$, $R_L^2 = .0511$, and five significant factors: airline business model, distance, city population of origin airport, per capita income in original airport, and number of competitors. The limitation of the study was that Baran measured market concentration by calculating Herfindahl–Hirschman Index (HHI) based on the number of seats available per mile (ASM) airlines performed on each route without the consideration of the load factor. Our current study solved the problem by measuring the market concentration and market shares based on the number of passengers airlines transported on each route.

Abdelghany and Guzhva (2010) investigated entry and exit decisions by using a panel dataset of 38 quarters beginning in the first quarter of 1998 with the largest 10,000 city pairs in the U.S. domestic market. The dependent variable of the study was estimated by the differences in number of airlines between two consecutive quarters; positive changes indicated airline entries, while negative changes indicated airline exits. The independent variables in the analysis included market concentration measuring by Herfindahl–Hirschman Index (HHI), quarterly changes in market concentrations (ΔHHI_{t-1}, ΔHHI_{t-2}, and ΔHHI_{t-3}), market size measuring the number of passengers, quarterly change in market size (ΔPX_{t-1}), distance between city pairs, average one-way fare, and seasonality represented by three dummy variables for Quarter 2, 3, and 4 (comparing to the reference Quarter 1). The advantage of this study was the utilization of a panel data analysis that combined a cross-section and time-series analysis. the results of *F*-tests and Breusch-Pagan Lagrange Multiplier (LM) test failed to reject the null hypothesis and thus yielded a pooled ordinary least squares (OLS) estimation. All independent factors were significant at the preset alpha of 5% in the overall model, and the adjusted $R^2 = .09$. The disadvantage of the study was that the estimation of the dependent variable failed to capture changes in each unit of analysis (quarter-route) when, for example, each of three different airlines adds one flight into a given route, concurrently an airline removes one flight from the route. In such cases, although the response shows airline entry decisions (i.e., a positive response with two flights added into the route), there is still one exit decision in the route during the given quarter. This current study technically solved the problem by separately measuring entry and exit decisions in each route, which was fully discussed in definition and data construction sections. Previous research examined market characteristics: market density, distance, endpoint city populations and income, and hub effects together with competition-related factors (Boguslaski, Ito, & Lee, 2004; Ito & Lee, 2003; Oliveira, 2008).

Based on the review of the literature, the motivation to conduct the current study was to partially replicate with the latest dataset as well as mostly using more robust estimation in the dependent variables, entry and exit decisions. The current study also followed and examined factors suggested by previous research relative to distinguishing patterns of airline entry and exit in the U.S. domestic market. The different points were that we decided to omit several suggested variables and added new variables into the analyses because we reconstructed the raw dataset and gained more insights. Specifically, we used the variable of total passengers in each route to represent the demand as opposed to using the cities' population and income, and we obtained some new variables such as LCC existence and the business model of the airline with the largest share.

Purpose

The purpose of the study was to identify factors that would shape route entry and exit decision patterns of commercial airlines in the U.S. domestic market. The two variables of interest, *entry patterns* and *exit patterns* on the city-pair market, were independent of each other. The targeted research factors consisted of 11 independent variables (IVs): total passengers, number of departures, average market fare, number of carriers, market concentration, distance between origin and destination airports, route type, existence of low cost carriers, business model of airline with the largest share, origin hub airport, and destination hub airport. The study was restricted to the U.S. domestic routes that have both origin and destination airports located within the United States. In addition, the study only considered route markets that had at least one operation of a commercial airline. The study was cross-sectional in nature and used the 2018 dataset of Quarter 1 that was archived in the Bureau of Transportation Statistics (BTS).

Research Questions

The research questions that guided the current study were as follows:

Research question 1: When examined from the entry pattern model, what is the relationship between the targeted variables and the dichotomous response variable that distinguished between airline route entry and non-entry decisions?

Research question 2: When examined from the exit pattern model, what is the relationship between the targeted variables and the dichotomous response variable that distinguished between airline route exit and non-exit decisions?

Hypotheses

The corresponding research hypotheses were as follows:

Research hypothesis 1: When examined from the entry pattern model, at least one of the targeted variables will have predictive value relative to distinguishing between airline route entry and non-entry decisions.

Research hypothesis 2: When examined from the exit pattern model, at least one of the targeted variables will have predictive value relative to distinguishing between airline route exit and non-exit decisions.

Definitions of Variables

Dependent Variables

The study consisted of two separate dependent variables of an airlines, the entry patterns and exit patterns, which are both critical strategies that an airline takes into consideration either to increase its market share or to exit from routes. Given a route, entry and exit patterns were initially constructed by the differences in the number of departures between Quarter 1 of 2018 and Quarter 4 of 2017. The positive differences across the given route were counted as entry decisions, which means that airlines either entered for the first time or increased their frequency. In the meantime, the negative differences across the given route were counted as exit decisions, which means that airlines either stopped their air service or reduced their flight frequency. If the difference returned 0 in that route, there were no entry and exit decisions. For example, the route from ABE to ATW in Quarter 1 of 2018 compared to Quarter 4 of 2017. There were two entry decisions: Delta Air Lines (DL) with a 10-flight increase and United Airlines (UA) with a 1-flight increase; at the same time, one exit decision was made by American Airlines (AA) with a 1-flight decrease, compared to Quarter 4 of 2017. Using dummy coding strategies, *entry patterns* were then coded in favor of nonzero values (i.e., 1 was coded as entry decisions made versus 0 coded as no change in flight departures across city-pair routes). Similarly, *exit patterns* were coded in favor of nonzero values (i.e., 1 was coded as exit decisions made versus 0 coded as no change in flight departures across city-pair routes). It was noted that the two entry and exit decisions were independent of each other; therefore, we gained two separate variables, entry patterns and exit patterns.

Independent Variables

Total passengers were an aggregated number of passengers carried by all airlines on a given city-pair route.

Number of departures was used interchangeably with the aggregated number of flights operated by all airlines on a given route.

Average market fare was defined as the average price of passenger transportation service that all airlines offered in a city-pair market.

Number of carriers counted all airlines operating on a given route.

Market concentration was scored by the Herfindahl–Hirschman Index (HHI) for each route, measuring the market structure and competition level of the market. Generally, the score is computed by a summation of squared market share of each airline, ranging either from 0 to 10,000 for a percentage-based computation, or from 0 to 1 for a computation without percentage consideration (Abdelghany & Abdelghany, 2009, pp. 47–48). The HHI in this study followed the latter technique, which varied from an approximation of 0 as a clue of a heavily competition level to 1 as a clue of a monopolistic market.

Distance was defined as the geographic distance in miles between origin and destination airports.

Route type was defined as either nonstop route market coded with 1, or connecting route market coded with 0. Conventionally, the number of coupons (i.e., referred to the number of boarding pass of a flight) speak to the characteristic of route market (Yuan, 2016). It is very commonly accepted in the literature that in a specific city-pair route, if the number of coupons is 1 and nonstop flights are served, the route is considered nonstop market; otherwise it is considered a connecting market (Coldren, 2005; Coldren, Koppelman, Kasturirangan, & Mukherjee, 2003; Garrow, 2010). For example, the route ABE-ATW was a connecting market due to no nonstop flight being served across airlines.

Existence of low cost carriers was defined as at least one operation of a low-cost carrier on a given route. The variable was coded as 1 if having at least one LCC, and otherwise it was 0.

Business model of airline accounting for the largest share in the given route was partitioned exclusively into low-cost carriers (LCC) and full-service carriers (FSC). The former was coded as 1 and the latter was coded as 0 using dummy coding strategy. A total of 36 commercial airlines reported as ticketing carriers in the 2018 dataset, and 7 of them correspond to the business model of a low-cost carrier, according to reports in their official websites. These LCCs includes Allegiant Air (G4), Frontier Airlines (F9), JetBlue (B6), Spirit Airlines (NK), Southwest Airlines (WN), Sun Country Airlines (SY), and Virgin America (VX) (i.e., Virgin America's flights continued to be reported in the study timeframe, but the airline will cease its operations as of April 2018 due to the consolidation with Alaska Airlines). The market shares were then calculated for each airline in a given route based on the number of passengers it transported during the Quarter 1 of 2018. Only the airline that had the largest share in each route was reflected in this variable.

Origin hub airport was a dummy variable coded as 1 if the origin airport is a large hub, and 0 if it is a non-large hub. The large hubs were primary commercial service airports and categorized by the Federal Aviation Administration (FAA) as having 1% and more of annual enplanements ("Airport Categories – Airports," n.d.).

Destination hub airport was a dummy variable coded as 1 if the destination airport is a large hub, and 0 if it was a non-large hub. The large hubs were primary commercial service airports and were categorized by Federal Aviation Administration (FAA) as having 1% and more of annual enplanements ("Airport Categories – Airports," n.d.).

Method and Data Construction

Method

The research methodology was retrospective, known as ex-post facto, and the corresponding design was cause-type. This methodology was appropriate to answer the research questions because we were determining the extent to which the targeted factors influenced whether airlines entered or exited routes. Furthermore, the effects on the two dependent variables, which were group memberships, had already occurred. As a part of the study, two statistical approaches, descriptive and inference, were utilized to answer the research questions. The latter approach was involved in logit analyses (i.e., logistic regressions), which were appropriate to answer the research problem because the dependent variables were binary nominal (Cameron & Trivedi, 2005; Greene, 2011; Hair, Black, Babin, & Rolph, 2010).

Greene (2011) suggested that if the two binary dependent outcomes are interrelated as opposed to independent and have a significant correlation coefficient, a bivariate logit model should be applied. An example used by (Katchova, 2013) for a bivariate logit model is an investigation on factors influencing the joint outcome of being in an excellent health status (Y_1) and visiting the doctor (Y_2). Another would be a business decision of whether to use marketing contracts or not (Y_1) versus whether to use environment contracts or not (Y_2). Given the current study, the correlation coefficient between entry and exit patterns were $r = -.3520$, $p < .0001$; however, each decision to enter or exit was made independently and the decisions were unrelated to each other. In a route, some airlines choose to enter/increase, while others choose to maintain their frequency, or even exit at the same time. Therefore, two separated binary logit models were more appropriate to estimate the effect of factors on the entry and exit decision patterns.

Table 1

Summary and Description of Independent and Dependent Variables Overall

Variables	Description
Total passengers	Continuous variable represented the aggregated number of passengers carried by all airlines on a route.
Number of departures	Continuous variable represented the aggregated number of flights on a route.
Average market fare	Continuous variable represented the average of price all airlines offered in a route.
Number of carriers	Continuous variable as all airlines operating on a given city-pair route.
HHI score	Continuous variable, range from 0 to 1, measuring market concentration by a summation of squared market share of each airline.
Distance	Continuous variables ad the geographic distance in miles between origin and destination airports.
Route type	Categorical (dichotomous) variable represented having at least one nonstop flight on a given route. Dummy coded with 1 as nonstop market and 0 as connection market (the reference group).
LCC existence	Categorical (dichotomous) variable represented having at least one LCC operation on a given route. Dummy coded with 1 as yes group and 0 as no group (the reference group).
The business model of the largest share airline	Categorical (dichotomous) variable represented the largest share airline is a LCC or FSC. Dummy coded with 1 as a LCC and 0 as a FSC (the reference group).
Origin airport	Categorical (dichotomous) variable represented the origin airport is a large hub or non-large hub. Dummy coded with 1 as a large hub and 0 as a non-large hub (the reference group).
Destination airport	Categorical (dichotomous) variable represented the destination airport is a large hub or non-large hub. Dummy coded with 1 as a large hub and 0 as a non-large hub (the reference group).
Entry Patterns	Categorical (dichotomous) variable represented the airline decisions of entering a new route or increasing the frequency in the existing route. Dummy coded with 1 as an entry decision and 0 as a no-entry decision (the reference group).
Exit Patterns	Categorical (dichotomous) variable represented the airline decisions of exiting from an existing route or reducing the frequency in a given route. Dummy coded with 1 as an exit decision and 0 as a no-exit decision (the reference group).

Note. The order of the variables was arranged for the convenience of the readers based on market-related factors: total passengers, number of departures, average market fare, number of carriers, and HHI; route-related factors: distance, route type, LCC existence, and the business model of the largest share airline; and airport-related factors: origin airport and destination airport.

Data Construction

The dataset used for analyses in this study was directly downloaded from the U.S. Department of Transportation (US DOT) Origin and Destination Data Bank 1B (DB1B). The stored database contains a 10% sample of tickets collected from passengers as they boarded aircraft operated by any of the U.S. airlines. The selected dataset was for Quarter 1 in 2018and it was subsequently imported through *JMP* software. In particular, the raw data provided quarterly demand information on the number of passengers transported between origin-destination pairs, itinerary information (e.g., ticketing carriers, operating carriers, number of coupons, distance…), and quarterly fare charged by each airline for a route that is averaged across all classes of service. Following Garrow's (2010) recommendation, we eliminated 127,429 routes from the total 6,093,175 routes due to missing data on ticketing carriers (i.e., missing ticketing carriers were coded either as "--" or 99 on the original dataset). The data were then reconstructed by sorting out all variables based on origin-destination airport pairs. There were N = 61,024 airport pairs after reconstruction, which were different from the original routes by the unique appearance of an airport pair. An example for the reconstructed data was that the ABE-ATW pair had 27 departures over the quarter from two airlines, while on the raw dataset, it had 27 repeated ABE-ATW pairs. However, on both datasets, the 27 departures were all connecting flights, which indicated a connecting route market as discussed earlier.

To construct the two dependent variables--entry and exit patterns--we sorted out the number of departures performed by each ticketing airline on each O&D airport pair. The same technique was applied to the dataset of Quarter 4 of 2017 to acquire the differences in entry and exit decisions made throughout Quarter 1 of 2018. The number of carriers, the existence of at least one LCC, and the number of departures were counted as nonzero values across sort-outs of ticketing airlines on each airport pair. To construct competition-related factors, total passengers, market shares of each airline, largest share and its respective airline business model, and HHI, we sorted out the number of passengers transported by each ticketing airline on each O&D airport pair. To construct average market fare, we averaged the market fare from all flights performed by all airlines on a given route. To construct distance, we took the minimum of the distance in miles flown because the minimum distances indicate the geographic distances between the O&D airport pairs in nonstop routes.

The size of the sample, N = 61,024 airport pairs, exceeded all recommendations for a minimum sample size of the logistic regression model in the literature. For example, Hosmer Jr, Lemeshow, and Sturdivant (2013) suggested a sample size greater than 400 observations, and Peduzzi, Concato, Kemper, Holford, and Feinstein (1996) called on researchers to obtain at least 10 times the number of independent variables in the model (i.e., the number of independent variables in the study, k = 11). Apart from a large sample size, a logistic analysis requires a sample size for each group membership of at least 10 observations per estimated parameter (Hair et al., 2010, p. 322), and each independent variable consists of a minimum of one cell frequency and no more than 20% of cell frequencies less than five (Tabachnick & Fidell, 2013). The dataset was valid and met all suggestions, thereby ensuring the study's statistical power, and this was confirmed by contingency tables discussed in the sections below.

Findings

Descriptive Analysis

Statistical summary of entry patterns. As reported in Table 2, on itineraries airlines made entry decisions, the mean of the demand was more than 277 passengers, which was higher than that on itineraries airlines had no change in their schedule with approximately 114 passengers. On such routes, airlines supplied more available seat per mile (ASMs) to meet the high demand, and thus had more departures with 128 quarterly flights, which was more than double the non-entry routes at 57 quarterly flights. The market concentration on entry routes was lower than non-entry routes with 0.72 versus 0.83 in the respective HHI scores, which was a sign of a heavier competition with more airlines. Higher average market fare and longer stage length in geographic distance exhibited as long haul flights with higher yield rate for entry routes. Abnormalities or potential outliers were spotted in the variables of average market fare and distance. For average market fare on entry route, the standard deviation (SD) was high at $1,163.19, while the figure for non-entry routes was $151.93. The maximum fare on the range of average market fare was $215,353.35, which probably belonged to charter flights and was identified as an outlier that discussed in the preliminary analysis below. For the variable of distance with the minimum at 11 miles between two airports, we retrieved the route from the dataset and uncovered that the O&D airport pairs are OAK (Metropolitan Oakland International Airport) and SFO (San Francisco International Airport), which the distance was only from East to West boundary of San Francisco Bay.

Table 2

Descriptive Statistics of Continuous Variables in the Model of Entry Patterns

Continuous Variables	Entry			No Entry			Overall		
	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range
Total passengers	277.37	1272.29	1 – 34,582	113.75	649.05	1 – 20,560	207.29	1,054.68	1 – 34,582
Departures	128.29	403.12	1 – 9,229	57.01	223.04	1 – 6,040	97.76	339.78	1 – 9,299
Average market fare	324.51	1,163.19	0 – 215,353.35	310.50	151.93	0 – 3,680.84	318.51	885.11	0 –215,353.35
Number of carriers	2.19	1.35	1 – 10	1.61	0.94	1 – 8	1.94	1.22	1 – 10
HHI	0.72	0.26	0.14 – 1	0.83	0.23	0.19 – 1	0.77	0.26	0.13 – 1
Distance	1,495.63	1,015.93	11 – 9,700	1,312.44	913.17	55 – 9,571	1,427.16	977.45	11 – 9,700

As reported in Table 3 and Table 4, entry routes accounted for 57.2% in the total of 61,024 routes. Overall, there were 8,468 routes (13.9%) having at least an operation of a LCC in which entry decisions appeared on 6,029 routes (17.3% of the total entry route) and exit decisions appeared on 2,439 routes (9.3% of the total exit route). By taking advantage of connecting flights to cover all airports in the nation, full-service airlines wholly dominated the overall network with 93.6% in terms of the largest share airline. On routes having entry decision made, there were only 7.3% if the largest share is a LCC, but 92.7% if a FSC. This was also the reason why connection market considerably overweighed nonstop one with 87.8% in comparison with 12.2%. Airlines made 85.9% entry decisions in the total on connection route market as opposed to 14.1% entry decisions made on nonstop route market. This implies that once airlines see a potential growth in connection itineraries, they could either increase their frequencies, or launch single-connecting in place of previous double-connecting flights, or even serve non-stop flights and make the route become nonstop route market. In case of O&D airport pairs are large hubs, approximately 15% entry decisions were made on such routes, which was by far lower than those on routes with non-hub airport pairs.

Table 3

Descriptive Statistics Relative to LCC Existence and Business Model of the Largest Share Airlines in the Model of Entry Patterns

			LCC existence				Business model of the largest share airline			
			Yes		No		LCC		FSC	
	N	%	N	%	N	%	N	%	N	%
Entry	34,886	57.2	6,029	17.3	28,857	82.7	2,545	7.3	32,341	92.7
No Entry	26,138	42.8	2,439	9.3	23,699	90.7	1,370	5.2	24,768	94.8
Overall	61,024	100	8,468	13.9	52,556	86.1	3,915	6.4	57,109	93.6

Table 4

Descriptive Statistics Relative to Origin, Destination Airport, and Route Type in the Model of Entry Patterns

			Origin Airport				Destination Airport				Route Type			
			Hub		Non-Hub		Hub		Non-Hub		Nonstop		Connection	
	N	**%**	N	%	N	%	N	%	N	%	N	%	N	%
Entry	34,886	57.2	5,404	15.5	29,482	84.5	5,223	15.0	29,663	85.0	4,919	14.1	29,967	85.9
No Entry	26,138	42.8	3,798	14.5	22,340	85.5	3,946	15.1	22,192	84.9	2,516	9.6	23,622	90.4
Overall	61,024	100	9,202	15.1	51,822	84.9	9,169	15.0	51,855	85.0	7,435	12.2	53,589	87.8

Statistical summary of exit patterns. As reported in Table 5, exit decisions were made on routes that had higher demand with the average of 298 passengers, but lower fare at $301.40 compared to 46 passengers and $348.69 on routes no exit decisions were made. The competition level in exit routes was stiffer and fiercer with at least two players and 0.7 HHI, and that in non-exit routes were easier with one operation of an airline and 0.89 HHI. When examining the distance between two groups, airlines tended to exit on shorter routes (mean at 1,340.74 miles) and make no exit decision on long routes (mean at 1,551.99 miles).

Table 5

Descriptive Statistics of Continuous Variables in the Model of Exit Patterns

Continuous Variables	Exit			No Exit			Overall		
	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range
Total passengers	298.38	1,277.40	1 – 34,582	46.60	394.55	1 – 18,249	207.29	1,054.69	1 – 34,582
Departures	138.86	409.36	1 – 9,299	25.26	129.26	1 – 5,141	97.76	339.78	1 – 9,229
Average market fare	301.40	124.40	0 – 3,680.84	348.69	1461	0 – 215,353.35	318.51	885.11	0 – 215,353.35
Number of carriers	2.28	1.33	1 – 10	1.35	0.71	1 – 8	1.94	1.23	1 – 10
HHI	0.70	0.26	0.13 – 1	0.89	0.20	0.21 – 1	0.77	0.26	0.13 – 1
Distance	1,340.74	896.45	54 – 9,571	1,551.99	1,093	11 – 9,700	1,417.17	977.45	11 – 9,700

As reported in Table 6 and Table 7, exit decisions were made on 38,947 routes, accounting 63.8% of the total observations of the study. There were 19.1% of the exit routes in conjunction with the appearance of at least one LCC operation. On routes that exit decisions were made, there were only 8.2% if the largest share is a LCC, but 91.8% if a FSC. Also, on routes that exit decisions made, nonstop market occupied only 16.7%, while the figure for connection market was 83.3%. Similar to entry pattern analysis, approximately 18% exit decisions were made on routes with departures and arrivals at large hubs.

Table 6

Descriptive Statistics Relative to LCC Existence and Business Model of the Largest Share Airlines in the Model of Exit Patterns

			LCC existence				Business model of the largest share airline			
			Yes		No		LCC		FSC	
	N	%	N	%	N	%	N	%	N	%
Exit	38,947	63.8	7,432	19.1	31,515	80.9	3,195	8.2	35,752	91.8
No Exit	22,077	36.2	1,036	4.7	21,041	95.3	720	3.2	21,357	96.8
Overall	61,024	100	8,468	13.9	52,556	86.1	3,915	6.4	57,109	93.6

Table 7

Descriptive Statistics Relative to Origin, Destination Airport, and Route Type in the Model of Exit Patterns

			Original				Destination				Route Type			
			Hub		Non-Hub		Hub		Non-Hub		Nonstop		Connection	
	N	%	N	%	N	%	N	%	N	%	N	%	N	%
Exit	38,947	63.8	7,042	18.1	31,905	81.9	7,080	18.2	31,867	81.8	6,520	16.7	32,427	83.3
No Exit	22,077	36.2	2,160	9.8	19,917	90.2	2,089	9.5	19,988	90.5	915	4.1	21,162	95.9
Overall	61,024	100	9,202	15.1	51,822	84.9	9,169	15.0	51,855	84.9	7,435	12.2	53,589	87.8

Preliminary analysis

The targeted independent and dependent variables were tested for compliance with the assumptions of logistic regression. First, the assumption of a dichotomous dependent variable was obtained through group memberships of both dependent variables. Entry patterns were coded either 1 for entering/increasing, or 0 for not entering/increasing flights in a route. Exit patterns were coded either 1 for exiting/reducing, or 0 for not exiting/reducing flights in a route. Second, the assumption of mutually exclusive categories on the dependent variables was fulfilled. Each route of airport pairs was a member of one group or the other, but not both, and therefore was exhaustive and mutually exclusive. Third, the assumption of independence of scores on the dependent variables was presumed to be compliant because the study's dataset was not the result of repeated measures or matched data. Instead, the data were acquired from an archival database of U.S. DOT, and thus the data for each targeted variable associated with each route of airport pairs were unrelated. Lastly, the assumption of correct specification of the model, which requires the hypothesized model only include independent variables that are relevant, was met. The reason was that the inclusion of the targeted variables in the hypothesized model was based on prior research, and the significant chi-square test for the fit of the null and convergent models discussed in primary analysis.

Although not required for a logistic regression, outlier analysis and the absence of multicollinearity in the independent variables were also addressed because these issues could be indicative of a poor predictive model. Outliers are extreme data points inconsistent with others, and it potentially could produce results that are not representative of the relationships in the remaining data. Outliers can be labeled as either contaminants or rare cases (Cohen J., Cohen P., West, & Aiken, 2003). We conducted a statistical analysis on the dataset with *N* = 61,024 routes, and determined 3,536 routes (5.8%) as potential outliers based on Jackknife distances. "The distance for each observation is calculated with estimates of the mean, standard deviation, and correlation matrix that do not include the observation itself. The jack-knifed distances are useful when there is an outlier." (SAS Institute Inc., 2016, pp. 50–51). Examination of these outliers revealed several instances in which there was an inconsistency; for example, the average fare in BGM-HNL was extremely high at $215,353.35 with only one carrier operating on the route, which was most likely a charter flight rather than a commercially-scheduled flight. To determine the impact of these outliers, we ran analyses before and after excluding the outliers, and then we compared the results of the models. All overall models yielded significant results with few differences; however, the estimations were impacted considerably. Therefore, we decided to eliminate all the flagged outliers from the primary models, and the sample size reduced to N = 57,488 routes.

Multicollinearity can occur if the independent variables in a model are highly-correlated, and it can be examined through a correlation matrix. Cohen et al. (2003) suggested an existence of multicollinearity if the correlation coefficient is $r > .8$ between two independent variables. As reported in Table 8, compared to the threshold, the number of carriers and HHI were labeled as multicollinearity, $r_{\text{Carriers vs. HHI}} = -.89$, which indicates the negative relationship that the more carriers, the smaller HHI score is. Evidence of serious multicollinearity also was found between the total passengers and the number of departures, $r_{\text{Pax vs. Departures}} = .91$, indicating a positive relationship when airlines have more flights, and thus, can carry more passengers. For the sake of interpretations in later sections, we decided to retain the number of carriers and total passengers in the model and to exclude HHI and number of departures from the final model. At this point, the number of independent variables was reduced, $k = 9$ in total.

Table 8

Correlation Matrix between Continuous Variables

	Carriers	Market Fare	Total Passengers	HHI	Departures	Distance
Carriers	1.0000	-0.1129	0.3835	-0.8906	0.5523	-0.0119
Market Fare	-0.1129	1.0000	-0.1659	0.0808	-0.1723	0.3811
Total Passengers	0.3835	-0.1659	1.0000	-0.2017	0.9142	-0.1093
HHI	-0.8906	0.0808	-0.2017	1.0000	-0.3398	0.0123
Departures	0.5523	-0.1723	0.9142	-0.3398	1.0000	-0.1053
Distance	-0.0119	0.3811	-0.1093	0.0123	-0.1053	1.0000

Primary Analysis

Two separate simultaneous models were developed by regressing two independent variables: Entry versus No entry and Exit versus No Exit, on the nine independent variables simultaneously. Following Warner's (2008) recommendations, the overall goodness of fit of null models, which regressed group memberships in the absence of nine independent variables, were compared to that of the full models. The assessments point to the log likelihood (*LL*) function and the chi-square statistic. The former is comparable to the sum of the squared residuals in multiple regression, while the latter is the difference between -2*LL* for the full model and -2*LL* for the null model (Warner, 2008).

Entry patterns models. As reported in Table 9, the full model was statistically significant, $\chi^2(9) = 3441.82$, $p < .0001$. In addition, Cohen et al. (2003) recommended reporting the Pseudo-R^2 (R_L^2) as a gain in prediction obtained from adding variables to a model. The full model provided a predictive gain of 4.36% over the null model ($R_{Lfull}^2 = .0436$, $df = 9$).

As reported in Table 10, the null model was significant, $\chi^2(0) = 785.17$, $p < .0001$. The null model's logit in the Entry group was $B_{\text{Constant}} = 0.235$, which means that in the absence of information provided the independent variables, the odds of entering/increasing flights in a route was $e^{0.235} = 1.26$. When applied the mathematical expression, $e^{0.235} / (1 + e^{0.235}) = 0.5575$, it indicated that 55.75% of the observations associated with entering/increasing flights in Quarter 4 of 2018. Because the omnibus test yielded a significant result, we examined the relationship between each IV and the DV—Entry patterns. In the full model, seven of nine IVs were significantly related to the group membership, Entry versus No Entry, in the presence of the other predictors.

Table 9

Significance of the Simultaneous Model of Entry Patterns

Model	Log Likelihood	*df*	χ^2
Null	39452.34		
Full	37731.43		
Difference	1720.91	9	3441.82***

Note. $N = 57{,}488$. $R_L^2 = .0436$, $^{***}p < .001$

Directions of relationships. The original logistic coefficient for total passengers was $B_{\text{Pax}} = 0.0003$, which indicates a positive relationship between total passenger variable and the group membership. As passengers increased, airlines were more likely to enter/increase their operations in the market route. Similarly, $B_{\text{Fare}} = 0.0002$, $B_{\text{Carriers}} = 0.5057$, and $B_{\text{Distance}} = 0.0003$ showed positive signs, which signified a likelihood of making entry decision in the market route when market fare, number of carriers, and the distance between origin and destination airports increased. For dummy nominal coded variables, $B_{\text{LCC}} = -0.2462$, $B_{\text{Origin}} = -0.3469$, and $B_{\text{Dest}} = -0.4281$ implied that airlines were less likely to enter/increase their flights in the market route in which there had been the appearance of at least one LCC operation, or either the origin or destination airport was a large hub. Two other nonsignificant variables, route type and business model of the largest share airline, were not interpreted.

Magnitude interpretations. To interpret the magnitude of the relationships, we turned our attention to the exponential coefficients (odds ratio) that are calculated by raising *e* to the original coefficients (B_{i}), $e^{0.0003} = 1.0003$ and its reciprocal $e^{-0.0003} = 0.9997$. In the case, $e^{Bi} > 1$ indicates a positive relationship, $e^{Bi} < 1$ indicates a negative relationship, and $e^{Bi} = 1$ indicates a no change in the odds for the membership relative to the discussion IV. In our study, it means that with an increase of one passenger, airlines were 1.0003 times more likely to be involved in entry decisions than maintaining their schedule or considering no new entry. Also, $e^{Bi} – 1$ equals the percentage change in odds in which the odds increased by 0.03% if the demand increased by one passenger, holding all other variables constant. In the same way, airlines were 1.0002, 1.6581, and 1.0003 times more likely to enter the route or increase their flights in the route as an increase of market fare by $1, or one more competitor, or 1 mile in the distance between the origin and destination airports. The corresponding odds ratios of making entry decisions also increased 0.02%, 65.81%, and 0.03% respectively. For negative signs in the relationships (i.e., in our entry pattern study, all significant dummy coded nominal variables were negative) reciprocals were reported as opposed to its odds ratios. Particularly, airlines were 1.2791, 1.4147, and 1.5343 times more likely to enter/increase the frequency in the route in which no LCC had existed, and either origin or destination airport was not a large hub. The corresponding odds ratios of making entry decisions in routes characterized by LCC existence, origin large hub, and destination large hub decreased by 21.82% (= 0.7818 – 1), 29.32% (= 0.7068 – 1), and 34.83% (= 0.6517 – 1), respectively.

Table 10

Summary of Logistic Regression Estimates for the Null and Simultaneous Model of Entry Patterns

	B_i	*SE*	χ^2	*p*	Odds Ratio	95% CI	Reciprocal
Null Model							
Constant	0.235	0.0084	785.17	<.0001***			
Full Model							
Constant	-0.9381	0.0302	960.50	<.0001***			
Total Passengers	0.0003	0.00006	25.54	<.0001***	1.0003	[1.0001, 1.0004]	0.9997
Market fare	0.0002	0.00007	5.81	<.0001***	1.0002	[1.0000, 1.0003]	0.9998
Number of carriers	0.5057	0.0112	2038.8	<.0001***	1.6581	[1.6221, 1.6949]	0.6031
Distance	0.0003	0.00001	429.87	<.0001***	1.0003	[1.0002, 1.0003]	0.9997
Route type	-0.0468	0.0448	1.09	.2963	0.9542	[0.8740, 1.0419]	1.0479
LCC existence	-0.2462	0.0499	24.27	<.0001***	0.7818	[0.7089, 0.8622]	1.2791
Business model of the largest share	0.051	0.060	0.71	.3998	1.0523	[0.9345, 1.1850]	0.9503
Origin hub	-0.3469	0.0271	163.28	<.0001***	0.7068	[0.6702, 0.7455]	1.4147
Destination hub	-0.4281	0.0271	248.20	<.0001***	0.6517	[0.6179, 0.6874]	1.5343

Note. $N = 57{,}488$. $R_L^2 = .0436$, $df = 9$ for the full model, $^*p < .05$. $^{**}p < .01$. $^{***}p < .001$

Another approach in understanding the magnitude of the relationships is to calculate marginal effects for the independent variables. Indeed, reporting marginal effects instead of odds ratio is more popular in econometrics (Cameron & Trivedi, 2005; Greene, 2011). Following Greene's (2011) instructions, we informed readers of two types: marginal effects at the mean and average marginal effects. The former is estimated for the average observation $(\bar{x})$ in the sample, while the latter is estimated as the average of the individual marginal effects. In both ways, the marginal effects reported in Table 11 were almost identical, so we only interpreted the marginal effects at the mean in this study. In our study, for an additional passenger in demand, $1 increase in market fare, one more competitor, and 1-mile increase in distance, airlines were 0.007%, 0.005%, 12.31%, and 0.007% more likely to make an entry decision, respectively. In contrast, under independent conditions, at least one LCC operation, origin large hub, or destination large hub, airlines were 6%, 8.45%, and 10.43% less likely to make an entry decision into the routes.

Table 11

Summary of Marginal Effects for the Logistic Model of Entry Patterns

	Mean (*M*)	Logistic Coefficient for Entry Patterns	Marginal Effects at the Mean[a]	Average Marginal Effects[b]
Total Passengers	68.32	0.0003***	0.00007	0.00007
Market Fare	310.80	0.0002***	0.00005	0.00005
Number of Carriers	1.80	0.5057***	0.1231	0.1246
Distance	1345.95	0.0003***	0.00007	0.00007
Route Type	0.09	-0.0468	-0.0114	-0.0115
LCC Existence	0.11	-0.2462***	-0.06	-0.0607
Business Model of the Largest Share	0.05	0.051	0.0124	0.0126
Origin Hub	0.13	-0.3469***	-0.0845	-0.0855
Destination Hub	0.13	-0.4281***	-0.1043	-0.1055

Note. $N = 57{,}488$. Logit equation = $0.0003X_{\text{Total Pax}} + 0.0002X_{\text{Fare}} + 0.5057X_{\text{Carriers}} + 0.0003X_{\text{Distance}} - 0.0468X_{\text{Route Type}} - 0.2462X_{\text{LCC}} + 0.051X_{\text{Largest Share}} - 0.3469X_{\text{Origin}} - 0.4281X_{\text{Dest}} - 0.9381$.

[a] Logit Value at the Mean was calculated by substituting the means of regressors into the Logit equation. Logit Value = 0.329. Odds = $e^{0.329} = 1.389$. Probability Pr (Y = 1 | X) = $e^{0.329} / (1 + e^{0.329}) = 0.58$, Pr (Y = 0 | X) = 1 - 0.58 = 0.42. Marginal Effect at the Means, $\delta_p/\delta_{xj} = f(\bar{x}'\beta) * (1 - f(\bar{x}'\beta)) * \beta_j$ (Greene, 2011), which in our study equals 0.58 x 0.42 x Logistic coefficients. [b] Average Predicted Probability were obtained from *JMP* output for each case before taking an average, Pr (Y = 1 | X) = 0.56, Pr (Y = 0 | X) = 0.44. Average Marginal Effects, $\delta_p/\delta_{xj} = \frac{\Sigma f(x'\beta)}{n} * (1 - \frac{\Sigma f(x'\beta)}{n}) * \beta_j$ (Greene, 2011), which in our study equals 0.56 x 0.44 x Logistic coefficients, $^*p < .05$. $^{**}p < .01$. $^{***}p < .001$

Exit patterns model. As reported in Table 12, the full model was statistically significant, $\chi^2(9) = 10249.31$, $p < .0001$. $R_{Lfull}^2 = .1348$, $df = 9$ indicated that the full model provided a predictive gain of 13.48% over the null model. As reported in Table 13, the null model was significant, $\chi^2(0) = 3564.8$, $p < .0001$. The logistic constant coefficient of the null model in the Exit group was $B_{\text{Constant}} = 0.5156$, which means that in the absence of information provided the independent variables, the odds of exiting/reducing flights in a route was $e^{0.5156} = 1.67$. When applied the mathematical expression, $e^{0.5156} / (1 + e^{0.5156}) = 0.6255$, it indicated that 62.55% of the observations associated with exiting/reducing flights in Quarter 4 of 2018. Because the omnibus test yielded a significant result, we examined the relationship between each IV and the DV—Exit patterns. In the full model, all nine IVs were significantly related to group membership, Exit versus No Exit, in the presence of the other predictors.

Table 12

Significance of the Simultaneous Model of Exit Patterns

Model	Log Likelihood	*df*	χ^2
Null	38005.80		
Full	32881.14		
Difference	5124.66	9	10249.31***

Note. $N = 57{,}488$. $R_L^2 = .1348$
*** $p < .0001$

Directions of relationships. The original logistic coefficient for total passengers (B_{Pax} = -0.0002), Market fare (B_{Fare} = -0.0003), Distance (B_{Distance} = -0.0003), and LCC existence (B_{LCC} = -0.2351) showed a negative relationship with the group membership. As each of the variables increased, airlines were less likely to exit/reduce their operations in a given route. Conversely, the logistic coefficients for the number of carriers (B_{Carriers} = 1.0272), route type ($B_{\text{Route type}}$ = 0.1908), the business model of the largest share airline ($B_{\text{Largest share}}$ = 0.2997), origin airport (B_{Origin} = 0.4350), and destination airport (B_{Dest} = 0.5029) showed positive signs. It signified a likelihood of making exit decisions in the market route when the number of carrier increase, when it is a nonstop market, when the largest share airline is a LCC, and when the origin and destination airports are large hubs.

Magnitude interpretations. As reported in Table 13, airlines were 1.0002, 1.0003, 1.0003, and 1.2651 times more likely to be involved in exit decisions than maintaining their schedule if there is a decrease by one passenger in demand, by $1 in market fare, by 1 mile in distance, and there is an operation of at least one LCC in a given route. The corresponding odds ratios of making exit decisions also decreased by 0.02% (= 0.9998 – 1), 0.03% (= 0.9997 – 1), 0.03% (= 0.9997 – 1), and 20.95% (= 0.7905 – 1), respectively. On the other hand, airlines were 2.7933, 1.2102, 1.3495, 1.5450, and 1.6534 times more likely to exit/reduce the frequency in the route if one more carrier enters the competition, if a nonstop market, if the largest share airline is a LCC, and if either origin or destination airport are large hubs. The corresponding odds ratios of making exit decisions in routes increased by 179.33%, 21.02%, 34.95%, 54.50%, and 65.34%, respectively.

Table 13

Summary of Logistic Regression Estimates for the Null and Simultaneous Model of Exit Patterns

	B_i	*SE*	χ^2	*p*	Odds Ratio	95% CI	Reciprocal
Null Model							
Constant	0.5146	0.0086	3564.8	<.0001***			
Full Model							
Constant	-0.8049	0.0324	616.05	<.0001***			
Total passengers	-0.0002	0.00008	5.52	.0188*	0.9998	[0.9996, 0.9999]	1.0002
Market fare	-0.0003	0.00007	16.79	<.0001***	0.9997	[0.9995, 0.9998]	1.0003
Number of carriers	1.0272	0.0140	5337.5	<.0001***	2.7933	[2.7717, 2.8713]	0.3580
Distance	-0.0003	0.00001	480.69	<.0001***	0.9997	[0.9996, 0.9997]	1.0003
Route type	0.1908	0.0592	10.40	.0013**	1.2102	[1.0777, 1.3590]	0.8263
LCC existence	-0.2351	0.0742	10.05	.0015**	0.7905	[0.6835, 0.9142]	1.2651
Business model of the largest share	0.2997	0.0890	11.33	.0008**	1.3495	[1.1334, 1.6068]	0.7410
Origin hub	0.4350	0.0310	197.04	<.0001***	1.5450	[1.4540, 1.6418]	0.6472
Destination hub	0.5029	0.0312	259.99	<.0001***	1.6534	[1.5554, 1.7576]	0.6048

Note. $N = 57{,}488$. $R_L^2 = .1348$
*** $p < .0001$

Alternatively, marginal effects for the independent variables were reported and interpreted in Table 14. Again, the marginal effects calculated in both ways were almost identical, and marginal effects at the mean were used for interpretations. For an additional passenger in demand, $1 increase in market fare, 1-mile increase in distance, and an existing LCC operation in a given route, airlines were 0.005%, 0.007%, 0.007%, and 5.28% less likely to make an exit decision, respectively. In contrast, under independent conditions, one more competitor, nonstop market, a LCC holding the largest share, origin large hub, or destination large hub, airlines were 23.05%, 4.28%, 6.73%, 9.76%, and 11.29% more likely to make an exit decision from the routes.

Table 14

Summary of Marginal Effects for the Logistic Model of Exit Patterns

	Mean (*M*)	Logistic Coefficient for Exit Patterns	Marginal Effects at the Mean[a]	Average Marginal Effects[b]
Total Passengers	68.32	-0.0002***	-0.00005	-0.00005
Market Fare	310.80	-0.0003***	-0.00007	-0.00007
Number of Carriers	1.80	1.0272***	0.2305	0.2394
Distance	1345.95	-0.0003***	-0.00007	-0.00007
Route Type	0.09	0.1908***	0.0428	0.0445
LCC Existence	0.11	-0.2351***	-0.0528	-0.0548
Business Model of the Largest Share	0.05	0.2997***	0.0673	0.0699
Origin Hub	0.13	0.4350***	0.0976	0.1014
Destination Hub	0.13	0.5029***	0.1129	0.1172

Note. $N = 57{,}488$. Logit equation = $-0.0002X_{\text{Pax}} - 0.0003X_{\text{Fare}} + 1.0272X_{\text{Carriers}} - 0.0003X_{\text{Distance}} + 0.1908X_{\text{Route Type}} - 0.2351X_{\text{LCC}} + 0.2997X_{\text{Largest Share}} + 0.4350X_{\text{Origin}} + 0.5029X_{\text{Dest}} - 0.8049$.

[a]Logit Value at the Mean was calculated by substituting the means of regressors into the Logit equation. Logit Value = 0.675. Odds = $e^{0.675} = 1.965$. Probability Pr (Y = 1 | X) = $e^{0.675} / (1 + e^{0.675}) = 0.66$, Pr (Y = 0 | X) = 1 - 0.66 = 0.34. Marginal Effect at the Means, $\delta_p/\delta_{xj} = f(\overline{x}'\beta) * (1 - f(\overline{x}'\beta)) * \beta_j$ (Greene, 2011), which in our study equals 0.66 x 0.34 x Logistic coefficients. [b]Average predicted probabilities were obtained from *JMP* output for each case before taking an average, Pr (Y = 1 | X) = 0.63, Pr (Y = 0 | X) = 0.37. Average Marginal Effects, $\delta_p/\delta_{xj} = \frac{\Sigma f(x'\beta)}{n} * (1 - \frac{\Sigma f(x'\beta)}{n}) * \beta_j$ (Greene, 2011), which in our study equals 0.63 x 0.37 x Logistic coefficients, *$p < .05$. **$p < .01$. ***$p < .001$

Classification accuracy. Classifications also can be used as supplementary analyses to determine the goodness of fit of a logistic regression model (Cohen et al., 2003; Hair et al., 2010). We compared the statistical classifications of group memberships in the full models to actual group memberships by determining predicted probabilities for each case and developing contingency tables of predicted versus actual group membership. With respect to the entry pattern model as reported in Table 15, 35201 (= 22416 + 12785) cases were classified as belonging to the Entry group, and 22287 (= 9695 + 12592) cases to the No Entry group in the full model. There were 35008 out of 57488 cases, which was 61%, correctly classified in the full model at the predicted probability cut of 0.5. These correctly classified cases consisted of 22416 cases (70% hit rate) and 12592 cases (50% correct rejection rate). With respect to the exit pattern model as reported in Table 16, 35154 (= 26456 + 8698) cases were classified as belonging to the Exit group, and 22334 (= 9525 + 12809) cases to the No Exit group in the full model. There were 39265 out of 57488 cases, which was 68%, correctly classified in the full model at the predicted probability cut of 0.5. These correctly classified cases consisted of 26456 cases (74% hit rate) and 12809 (60% correct rejection rate).

Table 15

Classification Matrix for Entry Pattern Model

	Predicted Group Membership	
Actual Group Membership	Entry	No Entry
Entry	22416	9695
	(Hits[a] = 70%)	(Misses[b] = 30%)
No Entry	12785	12592
	(False Alarms[c] = 50%)	(Correct Rejections[d] = 50%)

Note. N = 57,488. The probability cut was equal to $p_i = 0.5$. Actual group membership was 32111 Entry cases (56%) and 25377 No Entry cases (44%).

[a]Hits were the accurate classification of Entry cases to membership in the Entry group. [b]Misses were the misclassification of Entry cases to membership in the No Entry group. [c]False alarms were the misclassification of No Entry cases to membership in the Entry group. [d]Correct rejections were the accurate classification of No Entry cases to membership in the No Entry group.

Table 16

Classification Matrix for Exit Pattern Model

	Predicted Group Membership	
Actual Group Membership	Exit	No Exit
Exit	26456	9525
	(Hits[a] = 74%)	(Misses[b] = 26%)
No Exit	8698	12809
	(False Alarms[c] = 40%)	(Correct Rejections[d] = 60%)

Note. N = 57,488. The probability cut was equal to $p_i = 0.5$. Actual group membership was 35981 cases (63%) and 21507 No Entry cases (37%).

[a]Hits were the accurate classification of Exit cases to membership in the Exit group. [b]Misses were the misclassification of Exit cases to membership in the No Exit group. [c]False alarms were the misclassification of No Exit cases to membership in the Exit group. [d]Correct rejections were the accurate classification of No Exit cases to membership in the No Exit group.

Results of Hypotheses Testing

The research hypotheses of the current study are restated here in null form for testing purposes. The decision to reject or fail to reject a null hypothesis relied on the results of the respective primary analyses.

Null hypothesis 1: When examined from the entry pattern model, none of the targeted variables will have significant predictive value relative to distinguishing between airline route entry and non-entry decisions. As reported in Table 9, the simultaneous model was statistically significant, $\chi^2(9) = 3441.82$, $p < .0001$. Given a significant overall model, the individual variables within this model were examined for significance. As reported in Table 10, seven of nine variables were significant at the preset alpha level of .05: Total passengers ($p < .0001$), Market fare ($p < .0001$), Number of carriers ($p < .0001$), Distance ($p < .0001$), LCC existence ($p < .0001$), Origin hub ($p < .0001$), and Destination hub ($p < .0001$). Therefore, the decision was to reject the null hypothesis 1, and to accept the alternative hypothesis 1 that stated when examined from the entry pattern model, at least one of the targeted variables will have significant predictive value relative to distinguishing between airline route entry and non-entry decisions.

Null hypothesis 2: When examined from the exit pattern model, none of the targeted variables will have significant predictive value relative to distinguishing between airline route exit and non-exit decisions. As reported in Table 12, the simultaneous model was statistically significant, $\chi^2(9) = 10249.31$, $p < .0001$. Given a significant overall model, the individual variables within this model were examined for significance. As reported in Table 13, all nine variables were significant at the preset alpha level of .05: Total passengers ($p = .0188$), Market fare ($p < .0001$), Number of carriers ($p < .0001$), Distance ($p < .0001$), Route type ($p = .0013$), LCC existence ($p = .0015$), Business model of the largest share ($p = .0008$), Origin hub ($p < .0001$), and Destination hub ($p < .0001$). Therefore, the decision was to reject the null hypothesis 2, and to accept the alternative hypothesis 2 that stated when examined from the exit pattern model, at least one of the targeted variables will have significant predictive value relative to distinguishing between airline route exit and non-exit decisions.

Conclusions

With respect to entry pattern decisions, the simultaneous logistic regression yielded seven significant factors that distinguished between entry and non-entry decisions in a given U.S. route. For a 100-passenger increase, airlines were 7% more likely to enter a new route or increase the frequency in their existing routes. In this case, the purpose of making entry decisions is to increase available seats per mile (ASM) to meet the increasing demand on the given route. For a 100-dollar increase in market fare, airlines were 5% more likely to enter/increase their operations. A high air fare would be a clue of a profitable market, which are appealing on an eye of airline network planners. With an appearance of one new competitor on a given route, airlines were 12.31% more likely to increase their operations. The probable reason is that in order to maintain the current market share on the O&D airport pair, airlines are likely to compete against others by increasing the frequency, which would provide passengers a less total trip time (Belobaba, Odoni, & Barnhart, 2015). For a 100-mile increase in distance between O&D airports, airlines were 7% more likely to enter/increase the number of departures on that route. On long haul routes, airlines could leverage the economies of scale, low operating costs, high aircraft utilization. Additionally, passengers on long range flights usually have a high willingness-to-pay for ticket fares as well as additional on-board services.

On routes with at least one operations of a LCC, airlines were 6% less likely to make an entry decision. Indeed, competition on route market with the appearance of LCCs is stiffer and fiercer due to its large effect on average air fare (Brueckner, Lee, & Singer, 2013). Furthermore, airlines were 8.45% less likely to enter/increase their operations on the route in which origin airport is a large hub, and 10.43% less likely to enter/increase their operations in which destination airport is a large hub. Airlines, especially low-cost carriers, have a tendency to move their operations away of large hubs to avoid higher landing fees, terminal congestions, or self-uncontrollable delays. Instead, routes with departures and arrivals performed at secondary airports within the targeted airport's catchment area are strategically taken into consideration.

With respect to exit pattern decision, the simultaneous logistic regression yielded all nine significant factors that distinguished between exit and non-exit decisions in a given U.S. route. For an additional 100 passengers in demand, airlines were 5% less likely to make exit/reduce their operations in the given route. It was consistent between entry and exit patterns, which airlines tend to either enter the route or increase the frequency or at least maintain their frequency rather than making exit decision if the demand is growing. Moreover, the consistency in entry and exit patterns also were reflected through affective factors: market fare, distance between origin and destination airports, and origin and destination large hubs. For either 100-dollar increase in market fare and 100-mile increase in distance, airlines were 7% less likely to make an exit decision, but 9.76%, and 11.29% more likely to exit/reduce their flights if the origin and destination airports are large hubs in the given route. Obviously, airlines are considering long haul routes or those with high yield to be profitable market, at the same time, avoiding large hubs that might potentially cost airlines the most compared to medium or small hubs.

However, the two models also produced conflicting results that pointed to factors: number of carriers, route type, LCC existence, and the airline business model with the largest share. For one more competitor joining the competition, airlines were 12.31% more likely to increase their operations, and 23.05% more likely to reduce the operations or stop their service on the given route. The magnitude of making exit decisions were nearly double over that of making entry decisions. It indicates that although airlines could proactively increase their frequency to compete with others, they are still preparing exit strategies once the competition becomes heavier and fiercer and leads to a "thin-razor" profit margin. The operation of at least one incumbent LCC could put newcomer airlines on initial reluctance to enter their flights, but existing airlines were 5.28% less likely to make exit/reduce their flights. Although LCC operations could make the competition more difficult by introducing cheaper fares, the existing airlines do not consider it to be serious threats because of using other strategies such as higher frequencies, on-board entertainment, baggage lost-and-found services to offset their higher fares. Route type and the business model of the largest share airline were the two factors that not significantly affected entry decisions, but exit decisions. For nonstop route markets, airlines were 4.28% more likely to reduce their flights or cease their operations on the route. It is commonly accepted in the literature that the level of service with nonstop flights in a nonstop market is a the most important and significant factor in attracting the attention of passengers' choice (Coldren, 2005; Coldren et al., 2003; Garrow, 2010). Therefore, airlines having connecting flights are highly likely to lose their passengers to those having nonstop flights, and thus the former would cut down the frequency of connecting flights. If the largest share of a given route market is accounted by a LCC, airlines were 6.73% more likely to exit their operations out of the market or reduce their flights. Passengers on route markets with a LCC competition are mostly leisure travelers who are sensitive to price and thus are simply attracted by affordable fares of LCCs (Belobaba et al., 2015). Hence, once a LCC holds the largest share and dominates the route market, the market structure will probably be fixed, and consequently it is difficult for the remaining airlines to overturn the situation. The remaining airlines would reduce their frequency to avoid directly the competition with the largest LCC, or in worst scenarios, completely cease their operations on the route market.

Finally, the findings of the study make an implication to airline planners in understanding key drivers as well as barriers to entry and exit decisions. The tasks of airline planners in network planning are to draw the network and route map of airlines in general, and constantly evaluate the efficiency and profitability of each route on the network. Therefore, in aid of significant affective factors found in this study, they could gain predictive insights before making right decisions, and could assess their competitors' decisions in the same routes of the network. Further implication speaks to airport operators at large hubs in more and more airlines moving their operations to secondary airports in which the airlines have low operating costs.

Generalizability, Limitations, and Delimitations

The sample used in the study was also the accessible population that is indeed a census of the target population—10% random sample of all U.S. itineraries reported in the 2018 dataset for Quarter 1. For this reason, the sample analyzed in the study was somehow highly representative to the target population, and thus the results could be generalizable to the target population. However, the ecological generalizability could be limited to only the U.S. domestic market because of the unique characteristics of the market that make it difficult to transcend to other market. For example, on international itineraries, flights are predominantly operated in long haul routes, and these transcontinental flights usually place their operations at large hubs for connections to spoke cities.

One limitation of the study pointed to the data integrity, which means that we had no control over how the data were reported and stored in the DB1B database. Therefore, any changes are made to the dataset subsequent to the current study, then any replication studies could yield different results. In the meanwhile, the delimitation of the study was relative to the data collection period that was the 2018 dataset for Quarter 1; therefore, similar studies that use a different data collection period might not get the same results. Other minor delimitations were our choice of eliminating all outliers in the dataset and using dummy coding strategy for categorical variables in the study. Other studies that decide to keep outliers in the dataset for analyses and use other coding techniques such as effects coding or contrast coding might yield different results.

References

Abdelghany, A., & Abdelghany, K. (2009). *Modeling applications in the airline industry*. Abingdon, U.K.: Routledge.

Abdelghany, A., & Guzhva, V. S. (2010). Analyzing airlines market service using panel data. *Journal of Air Transport Management*, *16*(1), 20–25.

Airport Categories – Airports. (n.d.). Retrieved November 21, 2017, from https://www.faa.gov/airports/planning_capacity/passenger_allcargo_stats/categories/

Baran, S. (2018). *Survival in the U.S. domestic airline market: Strategies for entry, exit, and air fare competition*. Florida Institute of Technology.

Belobaba, P., Odoni, A. R., & Barnhart, C. (2015). *The global airline industry* (2nd ed.). Hoboken, NJ: John Wiley & Sons, Inc.

Boguslaski, C., Ito, H., & Lee, D. (2004). Entry patterns in the southwest airlines route system. *Review of Industrial Organization*, *25*(3), 317–350.

Brueckner, J. K., Lee, D., & Singer, E. S. (2013). Airline competition and domestic US airfares: A comprehensive reappraisal. *Economics of Transportation*, *2*(1), 1–17.

Cameron, A. C., & Trivedi, P. K. (2005). *Microeconometrics: Methods and applications*. Cambridge University Press.

Cohen, J., Cohen, P., West, S. G., & Aiken, L. S. (2003). *Applied multiple regression/correlation analysis for the behavioral sciences* (3rd ed.). Hillsdale, NJ: Lawrence Erblaum Associates.

Coldren, G. M. (2005). *Modeling the competitive dynamic among air-travel itineraries with generalized extreme value models*. Northwestern University.

Coldren, G. M., Koppelman, F. S., Kasturirangan, K., & Mukherjee, A. (2003). Modeling aggregate air-travel itinerary shares: logit model development at a major US airline. *Journal of Air Transport Management*, *9*(6), 361–369.

Garrow, L. A. (2010). *Discrete Choice Modelling and Air Travel Demand*. Farnham, England: Ashgate.

Greene, W. H. (2011). *Econometric analysis* (7th ed.). Upper Saddle River, NJ: Pearson Education.

Hair, J. F., Black, W. C., Babin, B. J., & Rolph, A. E. (2010). *Multivariate Data Analysis* (7th ed.). Upper Saddle River, NJ: Pearson Education.

Hosmer Jr, D. W., Lemeshow, S., & Sturdivant, R. X. (2013). *Applied logistic regression* (Vol. 398). New York, NY: John Wiley & Sons.

Ito, H., & Lee, D. (2003). Low cost carrier growth in the U.S. airline industry: Past, present, and future. *Brown University Department of Economics Paper*.

Katchova, A. L. (2013). *Bivariate probit and logit models example*. Retrieved from https://sites.google.com/site/econometricsacademy/

Oliveira, A. V. (2008). An empirical model of low-cost carrier entry. *Transportation Research Part A: Policy and Practice, 42*(4), 673–695.

Peduzzi, P., Concato, J., Kemper, E., Holford, T. R., & Feinstein, A. R. (1996). A simulation study of the number of events per variable in logistic regression analysis. *Journal of Clinical Epidemiology, 49*(12), 1373–1379.

SAS Institute Inc. (2016). *JMP® 13 Multivariate Methods*. Cary, NC: SAS Institute Inc.

Tabachnick, B. G., & Fidell, L. S. (2013). *Using multivariate statistics*. Upper Saddle River, NJ: Pearson Education.

Warner, R. M. (2008). *Applied statistics: From bivariate through multivariate techniques*. Thousand Oaks, CA: Sage Publications Inc.

Yuan, Z. (2016). *Essays on Network Competition in the Airline Industry* (Doctoral dissertation). University of Toronto.

Collegiate Aviation Review
International

Volume 36 | Issue 2 Peer-Reviewed Practice #1

6-22-2018

Able Flight at Purdue University: Case Studies of Flight Training Strategies to Accommodate Student Pilots with Disabilities

Wesley L. Major
Purdue University

Raymart R. Tinio
Purdue University

Sarah M. Hubbard
Purdue University

This paper documents flight training strategies used to accommodate student pilots with disabilities in the Able Flight at Purdue program; this program benefits participants as well as the institutional sponsor and the aviation industry. All training aircraft, procedures, and operations are compliant with Federal Aviation Administration (FAA) regulations, however, the program utilizes a tailored approach within the regulatory standards to meet the unique needs of each individual. The SHELL model (Software, Hardware, Environment and Liveware) is used as a theoretical framework to illustrate how flight training is adapted for individuals with limited dexterity or limited hearing. The Able Flight at Purdue program is explained, including the preparation before the students arrive on campus and the accelerated flight training program. Two case studies using the SHELL model illustrate training modifications for a pilot who uses a manual wheelchair and a Deaf pilot; both of these students successfully completed the program and earned an FAA Sport Pilot certificate. This Peer Review Practice paper also discusses the benefits of the program. There are direct benefits to the individual participants, both to the student pilots as well as to the certified flight instructors (CFIs), based on qualitative survey responses. The broader impacts of the program include support for diversity and inclusion realized by the institution, the aviation sector, and the community.

Recommended Citation:
Major, W.L., Tinio, R.R., & Hubbard, S.M. (2018). Able Flight at Purdue University: Case Studies of Flight Training Strategies to Accommodate Student Pilots with Disabilities. *Collegiate Aviation Review International,* 36(2), 120-141. http://dx.doi.org/10.22488/okstate.18.100492

Many developed nations recognize the benefits of social inclusion (Charity Commission, 2001; United Nations, 2007; World Bank, 2013) both for individual growth and for development of a healthy community and society. The World Bank has studied social inclusion (2013) and defines it as, "both an outcome and a process of improving the terms on which people take part in society." Social inclusion is the opposite of social exclusion, which can result from many factors, including age, sexuality, gender, race, religion, mental illness, and disability. Social inclusion seeks to empower marginalized individuals or groups through integration.

Social inclusion benefits individuals, groups, communities, and nations. The benefits to groups include benefits to companies. Companies that practice social inclusion and promote diversity have a more engaged workforce with increased satisfaction, a better workplace culture, and increased innovation (Moon, Todd, Morton, & Ivey, 2012; Pearce & Randel, 2004). Benefits of diversity and inclusion extend beyond worker satisfaction and culture; companies with greater social inclusion and diversity financially outperform companies that are not diverse (Hunt et al., 2015).

Historically, aviation has lacked social inclusion and diversity (Medland, 2015; Mills, 2017). Research by Hansen and Oster found that employment patterns, including diversity trends, result from a history of both explicit and implicit hiring policies for aviation jobs in the military and at the airlines (National Research Council, 1997). The U.S. Department of Labor estimates there are 595,000 employees in the air transportation sector and the majority of these employees (72 percent) identify as white; 40 percent are women and 17 percent are African American (Bureau of Labor Statistics, 2016). Pilot demographics are even less diverse. Based on Federal Aviation Administration (FAA) data, only 6.7 percent of the 584,362 active pilots are women, and only 1.1 percent of Airline Transport Pilots (ATP) are women (Federal Aviation Administration, 2017).

Initiatives that promote inclusion in aviation are important in all facets of the aviation workforce. Programs such as the Able Flight at Purdue program could have a positive impact by attracting individuals who would not traditionally be found in the aviation industry to a wide variety of possible employment options, including not only pilots, but also maintenance technicians, dispatchers, air traffic controllers, FAA employees, airline employees and airport employees. Programs such as the Able Flight at Purdue also provide the secondary benefits that inclusion promotes (Hunt et al., 2015; Moon, Todd, Morton, & Ivey, 2012; Pearce & Randel, 2004).

The Centers for Disease Control and Prevention identifies inclusion strategies targeting people with disabilities. Inclusion strategies include universal design principals, accessibility standards, reasonable accommodations, and assistive technologies (Center for Disease Control and Prevention, 2017). These strategies are very broad. This paper provides specific examples that illustrate how reasonable accommodations and assistive technologies can be incorporated into flight training to allow student pilots to obtain the Sport Pilot certification as well as to foster inclusiveness. Able Flight at Purdue is one program targeted to promote diversity and social inclusion in aviation. Able Flight is a nonprofit organization that provides aviation related scholarships to individuals with disabilities. Purdue University was one of Able Flight's first partners, and since 2010 Purdue University has successfully delivered flight training for pilots with a wide variety of disabilities in an inclusive environment.

Following a brief literature review that includes a discussion of STEM activities for people with disabilities, this paper presents information about the Able Flight at Purdue program including: an explanation of the program, two case studies regarding how flight training is adapted to meet the needs of pilots with disabilities using the SHELL model as a theoretical framework, lessons learned from eight years of program experience, and documentation of the program benefits based on the results of a qualitative survey and the continued involvement in aviation by program graduates. Benefits are realized by individuals, by the sponsor institution, and by the aviation community. The information provided in this paper will support the inclusion of pilots with disabilities at other flight training schools.

Literature Review

Inclusive Programs

Due to the technical nature of flight training, learning to become a pilot incorporates many aspects of Science, Technology, Engineering, and Mathematics (STEM) education. The National Science Foundation has emphasized the importance of developing a diverse STEM workforce in the United States (U.S.) (National Science Foundation, 2000, 2004; National Science Board, 2010); reports accentuate the benefits of broadening participation and the inclusion of individuals with disabilities and other populations that have been traditionally underrepresented in STEM programs.

STEM oriented programs targeted to individuals with disabilities have proven successful. Three successful programs that illustrate a range of approaches are described below.

- **Vocational Rehab.** The Experiential Learning for Veterans in Assistive Technology and Engineering (ELeVATE) program provided support to service members with a disability as they transition to postsecondary institutions. The main goals of the ELeVATE program were to create a model for veteran vocational rehabilitation transition and to demonstrate the success of such a program in terms of promoting academic and career success. Results indicate that participants were more confident in their ability to succeed upon completion (Goldberg, Cooper, Milleville, Barry, & Schein, 2015).
- **Learning Communities.** One university found that Student Learning Communities that provided knowledge, skills, and abilities curricula for students with disabilities were successful in engaging this unrepresented group to pursue STEM degrees (Izzo, Murray, Priest, & Mcarrell, 2011).
- **Mentorship.** Many studies have documented benefits from mentorship. One successful mentoring program was the Research Initiative for Science Excellence (RISE) program. This training program is specifically targeted to prepare and support students with disabilities as they obtain STEM degrees; the program provides both research experience and mentorship (Schultz et al., 2011).

Programs that specifically target people with disabilities are not the only way to promote social inclusion. The use of assistive technologies can help a person with a disability fully engage in life activities (Center for Disease Control and Prevention, 2017). Automobiles can be adapted with assistive technologies to allow the gas and brake to be operated with hand controls. Hand controls in an automobile grant greater independence and improve quality of life (Barnes, 1997; Tachakra, 1981). Other considerations related to adaptive technologies and the selection of the proper vehicle include the choice of vehicle, mode of access (ramp versus transfer), use of seat cushion, and steering wheel knob (Murray-Leslie, 1990).

People with disabilities are not the only individuals that may need adaptive technologies for full inclusion. Abled-bodied individuals of short stature may require assistive technology when piloting an aircraft. Pilot shops and some training centers provide elevator cushions to allow shorter people to see over the aircraft nose (Sporty Pilot Shop, 2018b). Other adaptive equipment includes rudder pedal extensions to bring the pedals closer to the pilot (Sporty Pilot Shop, 2018a).

Adaptive equipment, technologies or procedures may be required due to personal characteristics or medical conditions. Medical requirements vary for different kinds of pilots. The Sport Pilot rule allows a pilot to fly a light-sport aircraft without an FAA medical certificate as long as they have a current, valid U.S. driver’s license (Federal Aviation Administration, 2015). A Class I medical certificate (the most rigorous) is required for an Airline Transport Pilot; a Class II medical certificate is required for a Commercial Pilot; a Class III medical is required for a private pilot, student pilot or recreational pilot (Aircraft Owners and Pilots Association [AOPA], n.d.). A special issuance granted at the discretion of a Federal Air Surgeon may offset a disqualifying condition; this has an associated time limit and requires periodic interim medical reports. A waiver or Statement of Demonstrated Ability (SODA) may be issued for static conditions that are not likely to change such as monocular vision or an amputee (Aircraft Owners and Pilots Association (AOPA), n.d.). A waiver is part of the medical certificate and demonstrates that you have satisfied the FAA and can exercise the privileges of the certificate held (AOPA, n.d.). The Sport Pilot rule, the special issuance, and the SODA all provide avenues for pilots with disabilities.

Adaptation to the work environment may also be required for people with disabilities. Example adaptations to the work environment include specialized equipment, modifications to the work space, or adjustments to schedules, and can be referred to as reasonable accommodations (U.S. Department of Labor, n.d.). Reasonable accommodations are legally required under the Americans with Disabilities Act, so long the accommodation does not create *undue hardship* on the employer. For an individual with an ambulatory disability, a workstation or transportation can present challenges that may require accommodation strategies (University of Washington, 2018).

Generally, programs that target people with disabilities have a positive impact by providing resources, education, and guidance that otherwise might not be available due to a lack of inclusion. In addition to programs, assistive equipment, technologies and procedures can help bridge a gap and create an inclusive environment. This paper describes how an aviation program, Able Flight at Purdue University, has successfully provided an inclusive environment to deliver flight training tailored to meet the needs of individuals with disabilities.

Able Flight at Purdue

Able Flight is a national program that began in 2007, when the program's first Full Flight Training Scholarship was awarded. Able Flight currently offers four scholarships:

- *Full Flight Training Scholarships* for people to earn a Sport Pilot certificate,
- *Return to Flight Scholarships* for people who have pilot certificate and subsequently became disabled to return to flying under the Sport Pilot regulations,
- *Flight Training Challenge Scholarships* for people who would benefit from dual instruction only, and have no current plans to seek a Sport Pilot certificate,
- *Career Training Scholarships* for people to earn a Repairman Certificate (Light Sport Aircraft) with Maintenance Rating, or a Dispatcher License, or to defray academic expenses while training for an aviation career (Able Flight, 2016b).

In the first three years, Able Flight activities were limited in scope and conducted at a variety of locations, including a personal hangar in Oshkosh, WI. In 2010, Able Flight partnered with Purdue University, which allowed the program to expand and provide a more structured training experience that focusing on the Full Flight Training Scholarship.

The Purdue University School of Aviation and Transportation Technology has a large professional flight program and all education and flight training is conducted at the Purdue Airport (LAF) on campus. As a result, there are numerous university and aviation resources that provide excellent support for the Able Flight program, which typically starts in mid-May and finishes in early July. This summer schedule allows Able Flight participants to utilize university and aviation resources when the demand from university students is reduced.

Able Flight participants live in a recently constructed, fully accessible residence hall, and receive access to campus dining courts throughout their flight training. Each participant has their own private bath, which provides independence and privacy. Since basic housing and meals are provided, Able Flight participants can focus their time, energy, and attention on the flight training program, which requires a significant commitment from the student pilots. Many hours spent studying and flying are needed to become a confident, competent, and safe pilot. Confidence extends beyond the cockpit, which is recognized by Able Fight's mission statement, "individuals with a disability are presented with a unique way to challenge themselves through flight training, and by doing so, gain greater self-confidence and self-reliance" (Able Flight, 2016b). The following sections provide information about how flight training is tailored to address the individual needs of student pilots with disabilities.

Methodology

This paper documents how flight training can be adapted to accommodate pilots with disabilities, illustrated by two case studies that are described using the SHELL model. The SHELL model is a theoretical framework that provides a consistent method to describe the adaptations used in the Able Flight program in a format embraced by the aviation community. The two case studies selected, a student pilot who uses a manual wheelchair and a deaf student pilot, illustrate very different methods of accommodation and represent adaptations that have been implemented numerous times in the Able Flight Program at Purdue.

Benefits of the program are also discussed. Benefits are assessed based on the completion rate for participations, as well as qualitative benefits which are based on feedback from participants and flight instructors in the 2017 Able Flight class; and, all six instructors and six students participated in a survey and provided their perceptions and reflections of the 2017 summer program. Other benefits include broader impacts, which have accrued due to the news stories about the Able Flight at Purdue program.

SHELL Model: A Human Factors Approach to Flight Training

The SHELL model is a widely used framework for human factors in aviation. It was presented in 1972 (Edwards, 1972), modified more than a decade later by Frank Hawkins (Hawkins, 1987), and subsequently endorsed by ICAO (International Civil Aviation Organization, 1989). The SHELL model defines human factors in terms of the software, hardware, environment, and liveware components, which interact around a central liveware (humans), as illustrated in Figure 1a.

The SHELL model has been utilized to explain human factors considerations for pilots, maintenance technicians, and air traffic controllers (Chang & Wang, 2010; Kozuba, 2011; Wang & Dong, 2011). Based on Purdue's eight years of experience, the next section uses the SHELL model to explain flight training using the student pilot is the central liveware; this liveware interacts with the software, hardware and other liveware in the flight training environment as shown in Figure 1b. Following a general discussion of flight training and the Able Flight program, two case studies illustrate some of the most significant adaptations implemented to support the Able Flight training at Purdue.

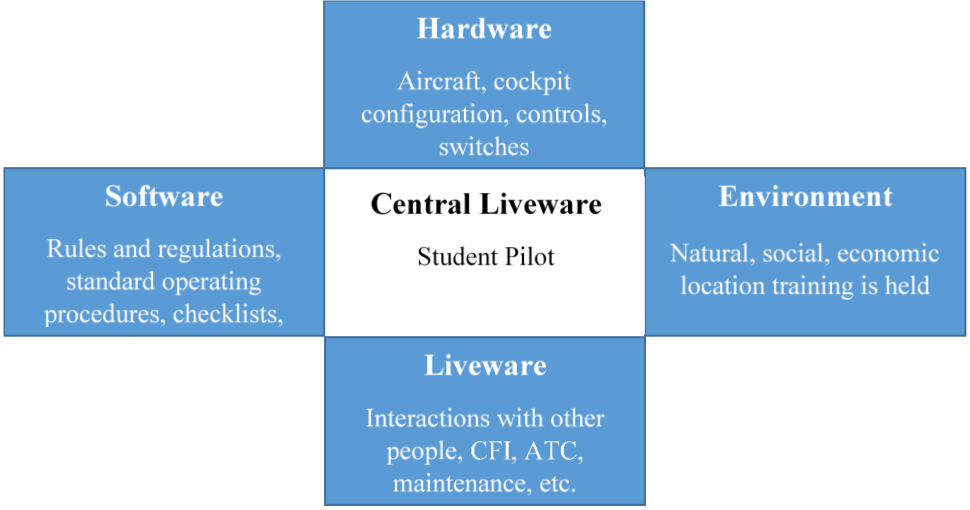
Findings

The findings include a general discussion of the SHELL model for flight training for student pilots, with discussion regarding how this is applied in the Able Flight program at Purdue. Two case studies illustrate specific adaptations that have been implemented successfully at Purdue. The first case study is for a student pilot who uses a wheelchair and the second for a student pilot who is deaf. Following these case studies, the program benefits are discussed.

Central Liveware. The student pilot is the central liveware. Traditionally, the first certification a student earns is a Private Pilot certificate which requires an FAA medical exam, as well as written and practical exams. The Sport Pilot license became an option on September 1, 2004, and does not require a medical exam if the pilot has a valid U.S. driver license (AOPA, 2004). All flight training requires a student pilot certificate which must be issued by FAA before training begins.

Application. In addition to obtaining the student pilot certificate, to receive a Full Flight Training Scholarship, all Able Flight at Purdue students must go through a two-phase selection process that includes a written application (personal statement, list of achievements, references, and future goals) and an in-person interview with an Able Flight representative. The thorough application process ensures that participants' interests and capabilities are compatible with the rigorous training schedule, and that flight training can be adapted to the individual's skill set and abilities.

(a) SHELL components include the Software, Hardware, Environment and Liveware centered around the human Liveware (Hawkins, 1987).



(b) SHELL model for flight training with student pilot as central liveware.

Figure 1. The SHELL Model for Human Factors.

Liveware-Software. Software consists of online training tools, and aviation regulations and laws. Software includes checklists, manufacturer's pilot operating handbook or airplane flight manual, and other written documents that encompass standard operating procedures.

Application. In addition to the standard software used in traditional flight training, the Able Flight program provides the King Schools online training course for student pilots two months before they arrive at Purdue (King Schools, 2018). Students are highly encouraged to complete the online course to ensure they are familiar with training topics before full-time training begins; this ensures success with the accelerated training schedule. The online module includes a wide variety of topics, such as aviation rules and regulations, performance measures, and airspace. In addition to online training, students must complete a comprehensive ground school that is conducted via daily classroom lectures at Purdue. While FAA regulations are always followed, enhancements and adaptations may be used to support inclusion, such as an American Sign Language (ASL) interpreter to support classroom activities, when needed.

Liveware-Hardware. Hardware includes the aircraft and aircraft components, such as the seats and cockpit instrument layout, the instrumentation and how it presents information. Most traditional student pilots can utilize any single piston aircraft for flight training, and the Cessna 152, Cessna 172, and Piper Warrior are commonly used training aircraft.

Application. Properly matching aircraft characteristics with the physical characteristics of the central liveware (student pilot) is extremely important. Since light sport aircraft are used for flight training, ensuring the aircraft is a good match for the student in terms of physical size is important for weight and balance to ensure a reasonable fuel supply is available without exceeding aircraft limitations. Aircraft used in flight training at Purdue include the Ercoupe 415C and Sky Arrow L600. Table 1 contained a list of aircraft and liveware compatibility characteristics.

Table 1.

Able Flight Pilot Liveware Must Be Matched with Aircraft Hardware to Ensure Compatibility

Aircraft	Aircraft Characteristics	Pilot Characteristics
B&F Fk9	Side by side pilot and co-pilot	Deaf or hard of hearing
Flight Design CTLS	Side by side pilot and co-pilot	Deaf or hard of hearing
	Larger cockpit	Tall pilot
	Hand control for rudder and brakes	Limited voluntary use of legs
	Ease of access to seat	Landing gear does not prevent wheelchair users from getting close
Ercoupe 415C	Hand control for rudder and brakes	Pilot with limited use of legs
Sky Arrow L600	Ease of access to seat	Landing gear does not prevent wheelchair users from getting close

The general guidelines in Table 1 are useful for conceptual discussion, however, individual characteristics and capabilities are more important than general guidelines. This is evidenced by Able Flight pilot Jessica Cox, who demonstrates that a lack of arms does not restrict her from using the standard operating controls in the Ercoupe 415C, as shown in Figure 2.

Figure 2. Jessica Cox was born without arms and flies an Ercoupe 415C (Able Flight, 2016a).

Liveware-Environment. The environment is the physical location where any of the other components (software, hardware, liveware) function, and can include the natural environment (weather and geography), social environment (interaction with peers), and economic environment (cost of flight training). Student pilots generally obtain flight training at a fixed-base operator, in a university setting, or through a community college.

Application. The Able Flight program provides an enhanced environment for flight training for a number of reasons. First, the social environment is focused on inclusion. All students are housed in the same resident hall, promoting social interaction. The value of a common living area was demonstrated by a study performed by Wilson, Bjerke, and Marin (2015); the results indicate that aviation students in Living Learning Community had greater success than those not surrounded by peers. Another component of the enhanced environment is the economic environment. The economic environment is positive because not only is flight training paid for, but so is housing and basic meals. Able Flight also makes accommodation for the natural environment, which may have a greater effect on Able Flight pilots than traditional pilots. For example, an individual with a spinal cord injury may not be able to regulate their body temperature, making them more susceptible to the heat. This can be accommodated by a training schedule that minimizes flights during the hottest part of the afternoon, and shifts flights to the early morning and evening when temperatures are lower. Daily ground school is conducted during the hottest time of the afternoon to ensure efficient use of time.

Able Flight has also positively affected the environment at Purdue. As a result of the program, accessible ramps and bathrooms were added to the flight operations buildings to ensure compliance with the Americans with Disabilities Act. During the program, extra accessible parking spaces are designated both at the airport and at the residence halls used by the Able Flight pilots.

Liveware-Liveware. Interaction between the liveware student pilot and other liveware is often via verbal communication during traditional flight training. Liveware includes air traffic controllers, certified flight instructors (CFIs), maintenance personnel, other student pilots, and administration staff. Verbal communication during flight training is often face-to-face on the ground and during ground school, and via the radio using aviation headsets while in the aircraft.

Application. Full Flight Training Scholarships have been awarded to deaf student pilots. This may require coordination and a common understanding for expectations regarding communication among the CFI, student pilot, and Air Traffic Controllers (ATC) since training is conducted in controlled airspace. At Purdue, deaf pilots rely on ATC to provide light gun signals when operating in a controlled airfield. The Purdue airport control tower upgraded their signal lamp to accommodate these operations.

Case Study: Paraplegic Wheelchair User

A person may use a wheelchair as a mobility aid for a variety of reasons, including congenital disorder, motor vehicle accident, skiing incident, military incident, or amputation due to disease. Just as the reasons for wheelchair use vary widely, the characteristics of individual wheelchair users vary widely, encompassing many body types and physical characteristics, as well as ranges of motion and dexterity for different movements. This case study describes flight training strategies to support the successful completion of the Able Flight program by one of the participants who uses a wheelchair due to a T6 complete spinal cord injury.

Central Liveware. The central liveware in this case is the student pilot with a T6 complete spinal cord injury, which means that there is no feeling or movement below the T6 vertebrae, resulting in no voluntary use of the lower extremities. This individual uses a manual wheelchair as a daily mobility aid, has full dexterity in their fingers, and has full range of motion with their arms. This individual cannot not stand or walk.

Liveware-Software. An important software component for flight training is the preflight checklist. In this case, the preflight checklist for the Sky Arrow L600 is a good match for this student pilot for a variety of reasons. Almost all tasks can be completed by the student pilot with assistance only needed for tasks related to height (e.g., oil check and fueling). The internal aircraft preflight checklist items require the fuel and instrumentation to be checked prior to engine start, the Sky Arrow’s cockpit controls and switches can be reached without getting into the aircraft, facilitating this process for a pilot that uses a wheelchair. The external preflight checklist includes a visual inspection of the wings to ensure that there is no damage and the leading edge of the wing is smooth. This visual inspection can be completed by “lowering the tail” of the aircraft (see Ffigure 3). Placing the aircraft in this position allows the student pilot seated in a wheelchair to see on top of the wings, which is necessary to successfully perform a thorough visual inspection.

The preflight checklist component that requires assistance for a wheelchair user is checking the oil and fueling the aircraft. On the Sky Arrow, the oil is located above the wing and checking the oil level requires a ladder. To successfully complete the oil check during pre-flight, the student pilot in a wheelchair uses the flight instructor. The student pilot provides verbal instructions and describes in detail what should be seen to the flight instructor, who checks the oil and takes a photo of oil level with a smart phone. The photo can then be inspected by the student pilot for compliance. The same method is used for fueling the aircraft. After the preflight inspection is complete, the student can get into the aircraft.


(a) Normal position

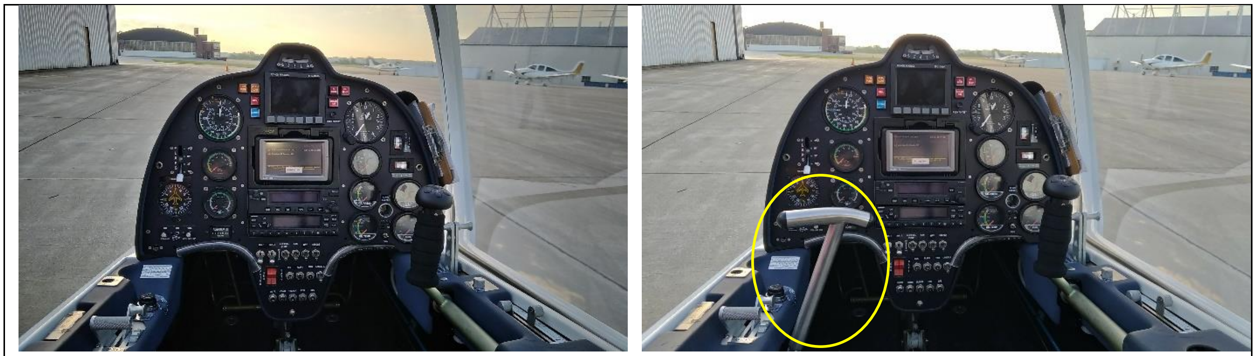
(b) Tail lowered for visual inspection of wings

Figure 3. Different static positions of the Sky Arrow during the preflight checklist

Liveware-Hardware. It is imperative to match the correct hardware, in this case the aircraft, to the characteristics of the central liveware, the student pilot. Just as all pilots have different characteristics, so do all aircraft. This pilot’s physical characteristics made the Sky Arrow L600 an ideal aircraft for training.

Getting into the aircraft requires minimal assistance from the flight instructor. Since the student cannot move their lower limbs voluntarily, the flight instructor assists by holding the wheelchair in a stable position and helping get their legs into the aircraft. For a wheelchair user, getting into the Sky Arrow is easier than getting into traditional training aircraft such as the Cessna 152. The Sky Arrow’s main landing gear is positioned behind the pilot and the aircraft’s wing strut is not in the way (Ffigure 3), this leaves ample space to bring a manual wheelchair close to the cockpit, facilitating transfer from the wheelchair into the front seat.

Once in the aircraft, flight controls are accessible using hand controls. The rudder, which is controlled with the feet in many general aviation aircraft, is controlled with a T-handle (Figure 4). This T-handle is an optional configuration from the manufacturer and can be installed in less than a minute without any specialized tools. The Sky Arrow also has differential finger brakes rather than toe brakes on the rudder pedals. Hand and finger controls makes the Sky Arrow L600 ideal for someone with limited use of their lower limbs.



(a) Without adaptive control

(b) With T-handle adaptive control

Figure 4. Photo of cockpit without (a) and with (b) adaptive T-handle in the Sky Arrow L600

Liveware-Environment. The environment includes the hangar and classroom where flight training was conducted, which are both fully accessible. The environment also includes the living arrangements while in the Able Flight program. The university resident hall where students live goes beyond required accessibility standards and includes a private wheelchair accessible bathroom and shower stall connected to the bedroom. A front-loading washer and dryer on the same floor as the bedroom facilitate independence.

Liveware-Liveware. No significant changes are required for liveware-liveware interactions in this case study.

Limitations. One of the negatives associated with the Sky Arrow for this student pilot and wheelchair user is that there is not enough cargo room in the aircraft to store a manual wheelchair. This makes it extremely difficult to land at another airport and exit the aircraft for a rest stop or for food. This could also present a challenge in an emergency landing, since the pilot is without their mobility aid.

Case Study: Deaf Pilot

A person may be deaf or hard of hearing for a variety of reasons, including congenital disorder, accident, or repeated exposure to loud noise. Hearing loss may be partial or complete. The characteristics of individuals vary widely; some people may use sign language and/or read lips; others may rely on written communication. This case study describes the adaptations used by an Able Flight participants who is Deaf and uses and prefers ASL for communication.

Prior to participating in Able Flight, this individual researched opportunities for flight training but was not able to find a CFI willing to train a deaf student pilot who had no prior flight experience. The Able Flight program at Purdue was able to provide a CFI interested in working with a deaf pilot, an interpreter certified in ASL for ground school, and a deaf-friendly environment for flight training.

Central Liveware. This case study describes a Deaf individual who successfully completed the Able Flight program and obtained a Sport Pilot certificate. This student pilot was pursuing an undergraduate degree in aviation from another university when they participated in the program, and had completed a Private Pilot ground course for college credit prior to the start of Able Flight.

The term *Deaf* (with a capital D) represents an individual who self identifies with the Deaf culture, while deaf with a small d refers to a physical condition based on medical terminology. Deaf sociolinguist, Dr. Barba Kannapel, defines the American Deaf culture as a, "set of learned behaviors of a group of people who are deaf and who have their own language (ASL), rules, values and traditions" (Gallaudet Univsersity, 2015, p. 2). Some people, particularly those who become deaf later in life or who are raised and educated primarily among non-deaf people, may not affiliate with the Deaf community, and as a result would typically describe themselves as deaf. In this case study, the term Deaf will be used to reflect the preference and self-identify of this Able Flight student pilot.

Liveware-Software. No significant changes are required for liveware-software interactions in this case study.

Liveware-Hardware. For this individual, the B&F Fk9 light sport aircraft is utilized. This aircraft has a side-by-side seat configuration, as was presented in Table 1 and shown in Figure 6. This seating configuration facilitates communication between the Deaf student and CFI. Details of this communication will be explained in greater detail in the liveware-liveware section of this case study. Other common training aircraft such as Cessna 152, Cessna 172, and Piper Warrior also have side-by-side cockpit seating configuration and would be suitable for training a deaf individual. Aircraft such as the Sky Arrow have a tandem seat layout which makes it difficult for a Deaf student pilot, since they would need to repeatedly look behind them to communicate with the flight instructor.

(a) Tandem seat layout

(b) Side-by-side seat layout

Figure 6. Two different seating configurations

Liveware-Environment. For this Deaf individual, creating an inclusive or deaf-friendly environment to support learning was key. The use of light gun signals, a CFI who was willing to learn basic sign language (i.e., numbers, airplane, and airport), access to an ASL interpreter, and a windsock on the airfield are all components of a deaf-friendly environment. Additionally, the resident hall is equipped with a visual alerting system (e.g. strobe lights) that provides notification in case of a fire or other emergency requiring evacuation. At Purdue, the CFIs do not have any formal training in ASL, however, the CFI works with the Deaf student pilot to learn the basic signs needed for communication. The ASL interpreter has extensive training and is certified to provide interpretation, as needed, in the classroom setting.

Liveware-Liveware. Communication is one of the first training issues that needs to be addressed while training this Deaf student pilot. For most people, verbal transmission and aural processing is the primary means of communication in aviation. Since ASL is the preferred means of communication for this student pilot, an interpreter is available for all classroom training. However, the ASL interpreter is only available during ground school, which is practical due to its regularly scheduled meeting time. Utilization of an interpreter is not possible in the aircraft during flight training because the training aircraft only has two seats.

Communication between the CFI and the Deaf student is an important consideration, since the CFI does not know ASL. To minimize flight deck distractions, each training lesson is discussed on the ground, using pen and paper or a computer, prior to flight. Initial communication in the aircraft is slow, and information is shared using a small white board, pen and paper or via text on cell phones. To maintain a safe training environment, communication in the aircraft necessitates that the Deaf student maintain straight and level flight while the CFI writes or reads (and vice versa). This requires that most communication occur during low risk phases of flight or on the ground. The student pilot taught the CFI basic signs related to flight instructions to expedite communication. Important ASL signs for the CFI to learn include “airplane” and the ability fingerspell numbers from zero to nine using one hand (as used in ASL). Since ASL is a visual language, the CFI can use the airplane sign in conjunction with orientation and movement to enhance communication. Numbers can be used to communicate the desired altitude after pointing the altimeter. This saves time and is preferable to writing on a small white board or typing on a phone. In this case, it is helpful to pair the Deaf student pilot with the same CFI throughout the program.

Another important liveware interaction for the Deaf student pilot is communication with ATC. Even though the FAA does not require verbal communication for pilot certification, hearing and talking on radio frequencies is standard protocol, especially at a controlled airport. Able Flight utilizes an airport that has an ATC tower during daytime operating hours. To facilitate communication and safety, prior to the student’s first flight, ATC representatives met with the Deaf student, the CFI, and an interpreter. This meeting establishes an operational protocol for all parties involved; this protocol utilizes standard FAA light gun signals as shown in Table 2. At Purdue University, the following protocol was developed and is used:

1. Prior to the start of each flight, the Deaf pilot calls the tower using a video relay service to get information about which runway is in use and let tower know the intentions of the flight (e.g. pattern work, local flight, cross country flight, etc.). Video relay service allows people who use ASL to communicate with voice telephone users through video equipment rather than typed text.
2. When ready to taxi from the ramp, the student pilot faces the nose of the aircraft to the airport tower.

3. When the ATC sees the Deaf pilot lined up in their aircraft, ATC communicates by using light gun signals (
4. Table *2*) to indicate the pilot is cleared to taxi. It is understood that the pilot needs to hold short of all runways until additional clearance is given.
5. Each time ATC signals the light gun, the Deaf student pilot clicks the radio's push-to-talk button twice to acknowledge the light signal and then proceeds accordingly until the runway in operation is reached.
6. After the run-up is performed, the Deaf pilot positions the nose of the aircraft to face the tower, now signifying they are ready for takeoff.
7. The student waits for a steady green light from ATC for takeoff clearance.
8. When the Deaf pilot intends to return to the home airport, they circle at an agreed upon location and wait for a light gun signal from the tower.
9. While flying at an airport without a controlled tower, the Deaf pilot uses visual cues (e.g., windsock or the pattern of other aircraft) to determine the appropriate runway for takeoff or landing and the pattern.

Table 2.

Airport Traffic Control Tower Light Gun Signals (Federal Aviation Administration, 2016)

Color and Type of Signal	Movement of Vehicles Equipment and Personnel	Aircraft on the Ground	Aircraft in Flight
Steady greed	Cleared to cross, proceed or go	Cleared for takeoff	Cleared to land
Flashing green	Not applicable	Cleared for taxi	Return for landing (to be followed by steady green at the proper time)
Steady red	STOP	STOP	Give way to other aircraft and continue circling
Flashing red	Clear the taxiway/runway	Taxi clear of the runway in use	Airport unsafe, do not land
Flashing white	Return to starting point	Return to starting point	Not applicable
Alternating red and green	Exercise extreme caution	Exercise extreme caution	Exercise extreme caution

When flying to other towered airports, this Deaf pilot uses pre-coordination to ensure safe flight and increase controller awareness. Pre-coordination allows controllers to inform other pilots that there is an aircraft without a radio in the area. For uncontrolled airports without an air traffic control tower, pilots are not required to use radio communication, and the Deaf pilot must see and avoid other aircraft.

Benefits of Able Flight

Able Flight is one example of a program that successfully supports diversity and inclusion in aviation. As of August 2017, Able Flight at Purdue has realized a 98% completion rate with 42 out of 43 individuals earning a Sport Pilot certificate. While an important outcome of a Full Flight Training Scholarship is a Sport Pilot certificate, the program benefits extend beyond certification. Additional benefits to participants include a sense of accomplishment and empowerment, and a better appreciation for personal capabilities; these benefits are realized due to their achievements as well as the inclusive environment. Secondary benefits include broadening the perspective of participating CFIs who interact with Able Flight participants, fostering an inclusive environment at Purdue, and positively influencing the culture and diversity in the larger aviation community.

Benefits are identified based on the results of surveys approved by Purdue University’s Institutional Review Board. Surveys were distributed before, during and at the end of the 2017 Able Flight program, and consisted of opened-ended questions to gain insight regarding the feelings, expectations, and experiences of the participating CFIs. Survey responses indicate initial CFI concerns include the accelerated training schedule, using a new aircraft, and trying to treat the student pilots as normally as possible. Concluding feedback from the CFIs indicate that the CFIs enjoy meeting and interacting with people from different walks of life, they expand their abilities because they need to adapt their training style and are more creative with their teaching skills. In one case, the CFI reports that they gained a new appreciation for the definition of “motivation.” Instructors also enjoy having flexibility to develop and tailor the training schedule, adapting it to best meet the needs of their student pilot. CFIs said that their perceptions of the disabled community change as a result of the program, giving them a new appreciation for the capabilities of people with disabilities, and making them more comfortable interacting with people with disabilities. Based on this feedback, the Able Flight program provides benefits that include fostering an inclusive environment at Purdue, changing the perspective of CFIs and increasing the exposure of the Purdue community to people with disabilities. These impacts may be significant, since the CFIs and other people who interact with Able Flight participants will carry these inclusive attitudes with them throughout their career in aviation.

Purdue University’s School of Aviation and Transportation Technology has increased diversity and inclusion through two actions. First, through the additions of accessible ramps and bathrooms to the flight operations buildings. Second, by having three students (seven percent of the Able Flight at Purdue cohort) enroll in the Aviation Management program after completing the Able Flight program. Other graduates of the Able Flight program have continued their involvement in aviation in a variety of ways, including the following:

- Randy Green was born without hands or feet, but earned his ATP rating, the highest pilot certificate FAA recognizes. Randy received training through a Career Training Scholarship from Able Flight and is now flying professionally.
- Kevin Crombie received an Able Flight Full Flight Training Scholarship in 2011. After completing Able Flight at Purdue, Kevin enrolled in Purdue University’s undergraduate aviation program. After graduation, Kevin took a job with FAA in the Commercial Space sector in 2015. Kevin purchased a Piper Cherokee 180 and continues to fly.

- Raymart Tinio is Deaf but dreamed to fly since he was a teenager. This dream became reality and was made possible through an Able Flight Full Flight Training Scholarship in 2015. After Able Flight, Raymart went on to earn a Private Pilot certificate, and as of fall 2017 is working on his Instrument Rating. Raymart is enrolled in the Aviation Management graduate program at Purdue University where he is conducting research is to improve communications between deaf pilots and air traffic controllers.
- John Robinson is a quadriplegic who received an Able Flight Full Flight Training Scholarship in 2015. After successful completion of the program, he founded AV84all, a 501(c)(3) public charity with a mission to provide aviation for all and allow pilots with disabilities to fly (Robinson, 2016).
- Wesley Major was paralyzed in a motorcycle accident prior to participating in Able Flight in 2012. As a result of his positive experience in Able Flight, Wesley enrolled in the graduate program at Purdue where he earned a master’s degree and is now a Ph.D. Candidate. Wesley’s graduate research focuses on improving the airline transportation experience for disabled passengers. He has been a volunteer in the Able Flight program at Purdue since his Able Flight graduation, providing administrative support and serving as a mentor, as well as recruiting program participants, interviewing candidates, and providing media outreach.

The participation of these Able Flight alumni in the aviation sector provides ongoing benefits to support diversity and inclusion in aviation. The Able Flight at Purdue program also supports inclusion in the community through public relations activities. Able Flight at Purdue accomplishments were featured in local and national news, including features on local television (Sullivan, 2015), in local newspapers (Flores, 2015; Higgins, 2015), on the internet (Holden, 2017), and on national programs such as the Big Ten Network (Tolley, 2016). This media attention fosters a broader impact by changing how individuals and society perceive people with disabilities, including their capabilities, accomplishments, and positive contributions to society.

Able Flight is a program that changes lives, and uses flight training to expand opportunities for people with disabilities while challenging societal norms. Purdue Professor Bernard Wulle initiated the Able Flight at Purdue program and recognizes that it is an important catalyst both for participants and all who have the opportunity to interact with these pilots (Wulle, 2015). Able Flight at Purdue changes how people think, and opens minds to the unlimited possibilities.

One limitation of this study is that it reflects only two disability types: paraplegia and deafness. As noted previously, even the same disability type can have varying levels of severity (e.g., two individuals with paraplegia may have different capabilities, and two individuals who are both deaf may be able to hear and communicate in different ways). The flight training methods in this case study may not work for all wheelchair users or deaf student pilots. Another limitation is that the qualitative survey results are from a small sample, and the experiences and perceptions from one year may not be representative of the experiences and perceptions for all participant in all years.

Conclusions

The Able Flight program at Purdue has successfully supported the certification of 42 pilots with disabilities, and has provided secondary benefits of supporting inclusion at Purdue University and in the aviation industry. Similar benefits could be realized elsewhere, if other flight schools provide flight training for people with disabilities. This paper describes basic components of the Able Flight program and uses the SHELL model as a framework to explain necessary modifications to allow flight training for people with disabilities.

In the SHELL model, the Able Flight pilot is the central liveware, and successful adaptation to the software, hardware, environment, and other liveware are critical to support the goal of Sport Pilot certification. A tailored approach to match student pilot capabilities with training methods and resources is important, and is demonstrated through two case studies which illustrate how the needs of a pilot who uses a wheelchair are very different from the needs of a pilot who is deaf.

The Able Flight program at Purdue is successful, as measured by a high completion rate: 98% of participants have attained their Sport Pilot certification at Purdue University since the program began in 2010. The Able Flight program at Purdue is also successful as measured by other benefits. Benefits extend beyond the completion rate, with broader impacts both to the individual participants, CFIs, the institution, the aviation sector and the community, reflecting the positive impact the program has on promoting diversity and social inclusion at all levels.

The mainstream media generated by Able Flight supports broader impacts in the community with compelling illustrations that highlight the capabilities of people with disabilities; this challenges preconceptions, and changes the public perception, focusing attention on the capabilities and positive contributions to society by people with disabilities.

Flight training opportunities for people with disabilities, such as the Able Flight program at Purdue, can be implemented elsewhere using the human factors model explained in this paper. Future research to document case studies that illustrate training adaptations for other types of disabilities would be useful for the aviation community. Additional quantification of the benefits, including the perceptions of the aviation community and employment in the aviation sector by program participants, is also recommended for future research.

References

Able Flight. (2016a). Meet the Able Flight pilots. Retrieved from http://ableflight.org/meet-the-scholarship-winners

Able Flight. (2016b). Scholarships. Retrieved from http://ableflight.org/scholarships

Aircraft Owners and Pilots Association (AOPA). (n.d.). Airman medical certification. Retrieved from https://www.aopa.org/go-fly/medical-resources/airman-medical-certification

Aircraft Owners and Pilots Association (AOPA). (2004). Sport pilot begins: Fly with 'driver's license medical'. Retrieved from https://www.aopa.org/news-and-media/all-news/2004/january/09/sport-pilot-begins-fly-with-drivers-license-medical

Barnes, M. P. (1997). Driving for disabled people. *Critical Review in Physical and Rehabilitation Medicine,* 9(1), 75-92. doi:10.1615/CritRevPhysRehabilMed.v9.i1.40.

Bureau of Labor Statistics. (2016). Labor Force Statistics from the Current Population Survey. Retrieved from https://www.bls.gov/cps/cpsaat18.htm

Center for Disease Control and Prevention. (2017). Inclusion strategies. Retrieved from https://www.cdc.gov/ncbddd/disabilityandhealth/disability-strategies.html

Chang, Y., & Wang, Y. (2010). Significant human risk factors in aircraft maintenance technicians. *Safety Science,* 48, 54–62. https://doi.org/10.1016/j.ssci.2009.05.004

Charity Commission. (2001). The promotion of social inclusion. Retrieved from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/359358/socinc.pdf

Edwards, E. (1972). Man and machine: Systems for safety. In *Proceedings of British Airline Pilots Associations Technical Symposium,* (pp. 21–36).

Federal Aviation Administration. (2015). Sport pilot medical certification questions and answers. Retrieved from https://www.faa.gov/licenses_certificates/medical_certification/sportpilots/

Federal Aviation Administration. (2016). Aeronautical Information Manual. Retrieved from https://www.faa.gov/air_traffic/flight_info/aeronav/acf/media/Presentations/16-02-RD307-Light_Gun_Chart_AIM_Fecht.pdf

Federal Aviation Administration. (2017). U.S. Civil Airmen Statistics. Retrieved from https://www.faa.gov/data_research/aviation_data_statistics/civil_airmen_statistics/

Flores, T. (2015). Able Flight at Purdue on path to expand. Retrieved from http://www.jconline.com/story/news/2015/06/19/able-flight-purdue-path-expand/28996309/

Gallaudet University. (2015). American deaf culture. Retrieved May 28, 2018, from http://www3.gallaudet.edu/clerc-center/info-to-go/deaf-culture/american-deaf-culture.html

Goldberg, M., Cooper, R., Milleville, M., Barry, A., & Schein, M. L. (2015). Ensuring success for veterans with disabilities in STEM degree programs: Recommendations from a workshop and case study of an evidence-based transition program. *Journal of STEM Education*, 16(1), 16–24. Retrieved from http://jstem.org/index.php/JSTEM/article/view/1841/1644

Hawkins, F. H. (1987). Human factors in flight (2nd ed.). Aldershot, UK: Ashgate.

Higgins, K. (2015). Disabled from waist down, pilot enables scholarship recipients. Retrieved from http://www.purdueexponent.org/features/article_f7d56221-25e6-59c9-bbef-5e019105b51b.html

Holden, M. (2017). Physical disabilities don't stop future pilots at Purdue. *Washington Times*. Retrieved from http://www.washingtontimes.com/news/2017/jul/1/physical-disabilities-dont-stop-future-pilots-at-p/

International Civil Aviation Organization. (1989). Fundamental Human Factors concepts (Circular 216-AN/131). *Human Factors Digest*, No. 1.

Izzo, M. V., Murray, A., Priest, S., & Mcarrell, B. (2011). Using Student Learning Communities to recruit STEM students with disabilities. *Journal of Postsecondary Education and Disability*, 24(4), 301–316. Retrieved from http://www.ahead-archive.org/uploads/publications/JPED/jped24_4/JPED%2024_4.pdf

Kings School. (2018). Sport pilot practical test. Retrieved from http://www.kingschools.com/ground-school/sport-pilot/courses/checkride

Kozuba, J. (2011). Impact of human factor on likelihood of aircraft accident. *Transport System Telematics*, 4(2), 29–36.

Medland, D. (2015). Global airline industry: Diversity is stuck on the ground. Retrieved from https://www.forbes.com/sites/dinamedland/2015/12/17/global-airline-industry-diversity-is-stuck-on-the-ground/#5cb54edf6cf4

Mills, A. J. (2017). Man/aging subjectivity, silencing diversity: Organizational imagery in the airline industry. The Case of British Airways. *Insights and Research on the Study of Gender and Intersectionality in International Airline Cultures*, (pp. 367–392). https://doi.org/10.1108/978-1-78714-545-020171020

Moon, N. W., Todd, R. L., Morton, D. L., & Ivey, E. (2012). Accommodating students with disabilities in Science, Technology, Engineering, and Mathematics (STEM): Findings from research and practice for middle grades through university education. Atlanta, GA: Center for Assistive Technology and Environmental Access, Georgia Institute of Technology. Retrieved from https://hourofcode.com/files/accommodating-students-with-disabilities.pdf

Murray-Leslie, C. (1990). Aids for disabled drivers. *BMJ: British Medical Journal*, 301(6762), 1206-1209. https://doi.org/10.1136/bmj.301.6762.1206

National Research Council. (1997). *Taking flight: Education and training for aviation careers*. National Academies Press. Retrieved from https://www.nap.edu/catalog/5433/taking-flight-education-and-training-for-aviation-careers

National Science Board. (2010). Preparing the next generation of STEM innovators: Identifying and developing our nation's human capital. Retrieved from https://www.nsf.gov/nsb/publications/2010/nsb1033.pdf

National Science Foundation. (2000). Land of plenty: Diversity as America's competitive edge in science, engineering and technology. Retrieved from https://www.nsf.gov/pubs/2000/cawmset0409/cawmset_0409.pdf

National Science Foundation. (2004). Women, minorities, and persons with disabilities in science and engineering (No. NSF-04-317). Retrieved from https://www.nsf.gov/statistics/archive-goodbye.cfm?p=/statistics/wmpd/archives/wmpd_2004.zip

Pearce, J. T., & Randel, A. E. (2004). Expectations of organizational mobility, workplace social inclusion, and employee job performance. *Journal of Organizational Behavior*, 25(1), 81–98. https://doi.org/10.1002/job.232

Robinson, J. (2016). AV84All. Retrieved from http://www.av84all.org/home.html

Schultz, P. W., Hernandez, P. R., Woodcock, A., Estrada, M., Chance, R. C., Aguilar, M., & Serpe, R. T. (2011). Patching the pipeline: Reducing educational disparities in the sciences through minority training programs. *Educational Evaluation and Policy Analysis*, 33(1), 95–114. https://doi.org/10.3102/0162373710392371

Sporty Pilot Shop. (2018a). Cessna rudder pedal extensions. Retrieved from http://www.sportys.com/pilotshop/cessna-rudder-pedal-extensions.html

Sporty Pilot Shop. (2018b). Pilot's elevator cushion. Retrieved from http://www.sportys.com/pilotshop/pilot-s-elevator-cushion.html

Sullivan, K. (2015). Purdue teaches people with disabilities how to fly; plans for expansion. Retrieved from http://wlfi.us/2015/06/12/purdue-teaches-people-with-disabilities-how-to-fly-plans-for-expansion/

Tachakra, S. S. (1981). Driving for the disabled. *BMJ: British Medical Journal (Clinical Research ed.),* 283(6291), 589-591. https://doi.org/10.1136/bmj.283.6291.589

Tolley, J. (2016). Pilots with disabilities soar via Able Flight program at Purdue. Retrieved from http://btn.com/2016/10/16/pilots-with-disabilities-soar-via-able-flight-program-at-purdue-btn-livebig/

United Nations. (2007). Participatory dialogue: Towards a stable, safe and just society for all. Retrieved from http://www.un.org/esa/socdev/publications/prtcptry_dlg(full_version).pdf

University of Washington. (2018). Access to the future: Preparing college students with disabilities for careers. Retrieved from https://www.washington.edu/doit/access-future-preparing-college-students-disabilities-careers

U.S. Department of Labor. (n.d.). Job accommodations. Retrieved from https://www.dol.gov/general/topic/disability/jobaccommodations#

World Bank. (2013). Social inclusion. Retrieved from http://www.worldbank.org/en/topic/social-inclusion

Wang, Y. G., & Dong, B. J. (2011). Analysis of human error influence factors and evaluation indexes weights determination for air traffic controller. *Journal of Safety Science and Technology*, 7(2), 28–33. Retrieved from http://en.cnki.com.cn/Article_en/CJFDTOTAL-LDBK201102004.htm

Wulle, B. W. (2015). Expanding industry's understanding the skills people with disabilities can bring to the workplace. Presentation presented at the 2015 Able Flight Luncheon, West Lafayette, IN.

Collegiate Aviation Review International

Volume 36 | Issue 2 Literature Review #1

8-25-2018

An Analysis of Cabin Ozone Regulations

Taylor L. Pottinger
Embry-Riddle Aeronautical University

Cheryl L. Marcham
Embry-Riddle Aeronautical University

Exposure to elevated levels of ozone have been reported to be associated with complaints of discomfort such as dry mouth, eye irritation and dryness, nasal irritation coughing, and headaches. The Federal Aviation Administration (FAA) established regulatory requirements in 1980 to limit cabin ozone levels to no more than 0.25 parts per million (ppm) at any time or 0.1 ppm averaged over a 3-hour interval for any flight over four hours in length. The FAA also published an Advisory Circular (AC), AC 120-38, to provide guidance to air carriers on how to comply with these then new ozone regulations. Methods of compliance include the use of catalytic converters, or ozone filters, designed to remove ozone, utilizing statistical methods to prove that ozone concentrations will not exceed limits for the carrier's route structure and flight planning to avoid areas of reported high concentrations of ozone. The calculations used to determine cabin ozone concentration from manufacturer's filter efficiency data and ozone levels are to be based on published ozonesonde data found in the AC 120-38 or an equivalent data set. Unfortunately, the published ozonesonde data in the AC 120-38 are outdated and the AC does not point to any other data source that is acceptable to the FAA to conduct the required statistical analysis. In addition, once compliance is shown, no follow-up measurements are required to ensure that ozone levels remain below these required levels. Actual ozone concentrations have been measured in the aircraft by several researchers that exceed these regulatory levels. Finally, FAA ozone regulations and AC 120-38 do not address cumulative effects of ozone exposure to crewmembers over multiple flights and do not offer any protection against ozone exposure for crewmembers on non-passenger carrying flights. A revision of federal regulations to afford protection to all crewmembers, account for cumulative effects, and updated compliance methods that rely on current ozonesonde data and periodic ozone monitoring should be accomplished to ensure crewmembers are not subjected to ozone levels that could potentially result in serious health concerns.

Recommended Citation:
Pottinger, T.L. & Marcham, C.L. (2018). An Analysis of Cabin Ozone Regulation. *Collegiate Aviation Review International,* 36(2), 142-151. http://dx.doi.org/10.22488/okstate.18.101002

In 1980, the Federal Aviation Administration (FAA) enacted regulations that prohibited air carriers from operating aircraft in which cabin ozone levels exceeded 0.25 parts per million (ppm) at any time or 0.1 ppm averaged over a 3-hour interval for any flight over four hours in length (Cabin Ozone Concentrations, 1980). These regulatory requirements were established after crewmembers reported experiencing headaches and respiratory issues while operating in upper latitude regions at high altitudes (FAA, 1980). Research indicated that these symptoms could be related to high levels of ambient ozone in the aircraft cabin (FAA, 1980). Subsequently, the FAA also published an Advisory Circular (AC), AC 120-38, with the intent to provide guidance to air carriers on how to comply with these then new ozone regulations. A common method of compliance amongst air carriers is the installation of catalytic converters, or ozone filters, that are designed to remove a majority of the ozone in the aircraft air circulation system before it is circulated throughout the cabin. AC 120-38 requires air carriers to initially demonstrate that "the equipment installed will reduce the cabin ozone concentration to acceptable levels" (FAA, 1980, p. 5) through analysis and/or tests that include inflight measurements or acceptable ozone statistical data. However, air carriers are not required by any regulation to continuously monitor ozone levels onboard their aircraft beyond these initial tests or analyses to establish equipment removal efficiency. Multiple studies conducted onboard aircraft in which actual ozone levels were measured indicate that ozone levels can regularly exceed these FAA-required exposure limits on U.S. air carriers (Bekö, Allen, Weschler, Vallarino & Spengler, 2015; Spengler, Ludwig & Weker, 2004). Ozone levels have routinely exceeded 0.1 ppm onboard aircraft on long-haul flights at high latitudes, even those equipped with catalytic converters (Spengler et al., 2004). Passengers have reported experiencing many health concerns, such as headache or sinus irritation, while on board aircraft, and later research has determined that these symptoms could be attributed to high levels of ozone within aircraft cabins (Bekö et al., 2015). These findings indicate a need for better supervision of air carriers by the FAA in regard to ozone compliance.

Additionally, AC 120-38 allows operators to perform calculations to determine cabin ozone concentration from manufacturer's filter efficiency data and ozone levels based on published ozonesonde data in the AC 120-38 or an equivalent data set (FAA, 1980). Ozonesonde data are measured ozone concentration at various altitudes collected with a balloon-type instrument (National Oceanic and Atmospheric Administration [NOAA], 2008). AC 120-38 states that data collected during the Global Air Sampling Program (GASP) by the National Aeronautics and Space Administration (NASA) are not acceptable because they "do not show the necessary resolution elements" (FAA, 1980, App. 2). Further, both sets of ozonesonde data were collected prior to 1980 (FAA, 1980; National Center for Atmospheric Research, 1992), so are outdated because ozone levels throughout the atmosphere have changed since then due to increased efforts from governments to prevent ozone destruction in the stratosphere (Environmental Protection Agency [EPA], 2018). The AC does not point to any other data source that is acceptable to the FAA to conduct the required statistical analysis.

Finally, FAA ozone regulations and AC 120-38 ignore the cumulative effects of ozone exposure to crewmembers over multiple flights and do not offer any protection against ozone exposure for crewmembers on non-passenger carrying flights. A revision of federal regulations to afford protection to all crewmembers, account for cumulative effects, and updated compliance methods that rely on current ozonesonde data and periodic ozone monitoring should be accomplished to ensure crewmembers are not subjected to ozone levels that could potentially result in serious health concerns.

Review of Literature

Ozone levels in the atmosphere

The highest concentration of ozone is found in the stratosphere where it is commonly referred to as the *ozone layer*. The ozone layer prevents harmful ultraviolet radiation from reaching the surface of the earth by absorbing most of the ultraviolet radiation that enters the atmosphere (EPA, 2017c). According to the NOAA (2010), the remaining 10% of ozone that makes up our atmosphere is found between 32,000 and 52,000 feet above sea level. This relatively large concentration of ozone is within the typical cruising range of commercial jet aircraft. Prior to the establishment of the Clean Air Act in 1970, surface ozone levels had also been on the rise due to increases in pollutants emitted by automobiles and industrial factories (EPA, 2017c). Since the initial implementation of the Clean Air Act, surface air pollutants overall have dropped by 70%; however, high ozone levels at the surface still threaten the health of the environment and general public (EPA, 2017c).

Adverse health effects of ozone on the human body

Although the ozone layer plays a vital role in preventing harmful ultraviolet radiation from reaching the surface of the earth, a buildup of ozone at surface level or within an aircraft cabin can be harmful to humans. Ozone primarily has negative health effects on the respiratory system when inhaled, but it can also cause eye irritation (EPA, 2017a). A large amount of ozone that is inhaled will reach the lower respiratory tract where it will be absorbed by the fluid lining of the airways entering the lung (EPA, 2017a). The absorbed ozone damages the cells of the lining causing inflammation of the lungs (EPA, 2017a). The main symptom experienced after inhaling high concentrations of ozone is decreased lung capacity, but other symptoms may include coughing, shortness of breath, chest tightness, throat irritation and wheezing (EPA, 2017a). It should be noted that not all individuals react the same to high concentrations of ozone. Factors such as age, genetics, or body mass index can play a role in how an individual will react (EPA, 2017a). Individuals with predisposed illnesses such as asthma are likely to experience more severe symptoms of the disease (EPA, 2017b). Some studies have shown a correlation between high ozone levels and increased asthma attacks and increased use of medication for asthma (EPA, 2017b).

Regulatory Standards and Guidance for Ozone

Agencies such as the Occupational Safety and Health Administration (OSHA), the National Institute for Occupational Safety and Health (NIOSH), and the American Conference of Governmental Industrial Hygienists (ACGIH) are responsible for establishing regulatory standards and guidance regarding toxic substances to protect American workers. It should be noted that while OSHA does not have jurisdiction over employee exposures while the aircraft is in flight (FAA, 2014), the health and safety of flight crewmembers working onboard commercial aircraft are at risk if exposed above OSHA permissible limits regardless of the location or regulatory jurisdiction. Since most commercial airliners fly at altitudes where ozone is more prevalent in the outside air, aircraft crewmember exposure to ozone should be monitored even more closely.

OSHA (2017) has established the *permissible exposure limit* (PEL) at 0.1 ppm at an 8-hour time-weighted average (TWA) and the 15-minute *short-term exposure limit* (STEL) at 0.3 ppm for ozone. The recommended exposure limit set by NIOSH for ozone is also 0.1 ppm and this exposure level cannot be exceeded at any time (Centers for Disease Control and Prevention, 2016). NIOSH (2016) has established the level at which exposure to ozone would be *immediately dangerous to life or health* (IDLH) at 5.0 ppm. This IDLH concentration was established based on a historical case in which welders developed pulmonary edema after being subjected to ozone levels at 9.0 ppm (Leikauf & Prows, 2012).

The ACGIH (2018) established threshold limit values (TLVs) based on the intensity of workload. The ACGIH TLV is 0.05 ppm for an 8-hour TWA for heavy work, 0.08 ppm 8-hour TWA for moderate work, and 0.1 ppm 8-hour TWA for light work. For all workloads, if the exposure is less than 2 hours, the established TLV is 0.2 ppm (ACGIH, 2018).

NIOSH (2016) suggests that an individual should attempt to move to an area of fresh air or be provided with 100% oxygen in the event that he or she breathes in too much ozone. Aircraft crewmembers are not able to move to an area of true *fresh air* in the cabin because aircraft air circulation systems provide a mixture of both fresh air and recirculated air to the cabin. That being said, NIOSH's recommendation to move to an area of fresh air or be provided with 100% oxygen is most applicable to situations in which an individual is exposed to ozone levels closer to the 5.0 ppm IDLH. Although supplemental oxygen is available for crewmember use, it is unlikely crewmembers would utilize supplemental oxygen in the event they are exposed to high levels of ozone because symptoms of ozone exposure are generic and can be attributed to other possible illnesses.

FAA regulations prohibit certificate holders operating transport category aircraft from allowing cabin ozone concentrations to exceed 0.25 ppm any time above 32,000 feet (Cabin Ozone Concentration, 1980). For flight above 27,000 feet, cabin ozone may not exceed 0.1 ppm (averaged over a 3-hour interval) if that flight is longer than four hours above that altitude (Cabin Ozone Concentration, 1980). AC 120-38 further clarifies that at altitudes above 18,000 feet, ozone concentration may not exceed 0.25 ppm at any time and may not exceed 0.1 ppm for flights over four hours (FAA, 1980). In other words, ozone concentrations exceeding 0.1 ppm are permissible for flights with a duration of four hours or less (FAA, 1980).

Although it is stated in AC 120-38 that current ozone regulations found in 14 CFR 121.578 were prompted by crewmember complaints of discomfort such as eye irritation, coughing and chest pains (FAA, 1980), 14 CFR 121.578 contains a caveat in which the air carrier does not have to comply with ozone regulations provided the flight contains only crewmembers (1980). Any non-passenger carrying flight, such as an all-cargo flight, maintenance ferry flight, or repositioning flight, is not subject to any ozone regulations. For the purpose of the following analyses, we will assume that the scenario flights are passenger-carrying, which affords crewmembers protection from ozone exposure according to the regulations found in 14 CFR 121.578.

Analysis of Ozone Regulations

While FAA regulations allow exposures up to 0.25 ppm for flights four hours or less, this does not necessarily indicate the employee exposure will exceed the permissible limits that have been established by OSHA since the OSHA PEL is based on an 8-hour TWA rather than a 4-hour TWA. However, it is important to note that airline pilots and flight attendants do not usually fly only one flight during their duty period. 14 CFR 121.578 and AC 120-38 ignore the cumulative effects of exposure over successive flight segments. For example, if a pilot were to fly a four-hour flight exposed to 0.25 ppm, spend two hours indoors on the ground exposed to 0 ppm, and then fly another two-hour flight exposed to 0.25 ppm, he/she would be exposed to a cumulative 0.19 ppm over an eight-hour time-weighted period. An exposure concentration of 0.19 ppm is nearly twice the established OSHA PEL and the NIOSH REL.

$$\frac{(4 \ x\ 0.25)+(2\ x\ 0)+(2\ x\ 0.25)}{4+2+2} = 0.19 \text{ ppm eight-hour TWA}$$

As another example, if a pilot were to fly a four-hour flight exposed to 0.25 ppm, spend one hour on the ground exposed to 0.05 ppm, which is the average ozone concentration outside at ground level (EPA, 2017d), and then fly a three-hour flight exposed to 0.25 ppm, he/she would be exposed to a cumulative 0.225 ppm over an eight-hour time-weighted period. An exposure concentration of 0.225 ppm is over twice the established OSHA PEL and the NIOSH REL

$$\frac{(4\ x\ 0.25)+(1\ x\ 0.05)+(3\ x\ 0.25)}{4+1+3} = 0.22 \text{ ppm eight-hour TWA}$$

In fact, if a pilot were to fly a four-hour flight exposed to 0.25 ppm and then spend the next four hours on duty exposed to 0.05 ppm, he/she would still be exceeding the established OSHA PEL and NIOSH REL with an exposure of 0.15 ppm over an eight-hour time-weighted period.

$$\frac{(4x0.25)+(0.05x4)}{4+4} = 0.15 \text{ ppm eight-hour TWA}$$

Therefore, there is a discrepancy between what is permitted by OSHA and what is permitted by CFR 121.578. Since OSHA does not have jurisdiction over the health and safety of crewmembers while the aircraft is in flight (FAA, 2014), the scenarios presented by the previous three examples do not violate any federal regulations; however, it does beg the question of why is it permissible to expose aircraft crewmembers to almost twice the permissible exposure limit for other American workers. It could be that more lenient permissible limits have been established for air carriers since higher levels of ozone are unavoidable at the cruise levels of typical airliners. Also, it seems that 14 CFR 121.578 may have been intended to protect paying passengers who are not regularly subjected to higher than normal ozone levels rather than flight crewmembers, especially in light of the fact that crewmember ozone exposure is not regulated at all if the flight segment is non-passenger carrying.

Approved Methods to Comply with FAA Ozone Limits

According to AC 120-38, there are several ways in which a certificate holder can comply with ozone regulations (FAA, 1980). Two of the approved techniques are utilizing statistical methods to prove that ozone concentrations will not exceed limits for the carrier's route structure and flight planning to avoid areas of reported high concentrations of ozone (FAA, 1980). These two methods may be impractical because ozone levels and location vary with seasons and weather activity. An air carrier may also comply by modifying operating procedures, such as recirculation controls, or making modifications to the aircraft itself, such as installing catalytic converters (FAA, 1980). Catalytic converters are a commonly used compliance method amongst air carriers. There are other methods of removing ozone, such as thermal decomposition or gas absorption, but catalysts have proved most effective (Lu, Zhao, Wang, Yang, Zhang & Yang, 2014). Catalytic converters are easily obtained and relatively inexpensive. This method also allows the certificate holder to flight plan through areas of high ozone concentrations. Some statistical analysis is still required when using catalytic converters because filter efficiency must be demonstrated to maintain cabin ozone below permissible levels. The following is a selected equation for determining if exposure is maintained below 0.25 ppm:

$$OZMAX = (1-E)(OZ16)(R)(P/P_O)$$

Where E = filter efficiency, OZ16 = estimated ambient ozone concentration, R = retention ratio of the ambient air that flows through the aircraft air conditioning system, and P/P_O *= the ratio of cabin pressure to sea level pressure* (FAA, 1980)

A drawback of using the equations included in AC 120-38 is that the *OZ16* value, or estimated ambient ozone concentration, is calculated using ozonesonde statistics that were collected before 1980. The air carrier is permitted to use an alternate data set as long as the data meet equivalent standards to the

AC's ozonesonde data (FAA, 1980). Similar to the limitations of the AC's data, if an air carrier were permitted to use the NASA GASP data that are discussed in the AC, it would encounter the same drawback. The NASA GASP ozone data were collected between 1975 and 1979 (National Center for Atmospheric Research, 1992). The AC does not point to any other data source that is acceptable to the FAA to conduct the required statistical analysis.

Ozone Filter Efficiency

Both 14 CFR 121.578 and AC 120-38 require the air carrier to demonstrate that installed ozone filters maintain cabin ozone levels at or below permissible limits (Cabin Ozone Concentrations, 1980; FAA, 1980). It is insufficient for the air carrier to install an ozone filter and simply assume that permissible levels will be maintained. Filter efficiency must be initially tested or otherwise demonstrated by the air carrier (FAA, 1980). Studies have been conducted over the last several decades to monitor ozone levels on United States commercial aircraft at cruise altitude. Findings from these studies indicate that, even with installed catalytic converters, ozone levels routinely exceed the exposure limits established by 14 CFR 121.578 (Bekö et al., 2015: Spengler et al., 2004; Lu et al., 2014).

1992-1993 Ozone Sampling

Spengler, Ludwig & Weker (2004) compiled ozone-sampling data from 106 flights between 1992 and 1993 primarily operated over the Pacific Ocean, Asia, and the United States. Sampled aircraft included Boeing 737, Boeing 757, Boeing 747, McDonnell Douglas DC-10, Airbus 300, Airbus 320, Fokker aircraft, and Tupolev TU-134 (Spengler et al., 2004). Sampling was conducted by placing an ozone direct-reading instrument at breathing level in the forward portion of the cabin (Spengler et al., 2004). Blank samples were also distributed at breathing level throughout the cabin as a control (Spengler et al., 2004). Findings from this study indicated that 20% of sampled flights experienced ozone levels exceeding 0.1 ppm and 11% of sampled flights experienced ozone levels exceeding 0.12 ppm (Spengler et al., 2004). These findings may indicate a prevalence of noncompliance with 14 CFR 121.578; however, the study does not indicate the flight length for each sample, which is a required value to determine noncompliance. A specific sample was cited in the study in which an ozone concentration of 0.208 ppm was measured on a Boeing 757 (B757) flying between Boston and Los Angeles (Spengler et al., 2004). The flight time between Boston and Los Angeles for a B757 is well over four hours, so this measured ozone level is in clear violation of 14 CFR 121.578. It is unclear whether this B757 was equipped with a catalytic converter because the authors (Spengler et al., 2004) stated in the study that it was impossible to determine which aircraft were equipped with catalytic converters and which were not. It is reasonable to assume that most of the aircraft sampled were equipped with ozone filters as it is fairly common now for ozone filters to be included in the standard package offered by the manufacturer. It is also likely that older aircraft that are still in operation today are equipped with ozone converters as air carriers have likely installed converters in an attempt to meet ozone regulations.

Although this paper provides the reader with little insight into ozone filter effectiveness, it does provide evidence that air carriers may not be complying with federal ozone regulations or that these compliance methods are not extensive enough to ensure continued compliance. Spengler, Ludwig & Weker (2004) suggest that remedial measures, such as proper maintenance of ozone filter equipment and close monitoring of ozone levels onboard aircraft flying at high altitudes and latitudes, should be implemented.

2006-2010 Ozone Sampling

During 2006-2007, real-time ozone monitoring was performed on 76 flight segments exceeding 3.5 hours occurred in the passenger cabin while the plane was above 10,000 feet (Nazaroff & Weschler, 2010). Ozone concentrations above 0.1 ppm occurred on eight domestic flights and ozone concentrations above 0.25 ppm occurred on one transcontinental flight, all on planes not equipped with ozone catalysts (Nazaroff & Weschler, 2010). Nazaroff & Weschler also evaluated human subject's symptoms related to air quality and comfort related to ozone concentrations, and found that complaints such as headache, eye achiness, nasal irritation and skin dryness were increased when ozone concentrations were as low as 0.06 ppm.

Between 2008 and 2010 a study was conducted by Bekö, Weschler, Vallarino and Spengler (2015) in which cabin ozone concentrations were measured on 83 U.S. domestic and international flights. This study also included a component in which passengers were asked to complete a questionnaire about any adverse health symptoms they experienced during the flight (Bekö et al., 2015). Ozone measurements were taken using a "2B Tech model 205 ozone monitor" (Bekö et al., 2015, p. 3) that was placed in the aisle or middle seat in the middle of economy class. The findings of this study indicated that 16% of the flights experienced ozone levels above 0.060 ppm and 10% of the flights experienced ozone levels above 0.075 ppm (Bekö et al., 2015). The highest average ozone level for a single flight was measured at 0.114 ppm, which is above the permissible limit of 0.1 ppm for a flight over four hours in length; however, the study did not indicate the flight time for this specific sample (about 66% of the sampled flights were over four hours in length), so it is impossible to verify if this particular flight did exceed regulatory limits set by 14 CFR 121.578. The highest peak ozone level was measured at 0.256 ppm (Bekö et al., 2015), which did exceed the 0.25 ppm FAA limit that should not be exceeded at any time. These measured concentrations are fairly lower than reported concentrations in the study conducted by Spengler, Ludwig and Wekler (2004). Bekö et al. (2015) believed that lower ozone concentrations were measured because a majority of the sampled flights, about 60%, were along equatorial routes. Ozone levels tend to be higher in polar regions at high altitudes (Bekö et al., 2015). Even though a majority of cabin ozone levels reported in this study are below the FAA limits, about 26% of the reported ozone levels are close to exceeding the allowable limits established by federal regulations (Bekö et al., 2015).

Results from the questionnaire indicated that passengers experienced multiple symptoms related to high levels of ozone (Bekö et al., 2015). Bekö et al. (2015) used regression analyses to associate higher levels of ozone with multiple passenger reported symptoms. On average, 52 passengers per flight completed the questionnaire (Bekö et al., 2015). The highest reported symptoms were dry mouth, dry eyes and irritated sinuses (Bekö et al., 2015). Approximately 25% of passengers indicated that they experienced symptoms related to headache or dizziness, and 33% of passengers indicated that they experienced symptoms related to upper respiratory irritation (Bekö et al., 2015). Although crewmembers' symptoms were not reported, it is reasonable to assume that crewmembers experienced similar symptoms during these sampled flights.

These findings suggest that, particularly for aircraft not equipped with catalytic converters or flying in regions of the world where ambient ozone levels are typically higher, cabin ozone levels can exceed regulatory limits established by 14 CFR 121.578. High ozone levels also contribute significantly to passenger and crewmember discomfort and adverse health effects that are experienced while onboard.

Discussion and Conclusions

Since the initial implementation of 14 CFR 121.578 and AC 120-38, it seems little has been done by any federal agency to oversee compliance with these regulatory limits beyond initial demonstration of filter efficiency required by AC 120-38. Three primarily pitfalls of aviation ozone regulations can be identified from this research. Firstly, the regulations established by 14 CFR 121.578 allow crewmembers to be subjected to ozone levels above what is permissible for the average American worker under OSHA regulations, and does not account for the cumulative effects of multiple flights within one duty period. Secondly, data that are required to be used by the air carrier to demonstrate compliance with ozone regulations was collected nearly forty years ago. Thirdly, research conducted on actual flights shows that air carriers are either not utilizing the required compliance methods (ozone filters, flight planning, statistical analysis, etc.) to ensure compliance, or that the compliance methods prescribed by AC 120-38 are not adequate to ensure that crewmembers and passengers are not exposed to potentially harmful ozone levels.

The exposure limits for ozone established by 14 CFR 121.578 do not address the cumulative effects of exposure to ozone over a period of several flights. Under the current regulation crewmembers can actually be exposed to ozone exceeding 0.1 ppm TWA during an eight-hour duty day. An *unaugmented crew* (a flight crew consisting of only two pilots) is restricted to eight or nine flight hours during a single duty period, but is not limited on the number of flight segments it is permitted to fly (Flight Duty Period: Unaugmented Operations, 2012). Therefore, a four-hour flight with an exposure of 0.25 ppm preceded by a flight that is four hours or less with a similarly high ozone level can cause the eight-hour TWA to be twice the established limit for flights over four hours in length, and subsequently exceed the OSHA PEL. Although OSHA PELs do not apply to crewmembers while onboard an aircraft in flight (FAA, 2014), the permissible limit established by 14 CFR 121.578 may need to be altered in order to account for cumulative effects. Furthermore, for non-passenger carrying flights, crewmembers are not afforded any ozone exposure protection under the law. There are known adverse health effects associated with high levels of ozone, and the type of operation should not dictate the applicability of the regulation.

The guidance for air carriers to comply with ozone regulations that is provided in AC 120-38 is based on very outdated data. A revision to this AC may be warranted as the document instructs air carriers to calculate ozone levels by using the data provided in the AC or by using equivalent data, but does not reference or point to appropriate sources of current equivalent data to be used for compliance. Although the FAA may grant air carriers the ability to use updated data on a case-by-case basis, the fact remains that official FAA guidance still points towards outdated data.

AC 120-38 requires air carriers to initially demonstrate compliance with testing, statistical analysis or modeling, but research suggests that ozone levels can still exceed the established regulatory limits of 0.1 ppm for flights longer than four hours and 0.25 ppm at any time. The conclusion can be drawn that either air carriers may not be using the prescribed methods, whether that be flight planning or aircraft modifications, to ensure cabin ozone is below FAA-mandated limits, or the compliance methods located in AC 120-38 are not sufficient to ensure crewmembers and passengers are not overexposed. An air carrier may not be aware that the compliance method it is utilizing to reduce ozone concentrations is not effective since the FAA does not require continuous or periodic monitoring of ozone levels onboard aircraft. A revision of federal regulations should be considered to afford protection to all crewmembers, account for cumulative effects, and updated compliance methods that rely on current ozonesonde data and periodic ozone monitoring to ensure crewmembers are not subjected to ozone levels that could potentially result in serious health concerns.

References

American Conference of Governmental Industrial Hygienists. (2018). *2018 TLVs and BEIs.* Cincinnati, OH: ACGIH.

Bekö, G., Allen, J. G., Weschler, C. J., Vallarino, J., & Spengler, J. D. (2015). Impact of cabin ozone concentrations on passenger reported symptoms in commercial aircraft. *PloS One, 10(5),* e0128454. doi:10.1371/journal.pone.0128454

Cabin Ozone Concentration, 14 CFR § 121.578 (1980)

Centers for Disease Control and Prevention. (2016). NIOSH pocket guide to chemical hazards: Ozone. Retrieved from https://www.cdc.gov/niosh/npg/npgd0476.html

Environmental Protection Agency. (2017a). Health effects of ozone in the general population. Retrieved from https://www.epa.gov/ozone-pollution-and-your-patients-health/health-effects-ozone-general-population

Environmental Protection Agency. (2017b). Health effects of ozone in patients with asthma and other chronic respiratory disease. Retrieved from https://www.epa.gov/ozone-pollution-and-your-patients-health/health-effects-ozone-patients-asthma-and-other-chronic

Environmental Protection Agency. (2017c). Ozone pollution. Retrieved from https://www.epa.gov/ozone-pollution/basic-information-about-ozone#regulations

Environmental Protection Agency. (2017d). Ozone trends: National trends in ozone levels. Retrieved from https://www.epa.gov/air-trends/ozone-trends#oznat

Environmental Protection Agency. (2018). Stratospheric ozone levels over North America. Retrieved from https://cfpub.epa.gov/roe/indicator.cfm?i=18

Federal Aviation Administration. (1980). *Transport category airplanes cabin ozone concentrations* (Advisory Circular 120-38). Retrieved from https://www.faa.gov/documentLibrary/media/AdvisoryCircular/AC120-38.pdf

Federal Aviation Administration. (2014). *Memorandum of understanding between the Federal Aviation Administration U.S. Department of Transportation and the Occupational Safety and Health Administration U.S. Department of Labor*. Retrieved from https://www.faa.gov/about/initiatives/ashp/media/FAA_OSHA_MOU_2014.pdf

Flight Duty Period: Unaugmented Operations 14 CFR § 117.13 (2012)

Leikauf, G.D. & Prows, D.R (2012). Inorganic compounds of carbon, nitrogen, and oxygen. In Bingham, E. & Cohrssen, B. (Eds.), *Patty's Toxicology* (6th ed.), pp. 949-1032. Hoboken, NJ: John Wiley & Sons, Inc.

Lu, Y., Zhao, X., Wang, M., Yang, Z., Zhang, X., & Yang, C. (2014). Feasibility analysis on photocatalytic removal of gaseous ozone in aircraft cabins. *Building and Environment, 81,* 42-50. doi:10.1016/j.buildenv.2014.05.024

National Center for Atmospheric Research. (1992). NASA GASP (Global Atmospheric Sampling Program) aircraft observations, 1975Mar-1979Jul. Retrieved from https://rda.ucar.edu/datasets/ds368.0/

National Oceanic and Atmospheric Administration. (2008). Ozonesonde. Retrieved from http://www.ozonelayer.noaa.gov/action/ozonesonde.htm

National Oceanic and Atmospheric Administration. (2010). *What is ozone and where is it found in the atmosphere?* Retrieved from https://www.esrl.noaa.gov/csd/assessments/ozone/2010/twentyquestions/Q1.pdf

Nazaroff, W.W. & Weschler, C.J. (2010). *Ozone in passenger cabins: Concentrations and chemistry* (Report No. RITE-ACER-CoE-2010-2). Retrieved from https://www.researchgate.net/profile/Charles_Weschler/publication/267969277_Ozone_in_Passenger_Cabins_Concentrations_and_Chemistry/links/54bd0cbd0cf218da9390b5d9/Ozone-in-Passenger-Cabins-Concentrations-and-Chemistry.pdf

Occupational Safety and Health Administration. (2017). Table Z-1 limits for air contaminants. Retrieved from https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9992

Spengler, J. D., Ludwig, S., & Weker, R. A. (2004). Ozone exposures during trans-continental and trans-pacific flights. *Indoor Air, 14*(s7), 67-73. doi:10.1111/j.1600-668.2004.00275.x

University Aviation Association
2787 North 2nd Street
Memphis, TN 38127
(901) 563-0505
uaamail@uaa.aero