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These proceedings would not have been made possible without the valuable contributions of our Track Chairs and reviewers for the time and effort they spent reviewing the papers.

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MEASURING WILLINGNESS TO FLY ONBOARD AIRCRAFT EQUIPPED WITH TWO PILOTS, A SINGLE PILOT, AND A SINGLE PILOT WITH ARTIFICIAL INTELLIGENCE

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Abstract

Passengers' Willingness to Fly onboard commercial aircraft was evaluated in three configurations: two pilots with traditional automation, single pilot with traditional automation, and single pilot and artificial intelligence (AI). Amazon MTurk participants rated their willingness to fly in all three aircraft/pilot configuration scenarios. A total of 254 responses were recorded, with an average age of 32.9 years old and average annual flight frequency of 6-10 flights per year. Average willingness to fly was 1.01 for the two-pilot scenario, 0.97 for the single-pilot with traditional automation scenario, and 0.96 for the single-pilot with AI scenario. The results showed that the difference in willingness to fly between the three configurations was not statistically significant. This may indicate to aircraft manufacturers that consumers are not significantly more or less willing to fly onboard single-pilot aircraft with AI compared to traditional automation, which could help to foster the development of this technology.

Keywords: *Artificial Intelligence (AI); Willingness to Fly; Consumer Perceptions*

1. Introduction

Over the past several decades, airline transport category aircraft have reduced the number of required flight crew as flight deck technology has become more advanced. Aircraft manufacturers have already started developing and implementing single-pilot aircraft. Simultaneously, artificial intelligence (AI) has experienced intense development in the last few years, exhibiting exponential leaps in its capability. Because of these advancements, "machines [equipped with AI] are now able to do certain types of scientific discovery on their own. They are capable of creating hypotheses, and…they can design themselves to solve problems and discover new knowledge" (Dhar, 2016, p. 6). These capabilities could theoretically be integrated into the cockpit to provide higher levels of safety and efficiency than even highly trained human pilots. However, for these new technologies to gain a foothold in the aviation industry, passengers must be comfortable flying on aircraft that employ them.

The purpose of this study was to evaluate passengers' Willingness to Fly (Rice et al., 2020) onboard a transport category aircraft with three different pilot/automation configurations: an aircraft equipped with two pilots and traditional automation systems, an aircraft equipped with a single pilot and traditional automation systems, and an aircraft equipped with a single pilot and AI.

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The sample population was adults in the United States recruited using Amazon MTurk. The independent variable was the pilot/automation configuration, and the dependent variable was willingness to fly. Willingness to fly was measured using the seven-question scale developed by Rice et al. (2020), which has demonstrated high values of validity and internal reliability since its inception.

This study provides data on the willingness of potential passengers to fly onboard a transport category aircraft with two pilots and traditional automation systems, an aircraft equipped with a single pilot and traditional automation systems, and an aircraft equipped with a single pilot and AI. Such data will allow the aviation community to better understand the openness of the general population to the introduction of this new technology. One study found that only about 49% of the general population currently feels confident in flying an aircraft with a single pilot. Those, who responded that they do not feel confident flying onboard single-pilot aircraft, cited fears about the pilot's physical health and a lack of trust in current technology (Stewart & Harris, 2019). As AI has grown to become very advanced, it could theoretically be trained to handle unusual situations at similar or higher levels of safety than even a highly trained human pilot. However, developing and implementing artificial intelligence in the flight deck depends in part on the public being willing to fly onboard such an equipped aircraft. Airline manufacturers and airlines would be less likely to devote time, money, and resources to developing single-pilot aircraft with AI if passengers are unwilling to fly onboard these aircraft.

Therefore, the research question was: are passengers more willing to fly onboard a two-pilot aircraft equipped with traditional automation, a single-pilot aircraft equipped with traditional automation, or a single-pilot aircraft equipped with AI? We hypothesized that there would be a difference in passenger willingness to fly on a single-pilot aircraft equipped with AI compared to a single-pilot aircraft equipped with traditional automation. Because it is the status quo, passengers will be more willing to fly on an aircraft equipped with two pilots and traditional automation than in either single-pilot scenario. The results of this study are generalizable to potential adult airline passengers in the United States of America. However, consideration must be given to the fact that MTurk users may be more trusting of technology, as indicated by their willingness to work and take surveys online.

2. Literature Review

The past few decades have seen explosive growth in the capabilities of technology. One example that has seen particularly significant gains in capability is AI. AI is finding its way into more and more industries, including the aviation industry. However, it has not yet been applied to piloting commercial airline flights in the United States. If applied correctly, it could theoretically be capable of providing a higher level of safety of flight than today’s traditional automation.

2.1 Existing Automation

At its core, automation aids in providing and supplementing cognitive functions for operators. Vu et al. (2018) explained how technological advancements led to a reduction in crew sizes from the 1950s to the 1980s, dropping from five (consisting of two pilots, an engineer, a navigator, and a radio operator) down to just two pilots. The role of the flight engineer was eliminated as jet engines, which were more reliable and needed little to no mid-flight adjustment compared to reciprocating engines, were developed. As navigational aids became more robust, the need for navigators and radio operators was eliminated. As trends continue, there is a push to minimize the crew size further to lower costs for the airlines. Attempts to decrease pilot tasks include automating ground-based operator functions and cockpit-based technologies to reduce the amount of work (Vu et al., 2018).

Therefore, as technology continues to be developed, it can be inferred that the next step may be to reduce the human pilots' role within the cockpit to one of a supervisory nature or eliminate one or both human positions entirely.

Human interaction with computers is the focal point of cockpit-based technology and can have benefits and pitfalls; mainly, when there is a workload reduction, pilot alertness is severely hindered while monitoring the interface. Reports indicate that 88% of the causes of fatal aviation-related accidents stem from pilot error (Gil & Kaber, 2012). As such, augmented cognitive systems are being developed, as well as methods for understanding human processing in a cognitive sense. While many concepts to establish single pilot operations have been presented, there has been no indication that any one is superior to another. Shively et al. (2017) theorized that rather than automation as a tool to use in the cockpit, it is instead the missing co-pilot in the cockpit. They stated that the problem with current automation is that it exists in a state of brittleness, existing for the set of operations it is designed to accomplish and requiring human input to manage situations outside of those set parameters (Shively et al., 2017). While this is not an issue for some tasks, it is a problem for aviation, where flying in the real world can and regularly does transition from the expected to the unexpected. Dynamic weather, unpredictable movements of other aircraft, nonstandard air traffic control instructions, emergency situations, or a combination thereof represent a set of circumstances that traditional logic-based automation may not be able to react to correctly.

2.2 Artificial Intelligence (AI)

AI is just one of many new technologies being developed extensively in the 21st century. Borana (2016) defined AI as the ability of a computer or other device to solve complex problems. He summarizes intelligence as the ability to perceive something, analyze what it means, and react appropriately. AI has already begun to find its way into the aviation industry. According to Kulida and Lebedev (2020), AI is currently used in various aviation-related applications, including aviation training, maximizing route and airspace structure efficiency, and preventing midair collisions. AI can also be used for weather forecasting (Borana, 2016). However, no application of true AI acting as a flight crewmember or having control of a commercial aircraft during normal operations currently exists.

Given the recent trends in the development of AI technology, it stands to reason that manufacturers may begin developing AI-controlled aircraft in the near future, initially for cargo operations but then also possibly for commercial passenger operations. For this to be practical, however, passengers must be willing to fly on an airplane with AI in control (Talley, 2020). Willingness depends heavily on public perception of AI. The public is aware of AI and interacting with various levels of AI on a regular basis; Fast and Horvitz (2017) discovered that AI has become an increasingly prevalent topic within the last ten years. They also noted that news outlets have primarily covered AI in a positive manner, about twice as often as negative portrayals (Fast & Horvitz, 2017). Additionally, Gao et al. (2020) found that nearly a third of people, who posted on social media about the use of AI in the medical field, spoke of it positively and optimistically (Gao et al., 2020). While this pertains to the medical field, the application of AI in medicine is similar to that of aviation in that it could be in control of the end user's safety. Despite this, it must be kept in mind that many of the participants expressing their opinions may not have yet faced a situation where AI was directly responsible for their safety in an airline context.

Despite the generally positive opinion, there are still concerns. For example, Fast and Horvitz (2017) analyzed internet search data and found that loss of control of AI is an increasing concern among the public. According to Dhar (2016), due to the sheer amount of information ingested by AI systems to train themselves, they may begin to operate in a manner that exceeds the human operator's understanding of them. This may lead to the possibility of a loss of control of the AI. This would be a hazardous scenario if such an AI were in control of an aircraft. It would be possible then that the AI could make a decision without communicating it to the humans in the system, significantly compromising safety. Another challenge is that some people simply do not trust companies that develop and manage AI. According to Gao et al. (2020), approximately 25% of negative opinions toward AI result from such a lack of trust. Finally, in aviation, there is aa risk that terrorists could impact AI. These represent just a few challenges facing AI and sources of public distrust.

2.3 Willingness to Fly Onboard Single-Pilot Aircraft

Rice et al. (2020) identified that a valid scale measuring passengers' willingness to fly is necessary to evaluate their needs and probable responses, which is critical to the development of crew training, aircraft design, and passenger safety messaging. Therefore, they chose to develop a scale to measure passenger willingness to fly. Their method involved selecting willingness to fly terminology using existing literature and consulting with aviation experts and passengers. It was subjected to nominal and Likert-scale pairing, factor analysis, reliability testing, and a sensitivity test. The result was a comprehensive seven-question scale that demonstrated high levels of internal reliability; when participants recruited from Amazon Mechanical Turk (n = 242) were presented with two willingness to pilot scenarios, their responses demonstrated Cronbach's Alpha values of .975 and .980, and Guttmann's Half Split values of .949 and .963 (Rice et al., 2020). This scale has demonstrated validity since its inception; it has been used and found to be reliable by several research studies measuring Willingness to Fly (D'Albert, 2022; Wheeler, 2020; Winter, 2017).

Over the past decade, there has been an increasing interest in transitioning to single-pilot commercial aircraft operations. This interest comes from even the United States government, as the U.S. Congress in 2018 directed "the [Federal Aviation Administration], in consultation with [the National Aeronautics and Space Administration]," to "establish a research and development program in support of single-piloted cargo aircraft assisted with remote piloting and computer piloting" (FAA Reauthorization Act of 2018, p. 509). While this directive only applies to cargo aircraft, it can be inferred that the results of this research will soon be used to develop more single-pilot aircraft, for cargo and then passenger aircraft. Gearhart (2018) and Liu et al. (2016) both evaluated the human factors considerations involving single-pilot airline operations and concluded that in order for them to be feasible and safe, their avionics must include a form of intelligent pilot-aircraft interface that continuously monitors the physical and psychological state of the single pilot to determine both the level of automation that is required as well as whether the human pilot is fit to fly. This may be a solution to implementing single-pilot operations in commercial aircraft; however, more research is needed to determine the feasibility and passenger willingness to fly onboard such an equipped aircraft.

In 2010, Brazilian aircraft manufacturer Embraer evaluated the feasibility of single-pilot operations in their aircraft and concluded that although the technology could exist by the years 2020-2025 due to advances in technology under the FAA's NextGen program, they were unsure of passengers' willingness to fly onboard these aircraft (Doyle & Learmount, 2010). To measure this, Stewart and Harris (2019) studied passenger attitudes toward flying onboard single-pilot aircraft. Their study surveyed 109 participants of various ages, backgrounds, and genders, asking whether they were willing or unwilling to fly onboard a single-pilot aircraft. They found that only 46% of respondents were willing to fly, 6% responded "maybe," and 49% responded that they were unwilling. This study's generalizability is limited by the fact that it only surveyed participants in the United Kingdom, and validity in that they used their own three-response scale to determine willingness to fly rather than any peer-reviewed, validated scale, such as the one developed by Rice et al. (2020). The survey also did not include any mention of the avionics or equipment onboard the theoretical aircraft.

Advances in aircraft automation over the last several decades have reduced the required number of crew to operate most commercial aircraft down to just two (Vu et al., 2020). Aircraft manufacturers and the United States government alike have expressed interest in transitioning to single-pilot operations; however, passengers must be willing to fly onboard these aircraft in order to foster their development. AI has become extremely advanced, exhibiting high levels of decision-making and autonomy. These skills could enable such a system to perform cockpit tasks at around the same level as a highly trained human pilot. Therefore, an aircraft equipped with a single pilot and AI could theoretically be safer than one equipped with traditional automation. The aviation industry needs to determine the extent to which passengers would be willing to fly onboard an aircraft equipped with such an AI system and monitor this as AI uses become more common place in society and the aviation industry specifically.

3. Methods

This study targeted all commercial airline passengers (above the age of 18) in the United States. The accessible population was participants from the United States above the age of 18 from Amazon® Mechanical Turk™ (MTurk). Willing participants were solicited from MTurk and at least 18 years old.

This study was a within-subjects, quasi-experimental design utilizing a questionnaire. First, an Institutional Review Board exemption was approved before conducting the study (23-028) because of the extremely low risk to human participants. No identifying information was collected using Qualtrics. A convenience sample of participants were recruited using Amazon® Mechanical Turk® (MTurk), through which they were provided a link to a Qualtrics questionnaire. At the beginning of the survey, participants confirmed they are at least 18 years of age and indicated their informed consent by continuing the survey as instructed. Then, they were asked seven questions to determine their Willingness to Fly (Rice et al., 2020) onboard a commercial airline flight equipped with either a cockpit with two human pilots and traditional automation, a cockpit with one human pilot and traditional automation, and a cockpit with one human pilot and a highly advanced AI system integrated into the avionics. Each participant was presented with all three scenarios, which were presented in random order. The willingness to fly scale was developed and tested for validity and reliability by Rice et al. (2020) and has been used successfully in this population and with convenience sampling. Calculations for checking both internal reliability and statistics will follow previously published studies using this validated scale (e.g., D'Albert, 2022; Rice et al., 2020, Wheeler, 2020; Winter, 2017). Participants were asked several questions about their demographics, including their age, ethnicity, the average number of times they fly onboard a commercial aircraft per year, and their familiarity with aviation and AI on a 5-point scale from “Very Unfamiliar” to “Very Familiar.” At the conclusion of the questionnaire, they were instructed to enter a code into MTurk to verify that they had completed the survey to receive compensation totaling approximately 35 cents for their time.

Data were downloaded from Qualtrics into a Microsoft Excel spreadsheet. The Likert scale responses used by the Willingness to Fly scale (Rice et al., 2020) were converted to numerical values, where a response of “Strongly disagree” was assigned a value of -2, “Disagree” was assigned -1, “Neutral” was assigned 0, “Agree” was assigned 1, and “Strongly agree” was assigned 2. Per the procedure listed in the creation of this scale, values from all seven willingness to fly responses per scenario were averaged to provide a single mean value for each scenario per participant. Flight frequency responses were categorized: 0 was assigned "0 flights per year," 1 was assigned "1-5 flights per year," 2 was assigned "6-10 flights per year," 3 was assigned "11-19 flights per year, and 4 was assigned "20+ flights per year." Additionally, familiarity with commercial aviation and AI responses were converted into numeric format, with 0 being assigned "Very Unfamiliar" to 4 being "Very familiar." Descriptive statistics, including each scenario's mean, median, mode, range, and standard deviation of responses, were calculated using Microsoft Excel. Inferential statistics, including Cronbach's alpha to ensure internal reliability of the scale within each scenario, one-way repeated measures ANOVA, and an eta-squared test to determine effect size, were calculated using R Studio Version 2023.03.0.

4. Results

In total, the questionnaire received 257 responses. Three responses were deleted because those respondents indicated that they were not above the age of 18. Therefore, this study's total sample size is 254. The average age of respondents was 32.9 years old, and age ranged from 18 to 63. Participants' familiarity with commercial aviation, converted to numerical form on a scale of 0-4, was 2.52 on average (SD = 0.96), or between "Moderately Familiar" and "Very Familiar." Familiarity with AI was similar with a mean of 2.47 (SD = 0.96). Participants' annual frequency of flights, converted to numerical form on a scale of 0-4, was 1.97 (SD = 0.79), indicating an average response of around 6-10 flights per year (see Figure 1). This indicates that that although a convenience sample was used, the respondents did represent a range of regular aviation consumers. Cronbach's alpha values were 0.80 for the 2-pilot scenario, 0.83 for the single-pilot with traditional automation scenario, and 0.83 for the single-pilot with AI scenario. These were reasonably high indicators of internal reliability; therefore, Likert scale values (-2 for strongly disagree to 2 for strongly agree) were averaged for all seven Willingness to Fly (Rice et al., 2020) items for each scenario, yielding a final willingness to fly value per participant for each scenario.

Table 1 and Figure 2 show the descriptive statistics for willingness to fly in the three scenarios. Average willingness to fly in the 2-pilot scenario is slightly higher (M = 1.01) than in either single-pilot scenario. Median values for the 2-pilot and single-pilot with traditional automation scenarios are the same at 1.14; however, the single pilot with AI scenario value is lower at 1.00. Willingness to fly responses in the single-pilot with AI scenario exhibited the widest range, from -1.29 to 2.00. The standard deviation of responses was 0.57 for the 2-pilot scenario, 0.60 for the single-pilot with traditional automation scenario, and 0.61 for the single-pilot with AI scenario, indicating a very slightly higher variance of responses for this scenario. The one-way repeated measures ANOVA was not significant; $F(2, 758) = 0.23$, $p = .76$. The eta-squared was 0.0015, which indicates a very small effect size.

Table 1. Descriptive Statistics for Willingness to Fly on Multiple Aircraft Configurations

Scenario	Mean	Median	Mode	Range	Standard Deviation
2 Pilots	1.01	1.14	1.43	-1.14 to 2.00	0.57
1 Pilot + Traditional Automation	0.97	1.14	1.43	-1.00 to 2.00	0.60
1 Pilot + AI	0.96	1.00	1.57	-1.29 to 2.00	0.61
Overall	0.98	1.10	1.48	-1.29 to 2.00	0.59

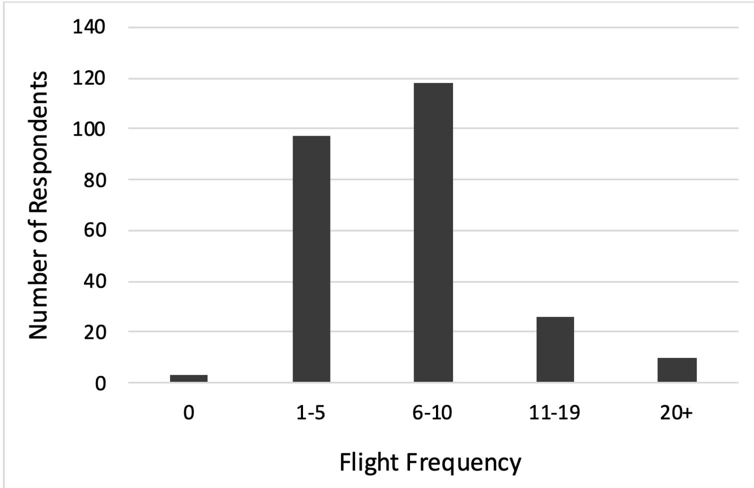

Figure 1. Number Of Respondents Per Range of Annual Flight Frequency

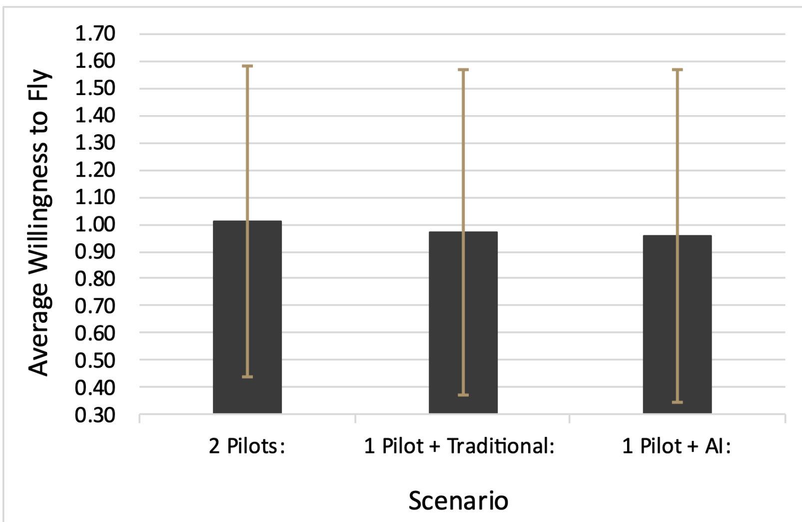

Figure 2. Average Willingness to Fly for Three Pilot/Automation Configurations, With Standard Deviation Error Bars

5. Discussion

This study finds that there is not sufficient evidence to conclude that pilot/automation configuration has a statistically significant impact on passenger willingness to fly. The data support accepting the null hypothesis ($p = .76$). The initial research hypothesis that there would be a difference in consumer willingness to fly across the pilot configuration scenarios was not supported. Although consumers in the United States are very slightly more willing to fly on a two-pilot commercial aircraft ($M = 1.01$) than a single-pilot commercial aircraft with traditional automation ($M = 0.97$) with AI ($M = 0.96$). There is no statistically significant difference between the scenarios overall (see Figure 2). The lower willingness to fly on a single-pilot airliner somewhat aligns with Stewart and Harris' (2019) study, which found that only 46% of surveyed participants ($N = 109$) were willing to fly onboard a single-pilot aircraft, compared to 49% being unwilling. This study's lack of a statistically significant difference between configurations could, in part, be caused by a lack of basic understanding of the roles of humans, automation, and AI in the cockpit. Respondents may not know the levels at which humans versus automation have control in the flight deck, nor how much input is required to pilot a commercial aircraft. Additionally, they may not understand what AI actually is; as presented, “artificial intelligence” could refer to anything from well-developed traditional programming to true AI, which relies on machine learning and model training to develop decision-making capabilities. Another possible explanation is that the participants already feel comfortable with AI through exposure in day-to-day life and thus willingness to fly is not currently impacted by consumer perception of AI.

This study’s largest limitation is that there is a lack of real-world examples of AI in the cockpit, meaning that measured willingness to fly is based upon an aircraft configuration that is entirely theoretical. The benefits, risks, and operational considerations of integrating AI into commercial aircraft are largely unknown simply because it has not been done before. Future research should therefore be more applied in nature and could include simulating or integrating AI into the flight decks of commercial aircraft to better understand its feasibility. This could include conducting similar Willingness to Fly or Willingness to Pilot (Rice et al., 2020) studies with these examples as well as studying the effect of AI on pilots’ safety, efficiency, and ease of use.

Additional future research could involve conducting a similar willingness to fly study but evaluating the effect of educating consumers about single-pilot operations or AI in the flight deck on their willingness to fly. This research could show aircraft manufacturers and airlines whether marketing and consumer education make consumers more or less likely to fly. Studies could also be conducted presenting only the two single-pilot scenarios in order to better target the difference caused by AI. Lastly, future research could survey commercial airline pilots to determine their Willingness to Pilot (Rice et al., 2020) with the same three scenarios: with two pilots and traditional automation, a single pilot and traditional automation, and a single pilot with AI. Consumer willingness to fly should be monitored over time as AI becomes more prevalent and when it is incorporated into cockpits of for cargo and commercial transportation operations.

The aim of this research study was to evaluate aviation consumers’ Willingness to Fly (Rice et al., 2020) onboard commercial aircraft equipped with two pilots, a single pilot with traditional automation, and a single pilot with AI. This study surveyed 254 adult participants in the United States and found that there is no statistically significant difference between consumers’ willingness to fly with two pilots, with a single pilot and traditional automation, and with a single pilot and AI. One possible explanation is that consumers simply do not understand the relationship between pilots and automation in the cockpit. Another possibility is that, as presented, “artificial intelligence” may have different meanings to different participants or even that currently aviation consumers are equally willing to fly with AI and a pilot. These results may demonstrate to aircraft manufacturers and airlines that passengers are not significantly less likely to fly onboard a single-pilot commercial aircraft with AI compared to more traditional configurations, so development of this technology may be more feasible. However, the lack of current implementations of AI in the cockpit means that significantly more research is necessary, which may include developing these technologies in the real world and evaluating the effect of educating consumers about AI and commercial aviation on their willingness to fly.

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FLIGHT LESSON CANCELLATION TRENDS BASED ON TYPE: BETWEEN 2010-2019 IN PART 141 FLIGHT SCHOOL IN THE SOUTHEASTERN UNITED STATES

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Abstract

This study examined trends over time based on flight lesson cancellation types at Part 141 flight school in Florida from 2010 to 2019. Identifying such trends is crucial for developing strategies for reducing future flight cancellations. Flight lesson cancellations were pre-categorized into four types: weather-related, student-related, instructor-related, and maintenance-related. The hypothesis was that there would be a significant trend over time for each flight cancellation type from 2010 to 2019 in part 141 of the collegiate flight program in Florida. Using a predictive correlational design, this study analyzed the archival cancellation data. Between 2010 and 2019, the total number of flight lesson cancellations was 27,320, based on archival data from 544 students. Based on the descriptive statistics, weather-related cancellations had the largest mean (22.43) and standard deviation (18.21), suggesting greater unpredictability. Linear regressions for each type of flight cancellation showed statistically significant trends that decreased from 2010 to 2019. These findings contribute to our understanding of cancellation trends, emphasizing the ongoing reduction in cancellations during the study period.

Keywords: *Flight Lesson Cancellations; Part 141 Flight Schools; Pilot Shortage*

1. Introduction

Professional aviation has recently grown in popularity as a career choice, leading to a substantial influx of aspiring pilots enrolling in Part 141 flight schools. As a result, Part 141 flight schools have been bombarded with many new students interested in their flight programs. Although this is an exciting career choice for young pilots, many flight students do not initially recognize the challenges and setbacks of enrolling in a Part 141 flight programme. Arguably, one of the biggest setbacks impacting students participating in flight training is the cancellation of lessons. By examining the patterns of cancellations over time, we can gain insights into the dynamics of the flight training challenges faced by students, instructors, and maintenance personnel. Understanding these trends is crucial for enhancing the effectiveness of flight training programs, mitigating cancellations, and improving the overall experience of individuals pursuing careers in professional aviation.

This study aimed to determine trends over time among flight cancellation types from 2010 to 2019 enrolled in a part 141 collegiate flight program in Florida. Cancellations were pre-classified into four types: maintenance-, weather-, instructor-, and student-related. The annual cancellation rate is a tally of the total cancellations for each type. The trend over time in this study was defined as the discernible patterns or changes observed in the frequency and distribution of flight cancellation types among students enrolled in a Part 141 collegiate flight program in Florida from 2010 to 2019.

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Analyzing trends in flight cancellation types over time provides an opportunity to gain a comprehensive understanding of the factors contributing to students' training delays, potentially explaining the time required to complete flight training. This exploration of the temporal dynamics of flight cancellations is informative for iterative improvements in flight training programs, ultimately facilitating a more effective and streamlined progression for aspiring pilots.

The results are generalizable to other collegiate Part 141 flight students at this specific university in Florida. Part 141 of the training programs have FAA-regulated training standards, shared external challenges, particularly weather-related factors, in similar regions, and similar student demographics. Therefore, insights may also provide a broader understanding of cancellations in Part 141 programmes in similar Part 141 training settings in Florida.

1.1 Research Question and Hypothesis

What are the trends over time in weather-related, student-related, instructor-related, and maintenance-related flight cancellations within a Part 141 collegiate flight program in Florida from 2010 to 2019?

The hypothesis for this study will be: There will be significant trends over time for each flight cancellation type (weather-related, student-related, instructor-related, and maintenance-related) from 2010 to 2019 in a Part 141 collegiate flight program in Florida.

2. Literature Review

This review contextualizes the observed cancellation trends, providing insights into the multifaceted factors influencing flight training lesson cancellations within a specified context. To comprehensively understand cancellations in Part 141 flight schools, an exploration of maintenance issues, a broader pilot shortage (beyond flight instructors), weather-related cancellations (including regulatory aspects and visibility/ceiling minimums), and student-related cancellation factors are crucial.

2.1 Late Aircraft, Weather, and Maintenance Issues

In the aviation industry, cancellations and delays pose significant challenges to flight schedules, resulting in substantial profit losses (Shu, 2021). Airlines and airports have proactively implemented measures to mitigate the impact of factors that lead to cancellations and delays. Despite these efforts, unexpected circumstances continue to arise, contributing to financial losses. Shu (2021) analyzed commercial domestic flight data spanning the years from 2009 to 2019 and found that the primary causes encompassed air carriers, adverse weather conditions, issues within the National Aviation System, security concerns, and late-arriving aircraft. Late-arriving aircrafts have emerged as the primary cause of flight delays and cancellations. Both flight crew-related and weather-related factors play significant roles in canceling domestic flights (Shu, 2021), indicating that these may also be concerns within collegiate flight training programs.

Mott et al. (2016) examined the utilization of a Cirrus aircraft within the framework of a Midwestern University. The imposition of elevated weather minima such as ceiling and visibility, as mandated by both university policies and the Federal Aviation Regulations, resulted in instances of grounded aircraft and subsequent cancellations of flight lessons. Concurrently, maintenance-related issues have emerged as a significant impediment to the optimal utilization of the fleet of 13 aircrafts (Mott et al., 2016). Flight dispatchers responsible for allocating flights to students have been compelled to consider the availability of aircraft undergoing maintenance independently of flight scheduling procedures. Mott et al. (2016) emphasized that maintenance-related issues represent a variable beyond the simple control of flight school fleet management. Thus, the combination of maintenance and weather minima is an important reason for flight lesson cancellation.

2.2 Instructor-Related Cancellations

One of the recent issues in the aviation industry is pilot shortage. According to Government accountability office (GAO), Unfortunately, a pilot shortage exists not only in the airline industry but also all the way back to student pilots in training and certified flight instructors (CFIs; GAO, 2018). The prominent CFI shortage poses an issue because it constitutes a much higher number of instructor-related cancellations, perhaps because of exhaustion, overlapping student schedules, and interference with personal life. CFIs are progressing rapidly to airlines, and the expedited progression results in more frequent CFI turnover for student pilots (GAO, 2018), possibly causing an increased number of student-related cancellations and delayed training. Many flight schools struggle to keep instructors who are qualified to teach at higher levels, such as giving check rides and teaching students who are working towards obtaining their flight instructor certification. These issues cause major setbacks and cancellations because students will have to cancel check rides due to a shortage of qualified instructors to give them (GAO, 2018).

Fatigue significantly affects the aviation industry, impacting the well-being and safety of pilots during training and throughout their careers, especially at the CFI level (McDale, 2008). In this study, 175 CFIs from 11 programs (both Part 141 and 61) were used to determine the influence of fatigue on CFIs and the consequent disruption to flight training programs. Factors contributing to fatigue include time of day, sleep quality, overall health, and age. These elements pinpoint critical areas that require targeted interventions to alleviate the effects of fatigue (McDale, 2008) and thus avoid CFI-induced cancellations.

Flight cancellations play a vital role in the aviation industry by affecting pilot training. They provide essential lessons that contribute to long-term safety. Cook (2008) emphasized the potential of cancellation to either positively or negatively impact student pilots. When not handled appropriately, flight cancellations can have adverse effects, such as cancelling flights too readily, which may lead to an overly cautious attitude towards go or no-go decisions (Cook, 2008). This, in turn, could cause students to cancel their lessons more often and increase student-related cancellation.

2.3 Student Issues Relating to Cancellations

Academic Success: Part 141 flight programs often heightened students' stress levels because they not only entailed earning a degree in four years, but also required obtaining multiple licenses and ratings within that same period (Dolnik et al., 2023). Increased stress levels are linked to a heightened academic workload, which could also lead to an increase in student-related cancellations. Determining how to balance academic workload with flight training proved challenging and impacted students' willingness to become pilots (Dolnik et al., 2023). Students who are concerned primarily with succeeding in their flight training may achieve this at the expense of academics. Students (N=625), who were particularly focused on flight training rather than academia, had a less noticeable trend of student-related cancellations (Wilson et al., 2015). Chaparro et al. (2020) found that many student pilots in training lacked a degree of conscientiousness, which also contributed to their cancellations. However, Wilson et al. (2015) concluded that flight students had more successful academic performance overall than those who were not aviation majors at the university they examined. Regardless, students must balance flights and academics in collegiate programs.

Recently, competition among college students has increased immensely, leading some students to feel a greater sense of urgency in collegiate education (Peltier et al., 2000). Fo r many Part 141 collegiate flight students, balancing a full course load in addition to pursuing flight training can be increasingly difficult, becoming extremely stressful, overwhelming, and exhausting. This can become problematic because students may cancel their training lessons because of fatigue and exhaustion. Pilot persistence is also prominent alongside urgency because if students feel a sense of urgency towards flight training, this increases their persistence, which then causes them not to cancel a lesson that should be canceled (Peltier et al., 2000). This poses an issue because a student should never fly when they are intensely fatigued; however, this would cause them to fall behind even further in their flight training if they make a habit of canceling for fatigue (Peltier et al., 2000). This increase in student-related cancellations due to stress and fatigue causes some students to fall behind during flight training.

Fatigue has been a significant issue in collegiate aviation, hindering effective flight training and presenting broader implications for the aviation field (ICAO, 2012). Levin et al. (2019) studied 141 flight schools and 350 pilots to highlight the primary themes related to fatigue in collegiate aviation. Most respondents faced fatigue, primarily due to personal choices, many of which were under the individual's control or influence. Moreover, these respondents acknowledged their capacity to modify their habits (Levin et al., 2019). The habits and personal choices of pilot's influence student-related cancellations.

Based on what is known about the personality types and traits of pilots, most pilots are decisive, driven, and goal oriented (Chaparro et al., 2020). Student pilots are typically more persistent than those who do not student pilots (Peltier et al., 2000). Despite prior work, a decisive conclusion has never been drawn regarding definitive differences between pilot and non-pilot personalities (Chaparro et al., 2020), but we can conclude that this will impact flight lesson cancellation trends. Although the personality traits of most pilots are similar, there are always going to be outliers who may not follow the typical personality trends (Chaparro et al., 2020). These outliers may be slightly less driven or more indecisive, which may cause them to cancel their flight training lessons more often than those who display "typical" pilot personality traits. This indecisiveness may also increase weather-related cancellations because certain students may not be as confident in training in questionable weather conditions as others. Likewise, the background of pilot training heavily influences different personality traits, which may also impact confidence levels (Chaparro et al., 2020). Lack of confidence in pilots during training often leads to far more student- and weather-related cancellations.

The relationship between motivation and stress plays a crucial role in students' decisions to cancel. Frederick-Recascino and Hall (2003) investigated the relationship between cancellations and overall performance based on intrinsic and extrinsic factors and found that a higher frequency of cancellations was associated with lower performance outcomes. A decline in students' willingness to pursue a career as a pilot due to academic stress has contributed to cancellation. The results indicated that motivation level significantly influenced cancellations.

2.4 Prior Flight Training School Research

Many collegiate flight programs are striving to enhance pilot training initiatives to bridge the gap between the airline requirements for well-trained pilots. However, flight training programs are still actively working to improve both student satisfaction and success rates (Osman et al., 2022).

Indiana State University (ISU) faced similar challenges, receiving complaints from 66 students enrolled in a flight training program (Schwab, 2004). ISU collaborated with two contracted flight schools operating at the same local airports, and an evaluation of student satisfaction was conducted using the researcher-designed Flight School Evaluation Survey (FSES) (Schwab, 2004). In employing a cross-sectional survey design, this assessment adhered to the Federal Aviation Regulations (FAR) Part 61 guidelines. Among the identified concerns were reluctance to embrace improvement, aircraft maintenance inadequacies resulting in cancellations, and training delays or denials for several reasons, all of which significantly affected student satisfaction (Schwab, 2004). Bryan's (1996) comprehensive study of 106 flight training programs across the nation concurred, emphasizing that such delays not only imposed financial burdens on students but also disrupted their academic progress and impeded their career advancement in the field of aviation. Given the widespread challenges collegiate flight programs face, as evident from ISU and Bryan studies, various cancellation types led to student dissatisfaction. Adverse weather conditions, maintenance delays, and instructor-related issues have contributed to flight lesson cancellations.

Cancellation has emerged as a substantial concern, as it often leads to student discouragement and a subsequent decline in motivation, potentially instilling an external locus of control (Dille & Mezack, 1991). To understand the various factors influencing the success of pilot-in-training in a collegiate aviation flight degree program, this study examined the duration of the program and the persistence of pilot trainees before discontinuing their training. The data used for this investigation were drawn from a Part 141 collegiate program located in the Southeastern United States, encompassing all students majoring in Aviation Management and Aviation Science who undertook flight training between 2010 and 2019 (Office of Instructional Research (OIR), 2019). The research sample comprised 140 participants for the analysis of the Time to Graduate and 120 participants for the examination of Persistence Before Dropout. The study incorporated 19 predictor variables classified into five distinct sets encompassing individual differences, involvement, achievement, instructor interaction, and flight postponement variables (Osman et al., 2022). Notably, significant correlations emerged within individual difference factors, such as age, high flight costs, and number of transfer credits. Additionally, negative associations have been observed between adverse weather conditions and instructor-related flight postponements, as these were found to mitigate student loss of control and reduce motivation (Osman et al., 2022). Cancellations, particularly those related to weather and instructor availability, profoundly impact the motivation and subsequent success of pilot trainees in collegiate aviation programs. While individual factors such as age and economic constraints can influence a student's journey, external uncontrollable variables such as adverse weather and instructor-related postponements further aggravate the potential for discouragement, elongating time to graduation, and increasing dropout rates. Analyzing the type of cancellation that is most frequent seems necessary to enhance pilot training success in Part 141 collegiate programs.

Weather, maintenance, instructor, and student issues all contribute to flight-lesson cancellations. This research collectively underscores the complex web of influences on flight-lesson cancellation. Despite these valuable insights, the existing literature is yet to comprehensively investigate the commonly occurring types of cancellations. Therefore, filling this crucial research gap is necessary to understand flight lesson cancellations in Part 141 flight schools so that we can improve efficiency and student success in training programs.

3. Methodology

A predictive correlative design was used to analyze the cancellation trends over time. The research methodology is appropriate because, relationship among year and cancellations was investigated with respect to a single group, that is, Part 141 flight schools. According to Ary et al. (2010), a predictive correlational study helps identify relationship among variables, which then can be used to predict the trends in the future. An IRB exemption application (23-112) was approved for this study, with the justification rooted in the use of fully de-identified pre-existing data and the absence of direct human interaction. Archival data from Part 141 flight school in Florida were collected from the Education & Training Administration (ETA) system used by Part 141 flight school in the state of Florida and the Office of Institutional Research (OIR, 2019). The enrolled students majored in Aeronautical Science, Aviation Management, Aviation Meteorology, or Aviation Human Factors, and were trained between 2010 and 2019. To ensure the reliability and validity of the data, they were systematically recorded and maintained through standardized operational procedures at the school.

Flight cancellations were pre-classified by trained personnel at the institution based on clearly defined criteria: maintenance-, instructor-, weather-, and student-related. These classifications, logged immediately upon cancellation, are routinely checked for consistency, ensuring both the integrity of the study and its potential for replication by other researchers. Descriptive statistics, including means, medians, standard deviations, and ranges, were calculated for both the overall and cancellation types using RStudio 4.3.1. Linear regression was employed to determine whether there were significant linear trends over time for each cancellation category.

4. Results

From 2010 to 2019, there were 27,320 flight lesson cancellations from archival data from 544 students. The number of cancellations was recorded as follows: weather (12,201), student (6,478), instructor (5,032), and maintenance (3,609). We did not exclude any data because it represented actual, de-identified training information.

Table 1 shows the descriptive statistics for the weather cancellations of the flight lessons from 2010 to 2019. The weather cancellation averages varied from 29.00 in 2017 to 9.01 in 2019. Although there has been fluctuation over the years, no discernible pattern of steady rise or fall was visible. In 2019, there was the least variability in the frequency of cancellations (SD = 8.58), whereas in 2012, it was 23.04. The standard deviations suggest that the data for 2019 are less dispersed and more concentrated around the mean than the data for 2012. In 2017, the range of weather cancellations was the largest, from 0 to 106, and in 2019, the range was smaller, from 0 to 49.

Table 1. Descriptives Statistics for Weather Cancellations of Flight Lessons

Year	N[a]	Mean	SD	Range (Min – Max)
2010	48	20.33	18.17	0 - 77
2011	43	19.12	18.01	0 - 69
2012	45	26.47	23.04	0 - 76
2013	49	26.67	20.08	1 - 69
2014	46	28.09	17.75	0 - 73
2015	54	27.74	17.02	2 - 68
2016	60	26.08	16.66	0 - 72
2017	55	29.00	20.71	0 - 106
2018	63	19.44	12.43	0 - 62
2019	81	9.01	8.58	0 - 49

[a] *N (2010-2019) = 544*

Table 2 shows the descriptive statistics for students' cancellations of flight lessons from 2010 to 2019. Student cancellation means vary from 3.01 in 2019 to 20.33 in 2013. Similar to weather cancellations, there was a fluctuation in student cancellations across the study period. The mean number of student cancellations throughout the year showed no discernible trend. Student cancellation standard deviations vary from 2.93 in 2019 to 18.61 in 2013.

Table 2. Descriptive Statistics for Student Cancellations of Flight Lessons

Year	N[a]	Mean	SD	Range (Min – Max)
2010	48	15.46	15.75	0 - 36
2011	43	13.28	13.68	0 - 58
2012	45	17.31	13.64	0 - 71
2013	49	20.33	18.61	1 - 53
2014	46	16.93	12.35	0 - 75
2015	54	14.87	11.54	0 - 43
2016	60	8.82	6.85	1 - 67
2017	55	11.07	10.44	0 - 32
2018	63	6.76	4.62	0 - 56
2019	81	3.01	2.93	0 -18

[a] *N (2010-2019) = 544*

Table 3 shows the descriptive statistics for instructor cancellations of flight lessons from 2010 to 2019. The mean values for instructor cancellations range from 3.44 in 2019 to 13.96 in 2017. The mean number of instructor cancellations over time showed no discernible trend. For instructor cancellations, the standard deviation ranges from 3.06 in 2019 to 10.39 in 2017. There was the broadest range in 2017, between 0 and 47, and the narrowest range in 2019, between 0 and 17. Similar to previous weather and student cancellations, there was considerable variation in instructor cancellations across years.

Table 3. Descriptive Statistics for Instructor Cancellations of Flight Lessons

Year	N[a]	Mean	SD	Range (Min – Max)
2010	48	9.90	9.28	0 - 36
2011	43	7.70	7.17	0 - 35
2012	45	8.82	7.49	0 - 24
2013	49	8.88	7.56	0 - 27
2014	46	9.41	6.96	0 - 26
2015	54	12.91	9.83	0 - 38
2016	60	12.32	9.72	0 - 43
2017	55	13.96	10.39	0 - 47
2018	63	7.59	5.12	0 - 20
2019	81	3.44	3.06	0 - 17

[a] *N (2010-2019) = 544*

Table 4 shows the descriptive statistics for maintenance cancellations of flight lessons from 2010 to 2019. The typical values for maintenance cancellations varied from 1.23 to 12.17, and there was a discernible downward trend in the mean number of cancellations. The standard deviation values for maintenance cancellations vary from 1.41 in 2019 to 9.14 in 2010. The range of maintenance cancellations varied from 0 to 37 in 2010 to 0 to 6 in 2019, which became narrower. In later years, the annual maintenance cancellation rate became more consistent and lower.

Table 5 shows the descriptive statistics for each cancellation category for 2010-2019. Weather-related cancellations had the greatest mean (22.43) and standard deviation (18.21), suggesting greater unpredictability. The range of student cancellations was the most extensive (0–75), and the student cancellation mean was 11.91, the second highest by type. Instructor-related cancellations had a greater range (0–47) based on all types. Of the four categories, maintenance cancellations had the lowest mean (6.63), median (5), and standard deviation (6.48), suggesting the least fluctuation in cancellation rate.

Table 4. Descriptives Statistic for Maintenance Cancellations of flight lessons

Year	N[a]	Mean	SD	Range (Min – Max)
2010	48	12.17	9.14	0 - 37
2011	43	7.65	7.15	0 - 26
2012	45	8.44	7.95	0 - 26
2013	49	10.61	7.16	0 - 24
2014	46	9.26	5.66	0 - 23
2015	54	6.46	4.45	0 - 20
2016	60	6.27	4.64	0 - 17
2017	55	6.20	4.92	0 - 28
2018	63	3.24	2.57	0 - 9
2019	81	1.23	1.41	0 - 6

[a] *N (2010-2019) = 544*

Table 5. Descriptive Statistics for Flight Lesson Cancellations by Type for 2010 – 2019

Type	Mean	Median	SD	Range (Min – Max)
Weather	22.43	19	18.21	0 - 49
Student	11.91	8.00	12.49	0 - 75
Instructor	9.25	7.00	8.37	0 - 47
Maintenance	6.63	5.00	6.48	0 - 37

Note. *N = 544*

Figure 1 shows the cancellations by year with trend lines. All linear regressions conducted for each type of cancellation were statistically significant. Specifically, for weather cancellations regressed on year, the slope was -0.88 ($p < .001$), with an intercept of 1,796 ($p = .001$). The associated F-test yielded a statistically significant result, $F(1, 542) = 11.42$, with an R2 of 0.02. For instructor cancellations regressed by year, a significant slope of -1.50 ($p < .001$) was observed, along with an intercept of 3,029 ($p < .001$).

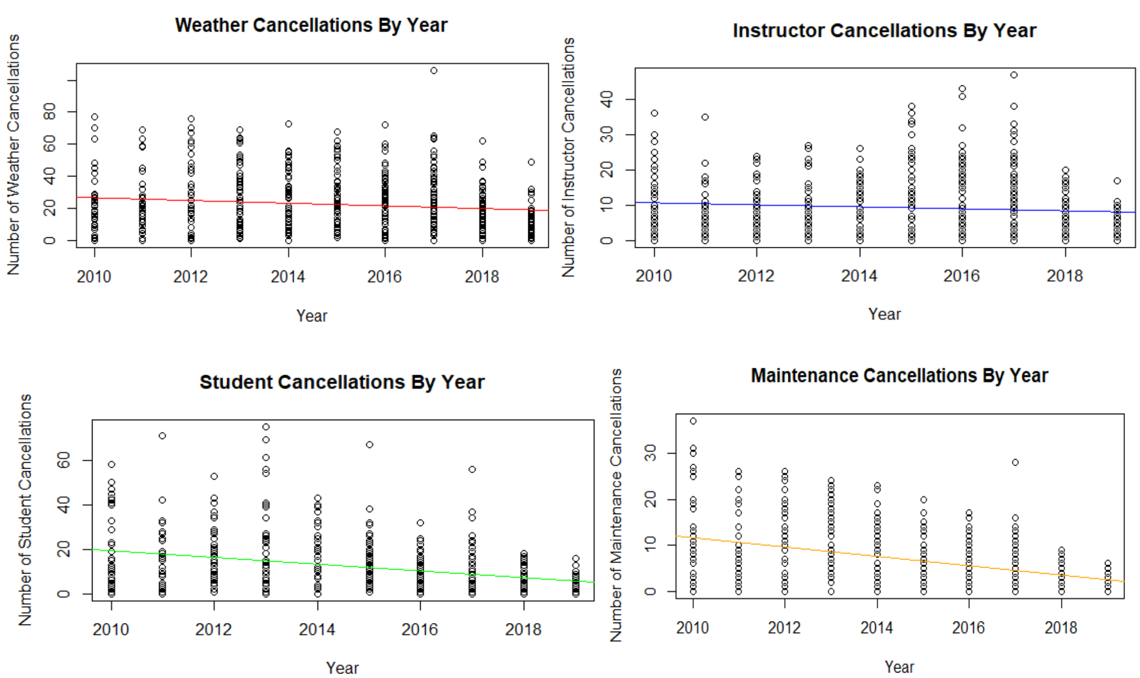

Figure 1. Weather, Instructor, Student, and Maintenance Cancellations by Year

5. Discussion

The data and regression analysis supported the research hypothesis, demonstrating that there was a significant, negative, linear trend over time for each flight cancellation type (weather-related, student-related, instructor-related, and maintenance-related) from 2010 to 2019 in part 141 of the collegiate flight program in Florida. Descriptive statistics indicated that the highest average cancellation rate was for weather-related flight cancellations (see Table 5). In contrast, the lowest average cancellation rate and lowest variability were observed for maintenance-related flight cancellations. This indicates that weather-related cancellations are the most influential barriers affecting student progression, leading to increased stress levels and a sense of urgency among students.

The inferential statistics revealed statistically significant regressions with medium effect sizes (Cohen, 1988). Approximately 2% of the variance in weather cancellations was explained by the year, indicating a significant regression ($F(1, 542) = 11.42$, $p = .001$). A negative relationship was identified between year and weather-related cancellations (slope = -0.88), with a medium effect size (Cohen's $f = 0.5$). Similarly, approximately 12% of the variance in instructor cancellations was accounted for by year, signifying a significant regression $F(1, 542) = 76.61$, $p < .001$) with a medium effect size (Cohen's $f = 0.4$). A negative relationship was also identified between years and instructor-related cancellations (slope = -1.50). For student cancellations, 1% of the variance was explained by year, yielding a significant regression ($F(1, 542) = 5.146$, $p = .02$) and a negative relationship (slope = -0.28) with a medium effect size (Cohen's $f = 0.3$). Lastly, maintenance cancellations displayed a significant regression, with approximately 21% of the variance explained by year ($F(1, 542) = 142.9$, $p < .001$), demonstrating a negative relationship (slope = 1.01) with a medium effect size (Cohen's $f = 0.5$). These medium effect sizes indicate a moderate or intermediate level of practical significance and a meaningful relationship among the studied variables. These findings are statistically significant and of practical relevance.

On average, for every one-year increase, the number of weather cancellations decreased by 0.9 units ($p < .001$), instructor cancellations decreased by 1.5 units ($p < .001$), student cancellations decreased by 0.2 units ($p = .02$), and maintenance cancellations fell by 1.0 unit ($p < .0001$). Although the R-squared values indicated a low fit of the models to the data, suggesting a limited proportion of variance explained, the linear trends were statistically significant, demonstrating a decreasing cancellation rate over the observed time period.

The findings suggest a significant decline of maintenance related and student related cancellations over time. The decline in maintenance related cancellations could be due to an improvement in the safety protocols by the flight school, using advanced aircrafts, and the managements emphases on the maintenance schedules. The decrease in student related cancellations could be attributed to enhanced student flight lessons scheduling technologies, less communication break downs, continuously advising students to manage workloads.

Possible explanations for outliers include variations in dispatch strictness, fleet evacuations due to hurricanes in specific years, and students' heightened efforts to manage their flight lessons. Additionally, the consistent annual decrease in all cancellations is noteworthy, suggesting a gradual overall improvement in minimizing the cancellation rates across each type over the observed period. The declining trend in student-related cancellations from 2010 to 2019 implies a potential tightening of Part 141 flight schools in Florida regulations, leading students to approach their flight lessons more seriously. Similarly, the decrease in maintenance-related cancellations indicates an enhancement in Part 141 of the flight school in Florida's maintenance infrastructure, thereby reducing factors contributing to cancellations that might affect students' lesson plans. Notably, instructor-related cancellations exhibited the least variability, suggesting that instructors played a relatively minor role in canceling students' lessons.

6. Limitation/Delimitations

6.1 The Limitations of This Study Will Be:

Demographic fluctuations and variations in the number of students and instructors at this Part 141 flight school in Florida are not explicitly considered in this analysis, potentially affecting the data across years. The trends in weather, including hurricanes, storms, and other meteorological factors, are inherently unpredictable and subject to change each year. These unpredictable weather patterns may introduce additional variability into the study's findings. This study is based on data from the period 2010 to 2019, as information beyond this timeframe was not accessible. Data for this research was sourced from the ETA. It's important to note that while the archival nature of the data implies no direct control over its collection accuracy, the inherent upkeep requirements of the 141 programs ensure a degree of reliability and consistency in data maintenance.

6.2 The Delimitations of This Study Will Be:

The study is focused exclusively on flight training for the collegiate 141 flight program in the state of Florida. Therefore, the data may not directly apply to other states' flight training. The study is confined to data collected from 2010 to 2019, limiting the scope to this specific time period. Consequently, potential developments or shifts outside of this timeframe are not considered in the analysis. The data was already categorized into four primary cancellation types: maintenance-related, weather-related, instructor-related, and student-related. Other potential causes for cancellation were not considered to align with specifications from this part 141 flight school in Florida.

7. Future Research

Future investigations may explore a more comprehensive classification of reasons for cancellation, considering additional factors that might contribute to cancellation. These factors could involve engaging with multiple flight schools or institutions to capture a broader spectrum of cancellation causes and trends within the aviation education context. A comparative analysis across various institutions could provide a better understanding of the factors influencing cancellations in collegiate flight training and contribute to both training efficiency and effective mitigation strategies.

Subsequent research could employ a survey approach involving current flight students to gather more recent and specific data, extending beyond 2010-2019. A survey-type method would yield insights into the individual factors influencing cancellation rates, considering variables such as flight course and experience hours. Furthermore, exploring cancellation trends based on flight courses rather than chronological years could represent a valuable step in enhancing the understanding of the factors influencing cancellations in aviation education.

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PERCEIVED STRESS FOR PILOTS

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Abstract

This study of occupational stress focused on the aviation industry, specifically student pilots, Certified Flight Instructors, airline pilots, and corporate aviation pilots in the United States. The objective of this exploratory, cross-sectional study was to explore existing theory in a new way to both quantify and qualitatively describe pilots' perceptions of their most common chronic stressors. Researchers employed a mixed methodology, using the Perceived Stress Scale for its applications in categorizing perceptions of chronic stress). In addition to descriptive, quantitative analysis using the PSS's Likert scale responses, researchers used Spradley's domain analysis to identify and further partition themes into sections called "Cover Terms." These terms, or themes, were organized further into sub-themes called "Included Terms." The first Cover Term was "Operational Challenges in Aviation." This cover term encompassed two Included Terms: "Managing" and "Unpredictability." Within the sample of pilots, roughly one-quarter of the respondents mentioned that the most stressful part of being a pilot was due to operational challenges in aviation. The second major Cover Term was "Balancing Work and Personal Life." This theme was expanded into three separate sub-themes: "Well-being," "Scheduling," and "Responsibility." These Included Terms were further categorized into six "Conjectures." Nearly half, 48%, of the respondents mentioned that the most stressful part of being a pilot was due to balancing their work and personal life.

Keywords: *Perceived Stress Scale (PSS); Pilot Occupational Stress; Spradley's Domain Analysis*

1. Introduction

According to The American Psychological Association (2018), stress is a natural response (whether physiological or, psychological, or both) to external and internal pressures occurring during daily life. This can manifest as a physical or psychological illness when experienced for longer durations, especially when it becomes chronic. Large-scale, ongoing studies on occupational stress levels have revealed that aviation jobs (specifically pilots) are typically ranked in the top three most stressful jobs out of hundreds of included professions (Bor et al., 2017). Other research has shown chronically elevated stress levels in the post-pandemic era compared with pre-pandemic levels. A recent international study showed that airline pilots experience elevated health risks from contracting the Coronavirus Disease of 2019 (COVID 19) repeatedly, in addition to the broader organizational strain placed on the industry by the pandemic, to which pilots are susceptible (Kilic, 2022).

Whether a student, Certified Flight Instructor (CFI), or an Airline Transport Pilot (ATP) flying professionally, pilots performing their daily jobs are subjected to stressors well beyond those of the average worker. They are responsible for maintaining flight safety from the walkaround to the

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debrief at the end of the day. These stressors include performing concurrent tasks, monitoring during high workloads, decision-making in fast-paced or ambiguous situations, and performing under physiological pressure, often without adequate rest or nutrition (Loukopoulos et al., 2016). These stressors, among other lifestyle factors examined further in this study, can lead to elevated levels of chronic stress for pilots.

According to a regional pilot and spokesperson for the Air Line Pilots Association International (ALPA) union, "exposure to such stress can result in cockpit performance issues" (Ruff, 2020, para. 6). ALPA (2020), the largest pilot union in the world, acknowledges that acute and chronic stressors can compromise effective communication and lead to being distracted from critical safety-related tasks. Although some peer support programs have been initiated, such as ALPA's Pilot Peer Support (PPS), stress remains an ongoing threat to pilots of all levels.

Given the significant impact of stress on pilot performance and safety, this study aims to address the following research question: What are the primary sources of stress for pilots across different levels of experience?

2. Literature Review

The earliest studies on stress were primarily focused on the physiology of acute stressors, such as those experienced in battle (Selye, 1936). As a social and psychological construct, the study of stress emerged in the middle of the 20th century, when psychiatrists Holmes and Rahe examined patient medical records to determine whether certain stressful life events could lead to health repercussions (Noone, 2017). This groundbreaking study demonstrated for the first time that there was, in fact, a physical-psychological connection.

To gain a method for measuring chronic stressors, in the early 1980s, a group of researchers developed the Perceived Stress Scale (PSS) (Cohen et al., 1983). The survey tool assessed people's perceptions of stress relating to overloaded and unpredictable situations. Researchers have used the PSS in various industries across many cultures. The present study utilized the PSS to assess the degree of stress perceived by pilots.

Recent advancements in stress research have further expanded our understanding. Epel et al. (2018) conducted a comprehensive review of stress measurement techniques, highlighting the importance of integrating biological, psychological, and social measures for a more holistic understanding of stress. Their work emphasizes the need for multidimensional approaches in stress assessment, particularly in high-stress professions like aviation.

In the context of pilot stress, recent studies have employed more sophisticated methodologies. For instance, Shahsavarani et al. (2015) used a combination of physiological measures (e.g., heart rate variability) and psychological assessments to evaluate stress levels in commercial pilots. Their findings underscore the complex interplay between cognitive demands, physiological responses, and perceived stress in aviation settings.

3. Methodology

This study employed a survey methodology to gather data on stress levels among pilots across different experience levels. A survey was chosen as the primary research instrument due to its ability to collect standardized data from a large sample efficiently, allowing for comparisons across different pilot groups.

Participants were recruited through a combination of convenience and purposive sampling. The survey link was distributed through a flight school network to reach student pilots and Certified

Flight Instructors (CFIs), and through professional pilot associations to access airline and corporate pilots. This approach ensured representation across various pilot experience levels.

A survey was administered to 78 survey respondents using Qualtrics after approval by the institutional review board at a university in Florida. The respondents were 18 years of age or older consisting of 28% student pilots, 53% Certified Flight Instructors (CFIs), 15% airline pilots, and 4% corporate aviation pilots. There were eleven questions; ten were close-ended using a Likert scale, and one was open-ended. Respondents provided informed consent to participate in the survey, acknowledging “consent” or “non-consent” before being given access to the questions. Although 78 survey respondents participated in the survey, not all respondents answered each question. As this was voluntary, respondents were instructed that they could stop participating at any time without penalty.

The survey questions were developed based on a comprehensive literature review of pilot stress factors and validated stress assessment tools. Specifically, questions one through ten utilized Cohen's (1994) PSS. The scale is organized from 1 to 10, where 1 is “not often,” 5 is “sometimes,” and 10 is “very often.” The survey data for these 10 questions were analyzed using descriptive statistics.

Question 11 was an open-ended question where Spradley’s (2016) Domain Analysis was used in identifying themes from the data collected. Domain analysis is a qualitative research method used to identify and categorize cultural themes or patterns within a specific context. The selection of domain analysis for this purpose is due to its effectiveness in uncovering meaningful categories and relationships within the qualitative data.

4. Results

The first survey question of the survey was: In the last month, how often have you been upset because of something that happened unexpectedly? Fifty-four survey respondents responded to the question (see Figure 1). The responses ranged from one to eight. The mean score was 4.17, indicating that the general sample of survey respondents felt that in the last month, they were sometimes upset due to something happening unexpectedly. Figures 1 through 10 depict a graphical representation of the responses with the percentage of survey respondents selecting each Likert-scale category.

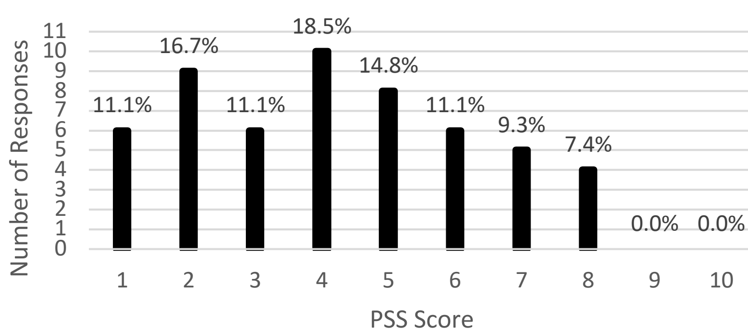

Figure 1. Question 1

The second survey question was: In the last month, how often have you felt that you were unable to control the important things in your life? Fifty-three survey respondents responded to the question (see Figure 2). The responses ranged from a one to a ten. The mean score was 4.40, indicating that the general sample of survey respondents felt that in the last month, they were sometimes unable to control the important things in their lives.

The third survey question was: In the last month, how often have you felt nervous and stressed? Fifty-five survey respondents responded to the question (see Figure 3). The responses ranged from a one to a ten. The mean score was 5.42, indicating that the general sample of survey respondents felt that in the last month, they were sometimes nervous and stressed.

The fourth survey question was: In the last month, how often have you felt confident about your ability to handle your personal problems? Fifty-six survey respondents responded to the question (see Figure 4). The responses ranged from a two to a ten. The mean score was 7.13, indicating that the general sample of survey respondents felt that in the last month, they were often confident about their ability to handle personal problems.

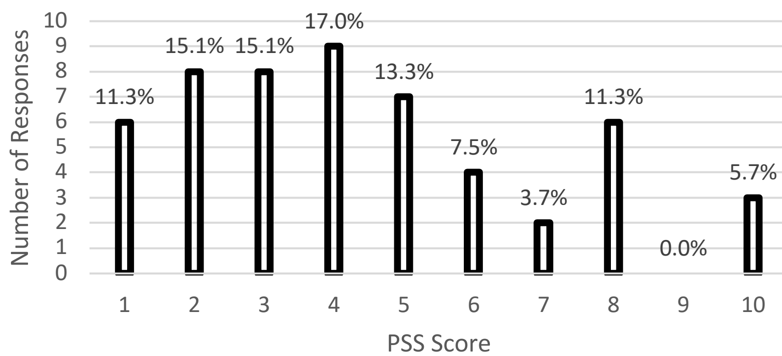

Figure 2. Question 2

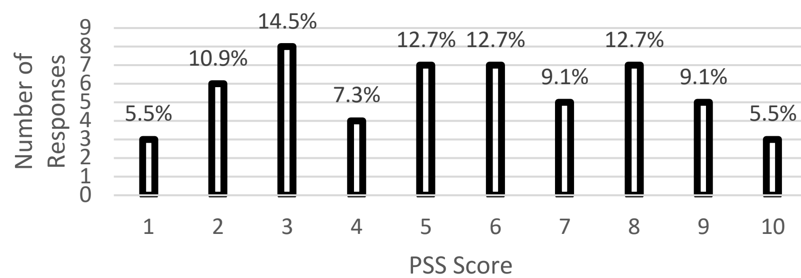

Figure 3. Question 3

The fifth survey question was: In the last month, how often have you felt that things were going your way? Fifty-seven survey respondents responded to the question (see Figure 5).The responses ranged from a one to a ten. The mean score was 6.33, indicating that the general sample of survey respondents felt that things were going their way in the last month.

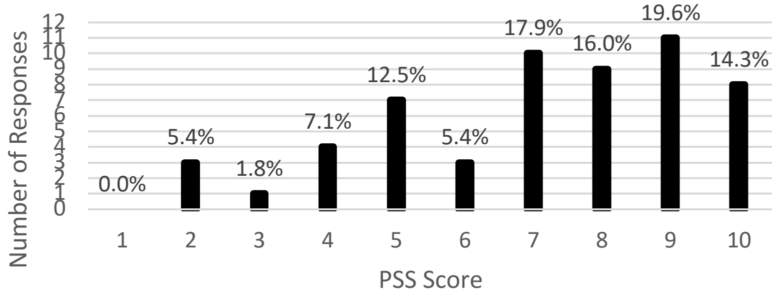

Figure 4. Question 4

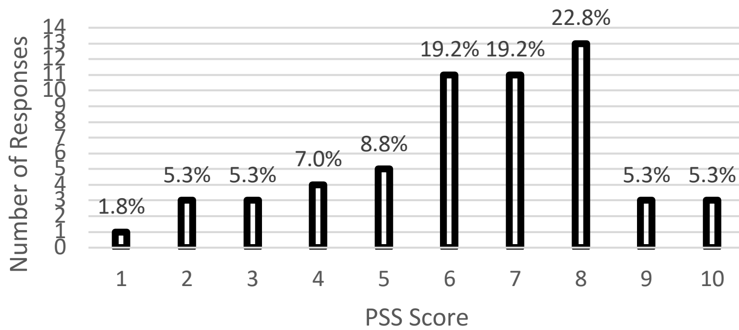

Figure 5. Question 5

The sixth survey question was: In the last month, how often have you found that you could not cope with all the things that you had to do? Fifty-one survey respondents responded to the question (see Figure 6). The responses ranged from a one to a ten. The mean score was 3.78 indicating that the general sample of survey respondents found that sometimes they could not cope with all the things that they had to do.

The seventh survey question was: In the last month, how often have you been able to control irritations in your life? Fifty-five survey respondents responded to the question (see Figure 7). The responses ranged from a one to a ten. The mean score was 6.36 indicating that the general sample of survey respondents found that sometimes they were able to control irritations in their lives.

The eighth survey question was: In the last month, how often have you felt that you were on top of things? Fifty-five survey respondents responded to the question (see Figure 8). The responses ranged from a one to a ten. The mean score was 6.78, indicating that the general sample of survey respondents found that they were sometimes/often on top of things.

The ninth survey question was: In the last month, how often have you been angered because of things that happened that were outside of your control? Fifty-four survey respondents responded to the question (see Figure 9). The responses ranged from a one to a ten. The mean score was 4.52 indicating that the general sample of survey respondents found that they were sometimes angered because of things that happened that were outside of your control.

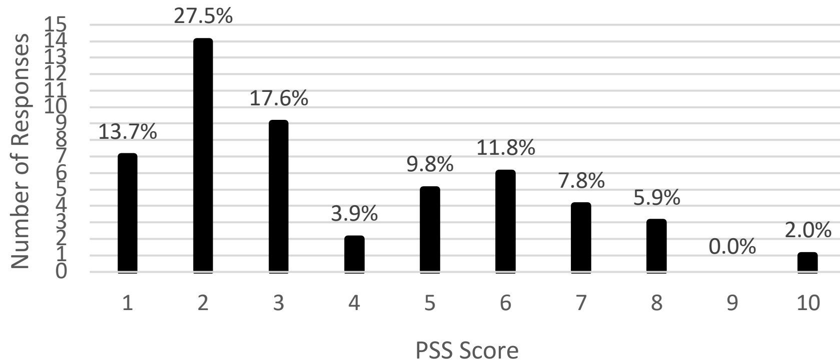

Figure 6. Question 6

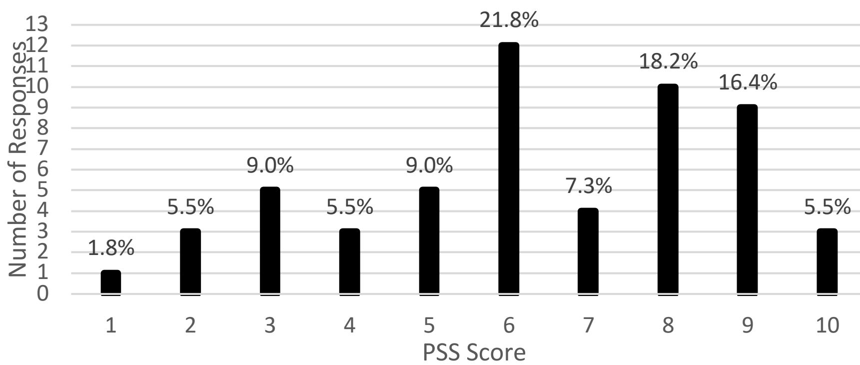

Figure7. Question 7

The tenth survey question was: In the last month, how often have you felt difficulties were piling up so high that you could not overcome them? Fifty-one survey respondents responded to the question (see Figure 10). The responses ranged from a one to a ten. The mean score was 3.82, indicating that the general sample of survey respondents did not often feel that difficulties were piling up so high that they could not overcome them.

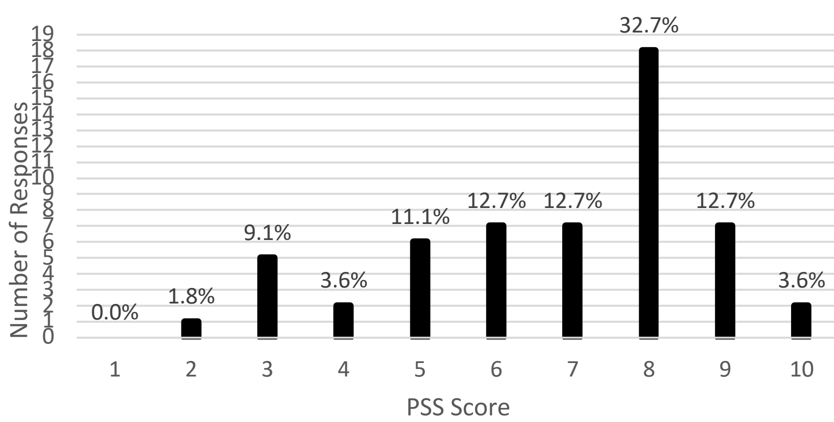

Figure 8. Question 8

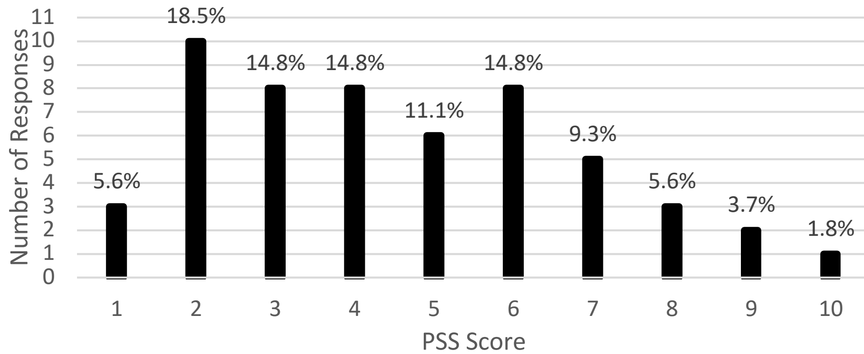

Figure 9. Question 9

The eleventh question of the survey was an open-ended question asking survey respondents to explain the most stressful part of their jobs. The responses to the question were used to understand stressors from survey respondents who are pilots in various aviation industry sectors. Therefore, the open-ended question responses were coded and analyzed using Spradley's (2016) domain analysis (see Table 1). The major domains were identified and further partitioned into "Cover Terms," which were partitioned into subsections called "Included Terms." After Cover and Included Terms were identified, patterns were compared with the closed-ended responses to draw conclusions about this study group's most prominent and common chronic stressors.

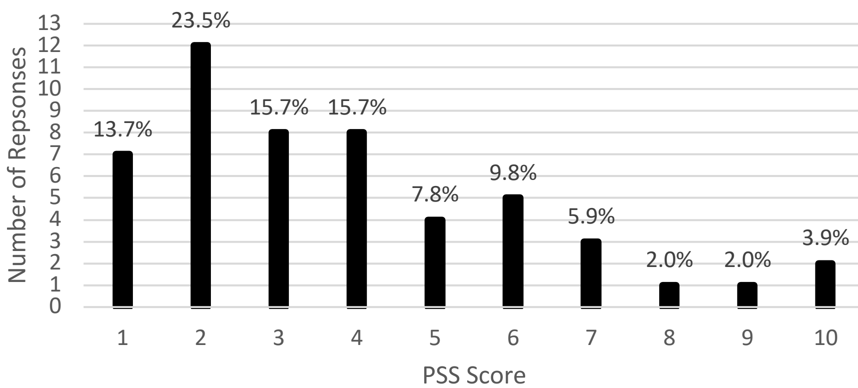

Figure 10. Question 10

Domain 1: Most Stressful Aspect of Being a Pilot

Table 1 identifies themes in the survey data from the survey respondents' responses to the open-ended question eleven, asking survey respondents to explain the most stressful part of their jobs. The table contains one domain, two Cover Terms, five Included Terms, and fifteen conjectures. Examples from the respondents within different categories are discussed using P1 through P44 to depict the 44 survey respondents that responded to Question 11.

Table 1. Domain 1

Domain 1: Most Stressful Part of Being a Pilot

Domain 1	Cover Term	Included Term	Conjectures
Most Stressful Part of Being a Pilot	Operational Challenges in Aviation	Managing	1.1 Dealing with people, students, and coworkers. 1.2 Managing different personalities. 1.3 Student supervision.
		Unpredictability	1.4 Airline reserve assignments. 1.5 Unexpected weather and weather delays. 1.6 Unexpected events.
	Balancing Work and Personal Life	Wellbeing	1.7 Low wages and long hours. 1.8 Lack of self-care. 1.9 Toxic work environment.
		Scheduling	1.10 Day to day scheduling challenges. 1.11 Succeed on a schedule. 1.12 Unpredictable schedule.
		Responsibility	1.13 Managing home responsibilities. 1.14 Students who avoid responsibilities. 1.15 Multitasking.

Cover Term 1: Operational Challenges in Aviation

Two main themes, or Cover Terms, emerged from the survey data. The first was “Operational Challenges in Aviation.” Study participants’ coded responses revealed two additional sub-themes as the main factors creating operational challenges in the aviation industry: “Managing” and “Unpredictability.” Nearly a quarter (23%) of respondents identified one or both sub-themes as the most stressful aspects of being a pilot.

Within the “Managing” sub-theme, survey respondents described common stressors that occurred when dealing with people, managing different personalities, and supervising students. For example, P2 stated “dealing with crazy people,” P5 stated “student supervision,” P8 stated “managing different personalities,” P20 stated “dealing with student pilots,” P33 stated “managing employees,” and P52 stated “dealing with other employees and expectations of customer companies.” These statements provide evidence that managing people and personalities can be categorized as an operational challenge in aviation.

The second sub-theme of the cover term, “Operational Challenges in Aviation” was “Unpredictability.” Some respondents answered the question by highlighting the stress of airline reserve assignments and unexpected weather, delays, and events. For example, P1 stated, “dealing with the stresses of on-time performance, weather, and external factors,” P14 stated “dealing with weather and unexpected events that hinder and delay operations,” P18 stated “dealing with the unpredictability of airline reserve assignments,” P35 stated “handling the multitude of issues that usually come all at once, such as right before closing the door and departing. Often, they are passenger related and therefore unpredictable,” and P53 stated a “constantly changing atmosphere that can be difficult to adapt to.” Based on the responses of these five survey respondents, it is evident that unpredictability is one of the most stressful parts of being a pilot.

Cover Term 2: Balancing Work and Personal Life

The second major Cover Term was "Balancing Work and Personal Life." This theme was expanded into three separate sub-themes: "Well-being," "Scheduling," and "Responsibility." These three terms were further broken down into six different conjectures. Nearly half (48%) of the respondents mentioned that the most stressful part of being a pilot was due to balancing work and personal life.

In the sub-theme of "Well-being," some respondents mentioned that they felt stress because of low wages, long hours, lack of self-care, and toxic work environments. For example, P4 stated, "workload, not being respected, and lack of employees for the amount of work given." P15 stated "sometimes overwhelming and fast-paced." P17 stated, "balancing my own needs." P19 stated, "being broke and no free time." P21 stated, "low wages and long hours." P28 stated, "dealing with toxic coworkers." P30 stated, "finding time to eat/sleep." P45 stated, "dealing with a department that doesn't look to improve and don't accept suggestions." This well-being sub-theme appeared more prominently and more often than any of the other sub-themes within the "Balancing Work and Personal Life" Cover Term. The researchers concluded that well-being stressors are the most impactful occupational and personal stressors.

"Scheduling" was the second most common theme within the balancing work and personal life section. Based on the responses, day-to-day scheduling, succeeding on a schedule, and unpredictable schedules were challenges that some of the survey respondents felt caused a significant amount of stress. For example, P22 stated, "day to day scheduling" and how "it is difficult to establish a consistent schedule from 7 AM to 6 PM every day." P24 stated, "scheduling," P29 stated, "the many competing demands on my time and schedule." P30 stated, "unpredictable scheduling," and P32 stated, "scheduling." These responses emphasize the role that scheduling plays in occupational stress.

Survey respondents' responses suggest another sub-theme, "Responsibility," also caused elevated perceptions of stress. Factors such as managing home responsibilities, multitasking, and students avoiding responsibilities were recurrent within this category. For example, P3 stated "dealing with multiple problems simultaneously." P10 mentioned, "multitasking." P17 stated, "trying to meet expectations and demands of students." P23 stated, "not being able to completely compartmentalize family, life, and work." P25 stated, "balancing my job and personal life." P43 stated, "student issues and balancing work with home responsibilities." P51 stated, "the balance between life, work, health, and studying." P54 stated, "dealing with parents and students that don't take responsibility for their actions." Based on these observations, pilot's responses reflected that there is stress due to responsibility, whether it was from their personal lives, professional lives, or from a combination of both.

5. Conclusion

The aviators surveyed consisted of 28% student pilots, 53% CFIs, 15% airline pilots, and 4% corporate aviation pilots. Despite the limitations of smaller sample size, the use of the PSS, along with an ethnographic, qualitative analysis of open-ended data, proved useful in providing a baseline to measure organizational and psycho-social factors exacerbating the already elevated levels of stress among aviators. Although the quantitative responses indicate that pilots did not feel that the stress piled so high that they could not overcome them, they still could feel angered due to the degree of stress they had. Therefore, the qualitative question responses provided information on the types of stressors that aviators have. As opposed to a measure of acute, situational stress, the goal of the present study was to provide a starting point for measuring chronic stress in pilots at all experience levels within the aviation industry, using a mixed method, cross-sectional approach. The choice of PSS in the survey instrument, in addition to an open-ended, qualitative question, reflects the researchers' goals to explore a more global approach to measuring pilot perceived stress factors on a chronic, or ongoing basis. The study limitations include the pilots and the authenticity of their responses. Therefore, if the current study was replicated with different pilots, the results might be different. Thus, the gap in research and value of this initial study is to provide a baseline for further studies that can create convergent validity for this methodological approach. Therefore, future research would consist of continuing this study methodology but within a wider, more diverse population of aviation professionals from general aviation to global major airlines could reveal more nuanced, actionable trends. This study's expansion of Spradley's (2016) ethnographic methodologies into new social science research on pilots can also inform future researchers in creating new analytical frameworks for describing cultural phenomena such as this study did with pilots' perceived stress levels.

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USING PRESSURE SENSORS AND CAD MODELING TO PREPARE FOR SIMULATION OF PRESSURE DISTRIBUTION IN BIOMEDICAL APPLICATIONS

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Abstract

This study developed a CAD model of a female foot using computed tomography (CT) data from the National Institutes of Health's Visible Human Project. The CT data was segmented and edited using Materialise Mimics and Geomagic Wrap. The refined models offer detailed NURBS-based geometries suitable for finite element analysis. Pressure distribution data, crucial for realistic biomechanical simulations, was obtained using a Tekscan pressure mat, allowing for the integration of applied loads into the models to simulate actual foot mechanics. The integration of anatomically precise CAD models with functional load data provides a simulation process that can lead to improved solutions for foot-related ailments. This methodology paves the way for future research to leverage these models in predicting biomechanical responses under various loading conditions, enhancing our understanding of foot dynamics and aiding in the development of targeted interventions.

Keywords: *Computed Tomography (CT) Segmentation; Human Foot Modeling; Visible Human Project, Mimics software; Geomagic Wrap Software; CAD Modeling; Foot Pressure Distribution*

1. Introduction

Sophisticated modeling of foot biomechanics aids in clinical diagnostics and therapeutic interventions and enriches our understanding of the structural and functional complexities of the foot. This research predominantly focuses on the generation of a high-fidelity CAD model of the foot from computed tomography (CT) data, utilizing state-of-the-art software tools such as Mimics and Geomagic Wrap. Such detailed models are crucial for the comprehensive study of both external pressures and internal anatomical responses.

External pressures on the foot have been studied through pedobarographs and in-shoe sensors, as demonstrated in seminal studies (Hodge et al., 1999; Raspovic et al., 2000). Additionally, there have also been insightful explorations into the pressure distributions under symptom-free feet, which are crucial for establishing baselines in both healthy and pathological foot conditions (Cavanagh et al., 1987). Additionally, the impact of these pressures on foot health, particularly under varying conditions such as walking and running, has been further elaborated (Hosein & Lord, 2000), providing a deeper understanding of plantar fascia stresses.

The integration of internal biomechanical insights, as illustrated by the study by Benjamin et al. (2006) on the mechanical properties of entheses, complements these external pressure studies by highlighting the interaction between external forces and internal structures like ligaments, fascia, and bones.

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Building upon this comprehensive body of knowledge, our study leverages advanced imaging and modeling technologies to develop precise 3D CAD models. By extracting material properties directly from CT scans obtained from the National Institutes of Health Visible Human Project and applying meticulous segmentation and editing techniques through Mimics and Geomagic Wrap, we develop models that serve as a critical foundation for future simulations. These models are intended to facilitate the simulation of realistic biomechanical interactions under various loading conditions, previously explored by researchers such as Taha et al. (2016), Cheung et al. (2005), and Chen et al. (2001).

While this research stops short of conducting Finite Element Analysis, the developed CAD models lay the groundwork for future studies to apply these techniques. Our approach aligns with and builds upon the methodologies used in prior studies while aiming to provide a refined and accurate model for future integration of pressure data, thereby enhancing predictive modeling and therapeutic solutions.

2. Methodology

This work consists of the development of CAD geometry from CT data and the acquisition of the pressure distribution of a subject standing on a pressure mat. The CAD model will be used as the geometry in a finite element model and the pressure data will be used for load application.

2.1 Geometry Development

In developing three-dimensional (3D) models of the foot, data was 1) acquired from the National Institutes of Health, 2) segmented and edited using Materalise Mimics, and 3) cleaned and smoothed using Geomagic Wrap.

2.1.1 CT Data Acquisition

The CT data was acquired from the National Institutes of Health Visible Human Project female subject (National Institutes of Health, n.d.). The scans were 0.33 mm apart along the longitudinal axes, matching the pixel sizing in the transverse plane. The total data set consists of a total of 5,189 images. The female scan is that of a 59-year-old woman who died from a heart attack (National Library of Medicine, n.d.).

2.1.2 *CT Data Segmentation and Editing*

When segmenting data for Computer-Aided Design (CAD) modeling, masks are developed. A mask refers to a digital overlay that is used to isolate and manipulate specific areas of interest within CT or MRI scans. Masks are crucial for segmenting different anatomical structures or regions from the surrounding tissues in the image. This segmentation process allows users to selectively focus on and analyze specific parts of the anatomy, such as bones and soft tissue. Masks can be adjusted, refined, and used to apply various computational operations to the targeted regions without affecting the rest of the image data. In generating the masks, the user specifies Hounsfield unit (HU) thresholds. Hounsfield units are a scale used in CT imaging to measure the radiodensity of a material or tissue, with each unit representing the relative density compared to water. Water has a value of 0 HU, while air is around -1000 HU, and dense materials like bone can be over +1000 HU. This scale helps in distinguishing different tissues in CT images based on their density, aiding in accurate diagnosis and analysis. In developing the outer geometry of the foot, a lower threshold of 220 HU and an upper threshold of 1808 HU was used to capture the tissue.

The data of the female foot presented several challenges in that the two feet were touching and had to be separated, a cable ran around the foot and had to be removed, and the toes were touching making modeling difficult.

In working with the data set in Mimics, views from the axial, sagittal, and coronal plane are provided along with a 3D image. Editing of the data consists of adding and removing pixels from the mask data set. This can be performed using various manual and automated techniques. In overcoming the problems of the foot, techniques such as thresholding, region growing, edit mask, split mask, multiple slide edit, 3D interpolation, Boolean operation, and various other manual and automated editing techniques were used.

In Figure 1 an image of the two feet touching is shown before editing the data and the image on the right shows a zoomed-in view of the right foot after separating it into an individual mask. This right image shows a flat area by the heel and medial eminence. Figure 2 provides a zoomed-in view of the toes which has a cable wrapped around them on the left and an image on the right of the geometry after manually editing that cable out within the Mimics software. This cable is also present in Figure 1. As seen in the right image of Figure 1, removing the cable from the mask, caused an indentation in the foot.

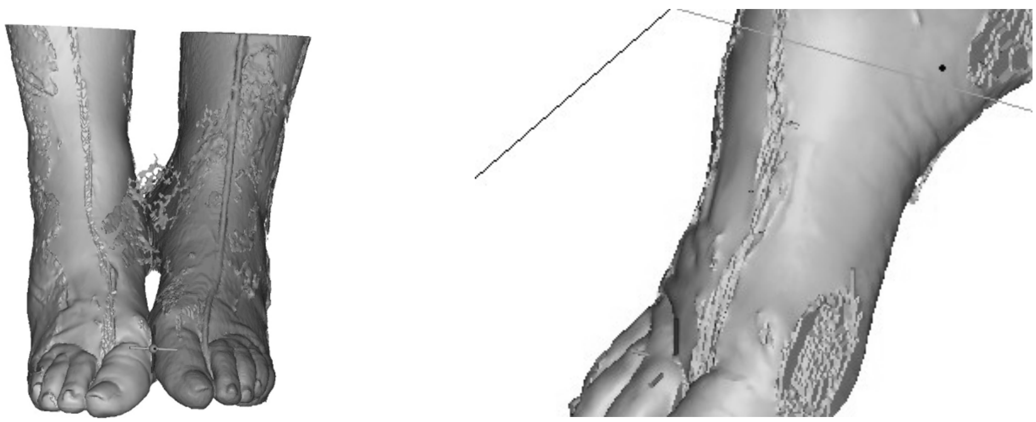

Figure 1. 3D Generation of Feet from CT Data Before Manual Editing. Image on Left Shows Feet Together and Image on Right Shows Geometry After Segmenting Out One of The Feet in Mimics

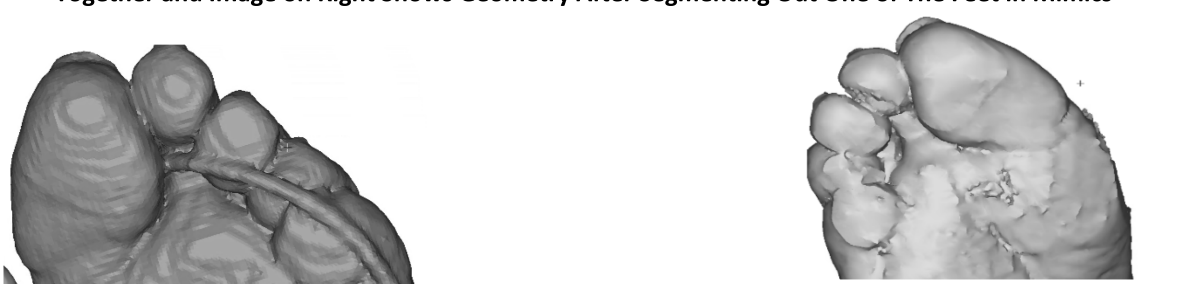

Figure 2. Left Image Shows A 3D Generation of The Toes Before the Cable Was Edited Out from The Mask in Mimics. The Right Image Shows the Toes After the Cable Was Manually Deselected from The Mask in Mimics

Once the feet were separated into separate masks and the cable partially edited out, efforts were made to separate the toes so that better computer models could be generated for future simulations. Approximately one pixel was removed between the first, second, and third toes. The fourth and fifth toes were too close together and in an orientation that made separation difficult. Figure 3 shows the masks before and after separating the toes.

Figure 3. Left Image Shows the Toes Before Separation. The Right Image Shows the Toes After Separating Them by Removing Voxels from the Mask

Once editing is complete, the resulting part was calculated using the calculate part command. This allows saving the file as an *. stl file so that the geometry can be used by other software packages. This *.stl file, or mesh data, stores the outer surface as a collection of triangles and their surface normal is recorded in the file. There is no internal structure, material, or texture associated with the file. Figure shows an image of the final mask from which the *.stl file was generated.

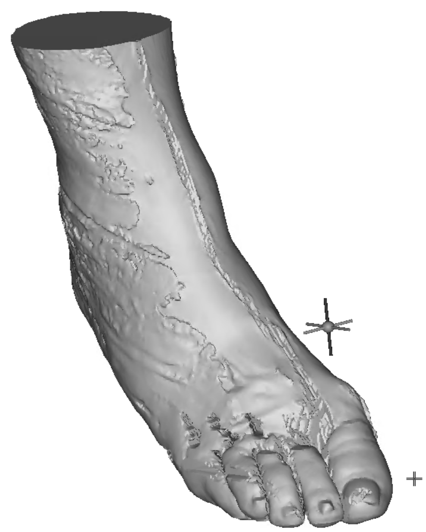

Figure 4. Final 3D Mask of Foot in Mimics Used in Geniting The *.stl File

2.1.3 CT data segmentation and editing

The masks generated in Mimics require additional smoothing and editing as well as generation of true CAD geometry, or geometry based on Non-Uniform Rational B-Spline Surfaces (NURBS). This type of geometry can be saved in various file formats so that it can be imported into CAD and finite element (FE) software packages for CAD manipulation and FE modeling and analysis. The smoothing and generation of the CAD models was conducted using Geomagic Wrap.

In Geomagic Wrap, the rough surfaces resulting from limitations of the CT scan, finite pixel sizes of 0.33 mm, editing, and interpolation in Mimics, were smoothed and unnecessary geometrical details were removed. Some of the editing and smoothing was conducted on a local level and some on a global level. For example, at the local level, the defeature command is used to smooth out the tissue where the cable was removed. Figure 1, shows an indentation ridge from the big toe backward as well as some geometric irregularities. Upon defeaturing this detail and applying smoothing algorithms, the resulting foot geometry is shown in the right figure.

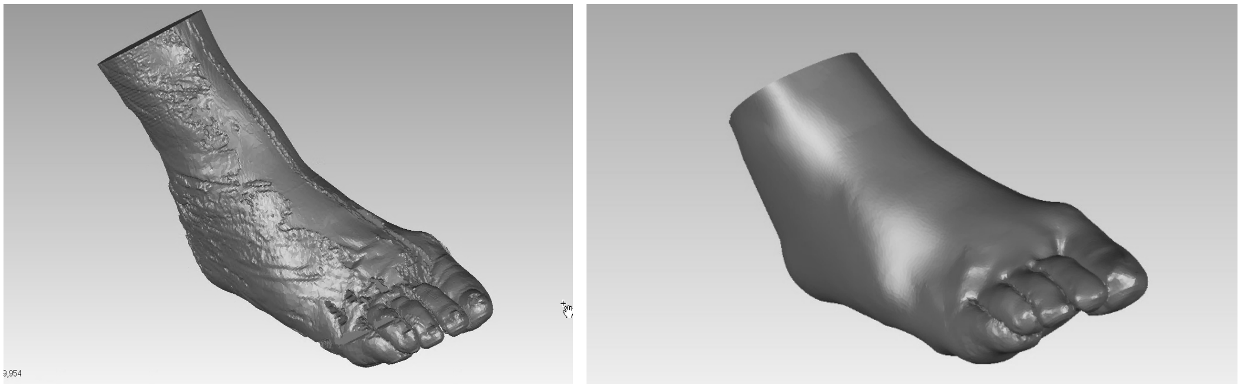

Figure 5. Foot In Geomagic Wrap. The Left Image Shows the Geometry Before Editing, And the Right Shows the Foot After Significant Smoothing of the Cable Region

Another problem with *.stl files is that they can contain small holes or spikes that make generating NURBS difficult, or impossible. As such, fill hole operations were performed. An example of a hole closing is shown in Figure 6. The lighter color on the left of the image is a hole in the geometry, making the surface open. To close the surface, commands such as fill hole were used. Other commands used were the Mesh Doctor which provides streamlined algorithms for removing spikes, filling small holes, removing small tunnels, and small components. Once the obvious problems from the geometry were resolved, smoothing commands were applied such as relax, sandpaper, and quick smooth.

Figure 6. The Light Region Shows Holes in the Imported Geometry

The CAD geometry was exported as a Parasolids file and imported into Siemens NX in preparation for FE analysis. A tetrahedral second order finite element mesh was applied to the model, as shown in Figure 7.

Figure 7. Finite Element Mesh Applied to Foot Geometry

2.2 Pressure Data Collection and Load Application

In order to properly apply the load to the model, the pressure data was collected using a Tekscan pressure mat, shown in Figure 8. In collecting the pressure distribution, the subject stands on the pressure mat. The sensors and the software are configured and calibrated to the subject's weight in Newtons. The pressure data is collected during an 8 second interval and saved as an ascii file. The ascii file is opened in Microsoft Excel where one cell in the spreadsheet corresponds to the pressure reading of one of the mat's sensors. A sample pressure distribution as seen in Excel is shown in Figure 9 where non-zero values, corresponding to some foot pressure, have been conditionally formatted. As can be seen, the non-zero values take the shape of a foot print.

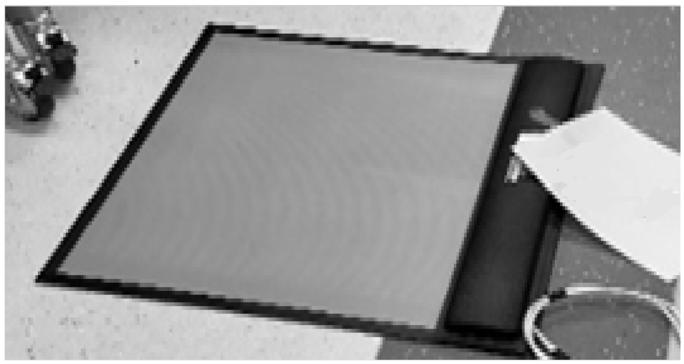

Figure 8. Tekscan Pressure Mat

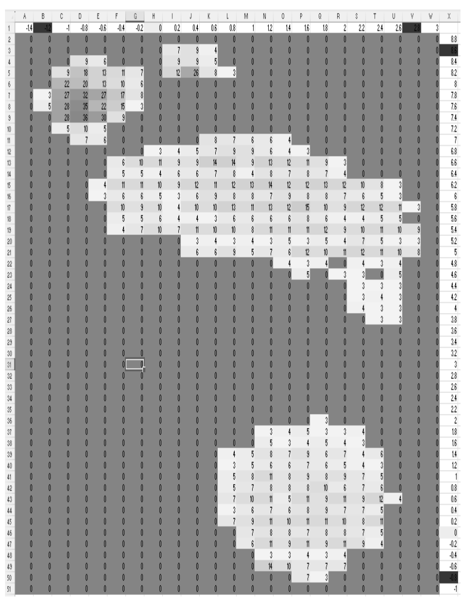

Figure 9. Pressure Distribution from Tekscan Pressure Mat as Seen in Microsoft Excel Using Conditional Formatting Colors

The cell data was reorganized into a format that can be imported as a load application in a Finite Element model in the form of a text file. This reorganization consists of creating a coordinate system and specifying the x- and y- locations of the pressure data. A portion of the reorganized text is shown in Figure 10. The figure shows the x- and y-positions along with a constant value for z, followed by the pressure measured in that cell.

X	Y	Z	P
-1.2	7.8	-0.18	3
-1.2	7.6	-0.18	5
-1	8.2	-0.18	9
-1	8	-0.18	22
-1	7.8	-0.18	27
-1	7.6	-0.18	28
-1	7.4	-0.18	28
-1	7.2	-0.18	5
-0.8	8.4	-0.18	9
-0.8	8.2	-0.18	18
-0.8	8	-0.18	20
-0.8	7.8	-0.18	32

Figure 10. Sample of Pressure Data Exported from Excel into a Text File. For Use in the Finite Element Model

3. Results and Discussion

The primary result of this study is the development and validation of a detailed process for generating high-fidelity CAD models from CT scans, utilizing advanced software tools such as Mimics and Geomagic Wrap. This process involved several critical stages, each contributing to the creation of a precise 3D model of the foot, which serves as a vital tool for further biomechanical analysis and simulations. In summary, the process developed includes: 1) Data acquisition: High-resolution CT scans from the National Institutes of Health Visible Human Project were used as the foundational data source. The scans provided detailed cross-sectional images of the foot, which were crucial for the subsequent modeling steps. 2) Segmentation and editing: Using Mimics, specific anatomical features of the foot were isolated and segmented to create accurate digital representations. Challenges such as separating overlapping geometries and removing artifacts like a cable were addressed during this phase. 3) CAD model development: Geomagic Wrap was employed to refine the segmented data into smoother and more precise geometries. The software enabled the transformation of segmented data into NURBS-based CAD models, suitable for finite element analysis.

Despite the successful development of the CAD models, there are several limitations to this study. First, the anatomy was obtained from a diseased female scanned while laying down. Scanning a live person standing would provide anatomy that better correlates with that of a standing person for which the load data was acquired. Second, the resolution of the CT scans was generally high, although there were areas with complex anatomy that could benefit from even higher resolution to enhance the accuracy of the models. Third, the model included a string around the foot that made modeling more complex and introduced inaccuracies. And lastly, the generalizability of the model was limited in that the study was conducted using the foot scans of a single individual, which may not represent the wide variability in foot anatomy across different populations.

To build upon the current work and address the limitations noted, it is recommended that a finite element analysis be conducted to study the biomechanical responses of the foot. To increase the generalizability of the models, acquiring and analyzing CT data from a diverse population with varying foot anatomies would be beneficial, and employing higher resolution scans for a standing condition in areas with intricate anatomy, could improve model accuracy. Also, future work should focus on developing models that accurately represent the material response of foot tissues, incorporating both hyperelastic and viscoelastic behavior. Such models would enable the analysis of solutions for conditions like plantar fasciitis. Orthotic devices could then be integrated into these models, allowing for comprehensive analysis of the foot and device together to assess their efficacy. This approach would facilitate the design and development of customized solutions tailored to individual needs.

In conclusion, this study has established a robust methodology for the creation of detailed CAD models from CT data, setting the stage for more comprehensive biomechanical analyses. While finite element analysis remains to be performed, the groundwork laid by this research is critical for future studies aiming to enhance our understanding of foot biomechanics and its implications for both diagnosis and treatment of foot-related ailments.

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INTEGRATING DISPARATE DATA SOURCES USING IIOT 4.0 TECHNOLOGIES TO ENHANCE OPERATIONAL PERFORMANCE OF DYNAMIC VALUE STREAM MAPS

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Abstract

This paper proposes a systematic framework for enhancing value streams by integrating the Industrial Internet of Things (IIoT) and Lean management, with a focus on Lean 4.0. Traditional Value Stream Mapping (VSM) is time-consuming and only provides periodic snapshots of a process. Integrating Cyber-Physical Systems (CPS), Information Communication Technology (ICT), and Lean principles address the gaps in traditional methodologies. CPS and ICT combined in the industry 4.0 era are collectively termed IIoT, while combining Lean management within Industry 4.0 is referred to as IIoT 4.0. Lean 4.0 defines the use of Industry 4.0 technology and Lean manufacturing principles for efficient, mistake-proof production systems. The study was conducted at a skeet equipment manufacturing industry in the Midwest of the United States. The company struggled with Lean management, high demand, limited plant capacity, and communication issues affecting production deadlines. The Digital Twin method was incorporated to replicate CPS and ICT, and it integrates well with other Industry 4.0 tools. A digital twin simulation for producing a base variant in one shift was constructed using real-time production data, ensuring it accurately imitates the actual process. This framework allows for analysis and testing without interrupting production and provides input for a Dynamic Value Stream Map (DVSM) to implement Lean practices and eliminate waste.

Keywords: *Digital Twin; Dynamic Value Stream Map; Industry 4.0; Industrial Internet of Things (IIoT)*

1. Introduction

Lean manufacturing, a management philosophy rooted in efficiency and continuous improvement, has revolutionized industries worldwide since its inception. This research study examines the historical underpinnings of Lean, tracing its evolution from its origins to contemporary applications. It explores the use of the Industrial Internet of Things (IIoT) and Industry 4.0 technologies to integrate data from distinct sources for use in Dynamic Value Stream Maps, which aim to identify and eliminate waste, thereby enhancing operational and financial effectiveness. The study begins by reviewing the foundational principles of Lean as developed in seminal texts such as "The Machine That Changed the World" and "Lean Thinking" by (Womack, 2007).

2. Lean Principles

Central to Lean are five core principles that serve as guiding tenets for organizations striving to streamline their operations and enhance value delivery. (Figure 1.)

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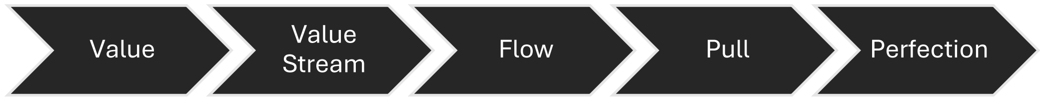

Figure 1. Five Principles of Lean

Lean manufacturing represents a fundamental shift in organizational management, emphasizing the relentless pursuit of efficiency, waste reduction, and continuous improvement. (Womack, 1996) states that by adhering to the foundational principles of Lean, organizations can unlock substantial value and achieve sustainable competitive advantage in today's dynamic business landscape (Arey et al., 2021).

2.1 Dynamic Value Stream Map

A value stream represents the sequence of activities required to deliver a product or service to the end customer, encompassing all processes from raw material acquisition to final delivery. By analyzing and improving the value stream, organizations can identify bottlenecks, streamline processes, and enhance overall value delivery. A Value Stream Map (VSM) utilizes process mapping and flowcharting methods to visualize and analyze the data from a value stream. The process map and flowchart visually represent the process flow, illustrating the sequential steps involved in a particular process, as well as the flow of materials, information, and resources throughout the value stream. This facilitates the identification of inefficiencies, bottlenecks, constraints, and opportunities for improvement.

A traditional VSM is periodic and does not represent the real-time state of a process. Most companies use data from a shift, a day, or a week to build a VSM for further analysis, which creates delays in improvement. This gap can be addressed through the integration of information communication technology and IIoT (Arey et al., 2021). Integration reduces the time taken for data collection and information flow, providing an opportunity to create a dynamic VSM. A dynamic value stream map (DVSM), as researched by (Balaji et al. 2020), provides real-time updates on process changes and statistics. This data assists in identification of waste (Ackerman, 2017) and highlight opportunities for Kaizen.

2.2 Industrial Internet of Things

The Internet of Things (IoT) can be defined as physical machines ("things") and their interconnectivity through a complex network of communication systems (Arey et al., 2021). The Industrial Internet of Things (IIoT) is similar to IoT but specific to industrial environments, facilitating interconnectivity between sensors, machines, and ICTs. IIoT consists of cyber-physical systems where sensors and physical instruments connect with computers through information and communication technology (ICT) and other software components, algorithms, logics, and communication protocols to enable a meaningful exchange of information between the physical and digital worlds (Onu et al., 2023), (Balaji et al., 2020).

2.3 Problem Statement

A skeet shooting equipment manufacturing industry in the Midwestern United States doubled its plant size to handle capacity and demand problems. The company does not practice Lean principles in its production process and struggles with material handling and production. They produce eight product variants with multiple customization options for each variant. This variability leads to delays in production, order planning, and labor scheduling, resulting in excess inventory being stored on-site.

The study designs a systematic approach to understand the process, identify and eliminate waste, and improve efficiency through the integration of Industry 4.0 technology with a Dynamic Value Stream Map (DVSM). To avoid interrupting production and meet high demand, the company requested alternative methods for analysis. Therefore, the DVSM framework was designed using simulation through Digital Twin technology (Solding, 2009). The study aims to address the following research questions:

RQ1: Does integration with IIoT 4.0 impact Lean Management? (see results)
RQ2: Would IIoT 4.0 technology and big data analytics suffice to identify defects and analyze root causes in a manufacturing or production environment? (see results)

3. Methods and Materials

To achieve a perfect replication of the current state of the process, the data must be accurate, and all production attributes must be captured and entered into the digital twin (DT). This ensures the analysis to be meaningful and relatable to the production process in the industry.

3.1 Data Collection Methodology

The study was conducted in a skeet shooting equipment manufacturing industry through regular site visits over a period of four weeks. For ease of study, the manufacturing process of a basic product variant was selected, and data collection and simulation were planned for only one shift per day, from 9:00 AM to 17:00 PM. Data collection involved two main methods: direct observation and intensive interviews. Two business owners and five tenured employees from various departments were interviewed to understand the production process, identify issues faced during shifts, and note gaps in the production process.

Direct observation involved collecting data related to station ergonomics. Walking distances were calculated in paces, with one pace scaled at three feet. Inventory was counted, and smaller part lots were weighed and divided by the weight of one part to achieve the total count of parts. Process times and setup times were noted during interviews and verified with a stopwatch to obtain nearly accurate data.

3.2 Data Types

Most of the data was captured through interviews, while physical measurements were quantitative and included worker motion and walking distances, raw material and finished product inventory counts, setup times, process times, inbound and outbound product orders, production and workforce schedules, and resource availability. Qualitative data encompassed ergonomic issues caused by tool and inventory positioning, human factors leading to delays, and other time-related wastes. Pictures were taken to study the product and identify the lean wastes present or created during the production process.

3.3 Simulation

The simulation was carried out using Siemens Tecnomatix Plant Simulation 2302 software (White paper: The Future of Manufacturing, 2020). Although multiple simulation software packages are available, Tecnomatix stands out with its user-friendly interface and capability to incorporate CAD models, making it useful for building a digital twin. The software also offers integration capabilities with Siemens PLC, external databases, and direct integration with the Value Stream module. In addition to the simulation software, Excel was used for data collection, where schedules and data tables were generated and subsequently utilized in the Tecnomatix simulator.

4. Framework

The designed framework is simplified in four stages:

1. Data collection
2. Data centralization
3. Data validation
4. Data visualization

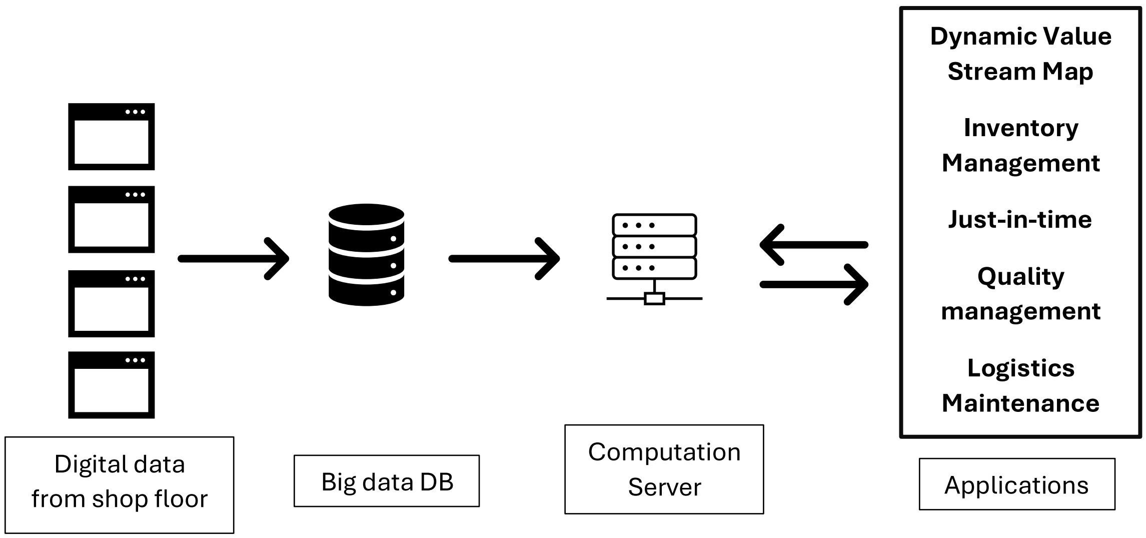

Figure 2. Framework for DVSM Mechanism

Phase 1: The IoT devices (see Table 2) on the production floor are integrated with cloud database to receive and store data. Which includes inventory data collected through NFC tags, parts movement data from assembly line that is captured using sensors and digital output from machines, which is later sorted into process start and end time, machine status, etc. The captured time stamps are later compared with KPI's to identify delays, downtimes, excess setup time, and other bottlenecks.

Phase 2: The raw information stored in the database is cleaned to provide computable information (see Table 1).

Table 1. Data Sorting Sample Format

Machine On time	Machine Off time	Part IN Line No.	Part Out Line No.	Process Start Cell No.	Process End Cell No.	Inventory Before Part No.	Inventory After Part No.

Phase 3: The computed data in the server now provides meaningful information about the production process and inventory. This information is matched with pre-defined KPI's, specific to the process and industry and any deviations is highlighted triggering a 'Kanban' on the Dynamic Value Stream Map.

Phase 4: Computed data is exported to Excel, Tableau, Share point or other tools for visualization through interactive dashboards.

The DVSM framework highlight bottlenecks in the value stream, ensures orders are pulled from succeeding process, measures and indicates inventory requirements and through further integration, it can automate order placement between cells (JIT), with suppliers and logistics.

4.1 IoT Device Integration

Table 2. IoT device

NFC	NFC tags and Scanners for inventory
PLC	Digital output from machines (idle time, process time, machine failure, etc.,)
Sensors	Proximity sensors for part and product movement
Server	Data storage and computation

5. Results

The Digital Twin with real-time attributes made it possible to observe the process from a holistic perspective and projected the current state of the process highlighting problems that could not have been identified through traditional methods and isolated focus on functional components. The integration had a huge impact on lean management as the DVSM triggered kanban when an inefficiency caused by deviation from KPI’s occurred (RQ1). This made planning 5s, Kaizen simpler and perfected JIT on production line. It is by the use of IIoT technology that we were able to collect precise time stamps in production and trace accurate inventory levels. This has helped in better computation resulting in a future state close to the ideal state. Though the captured data did reveal multiple bottlenecks in the process and reveal waste in motion, defects due to deviations from operating procedures, there were still defects whose root causes needed to be analyzed through human intervention (RQ2). Considering the limitations in IoT technology in the industry, it is safe to assume that incorporation of better technology and integration can overcome the gaps in research.

5.1 Standard Operating Procedures

Through interview it is observed that most tenure employees preferred process execution based on experience and convenience and no standards were in place. This resulted in unstructured training and novice employees contributed to more waste. Standard Operating Procedures (SOP) for the process aligning with Lean Principles were designed setting a generalized operating procedure throughout the plant. The SOP is ISO 9001 standards (International Organisation for Standards) compliant and is set at every station making it easily accessible by any employee in every shift.

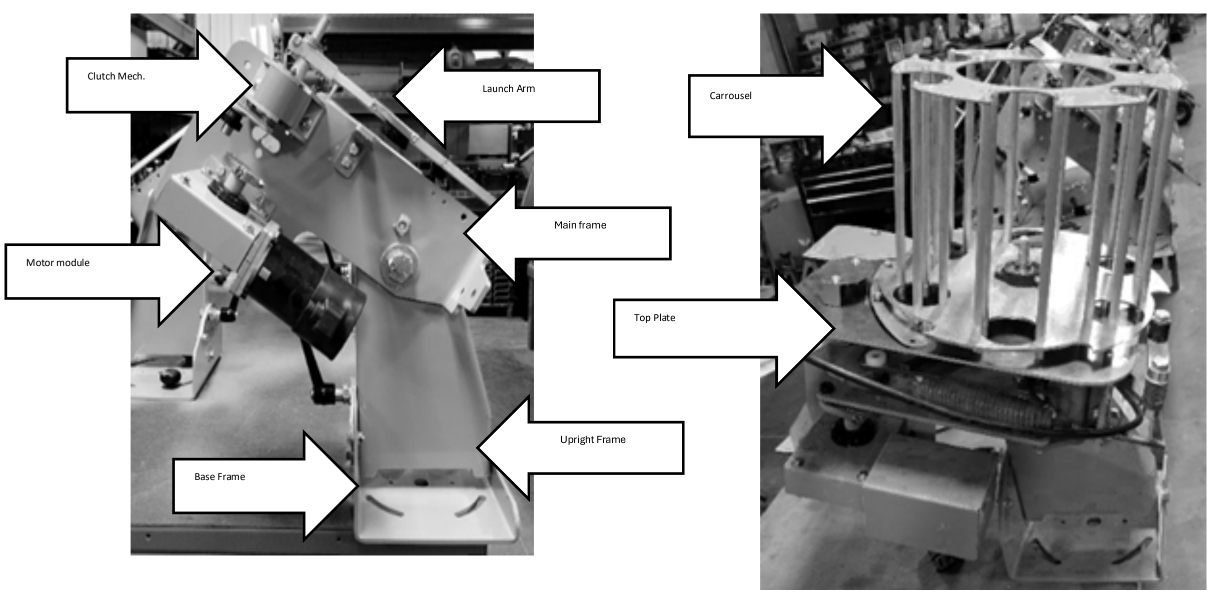

Figure 3. Main Parts of Product

5.2 Simulation Results

The simulation is done for both current state (Table 3) and for future state (Table 6) which was after elimination of waste and implementation of lean methodologies. The current state denoted throughput of 12 per shift which is lower than the planned throughput of 17 per shift.

Table 3. Current State Analysis

Object	Name	Mean Life Time	Throughput	TPH	Production	Transport	Storage	Value added	Portion
Shipping	AT150	4:17:41.6667	12	1	75.57%	24.43%	0.00%	42.69%	

Table 4. Current State Statistics

Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
CLUTCH_STATION	36.76%	0.05%	43.77%	19.41%	0.00%	0.00%	0.00%	0.00%	0.00%	
JACKSHAFT_STATION	36.76%	0.08%	42.51%	20.65%	0.00%	0.00%	0.00%	0.00%	0.00%	
PAINTSHOP	55.39%	3.48%	41.13%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
MOTOR_STATION	58.82%	0.20%	40.98%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Base_Assembly	61.76%	0.00%	13.01%	25.23%	0.00%	0.00%	0.00%	0.00%	0.00%	
Mainframe_Assembly	63.24%	0.30%	34.38%	2.09%	0.00%	0.00%	0.00%	0.00%	0.00%	
Launcharm_station	57.84%	0.10%	6.14%	35.92%	0.00%	0.00%	0.00%	0.00%	0.00%	
Launchmech_Assembly	53.81%	0.00%	42.86%	3.34%	0.00%	0.00%	0.00%	0.00%	0.00%	
Carrousel_station	70.00%	0.05%	29.95%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Carrousel_Assembly	25.49%	0.39%	70.69%	3.42%	0.00%	0.00%	0.00%	0.00%	0.00%	
Shipping	6.37%	0.20%	93.43%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	

The waiting periods are high with more than 20% – 30% blockages in multiple stations, the waiting periods at mainframe station is 34.38 %.

Table 5. Future State Statistics

Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
CLUTCH_STATION	49.02%	0.02%	50.96%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
JACKSHAFT_STATION	49.02%	0.02%	50.96%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
PAINTSHOP	70.46%	0.64%	28.91%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
MOTOR_STATION	77.06%	0.20%	22.75%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Base_Assembly	66.67%	0.00%	22.82%	10.51%	0.00%	0.00%	0.00%	0.00%	0.00%	
Mainframe_Assembly	75.00%	0.00%	23.24%	1.76%	0.00%	0.00%	0.00%	0.00%	0.00%	
Launcharm_station	66.67%	0.10%	13.54%	19.70%	0.00%	0.00%	0.00%	0.00%	0.00%	
Launchmech_Assembly	66.67%	0.00%	33.24%	0.10%	0.00%	0.00%	0.00%	0.00%	0.00%	
Carrousel_station	70.00%	0.05%	29.95%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Carrousel_Assembly	33.33%	0.39%	66.27%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Shipping	8.33%	0.20%	91.47%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	

Reduced blockages in all stations while eliminating blockages in 3 stations. Increased working/machine usage in all stations by at least 3% to 13% (approximately). The setup time was considerably reduced in all stations.

Table 6. Future State Analysis

Object	Name	Mean Life Time	Throughput	TPH	Production	Transport	Storage	Value added	Portion
Shipping	AT150	2:45:56.4706	17	1	75.86%	24.14%	0.00%	66.29%	

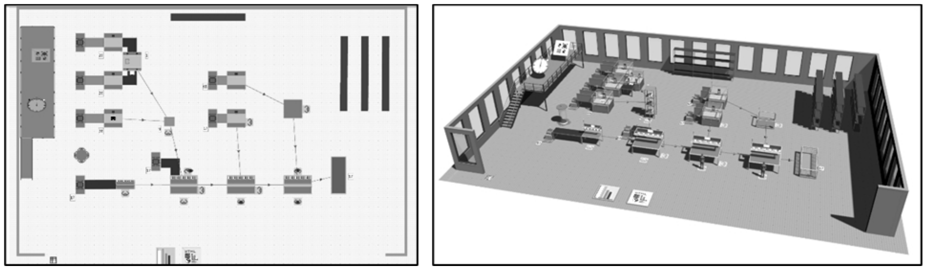

Figure 4. 3D Production Plant layout for one product variant

6. Discussion

6.1 Interpretations and Implications

The study was conducted in an industry with IoT integration capability but was observed to have low Lean understanding. To develop and implement DVSM framework it is important to collect accurate data reflecting the current state of the process. The implementation of methods and use of lean tools was a challenge as it interrupted the production process. So, as an alternative approach, simulation of the process was incorporated through building a Digital Twin (DT) of the process of a base variant. Experimenting with a production process of single variants rather than multi variant also reduced the complexity of research. The results from preliminary analysis required testing before achieving a future state for which Kaizen events were implemented. Employees were introduced to and trained in Lean principles and 5s (RO1). The credibility of future state was validated through a pilot cell which was monitored by Dr. Adam Carlton Lynch (Lean Professional) and two business owners.

The use of digital twin simulation was only to make analysis easier and prevent interruption in production and a drop in revenue due to the research. DT can be replaced with onsite implementation and achieve repeatability and reproducibility of framework.

6.2 Implications

The integration of modern technologies with lean tools unveils possibilities for better efficiency, quality and economic growth. DVSM (RQ2) will lead to quicker information flow, provide instant analytical reports and aid in change management. The holistic study and integration project exposed a university engineering student team to in-depth concepts in production technology, Lean and project management methods at a systems level which generally is not possible with individual study or an academic project. The research has also helped the industry to address the lack of enthusiasm and overcome the fear of accepting transformative ideas and advanced techniques. Digital twin and simulation approach helped in orchestration of strategies, without disrupting actual production. Government policies can be designed to integrate academia with the industrial projects leading a path to exchange of technology and innovation which will potentially impact innovation and economic growth.

6.3 Limitations and Suggestion

The study was limited to single product variant. The accessibility of simulation software was limited due to delays in procuring professional licenses. The work was done using a student version due to which integration capabilities and potential of study was restricted.

7. Conclusions

The study established a framework to integrate IIoT with Lean management tools, leading to waste elimination and improved efficiency and productivity. It shows that combining IIoT and Lean enhances production efficiency, with Kanban's triggered by the Dynamic Value Stream Map (DVSM) facilitated immediate action. While IIoT and Big Data expedite waste identification and data analysis, certain human-related waste remains undetected by standard Industry 4.0 technology. Further research on employee work patterns and machine learning for pattern recognition may be necessary to develop strategies for eliminating these specific wastes.

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BUILDING CONNECTIONS: DISCOVERING THE ENTREPRENEURIAL MINDSET BY CREATING A THREE STATEMENT FINANCIAL MODEL

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Abstract

This research evaluates the effectiveness of a project-based learning initiative involving the creation of a three-statement financial model within an undergraduate engineering course, aimed at enhancing financial decision-making capabilities related to capital equipment, sales, and operational expenses. To determine how the integration of KEEN's entrepreneurial mindset within a project-based curriculum impacts students' understanding of financial principles and their ability to apply these concepts in engineering contexts. We implemented the development of a financial model into the project for a hypothetical startup manufacturing company. This project served as the core task for the course, requiring students to apply newly learned financial concepts to create income statements, balance sheets, and cash flow statements. Data were collected from formal presentations and reports, including reflective essays. The findings indicate significant improvements in students' financial literacy and their ability to identify and leverage interdisciplinary connections. Participants reported increased confidence in handling complex financial tasks and a greater appreciation for the role of financial acumen in engineering practice. The project-based approach, enriched with the entrepreneurial principles of KEEN, effectively bridged the gap between theoretical knowledge and practical application. This method fostered a proactive and exploratory learning environment, thereby enhancing students' readiness for the professional challenges of the engineering sector.

Keywords: *Entrepreneurial Mindset; Project-Based Learning; Engineering Education*

1. Introduction

1.1 Background

Lately, there has been a surge in curiosity surrounding novel educational methods aimed at promoting active learning, real-world problem-solving, and fostering interdisciplinary collaboration. Project-Based Learning (PBL) fits these goals perfectly, allowing students to confront challenges through hands-on projects. This research focuses on a specific instance of PBL in an undergraduate engineering course on the Analysis of Decision Processes. The previous version of the course focused on data analytics, which did not align with the State Board of Regents' intentions to analyze decisions related to capital acquisition. Students lack prior knowledge of financial statements or key concepts of revenues, expenses, assets, liabilities, equity, or cash flow. This study centers on a project involving the creation of a three-

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involving the creation of a three-statement financial model for a startup company. The project aimed to help students better frame the myriads of decisions encountered during the startup of a manufacturing organization. Specifically, this research study is limited to the financial decisions concerning the capital equipment (assets), financing (liabilities) as well as the sales (revenues) and costs (expenses) arising from the operational ramp-up of such enterprises. This study is to investigate the advantages and hurdles encountered by students, the influence on knowledge retention and application, and the overarching effectiveness of nurturing comprehensive engineering professionals. The project strove to instill an Entrepreneurial Mindset (EM) developed by the Kern Entrepreneurial Engineering Network (KEEN). The aim is to elucidate engineering education realm through analysis, thus enabling the ongoing enhancement of pedagogical methods.

1.2 The Kern Entrepreneurial Engineering Network (KEEN) *

The KEEN initiative is transforming engineering education by blending theoretical knowledge and practical entrepreneurial skills for students. KEEN aligns the 3Cs of the entrepreneurial mindset: connections, curiosity, and creating value with crucial engineering skills forming the pillars to the initiative (Rae & Melton, 2017). This peer-reviewed article dissects the epistemological foundations of KEEN's 3Cs, examining the contribution to cognitive development, professional readiness, and entrepreneurial acumen of engineering students. By fostering interdisciplinary connections, continuous curiosity, and meaningful value mindsets creation, KEEN prepares students to innovate and excel in their future careers.

1.2.1 Connect

Within the KEEN framework, connections fosters collaboration with industry, academia, and the entrepreneurial community, enriching the learning journey, and improving risk management (Gorlewicz & Jayaram, 2020). Interaction with industry experts and entrepreneurs allows students to understand problem-solving techniques, discovering opportunities, prototyping, and executing of both technical and business solutions (Zappe, Cutler, & Gase, 2023).

1.2.2 Curiosity

KEEN Framework accentuates curiosity, a cornerstone of the entrepreneurial mindset, drives students to envision a better future by challenging norms. They are trained to discern and act on opportunities through informed choices, embracing continuous learning and inquiry (CURIOSITY, n.d.). Methods include fostering exploration, nurturing a growth mindset, promoting experiential learning, and tackling problems with analytical rigor, measured by a comprehensive scale (CURIOSITY, n.d.).

1.2.3 Create Value

KEEN foundation features creating value as an engineering and entrepreneurship fundamentals. Stressing the importance of solving problems while positively impacting individuals and society by going beyond technical aspects, making a meaningful difference in the world (CREATING VALUE, n.d.). Creating value prioritizes the impact on others by effectively communicating a sharp vision of achievable goals to stakeholders. A value-focused mindset allows engineers to address societal needs and deliver tangible benefits that meet real customer requirements (CREATING VALUE, n.d.). Creating value is about maximizing resources and thinking creatively to solve complex problems. It involves transforming underutilized resources into valuable assets and extending existing solutions to novel situations, all while striving for societal benefit (Team, 2023). Engineers can move beyond mere problem-solving to become innovators who drive positive global change by tackling the complex challenges of our time, developing solutions that benefit individuals, society, and the environment (What is Training and Development, n.d.).

1.3 Society for Decision Professionals (SDP)

Decision analysis is the discipline that combines decision theory, methodology, and professional practice to analyze problems and guiding decision-making under uncertainty (Keeney, 1982). This approach breaks down complex decisions into manageable parts. Decision theory integrates principles from mathematics, statistics, and psychology to evaluate decision options based on their potential outcomes and associated risks.

1.3.1 Framing & Structuring

The framing & structuring phase centers on clearly defining the decision problem by identifying objectives and key factors (De Almeida & Bohoris, 1995). This phase combines soft skills & facilitation with the use of framing tools & methods. Soft skills & facilitation create a supportive environment where stakeholders feel empowered to contribute ideas and voice concerns (Taylor, 2016). Among these soft skills are adaptability, communication, creative thinking, dependability, work ethic, time management, and conflict resolution. Framing tools and methods represent the tools used to systematically structure and visualize decision problems. Among these tools are decision trees, which include decision nodes representing points where choices are made, chance nodes encapsulating uncertain outcomes, and terminal nodes signifying results or endpoints.

1.3.2 Analysis and Modeling

Value-focused thinking centers on identifying and prioritizing decision objectives before considering alternative actions. It involves articulating clear objectives and assessing how different alternatives align with these objectives (Team, 2023) (Value-Focused Thinking, n.d.). Uncertainty and Risk Analysis describes decision analysis under uncertainty. Expected value analysis calculates expected outcomes, guiding decision-making of selecting the optimal alternative based on measures like PW or AW under risk (Engineering Economy by Leland Blank: Chapter 19, n.d.). Models like decision trees and influence diagrams represent potential outcomes of complex decisions. Decision trees illustrate decision paths and associated probabilities which aid in visualizing scenarios and calculating expected value (Engineering Economy by Leland Blank: Chapter 19, n.d.). Real Options theory extends decision analysis to incorporate flexibility and adaptability. It allows businesses to evaluate decisions as opportunities, akin to financial options, considering the value of waiting or altering strategies based on future uncertainties (Society of Decision Professionals, n.d.). Portfolio Decision Analysis involves evaluating interdependencies and resource allocations. It enables the selection of decisions that maximize value while managing risk across the entire portfolio. This promotes strategic decision-making in complex environments (Structured decision making, n.d.).

1.3.3 Organizational Capability

Organizational capability creates a competitive advantage where it is an intangible asset for a company (Spanos & Prastacos, 2004). Organizational capabilities are made up of three factors which include implementation of decision analysis, training and development, and embedded decision analysis (Society of Decision Professionals, n.d.). Implementation of Decision Analysis involves applying methodologies in a decision analysis to convert vague opportunities into an actionable plan with defined goals (Decision analysis, n.d.). This aids the organization in solving problems of variable difficulties and priorities (Team, 2023). Training and Development is the process where employees improve their work performance through professional help and development equipping them for new roles or responsibilities (What is employee training and development, n.d.). This develops an employee’s knowledge to obtain skill sets necessary to advance in their careers (What is Training and Development, n.d.). 00 is the direct integration of analytical data and functional applications of software which eases the access and evaluation of the data (What are Embedded Analytics, n.d.). Embedded analytics lowers complexity by placing necessary information where it is required, it increases the accessibility and actionability of data for a wider audience (Mostert, 2023).

1.3.4 Additional Topics of the SDP Framework

Cognitive Biases is the error in thinking that affects decisions. Errors such as overconfidence, confirmation bias, and availability heuristic are the few reasons for inaccurate decision-making. Game Theory explores the outcome for each participant, which depends on the actions of others. It addresses prisoners' dilemma and Nash equilibrium, highlighting predicting others' actions in decision-making processes. Societal Decisions involve choices made as a community that affect the public. These decisions involve managing competing interests and values, such as collective welfare and resource allocation. Personal and Life Choice Decisions involves choices concerning personal or familial circumstances. Risk assessment, long-term planning, and emotional factors can influence decisions.

1.4 Problem Statement

Using literature as a foundation, this research study uses Project/Problem-Based Learning to simulate undergraduate engineering students with respect to elements found within technical organizations other than Engineering Design & Manufacturing. The students' Curiosity (C1) is aimed to increase technical knowledge in their respective subject, build Connections (C2) to other information as well as collaboration among in class teammates and between paired teams of other courses.

1.5 Research Question (RQ)

RQ1: How does the implementation of the requirements to create a Three-Statement Financial Model impact on the student's ability to see broader connections from their course subject matter to their discipline and the engineering profession?

1.6 Contribution

This research study presents an extensive investigation into the epistemological foundations of the Frameworks of KEEN and SDP upon engineering education. By examining the Kern Engineering Education Network (KEEN) and its 3Cs for the Entrepreneurial Mindset, Curiosity, Connections, and Creating Value, along with the broader scope of Interdisciplinary Projects, this study makes significant larger contributions to this specific field of engineering pedagogy.

2. Methodology

2.1 Materials

Microsoft Excel was utilized for detailed financial analysis, while Microsoft Word was used to draft initial reports throughout the course. The final reports were formatted as PDF documents and the final in-class presentations were communicated through Microsoft PowerPoint. Online learning tools such as LinkedIn Learning and the Corporate Finance Institute (CFI) provide a better understanding of financial concepts such as financial statement analysis, ratio calculations, and financial modeling. An open-source, online Engineering Economics textbook from the University of Saskatchewan, provided foundational knowledge and practical examples.

2.2 Income Statement

Income statement is introduced through an overview of its purpose and components. Visual aids, real-world examples, and formulas aid in explaining revenue (Revenue = Price * Quantity), expenses (Total Expenses = Fixed Expenses + Variable Expenses), and net income (Net Income = Revenue - Total Expenses) (Cassidy, M., & Schmid, n.d.).

2.3 Balance Sheet

Balance Sheet concepts are introduced by providing an overview of its purpose and specific formulas related to structure, assets, liabilities, and equity. Visual aids, real-life examples, and formulas are implemented for concepts such as Assets (Total Assets = Current Assets + Non-current Assets), Liabilities (Total Liabilities = Current Liabilities + Non-current Liabilities), and Equity (Total Equity = Assets - Liabilities) (Cassidy, M., & Schmid, n.d.).

2.4 Ratios

Financial ratios are used to assess a company's financial health and operational efficiency (corporatefinanceinstitute.com, n.d.). Liquidity ratios like the Current Ratio (Current Assets / Current Liabilities) and Quick Ratio (Current Assets - Inventory) / Current Liabilities) evaluate short-term obligations. Leverage ratios include Debt-to-Equity Ratio (Total Debt / Total Equity) used to assess debt financing. Efficiency ratios measures asset utilization, such as the Inventory Turnover Ratio (Cost of Goods Sold / Average Inventory). Profitability ratios look at earning generations through like Return on Assets (Net Income / Total Assets). Market Value ratios include the Price-to-Earnings Ratio (Market Price per Share / Earnings per Share).

2.5 Cashflow Statement

Cash Flow statements are introduced through an overview of its purpose and components: operating activities, investing activities, and financing activities. Visual aids, real-world examples, and formulas helps in explaining Cash Flow from Operating Activities (CFO), Cash Flow from Investing Activities (CFI), Cash Flow from Financing Activities (CFF), and Net Cash Flow (Net Cash Flow = CFO + CFI + CFF) (Cassidy, M., & Schmid, n.d.).

3. Results

For each student team, the initial project economic feasibility was determined from a three-statement financial model, including the Income Statement, Balance Sheet, and Statement of Cash Flows. A sample of the typical financial model is shown in Figure 1. While Financial Ratios were calculated for each student project, they are not presented here due to space constraints, but typical financial ratios were calculated. Valuations Analysis using such methods of Benefit-Cost Ratio (BCR), Net Present Value (NPV), Internal Rate of Return (IRR), and discrete stochastic Sensitivity Analysis are not covered in this research study.

THREE-STATEMENT FINANCIAL MODEL								
(Sample for a Manufacturing Startup)		Historical (Actual)				Forecasts (Projected)		
INCOME STATEMENT		(from Traded Competitors)						
Fiscal Year	**2020**	**2021**	**2022**	**2024**	**2025**	**2026**	**2027**	**2028**
Sales Revenue	$110,000	$155,000	$170,000	$175,000	$180,000	$195,000	$205,000	$215,000
Cost of Goods Sold (COGS)	($65,000)	($87,850)	($106,600)	($112,830)	($115,000)	($125,250)	($130,250)	($135,250)
Gross Profit	$45,000	$67,150	$63,400	$62,170	$65,000	$69,750	$74,750	$79,750
Research & Development (R&D)	($2,500)	($2,429)	($2,429)	($2,429)	($2,429)	($2,429)	($2,429)	($2,429)
Selling, General, & Administration (SG&A)	($7,500)	($7,599)	($7,599)	($7,599)	($7,599)	($7,599)	($7,599)	($7,599)
EBITDA	$35,000	$57,122	$53,372	$52,142	$54,972	$59,722	$64,722	$69,722
Depreciation & Amortization Expense	$3,200	$4,850	$5,700	$6,900	$7,300	$8,870	$9,950	$11,250
Other Expense	($500)	($104)	($104)	($104)	($104)	($104)	($104)	($104)
Operating Project (EBIT)	$37,700	$61,868	$58,968	$58,938	$62,168	$68,488	$74,568	$80,868
Interest income / Expense (-)	$519	$520	$521	$523	$524	$525	$526	$527
Pre-Tax Profit	$38,219	$62,388	$59,489	$59,461	$62,692	$69,013	$75,094	$81,395
Tax Expense (-)	($8,200)	($14,000)	($13,000)	($8,259)	($8,258)	($8,257)	($8,256)	($8,255)
Net Income	$30,019	$48,388	$46,489	$51,202	$54,434	$60,756	$66,838	$73,140
BALANCE SHEET		*Historical (Actual)*				*Forecasts (Projected)*		
Fiscal Year	**2020**	**2021**	**2022**	**2024**	**2025**	**2026**	**2027**	**2028**
ASSETS								
Cash & Equivalents	$121,251	$146,761	$152,236	$152,250	$161,000	$165,250	$182,350	$191,750
Accounts Receivable (A/R)	$10,930	$13,100	$13,450	$14,300	$14,900	$15,600	$16,500	$17,250
Inventory	$800	$1,700	$1,825	$1,900	$1,975	$2,050	$2,175	$2,250
Property, Plant, & Equipment (PPE)	$15,450	$16,570	$19,650	$23,500	$26,000	$29,100	$30,750	$31,300
Furniture, Fixtures, and Equipment (FFE)	$5,478	$6,540	$3,816	$9,472	$5,468	$8,169	$4,672	$4,787
Acquired Intangible Assets	$8,031	$7,500	$6,500	$4,750	$3,500	$2,750	$6,500	$7,250
Total Assets	***$161,940***	***$192,171***	***$197,477***	***$206,172***	***$212,843***	***$222,919***	***$242,947***	***$254,587***
LIABILITIES					$0			
Accounts Payable	$21,100	$22,350	$22,900	$24,400	$25,500	$26,750	$28,200	$29,300
Accrued Expenses	$20,100	$23,900	$23,800	$23,925	$23,800	$23,500	$23,250	$24,500
Bank Revolver (line of Credit)	$1,500	$1,500	$1,500	$1,500	$1,500	$1,500	$1,500	$1,500
Long Term Debt	$0	$16,500	$16,500	$14,500	$13,750	$12,500	$11,700	$8,500
Total Liabilities	***$42,700***	***$64,250***	***$64,700***	***$64,325***	***$64,550***	***$64,250***	***$64,650***	***$63,800***
Common Stock	$16,400	$19,700	$21,750	$24,500	$25,750	$29,250	$31,750	$34,250
Paid in Capital	$1,500	$2,000	$2,500	$3,000	$3,500	$4,000	$4,500	$5,000
Retained Earnings	$101,340	$106,221	$108,527	$114,347	$119,043	$125,419	$141,247	$151,537
Total Equity	***$119,240***	***$127,921***	***$132,777***	***$141,847***	***$148,293***	***$158,669***	***$177,497***	***$190,787***
Total Liabilities & Equity	***$161,940***	***$192,171***	***$197,477***	***$206,172***	***$212,843***	***$222,919***	***$242,147***	***$254,587***
CASH FLOW STATEMENTS		*Historical (Actual)*				*Forecasts (Projected)*		
Fiscal Year	**2020**	**2021**	**2022**	**2024**	**2025**	**2026**	**2027**	**2028**
OPERATING ACTIVITIES								
Net Income				$51,202	$54,434	$60,756	$66,838	$73,140
Depreciation and Amortization		***There are no Cash Flow Statements***		$6,900	$7,300	$8,870	$9,950	$11,250
Accounts Receivable				($850)	($600)	($700)	($900)	($750)
Inventory		***for the historical data***		($75)	($75)	($75)	($125)	($75)
Accounts Payable				$1,500	$1,100	$1,250	$1,450	$1,100
Accrued Expenses		***as Cash Flows are forecasted***		$125	($125)	($300)	($250)	$1,250
Non-Current Liabilities				$3,000	$3,000	$3,000	$3,000	$3,000
Cash from Operating Activities				***$61,802***	***$65,034***	***$72,801***	***$79,963***	***$88,915***
INVESTING ACTIVITIES								
Capital Expenditures				($3,850)	($2,500)	($3,100)	($1,650)	($550)
Purchases of Intangible Assets				$1,750	$1,250	$750	($3,750)	($750)
Cash from Investing Activities		***There are no Cash Flow Statements***		***($2,100)***	***($1,250)***	***($2,350)***	***($5,400)***	***($1,300)***
FINANCING ACTIVITIES								
Long Term Debt		***for the historical data***		($2,000)	($750)	($1,250)	($800)	($3,200)
Bank Revolver				($1,500)	($1,500)	($1,500)	($1,500)	($1,500)
Cash from Financing Activities		***as Cash Flows are forecasted***		***($3,500)***	***($2,250)***	***($2,750)***	***($2,300)***	***($4,700)***
Net Change in Cash (during Period)				***$56,202***	***$61,534***	***$67,701***	***$72,263***	***$82,915***

Figure 1. Three Statement Financial Model

4. Discussion

4.1 Interpretation of results

Student teams showed the effectiveness of incorporating project-based learning and an entrepreneurial mindset into engineering education. Each team produced comprehensive results proving their financial knowledge involved in launching and sustaining a startup business (RQ1). Students presented their findings and strategies with confidence and clarity as financial professionals. This transformation suggests that the students were able to apply the theoretical content practically bridging the gap between academic learning and practical application.

4.2 Implications

4.2.1. Academia Pedagogy & Research

Integrating the KEEN Entrepreneurial Mindset into academia and research yields profound implications cultivating analytical skills, decision making and entrepreneurship.

4.2.2. Industry

Embracing the KEEN mindset and mastering the three-statement financial model prepares engineers to be ahead in a dynamic workforce that values problem-solving across domains.

4.2.3. Government

The appropriate government body to generate curricula to produce entrepreneurial-minded producers for industry that will utilize the natural resources found within its borders.

4.3 Limitations of the Study

The availability bias is when we make decisions based on information that is easy to remember, which leads to poor judgement (Tversky & Kahneman,1974). Mental accounting is where we assign subjective value to money based on its source or intended use, leading to illogical spending and budgeting habits (Thaler, 1999). The endowment effect affects both buyers and sellers, leading buyers to overspend due to psychological ownership and sellers to overprice their goods, fearing loss (Shefrin & Statman, 1985). The optimism bias affects personal and professional lives, encouraging unrealistic expectations and ignoring potential downsides (Weinstein, 1980).

4.4 Suggestions for Future Work

The authors aim to include a more balanced integration of training to enhance student learning outcomes. These next topics might include "Framing Tools," "Real Options," and "Cognitive Biases."

5. Conclusion

Integrating Kern Entrepreneurial Engineering Network's (KEEN) entrepreneurial mindset into an engineering curriculum through project-based learning (PBL) has demonstrated to improve students' financial literacy and interdisciplinary understanding (RQ1). This study not only improved students' grasp of complex financial concepts but also effectively connected these concepts with real-world applications. Our findings reveal that students exposed to this pedagogical approach exhibited significant advancements in their ability to analyze and synthesize information from diverse disciplines to solve complex problems. They developed a robust understanding of financial documents such as income statements, balance sheets, and cash flow statements, essential for making strategic decisions. The positive outcomes of this study underscore the value of incorporating PBL and the KEEN framework into engineering education. Students not only emerged as more competent in their technical fields but also gained a holistic perspective that integrates economic and managerial insights into engineering solutions. It is recommended that engineering programs globally consider adopting similar educational frameworks that align technical learning with entrepreneurial thinking. Future research should explore long-term impacts of such educational interventions on career success and professional adaptability.

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SIX SIGMA BLACK BELT CERTIFICATIONS – A PROCESS TO COMPARE & EVALUATE AVAILABLE CERTIFICATION OPTIONS: A CERTIFICATION REPORT CARD

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Abstract

Six Sigma certification remains as a popular credential among many quality professionals. With the vast number of options available, a comparison of these options is needed since cost, duration and curriculum varies significantly among the certification options. In this paper a method to evaluate Six Sigma Black Belt Certification curricula against the criteria outlined in ISO 18404 (ISO 2015) is presented. The paper will serve as a guide and comparison methodology for those looking to select an appropriate certification option. Additionally, it provides a baseline for evaluation of Six Sigma Certifications to satisfy college course (six sigma related courses) credit as prior learning experience (PLA).

Keywords: *Six Sigma; Certification, Black Belt*

1. Introduction

Professional certifications continue to be popular credentials for those seeking to add to their skill set, strengthen a resume and/or advance a career. Additionally professional certifications help employers select individuals with validated, specific skills sets that are needed in their organization. The benefits of professional certifications are vast, and many have outlined these benefits and are reference on the citations that follow below. Many credential seekers struggle with selecting an organization or institution that provides them with the best Six Sigma Black Belt (SSBB) Certification which will bolster their skill set and fulfill employer needs. Certifications are professional documents that verify one’s skills and ambitions. Having a certification, either Six Sigma or Lean Six Sigma, suggests that an individual can promptly resolve quality control concerns, remove factors of faults and errors, and maintain production efficiency, which is beneficial to one’s professional career. Certificates indicate that one has the ability and skills that could support an employer or a firm to lead it into a progressive path through the reduction in costs, increment in revenues, and profit margin (Indeed, 2022).

2. Motivation and Significance of the Study

Within the realm of Six Sigma BB certification, there are a vast number of providers and significantly varying curriculum. As a former quality professional and now a tenured, associate professor of Quality Systems, this author is often asked by students, employers, and other colleagues what is the best SSBB certification out there and how does one choose the right SSBB certification? Employers often want to understand “which SSBB should I accept as credible?” While this author has a personal preference, experience and knowledge of many popular certifications, by no means is this a comprehensive list or complete, objective evaluation. Furthermore, like many institutions, Bowling Green State University offers college level credit for prior learning assessment (PLA) via several methods (BGSU 2024). Three (3) of these assessment methods are, (a) portfolio assessment,

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(b) industry credential evaluations, and (c) credit by validation. In each of these assessment methods, professional certifications or coursework from a regionally non-accredited organization (i.e., those offering SS certification), or specifically evaluation of a SSBB certification are methods prospective students use to demonstrate proficiency in Six Sigma which in turn earns them college credit and saves them the time (and money) from taking a redundant course in Six Sigma. Similar to the question asked by employers and others (students, other institutions), our institution needs to understand which certification can be accepted. In addition to certifications offered by various providers and organizations, branches of the US Military such as the Air Force (U.S. Air Force Reserve Command, 2022) offer SSBB certification. How does one evaluate credibility and comprehensiveness of these various certifications with so many differences between them? Some require exams, while others do not; some require completion of a project, while others do not; the list of requirements and curriculum is seemingly endless and widely varies.

3. Problem Statement/Dilemma

Currently. there isn't a universally recognized or comprehensive comparison matrix that shows the differences between Six Sigma certifications from popular providers due to the vast number of organizations offering these certifications and the dynamic nature of their offerings. A need exists to have a baseline evaluation method to compare certifications, so individuals are informed to the requirements and curriculum of these certifications. A search for a certification comparison matrix using traditional search methods and the use of AI (Chat GPT 4.0) did not result in locating a comparison matrix. The only type of matrix identified was a comparison of organizations offering certification to promote using their company as a provider (The Council for Six Sigma Certification, n.d.). Therefore, a method is needed to allow a certification seeking individual to objectively assess the pros, cons and differences between Six Sigma Black Belt certifications.

4. Objectives of the Study

Objective 1: Develop a universal method to objectively differentiate between Six Sigma Black Belt certifications offered by independent vendors.

Objective 2: Evaluate SSBB certifications based on an objective measure of required competencies outlined in ISO 18404 (ISO 2015).

Objective 3: Develop and overall scorecard to relatively compare SSBB certifications allowing individuals a method to understand each certification strengths and weaknesses.

5. Limitations and Delimitations

The methodology developed specifically targeted Six Sigma Black belt certifications and associated competencies in ISO 18404 (ISO 2015), Lean Six Sigma certifications and competencies are not considered; however, the methodology developed from this study is universally transferable to the other competencies outlined in ISO 18404 (ISO 2015) which are Master Black Belt, Green Belt, Lean SS Master Black Belt, Lean SS Black Belt and Lean SS Green Belt. The objective review of Six Sigma certifications is limited to the information provided on the respective certification providers website; thus, it is possible some criteria may not be included in the review (i.e., not on the website or information offered by the provider). The author acknowledges that the use of Chat GPT 4.0 to search for Six Sigma certification has potential accuracy limitations.

6. Methodology

To establish a baseline to assess and compare SSBB certifications, an objective set of criteria must be established. The ISO 18404:2015 standard titled "Quantitative methods in process improvement – Six Sigma competencies for key personnel and their organizations in relation to Six Sigma and Lean Implementation" outlines 23 competencies for Master BB's, Black Belts, and Green Belts. Table 1 outlines only the competencies for a Six Sigma Black Belt.

Table 1. ISO 18404 Black Belt Competencies

ISO 18404 Competencies
Organizational benefits identification and prioritization
Business process improvement
Change management
Leadership development in self
Leadership development in others
Data acquisition for analysis
Creativity thinking
Customer focus
Decision making and taking
Interpersonal and team leadership skills
Motivating others
Numeracy
Practical problem solving (opportunity realization)
Presentation and reporting skills
Process thinking skills
Project management
Risk analysis
Self-review and development
Six Sigma tools
Stakeholder management
Statistical techniques
Statistical software use
Sustainability and control

After establishing this baseline for Six Sigma Black Belt Competencies, a list of popular certification providers was obtained. The list was established using three methods; (a) author knowledge and experience evaluating SSBB certifications, (b) systematic world wide web search, and (c) use of Chat GPT 4.0 to find a list of the prominent and popular SSBB certifications. This search method resulted in 32 certification providers. After examination of each of the 32 providers, the list was narrowed to providers who only offered Six Sigma Black Belt certifications. Eighteen (18) providers were eliminated from the original list of 32 because they only offered Lean Six Sigma Certification options. Table 2 below outlines this final list of providers.

Table 2. Sample Six Sigma Certification Providers

SSBB Certification Providers
6Sigma.com
ACO Six Sigma
American Society For Quality
ASU (Arizona State University)
Aveta Business Institute
Drexel University
Expert Rating
IASSC (International Association for Six Sigma Certification)
Institute of Industrial and Systems Engineers (IISE)
Management and Strategy Institute (MSI)
MoreSteam
Omnex Consulting
Quality Training Portal
The Council For Six Sigma Certification

The evaluation of Six Sigma providers consisted of reviewing each body of knowledge or published curriculum and assessing whether each competency as outlined in ISO 18404 (ISO 2015) was or was not addressed. Thus, the comparison consisted of evaluating how many elements of the ISO 18404 (ISO 2015) competencies are present in the curriculum of the certifications reviewed/evaluated. Of additional importance are two (2) criteria not listed in ISO 18404 (ISO 2015) but included by the author in this comparison model, that may separate certifications apart, these are the requirement to either complete a project as part of the certification process or have a valid industry project to be able to be considered for the certification. The second criterion was having a requirement to possess industry experience as a perquisite to becoming a certified Six Sigma Black Belt. Other important considerations that were not included in the evaluation are (a) accreditation, (b) experience/credentials of the instructors, (c) reputation of the organization, (d) considerations such as cost, delivery, and (e) if training/study materials are provided as part of the certification process. For each provider, the course curriculum was examined and compared to the ISO 18404 (ISO 2015) competencies. The number of competencies present and not present in the provider curriculum were tallied and percent of ISO 18404 (ISO 2015) competencies calculated and placed in table format (see discussion of findings section). Furthermore, a “pass” of “fail” is given to those providers requiring a completed black belt project to become certified and to those providers requiring experience to be eligible to pursue certification through their program. This resulted in a final scorecard presented below in the discussion of findings section.

7. Discussion of Findings

Using the methodology outlined above to review Six Sigma Black Belt certifications, an overall competency matrix and scorecard is developed allowing one to rate and compare Six Sigma (or others as identified in ISO 18404:2015) Black Belt certifications. Table 3 below represents the assessment of two Six Sigma Black Belt Certifications. The author has removed the provider names for anonymity and to simply demonstrate the methodology and not to discredit or misrepresent any particular provider. See conclusions and future opportunities for further discussion related to variance among providers.

Table 3. Comparison of Six Sigma BB Certification Providers

Six Sigma Black Belt Provider A		
ISO 18404 Competencies	**Yes/Pass**	**No/Fail**
Organizational benefits identification and prioritization		x
Business process improvement		x
Change management	x	
Leadership development in self		x
Leadership development in others		x
Data acquisition for analysis		x
Creativity thinking		x
Customer focus	x	
Decision making and taking		x
Interpersonal and team leadership skills		x
Motivating others		x
Numeracy		x
Practical problem solving (opportunity realization)	x	
Presentation and reporting skills		x
Process thinking skills	x	
Project management	x	
Risk analysis		x
Self-review and development		x
Six Sigma tools	x	
Stakeholder management		x
Statistical techniques	x	
Statistical software use	x	
Sustainability and control	x	
Total	**9**	**14**
Percent	**39.1%**	
Competency Score	**F**	
Experience Rating		F
Project Rating		F

Six Sigma Black Belt Provider B		
ISO 18404 Competencies	**Yes**	**No**
Organizational benefits identification and prioritization		x
Business process improvement	x	
Change management	x	
Leadership development in self	x	
Leadership development in others	x	
Data acquisition for analysis	x	
Creativity thinking	x	
Customer focus	x	
Decision making and taking	x	
Interpersonal and team leadership skills	x	
Motivating others	x	
Numeracy	x	
Practical problem solving (opportunity realization)	x	
Presentation and reporting skills	x	
Process thinking skills	x	
Project management	x	
Risk analysis	x	
Self-review and development		x
Six Sigma tools	x	
Stakeholder management		x
Statistical techniques	x	
Statistical software use	x	
Sustainability and control	x	
Total	**20**	**3**
Percent	**87.0%**	
Competency Score	**A**	
Project Rating	P	
Experience Rating	P	

Following the competency assessment and identifying the project requirements and experience factors, a final scorecard is developed, and these are depicted in figure 1 below.

Provider A Scorecard	
Criteria	
Competency	36%
Project	F
Experience	F
Overall	Yellow

Provider B **Scorecard**	
Criteria	
Competency	87%
Project	P
Experience	P
Overall	Green

Figure 1. Six Sigma BB Provider Scorecard

The competency score represents the overall percentage of ISO 18404 (ISO 2015) competencies covered by the providers SS BB curriculum. The project and experience ratings are either pass or fail; if a project is required as part of the certification, it is given a "P", and if a project is not required it is given and "F". The same scoring is used for the requirement of needing experience to obtain a Six Sigma BB or even to be eligible to take an exam for providers that offer the SSBB certification by only passing competency exam. The overall ranking is green or yellow; yellow indicates a SSBB certification that one may want to further investigate to see if it fits the needs of any particular stakeholder or themselves. The overall ranking can be viewed as a robustness" factor.

7.1 Additional Considerations

It is important to note that the wide variety of certification cost and the duration (hours of training) required to complete the certification. Many of the certifications examined in this study simply provide Six Sigma Black Belt certification by virtue of passing an exam, which may or may not indicate a level of competency, especially if only a few of the ISO 18404(ISO 2015) competencies are part of the exam. In some cases, the exam is supported by training material developed and supplied by the certification provider as part of the total cost. The cost for obtaining Six Sigma Black Belt certification ranged from $99.00 as the low value to $6985.00 as the high value. The training aspect, or duration of the training course/time (expressed in hours) to prepare for the certification exam ranged from no training requirement (simply pass the exam) to 160 of classroom time delivered either in person, hybrid or fully online. In brief some SSBB certification required classroom time, a completed project and successfully pass a final exam while others require only passing an exam and that exam may only have 40% of the competencies outlined in ISO 18404 (2015). This is a clear disparity and the only way to make these equivalent is to have a unified standard (ISO 18404:2015 as a base for at least competency identification) and any provider offering SSBB certification must have equal criteria to obtain the certification.

8. Conclusions and Future Opportunities

The primary objectives of this study have been met by developing the method to evaluate any

Six Sigma Black Belt certification provider and a scorecard to relatively compare Six Sigma Black Belt certification providers. While developing the assessment process was the intent of the study, the unintended, significant outcome is the clear disparity between Six Sigma Black Belt certifications. The need for standardization among this discipline is quite apparent. Consider the employer who advertises for a Quality Engineer and one of the preferred requirements is the successful candidate will possess a Six Sigma Black Belt certification. On one hand, an applicant may have gone through 120 hours of classroom training, lead and completed a Six Sigma project, passed a competency exam that covers 90% or more of the competencies outlined in ISO 18404 (ISO 2015) and has years of related experience. In contrast, another applicant also possessing a SSBB certification merely passed and exam that covered less than 40% of the competencies in ISO 18404 (ISO 2015). The disparity in skill set is astounding. Unfortunately, Six Sigma has been subject of much criticism lately and the disparity between certification and the certification process undoubtedly support the criticism. ISO 18404 (ISO 2015) was a good initial step to set a baseline, however there is no requirement for these providers to adhere to ISO 18404 (ISO 2015) and it may not be feasible to implement such a system similar to ISO 9001 registration/certification scheme. In lieu of a process, the objective method outlined in this paper may be a good tool for those looking to understand the total depth and breath of any particular Six Sigma Black Belt Certification. The method can be used by employers, perspective black belt seekers, institutions such as public universities that grant college credit for prior learning experience or any other stakeholder that simply wants to understand or compare Six Sigma Black Certifications. The same method can be applied directly to Lean Six Sigma certifications as these competencies are outlined in ISO 18404 (ISO 2015). At a minimum, this evaluation model brings awareness and attention to what many quality professionals feel is a sought after and credible credential, yet the skill set that an individual possesses based on the certification provider and their requirements varies significantly and cannot be overlooked.

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ANNUAL WILDLIFE STRIKE RATE BY DAMAGE CATEGORY IN THE UNITED STATES 2013-2022

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Abstract

Strikes between wildlife and aircraft are a common occurrence, posing many risks to aviators, aircraft, and passengers, in addition to harming wildlife. Previous studies have shown trends between wildlife collisions and bird migration, ways to mitigate wildlife strikes, costs due to strikes, and analyses of damage caused by different types of animals. These studies did not examine the frequency of wildlife strikes with respect to the severity of aircraft damage from the strike. Data on reported damage to aircraft due to strikes within the past ten years, from 2013 to 2022, were collected using the Federal Aviation Administration (FAA) Wildlife Strike Database. This research focused on determining whether there was a difference in the annual wildlife strike rate by damage category in the United States (US) between 2013 and 2022. Upon analysis, the results revealed that more wildlife strikes reported "none" or no damage to aircraft than minor, undetermined, substantial, and destroyed categories. While most reports reported no damage or minimal damage, collisions between wildlife and aircraft remained a continuous threat, for there were 64,224 reported strikes made within the US by aviators during this period.

Keywords: *Wildlife Strike; Aircraft Damage; Wildlife Strike Rate; FAA Wildlife Database*

1. Introduction

The purpose of this study was to determine whether there was a difference in the annual wildlife strike rate by damage category in the United States (US) between 2013 and 2022. Wildlife strike reports were downloaded from the Federal Aviation Administration (FAA, 2023) wildlife strike database and include all types of wildlife: birds and terrestrial mammals. The rate of wildlife strikes was measured annually; damage is a categorical variable in the wildlife strike database: none, minor, undetermined, substantial, and destroyed. Reports of strikes include all aircraft types, engine types, and times of day. Aircraft operations during strikes are all-inclusive.

This research offers vital insights to pilots, airlines, flight schools, and the broader aviation community regarding the recent patterns of wildlife strikes and the associated damage levels in the US. The findings can deepen understanding of the wildlife strike risks by assessing how often strikes result in varying degrees of damage. Knowledge of these trends is imperative, not only for commercial and GA pilots but also for the aviation industry and wildlife ecologists working with airports to minimize the impact of aviation. By understanding how wildlife strikes vary in damage category, global aviation safety can be enhanced.

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2. Literature review

Wildlife strikes pose a significant threat to aviation safety both in the US and globally; strikes also generate repair costs burdening the airline and aviation industries (Metz et al., 2020). Prior studies on wildlife strikes have shown that they have significant safety and monetary impacts on the industry. This review covers previous findings of studies on the hazard of wildlife strikes, the cost of aircraft damage due to wildlife strikes, and the different types of species involved in strikes.

The continued expansion of the aviation industry has amplified concerns about aviation safety owing to increased plane and wildlife encounters (Metz et al., 2020). Although these strikes occur globally, their severity is affected by factors such as wildlife size, species, and flight stages (Allan, 2000; Metz et al., 2020). Zhang et al. (2022) highlighted the urgency of this situation, noting specific examples of engine malfunctions caused by birds flying into plane engines during takeoff. Furthermore, overlapping bird habitats with environments around airports increases the risk of bird strikes (Dikerts de Tella et al., 2022). The COVID-19 pandemic has provided a unique perspective on this issue (Dikerts de Tella et al., 2022), as the decrease in human activity has increased the presence of wildlife around airports and emphasized the need for solid wildlife management strategies. Despite technological advances, the unpredictable nature of wildlife strikes necessitates the development of adaptive strategies for ongoing monitoring, reporting, and mitigation. Furthermore, changes in wildlife patterns during the pandemic underscore the importance of consistent research, assessment, and collaboration with wildlife experts to provide tools and insights for managing the evolving risks in the aviation industry.

The number of wildlife strikes has been increasing over the years in several countries, posing a substantial threat to aviation safety. Oruç et al. (2022) retrieved data from several countries, including Turkey, the US, the United Kingdom, Finland, and Australia, to evaluate bird strike trends. They documented that the rate of bird strikes per operation had increased. Oruç et al. (2022) found that in 2000, the number of wildlife strikes was 6,666 per 10,000 flights; by 2020, the number of strikes had increased to 18,580. These results indicate a significant increase in wildlife strikes in the US. They also documented a trend by month with increasing strikes in the middle of the year.

When aircraft are damaged by wildlife strikes, the aviation industry incurs a high cost. Allan (2000) used data retrieved from airlines worldwide and from the International Civil Aviation Organization (ICAO). Wildlife that harmed airplanes (i.e., wildlife strikes with damage) or caused a delay in a departure due to wildlife in the vicinity or at the airport resulted in significant financial losses for the airline industry. He also discovered that approximately 1.2 billion dollars is the estimated annual cost of wildlife strikes. The airline industry pays a high cost due to wildlife strikes (Allan, 2000). The cost of damage is a concern when speaking of wildlife strikes; knowing what these strike costs are can help encourage research into more effective solutions. Altringer et al. (2021) studied wildlife strike price tags in the US between 1990 and 2018 using the FAA wildlife strike data. They found that the average annual cost in the US between 1990 and 2018 was 54.3 million dollars. They suggested studying the risk of strikes by individual airports (Altringer et al., 2021). Regardless of the specific estimate, wildlife strikes are an expensive risk to aviation.

When an airplane is struck by wildlife, the damage sometimes exceeds the direct location of the hit on the external structure. Zhang et al. (2022) assessed bird strike damage to fuselage composite structures and found that stiffeners can help strengthen the aircraft fuselage and inhibit the damage caused by the strike-to-strike location. They concluded that aircraft structures can be modified to limit strike damage and reduce its effect (Zhang et al., 2022).

A better understanding of the causes of wildlife strikes can help reduce them, which means reducing the high cost of wildlife strikes through delayed flights or aircraft damage. Metz et al. (2020) collected data from several countries using the Civil Aviation Authority Database. They found that the total cost related to bird strikes in the US between 1990 and 2018 was 5.43 billion dollars. They concluded that bird strikes threaten aviation safety and significantly cost the airline industry (Metz et al., 2020). Strike mitigation appears to reduce the likelihood of occurrence and the level of damage (Martin et al., 2011). Common strategies to avoid potential collisions include deterrents and wildlife irritants. While mitigation is attempted to prevent the severity of damage due to strikes, some damage and a compromise of safety are almost always inevitable.

All types of wildlife threaten aircraft. Strikes involve a range of animal species, from terrestrial mammals, such as deer and possums, to birds. Average bird strike rates between 2.83 and 8.19 per 10,000 aircraft movements were reported in civil aviation for years (Metz et al., 2020). Damage due to bird strikes is rare and only occurs in two to eight percent of aircraft that experience a strike (Metz et al., 2020). Although those numbers seem low, they are not zero, making birds a risk to aviators.

Terrestrial mammals also threaten aircraft. Ball et al. (2021) documented that the annual rate of wildlife strikes is increasing globally. Incidents involving mammals account for 3-10% of all recorded strikes, and mammal strikes have cost more than 103 million dollars in the US over the past 30 years. As many as 44 mammalian families across 47 countries have and will continue to pose a risk to aviation (Ball et al., 2021). Predictably, most mammal strikes occur during landing and on runways (The Wildlife Society, 2021). Among the 79 countries examined, mammal strikes per million aircraft movements per year ranged between 1.2 and 38.7, and these collisions have increased up to 68% annually. Rabbits and wolves were hit most often in Canada, whereas bats and deer were involved in most mammal collisions in the US. In Africa, giraffes have been victims of aircraft collisions, as reported in 2013 (The Wildlife Society, 2021). With mammal-aircraft collisions reportedly increasing, pilots must be more vigilant with ground operations and airports need of wildlife management.

Knowing the types of wildlife that threaten aircraft is essential to measuring the safety risk of damage caused by a strike. Dolbeer et al. (2000) ranked hazardous species in the aviation industry between 1991 and 1998 by retrieving and analyzing data from the FAA database. They found that the gull species group had the highest number of strikes, with 2,599 out of 7,876 strikes. Although gulls have the highest strike rates, they only have a 20% damage rate to aircraft, while deer have 367 strikes and an 87% damage rate (Dolbeer et al., 2000). If more than one bird strikes the aircraft, gulls and doves are most likely involved; however, aircraft damage is most frequently caused by water birds (Dolbeer et al., 2021). The specific species that are threats will vary with location and may change over time, requiring further study as land use and available habitat around airports changes.

Wildlife strikes and collisions between animals and aircraft have significant safety and financial impacts on the aviation industry. Aviation professionals have concluded that bird strikes are more common than terrestrial mammal strikes, and there are studies on the costs accrued from strikes, strikes concerning altitude and region, and ways to mitigate strikes. However, the rate of strikes according to the extent of damage has not been well studied.

3. Methods

The FAA Wildlife Strike Database (FAA, 2023) contains reports of known wildlife strikes on aircraft in the US. Each report includes a variety of information, including strike date, time, airport, airline, aircraft, engine type, damage, and species. Some reports had missing information in one or more fields. Therefore, reports with missing damage information were omitted from the analysis. The variables examined were the calendar date of the wildlife strike report and the damage type. Reports submitted from January 1, 2013, to December 31, 2022 were extracted from the database. At the time of analysis, only some of the 2023 data were available, and therefore, the study was restricted to the 10-year period ending in 2022. The aircraft damage categories specified by the FAA (2023) are none, minor, undetermined, substantial, and destroyed. None indicates no reported damage. Minor damage occurs when only minimal repairs are required to reach airworthiness with no inspection needed. Undetermined is when there was known aircraft damage, but the report did not have details, meaning that the extent of damage was not obvious. Substantial damage includes major damage that affects the integrity of the aircraft and could cause operational issues or influence flight. Destroyed is selected when the damage is so extreme that the aircraft cannot be repaired, and thus, is considered a total loss.

The data in the wildlife strike database are reported to, processed by, and maintained by the FAA, making these reports the best available data on wildlife strikes in the US. However, these reports are voluntary and are submitted by professionals such as pilots, airport operations, and maintenance personnel. However, the data set is known to be incomplete because the database only provides the reported strikes and not all wildlife strikes.

The data were downloaded from the FAA (2023) Wildlife Strike Database for all strikes in the US from 2013 to 2022 and saved in an Excel file. Descriptive statistics were calculated using Microsoft Excel; a one-way ANOVA (Analysis of Variance) and a post-hoc Tukey's test were conducted using RStudio version 4.3.1 to determine if there were any differences in the mean rate of wildlife strikes by damage category. The independent variable was aircraft damage (five categories), and the dependent variable was the annual wildlife strike rate.

4. Results

Between 2013 and 2022, the total number of wildlife strikes reported to the FAA was 145,007. Of these reports, 80,783 were omitted from the analyses because of missing damage categories or reports outside of the specified geographical scope, the 50 United States. The total number of reported wildlife strikes in the US with damage category information was 64,224; this dataset was used for all the analyses. Of these reports, 59,391 were in the "none" or no damage category, 1,217 were strikes with minor damage, 585 were strikes with substantial damage, 9 destroyed the aircraft, and 3,022 strikes had undetermined damage categories.

The descriptive statistics for annual wildlife strikes by damage category from 2013 to 2022 are shown in Table 1. The category with the highest annual rate of strikes was none ($M = 5939.1$), and destroyed had the lowest annual rate of strikes ($M = 1.5$). Figure 1 shows the mean annual wildlife strike reports by the damage category. The none (no damage) category showed the highest variability (Table 1; Figure 2). Figure 3 shows the annual rates by damage category, with undetermined reports increasing over time.

The one-way ANOVA was significant, $F(4, 41) = 406.6$, $p < .001$. A post-hoc Tukey's multiple comparisons of means found that the no damage category reported significantly more annual wildlife strikes than the minor, undetermined, substantial, and destroyed categories ($p < .001$). The other damage category pairings were not significantly different ($p > .05$).

Table 1: Descriptive Statistics for Annual Wildlife Strikes by Damage Category 2013-2022

Damage	Mean	Median	Standard Deviation	Range
None	5939.1	6263	842.07	4118-6825
Minor	121.7	94	71.37	45-233
Undetermined	302.2	347	151.99	72-499
Substantial	58.5	29.5	50.41	19-144
Destroyed	1.5	1.5	0.54	1-2

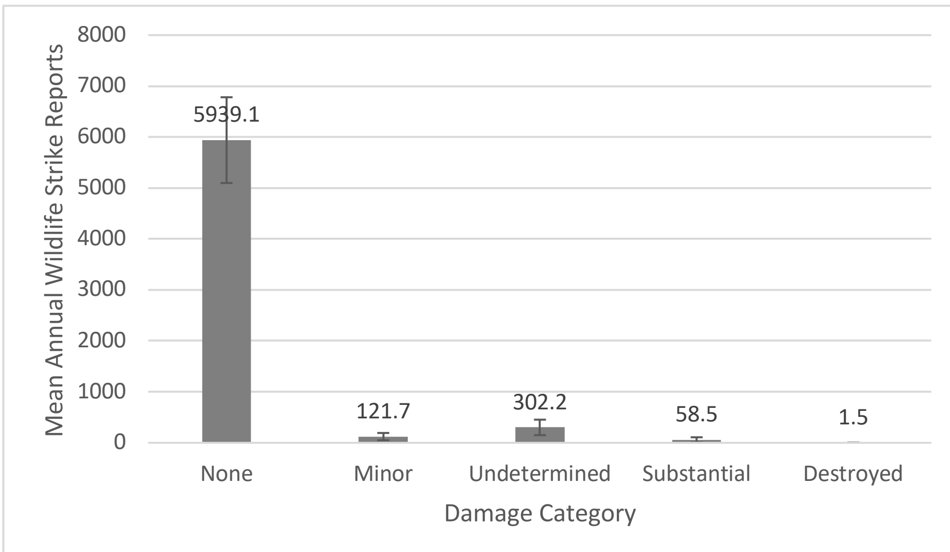

Figure 1: Mean Annual Wildlife Strike Reports by Damage Category 2013-2022

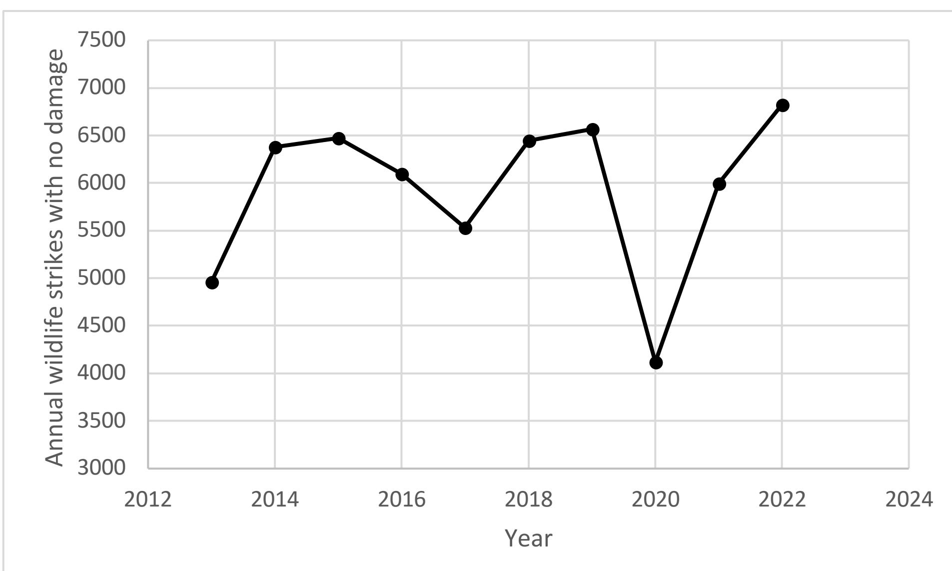

Figure 2: Annual wildlife strikes by year for “None” damage category 2013-2022

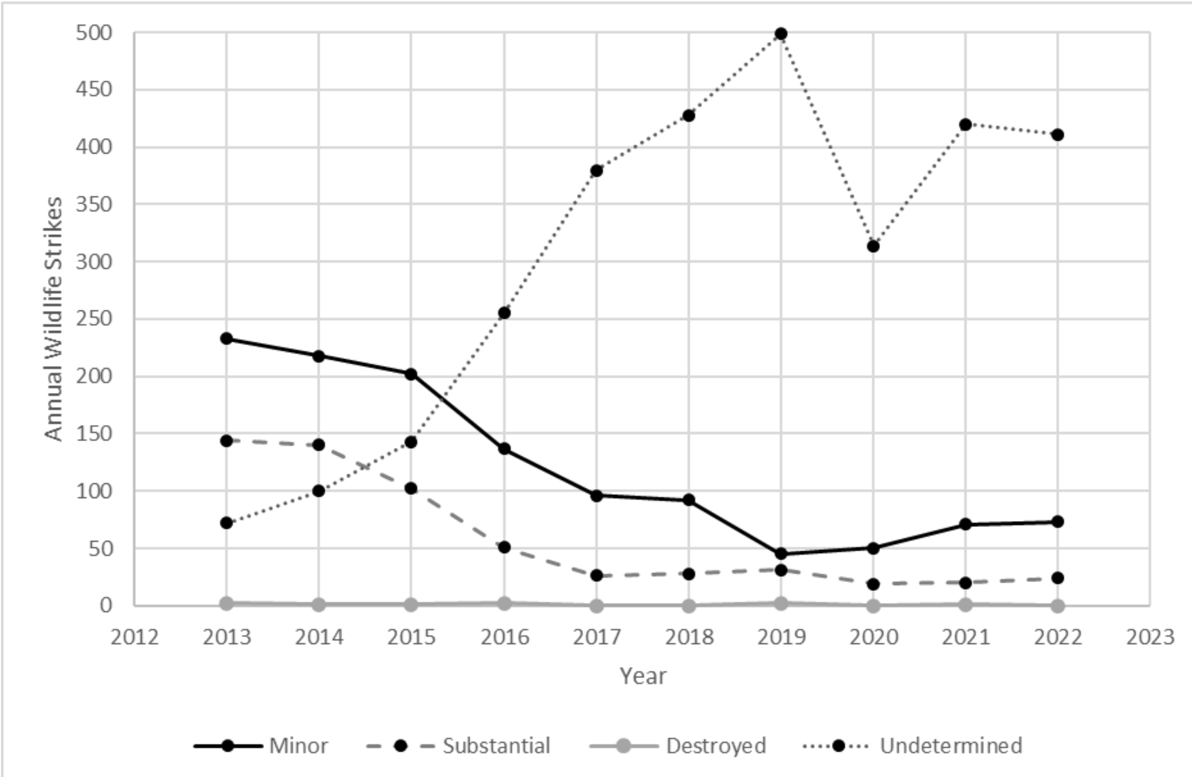

Figure 3: Annual Wildlife Strikes by Year And Damage Category 2013-2022

5. Discussion

From 2013 to 2022, there were more annual wildlife strike reports in the no-damage category in the FAA (2023) wildlife strikes database. The destroyed damage category had the least number of strike reports in the past ten years (Table 1, Figure 1). The significant ANOVA and post-hoc Tukey's test demonstrated that the no-damage category had greater annual wildlife strike reports than any other category and that the other categories were not statistically different in terms of mean annual wildlife strikes. These results indicate that wildlife strikes are much more likely to cause no damage to an aircraft than to destroy it or cause more substantial damage. This means that wildlife strikes have a minimal probability of causing an emergency owing to destruction or resulting in high repair costs. From a safety perspective, this is good news, although even a strike with no or minor damage can still be psychologically stressful. Some of the possible explanations for the larger number of no-damage reports are the relative size of wildlife compared to aircraft and that indirect hits may cause less damage in the event of a strike. Additionally, the large number of reports may be due, in part, to the large wildlife populations surrounding airports and the increasing numbers of operations. Pilot training may also play a part in the larger number of no-damage reports because all pilots train in a variety of emergency situations.

The other heartening pattern over time is the destroyed category, which remained consistently low across the entire decade (Figure 3). In all five damage categories (see Figures 2 and 3), there was a decrease in reports during 2020. This can be attributed to the decrease in the number of operations during the COVID-19 pandemic. Therefore, the risk of wildlife strikes was lower because the travel restrictions led to fewer flights in 2020. The two main limitations of this work are inherent in ex post facto research, in which the dataset is pre-existing. First, the reporting of wildlife strikes is voluntary; therefore, not all wildlife strikes are reported. Second, many reports lacked information regarding the level of damage due to the strike, and thus had to be excluded because that variable was missing. The reality is that assessing damage and making repairs takes time. The pilot or other individual submitting the report may not know the extent of the damage when it was submitted. The trend of reporting, but with incomplete information, seems to increase over time as illustrated in Figure 3 for the undetermined category.

From these findings, it can be concluded that there is a difference in the annual wildlife strike rate by damage category within the US between 2013 and 2022, with none being the most reported damage category, undetermined as the second most reported, minor as the third, substantial as the fourth, and destroyed as the fifth and least reported. Although the no damage category was the most frequent outcome of a strike, minor or substantial damage was still likely to occur. There were 64,224 reports of some degree of damage to the aircraft. Although the results found no damage, to be the most frequent outcome, the threat of wildlife striking aircraft still poses a safety risk to aviators and a financial cost when there is damage. The sheer number of wildlife strikes also underscores the importance for wildlife that we continue to work towards minimizing strikes.

Future research can build on these findings to determine if there is a relationship between the damage category and the type of aircraft or type of operation. This research can determine whether aircraft size is related to the level of damage caused by a strike. Further research on repair costs is needed, particularly with an increasing trend to report unknown damage. Most critically, research is needed on the effectiveness of methods to decrease wildlife strikes and which species are most impacted locally at airports, to inform management plans.

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EXTERNSHIP PROGRAM: INDUSTRY EDUCATOR PARTNERSHIP (IEP) MODEL

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Abstract

Technology is rapidly changing, and industries are upgrading their processes, products, and services with new developments. With the transformation of industries, there is a high demand for a skilled workforce. To prepare a skilled workforce according to industry demand, educators must continuously update their curriculum and their own knowledge and skills regarding current workplace practices, new techniques, and tools. Through the externship program, educators gain direct experiences with current technology, trends, required skills, opportunities, and challenges in industry related to their field of study. This enriches and strengthens their teaching and brings relevance to student learning. Educators improve their pedagogical practices by incorporating new methods, labor market information, and employment skills that meet current industry standards. This paper explains how Fitchburg State University organized the Perkins Teacher Summer Externship Program between 2018 and 2021, the challenges during Covid-19 pandemic, the benefits, and the outcomes of the program, and how this program offered the professional development opportunities for high school teachers by connecting the classroom to the workplace. It reports the benefits and challenges of the “Industry Education Partnership (IEP) Model” and explores industry experiences for teachers (IET) through externship programs. It examines their learning process and how they implemented the skills and knowledge they acquired in the classroom to educate future workforce. Additionally, this program assists educators in building relationships with companies and connecting employers with their future employees.

Keywords: *Externship; Industry Educator Partnership; IEP Model; Perkins*

1. Introduction

In the dynamic landscape of education, a teacher externship program is an innovative initiative aimed at creating relationships between educators and industry professionals (Mani, 2022). It is defined as a “summer work experience in an environment that engages the teacher in engineering or design-based activities in order to gain a practical understanding of how industry uses current tools, processes, and resources to solve technological challenges” (Bowen & Shume, 2018, p. 6). The externship program provides many direct benefits to participating teachers and industry professionals and indirect benefits to students. Major benefits include networking opportunities, professional development, industry immersion, and curriculum enhancement in line with current industry needs (Dresner & Worley, 2006). It provides a learning platform for teachers and fosters rich, relevant learning experiences for students as teachers immerse themselves in real-world industry settings.

Based on their discipline or academic background, they are given learning opportunities by involving themselves in local or regional businesses, research organizations, and technology companies. Collaborative externship projects between industry professionals & teachers, along with hands-on project experiences, enable teachers to gain practical insights that they can seamlessly

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integrate into their curriculum, ensuring that classroom content aligns with industry expectations (Mani, 2022; Saltz et al., 2013). Professional development events during the externship, such as workshops, seminars, and training sessions conducted by industry experts, enhance participating teachers' subject knowledge, and expose them to the latest advancements in their fields.

The externship program provides networking opportunities for teachers with industry professionals, fostering collaboration and creating a bridge between the classroom and the industry. After participating in the program, teachers can update the curriculum with fresh perspectives and include industry-specific projects or case studies as per current industry demand. There is a high demand for a skilled workforce with recent knowledge of technology and skills. The externship program plays a crucial role of transferring recent knowledge and skills to the future workforce (students) via teachers. It also enhances teaching dynamics and pedagogical approaches, improving student engagement and learning outcomes. Additionally, teachers can assist students in providing career guidance toward fields that align with their interests, aptitudes, and current industry trends.

Considering the many benefits of the externship program, Fitchburg State University organized the "Perkins Teacher Externship Summer Program," funded by the Massachusetts Department of Elementary and Secondary Education (DESE), between 2018 and 2021. This paper presents the externship methodology adopted for the Perkins Teacher Externship program and its outcomes. It discusses the industry-educator partnership model as a part of the externship program and its significance for updating curriculum and developing educational policy.

2. Background: Industry Educator Partnership Model and Externship Program

Historically, partnerships between industry and educational institutions were driven by the immediate needs of local or regional industries. In the early 20th century, vocational education programs emerged to provide practical skills to students in response to industry demand. The Smith-Hughes Act of 1917 in the United States supported vocational education programs and formal collaborations between academic institutions and industries (Moore, 2017). In the latter part of the 20th century, technical schools and community colleges-built partnerships with local industries to design and update their curricula. Work-based learning experiences were emphasized in the 1980s and 1990s (Hyland, 2003).

In recent years, the focus of educational institutes and industry partnerships has expanded to include a broader range of activities, such as internships, collaborative research projects, and curriculum development. The need for a highly skilled workforce in STEM fields and the demand for industry experience during high school and associate degree programs have made STEM education and the Pathways in Technology Early College High Schools (P-TECH) education model significant drivers of industry-educator partnerships (Abdul-Alim, 2017; Pattison, 2021).

The industry-Educator Partnership (IEP) model is a strategic alliance between educational institutions and industries designed to bridge the gap between academic learning and real-world applications. It emphasizes collaboration, mutual benefit, and a shared commitment to preparing students for the challenges of the professional world. Key features and benefits of the IEP model include curriculum alignment, internship and co-op programs, research collaboration, professional development for educators, guest lectures and workshops, resources enhancement, innovation and adaptability, professional networking opportunities, and improved employability for students (Nsanzumuhire & Groot, 2020; Watters et al., 2013).

Educational institutes collaborate with industry partners to collect feedback on their curriculum and update them to meet current industry standards and demands. This involves adopting new technologies and tools to prepare a skilled, industry-ready future workforce (Bowen, 2016). Guest lectures and workshops allow professionals to provide students with insights into industry practices, prepare them for potential challenges, and familiarize them with emerging trends and technology. The IEP model facilitates internships and co-op programs, offering students hands-on experiences in real-industry settings and preparing them for their career pathways. The model also encourages collaborative research on cutting-edge technology among industry partners, educators, and students, promoting innovation and a culture of learning. Additionally, this collaboration extends to the professional development of educators through relevant training, workshop, and externship programs.

Externship programs, also known as job shadowing or observational internships, emerged in the mid-20th century in legal and medical fields to provide hands-on or practical learning opportunities for students (Shipman, 2014). Today, externships are used in many fields, including business, engineering, and education. They are generally shorter than internships and are available to both students and teachers, offering immersive experience in industry setting. A typical teacher externship program is described as "a summer work experience in an environment that engages the teacher in engineering or design-based activities to gain a practical understanding of how industry uses current tools, processes, and resources to solve technological challenges" (Bowen & Shume, 2018, p. 6).

The National Science Foundation's Scientific Work Experience Programs for Teacher (SWEPT) and Research Experiences for Teacher (RET) are two popular externally funded programs for teachers to gain industry and research experiences (Bowen & Shume, 2018). The Ignite program (formerly known as the Industry Initiatives for Science and Math Education Program), initiated in 1985, places teachers in industry positions in STEM-related fields for eight-weeks summer work experiences in California. After completing their on-site experiences, participating teachers are required to produce an Education Transfer Plan to integrate the knowledge gained through the work experience into the classroom (Ignite, 2017). Since 1991, the Georgia Institute of Technology has sponsored the Georgia Intern Fellowships for Teachers (GIFT) program, placing an average of more than 75 teachers per year in university and industry settings to gain practical knowledge about current industry practices (CEISMC, 2017). In collaboration with university faculty, local economic development corporations, education cooperatives, and businesses in the upper Midwest region, the Educators in Industry: K-12 Externship program was initiated in 2011 to provide in-service teachers with opportunities to experience how corporations use the engineering design process (EDP) and 21st century skills to solve technological challenges (Bowen & Shume, 2018).

3. Methodology: Framework For IEP Model and Externship Program

Fitchburg State University administered the Perkins Teacher Summer Externship program for academic and vocational programs. This program serves as a common platform for the professional development of high school teachers in Massachusetts. The objective of this program is to provide actual field experience, where teachers spend time in a workplace to learn directly about current technology, trends, required skills, opportunities, and challenges in industry related to their field of study. This experience aims to enrich and strengthen their teaching and bring relevance to student learning (Career Academy Support Network, 2010).

Administering a teacher externship program is challenging, as it requires thorough knowledge of processes, detailed information, and collaborations with various stakeholders. To address this, the author of this paper, a member of the Fitchburg State University externship team, conducted literature reviews to determine the extent of existing research on externship related topics. The primary goal of these literature reviews was to establish an effective mechanism and create necessary documents and forms to ensure the successful organization of the Perkins Teacher Summer Externship program and achieve its targeted benefits for participating teachers and the Massachusetts Department of Elementary and Secondary Education (DESE).

Based on experiences working on this project, the author developed “Industry Educator Partnership (IEP) Model” (Figure 1) and an externship program flow chart (Figure 2). The author also investigated the extent to which the phenomenon of teacher externships can be used as an initiative for creating long-lasting and strong collaborations between institutions of higher education, public organizations, and private organizations in Massachusetts.

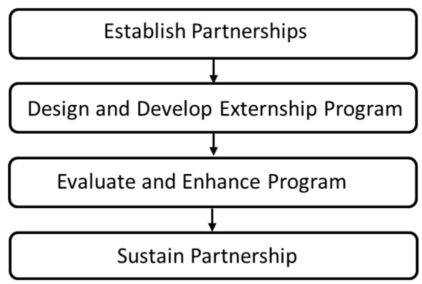

Figure 1. Industry Educator Partnership (IEP) Model

3.1 Establish Partnerships

Developing a robust “Industry-Educator Partnership (IEP)” model for externship program involves creating a structured and collaborative framework that aligns educational outcomes as per current industry needs. Figure 1 shows a framework for the IEP model. First, it is necessary to identify relevant stakeholders and define objectives for the partnership. The stakeholders include educational institutions, industry partners, and facilitators who build and manage the partnership relationship.

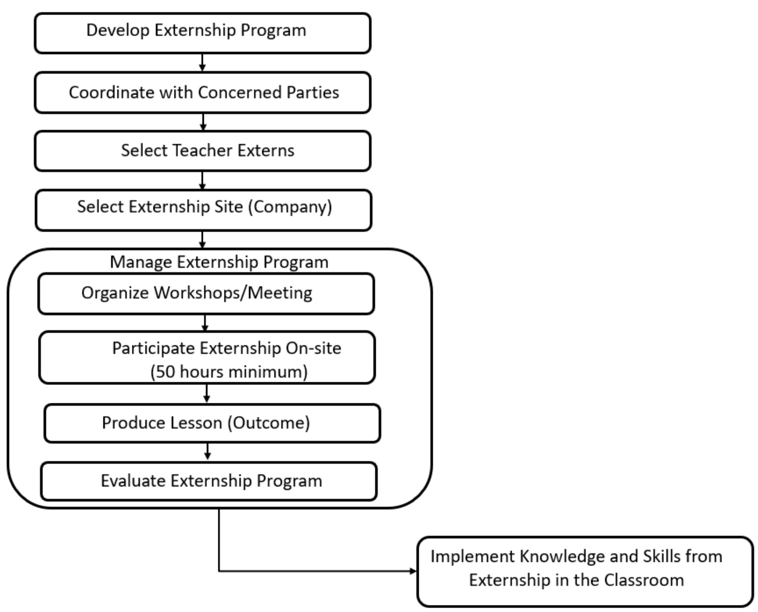

Figure 2. Externship Program Design Flow Chart (Mani, 2022)

The Massachusetts Department of Elementary and Secondary Education (DESE) initiated and funded the Perkins Teacher Externship program. Fitchburg State University administered the program in collaboration with Regional MassHire Workforce Boards to select teachers from high schools and local or regional industries for externship sites. The externship program addresses dual objectives – educational and industry goals. The educational goals including enhancing teachers' (externs') knowledge and skills through practical experiences in an industry setting and aligning curriculum with current industry standards. The industry goals focus on contributing to the development of a skilled workforce.

3.2 Design and Develop Externship Program

The next step is to design the externship program structure by defining the length of the program and creating flexible scheduling to accommodate teacher externs and industry partners. The Perkins Teacher Externship program was scheduled for the summer, with a minimum of 50 hours of on-site work by externs, excluding time for lesson plans preparation, orientation, and workshops at Fitchburg State University. The externship sites were determined based on the academic background of the extern teachers so they could reinforce theoretical knowledge with practical applications relevant to current industry needs. Additionally, extern teachers had the opportunity to earn extra graduate credit by preparing additional lesson plans.

3.2.1 Set Goals and Needs Assessments

Figure 2 shows the flow chart – a methodology of the Perkins Teacher Externship program. Considering the potential benefits of the externship, the Massachusetts Department of Elementary and Secondary Education (DESE) decided to develop a summer externship program for high school teachers in 2018. The DESE selected Fitchburg State University's (FSU) proposal to administer the Perkins Teacher Externship Program from a competitive process based on technical and administrative competence. After discussions, the DESE and FSU team defined the scope, working procedure, and outcomes of the externship program.

3.2.2 Coordinate with Concerned Parties

The major stakeholders for this program are the DESE, Fitchburg State University (FSU) project team members, Regional MassHire Workforce Boards, selected teachers for externship, and employers (companies who provide externship sites for teacher externs) as shown in Figure 3. The DESE also coordinated with the Fitchburg State University Externship Program management/instructional team and regional MassHire Workforce Boards, actively monitored the work progress.

3.2.3 Select Teacher Externs and Externship Sites

Twelve regional MassHire Workforce Boards were represented in the program across the State of Massachusetts. Each Board selected two to four high school teachers based on their regional prioritized selection criteria. The Regional MassHire Workforce Boards were responsible for selecting externship sites based on the teachers' career fields and the course they taught. For example, teachers who taught health careers and health technology completed their externship in hospitals or medical centers. The DESE ensured that the selection of extern teachers promoted diversity and inclusion.

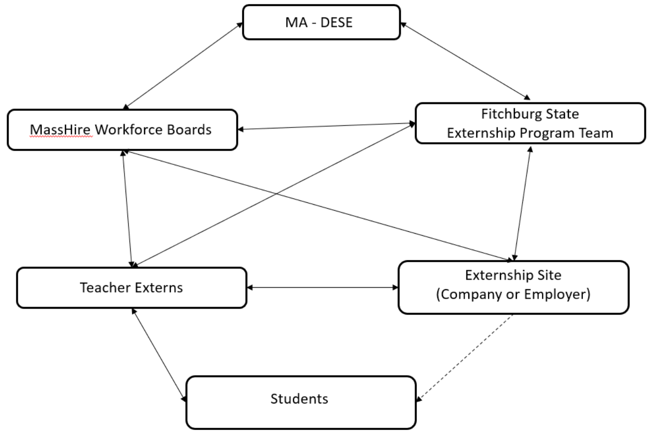

Figure 3. Stakeholders' Relationship for Externship Program

3.2.4 Manage Externship Program

The FSU externship team was responsible for managing and administering the externship program. The management team consisted of three full-time faculty (Dr. James Alicata, Dr. Wayne Whitfield, and Dr. Nirajan Mani) and one Adjunct faculty (Andrew Patenaude) from the Engineering Technology Department. The management team organized three one-day externship meetings. The first meeting was an orientation program that provided participating teachers with information about the externship program, including an overview of the project, externship site visits, administrative processes, available resources, expected outcomes, and the implementation of knowledge and skills obtained from the externship in their classrooms. A Zoom webinar was conducted as a second meeting to inform participating teachers about upcoming meetings, provide additional information about assessment instruments, and outline assignments. During discussion sessions in the third follow-up meetings, teacher externs shared their project experiences with each other and worked cooperatively on developing their lesson plans. The on-site supervisor acted as an industry mentor, providing necessary training, support, and performance evaluations for the extern teachers.

This externship program aimed to provide valuable professional development opportunities for teachers, supporting the integration of academic and technical skills for students. This experience enabled teachers to engage with new and emerging technologies, ensuring rigor and relevance in their curricula and instructional methods. The extern teachers were required to actively participate in workshops held at FSU; complete a minimum of 50 hours of approved externship and submit a lesson plan. Extern teachers also had the opportunity to earn additional graduate credit by preparing extra lesson plans. The site supervisor at the externship employer site provided necessary site-specific information, acted as resources for extern teachers in the development of their lesson plans, and monitored and evaluated each individual extern based upon their successful experience with the program.

3.2.5 Implement Knowledge and Skills

All lesson plans submitted by externs were reviewed and approved by the FSU team and then posted on the Contextual Learning Portal for future references. All externs were encouraged to utilize these lesson plans for teaching in their classrooms and to share their externship experiences with others.

3.3 Evaluate and Enhance Program

The FSU externship team assessed extern teachers based on their performance, skills development, and the learning outcomes achieved during the externship. Additionally, feedback from both extern teachers and site supervisors (industry partners) was collected and analyzed to evaluate the effectiveness of the externship program and identify areas for improvement.

3.4 Sustain Partnerships

There is a need to establishing sustainable partnerships between educational institutions and industry partners for long-term collaboration and commitment. The Engineering Technology Department at Fitchburg State University has established an Industry Advisory Board, inviting representatives from various industry partners. To further incentivize industry partners for future contribution, offering awards, recognition, or incentives for their participation in the externship program would be beneficial.

4. Results and Discussion

In 2018 and 2019, a total of 66 and 55 lesson plans were received from extern teachers, respectively. In 2020, a total of 44-unit plans were received, each consisting of five lesson plans. After thoroughly reviewing these plans, they were classified into different clusters, such as Academics (Math), Academic (English), Agricultural and Natural Resources, Art and Communications Services, Business and Consumer Services, Education, Health Services, Hospitality and Tourism, Information Technology Services, and Manufacturing, Engineering and Technology. Selected plans were posted on the Contextual Learning Portal (http://contextuallearningportal.org/).

Due to the Covid-19 pandemic, virtual orientation and follow-up meetings were conducted in 2020 and 2021. In 2021, the DESE suggested collecting only externship reflections from extern teachers after the completion their minimum 50 hours of on-site work. The FSU team received a total of 40 externship reflections in 2021. Many extern teachers were interviewed individually either on-site or online (during the pandemic). These interviews included discussions with both the externship site supervisor and the externs themselves. They discussed assigned responsibilities, individual strengths, specific details, respecting corporate trademarks and product confidentiality agreements between the teacher and the employer.

The interviews identified specific knowledge and skills (such as technical skills, interpersonal skills, job-specific skills or personal qualities, mathematical reasoning, scientific concepts or methods, creative thinking, and problem-solving skills) that teachers brought to their employer. General job demands, such as measurement, calibration, and familiarity with specific commercial software, were also recognized. Minimal review of individual career and technical education curricula and strands were discussed during the meetings. Many employers prioritized employability skills over specific technical skills, valuing consistent attendance and attention to work details from their employees. Several teachers' specific services for their employers which were reflected in their lesson plans or unit plans.

All industry partners recognized the value that extern teachers brought in communicating opportunities available through their organizations to their students upon their return to schools. Employers were interested in developing pathways to encourage and recruit future employees, viewing teachers as conduits in this process. They acknowledged education's role in providing skills like problem-solving and applying academic subjects in real work situations. Industry partners also sought foundational skills upon which they could enhance and build to meet their organization's specific needs. Several employers noted that employees demonstrating a willingness and aptitude to learn, along with a positive attitude, could advance to the highest levels within their organization.

5. Conclusions

The well-defined Industry-Educator Partnership (IEP) model for the externship program fosters a collaborative environment that benefits stakeholders, such as educational institutions, industry partners, extern teachers, and ultimately students. By implementing effective strategy to build sustainable industry-educator partnerships and align educational curricula with current industry needs, along with necessary support systems, we can improve the quality of education and develop a skilled workforce. The externship program provides actual field experience and an opportunity to learn directly about current technology, trends, required skills, opportunities, and challenges in the industry related to their field of study. This enriches and strengthens teaching practices, making learning more relevant for students.

The Perkins Teacher Externship program, funded by the Massachusetts Department of Elementary and Secondary Education (DESE) and administered by Fitchburg State University, has been successfully completed. The initial goal of this program was to identify specific skills needed for different employment levels in organizations offering externships to high school teachers. We believed that students could enter companies at various levels based on the skills required for each position. Through this program, we learned that the economic demand for a trained workforce is significant, prompting companies to take responsibility for training and advancing positions they wish to fill.

Several employers have identified a new model for employee career advancement. Historically, employees pursued post-secondary education to obtain associate, bachelor's, and graduate degrees before seeking employment. With advancements in technology and distance learning, employers are now willing to guide and sponsor an individual's training and advancement while they remain employed (Mani, 2022). As employees progress in degree programs or skills certifications, they become eligible for advancement within their organizations.

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STRENGTHENING THE CONNECTIONS: THE IMPACT OF MONTE CARLO SIMULATION ON THE ENTREPRENEURIAL MINDSET OF ENGINEERING UNDERGRADUATES

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Abstract

This study explores the integration of financial modeling into the curriculum of engineering decision analysis, to enhance student learning, while preparing them for real-world challenges. We employed frameworks from the Kern Entrepreneurial Engineering Network (KEEN), the Society of Decision Professionals (SDP), and the Corporate Finance Institute (CFI). Undergraduate engineering students participated in a two-phase project: Phase 1 involved creating a 3-Statement Financial Model which consists of Income Statement, Balance Sheet, & Statement of Cash Flows, while Phase 2 expanded this model's complexity. Students conducted discrete scenario analyses and incorporated Monte Carlo simulations to assess financial outcomes under uncertainty. Verification and validation processes ensured model accuracy and reliability. The study demonstrated significant improvements in students' decision-making and practical skills, bridging engineering and finance. In the future, we will explore the relationship between engineering, finance, operations research, marketing, and innovation management. The use of SDP and CFI materials facilitated a robust learning experience, improving student's risk management and ability to make informed decisions. The interdisciplinary approach fostered collaboration, critical thinking, and entrepreneurial mindset. The methodology provided a scalable template for integrating financial modeling into various educational settings, to benefit both academic pedagogy and industry practices. The findings show the importance of experiential learning and interdisciplinary education in shaping proficient, adaptable professionals and engineering entrepreneurs. These insights can inform government policy, promote data-driven decisions in public sector projects, leading to effective and resilient policies.

Keywords: *KEEN Entrepreneurial Mindset; Project-Based Learning; Financial Decision-Making*

1. Introduction

1.1 Background

Project-Based Learning (PBL) emerges as a promising approach with increased interest in educational methods that promote active learning, real-world problem-solving, and collaboration. In engineering education, PBL engages students in practical, team-oriented projects, honing their skills and deepening their understanding through active participation in real-world scenarios. This study focuses on the second phase of PBL implementation in an undergraduate engineering course

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on the Analysis of Decision Processes. During this phase, students enhanced their projects by developing advanced 3-statement financial models (income statement, balance sheet, and cash flow statement) for a startup company. They also incorporated sensitivity analysis using Monte Carlo simulations to explore various financial scenarios. The study evaluates the effectiveness of PBL in improving students' understanding of financial decision-making and the development of an Entrepreneurial Mindset (EM) as promoted by the Kern Entrepreneurial Engineering Network (KEEN). Insights are provided for enhancing engineering education. (Guo et al., 2020; Hylton et al., 2019).

1.2 The Kern Entrepreneurial Engineering Network (KEEN)

The KEEN initiative is revolutionizing engineering education by integrating theoretical knowledge with practical entrepreneurial skills. Central to this initiative are the 3Cs of the entrepreneurial mindset: connections, curiosity, and creating value (Rae & Melton, 2017). KEEN aligns these principles with essential engineering skills to foster a comprehensive learning experience. Connections aim to create a collaborative and interconnected learning environment. This involves forming significant partnerships with industry, academia, and the entrepreneurial community, enriching the educational journey, and improving risk management (Gorlewicz & Jayaram, 2020). Interaction with industry experts and entrepreneurs provides students with a comprehensive understanding of problem-solving techniques, opportunity discovery, prototyping, and the vetting of technical and business solutions (Zappe, Cutler, & Gase, 2023). Curiosity is essential for cultivating an entrepreneurial attitude. It emphasizes encouraging engineers to actively seek current information and adapt to their environment. This desire for discovery and comprehension allows engineers to ask critical questions, find unique opportunities, and create novel solutions. This enhances their educational experience besides preparing them to contribute meaningfully to their industries (Kavale, et.al, 2023). Creating value focuses on making a positive societal impact. Engineers are encouraged to prioritize others, set clear goals, and communicate effectively. Addressing real needs, using resources creatively, and transforming underutilized assets, engineers shift from solving problems to becoming innovators who drive global change, to deliver solutions that benefit people, society, and the environment (Williams & Kline, 2020).

1.3 Society for Decision Professionals (SDP)

Decision analysis is the discipline that combines decision theory, methodology, and professional practice to responsibly analyze problems, guiding decision-making under uncertainty. (Keeney, 1982) This systematic, quantitative, and visual approach breaks down complex decisions into manageable parts. The methodology typically follows four steps: framing and structuring, analysis and modeling, organizational capability, and additional topics. A fundamental aspect of decision analysis is decision theory, which integrates principles from mathematics, statistics, and psychology to evaluate decision options based on their potential outcomes and associated risks. It encompasses the circumstances and laws governing decision-making, including actions, outcomes, loss and utility gain considerations, multi-attribute utility theory, elicitation, consistency checking, optimization, and sensitivity analysis.

1.3.1 Frame and Structure

The frame & structure phase centers on clearly defining the decision problem by identifying objectives and key factors. (De Almeida & Bohoris, 1995) This phase combines soft skills & facilitation with the use of framing tools & methods. Establishing a structured foundation allows decision-makers to systematically evaluate options, resulting in informed and robust decisions. Soft skills & facilitation create a supportive environment where stakeholders feel empowered to contribute ideas and voice concerns, which leads to comprehensive problem structuring. (Taylor, 2016) Among these soft skills are adaptability, communication, creative thinking, dependability, work ethic, teamwork, positivity, time management, problem-solving, and conflict resolution. Framing tools and methods represent the approaches employed to structure and visualize decision problems that facilitate comprehension and analysis. Among these tools are decision trees, which show decision nodes, chance nodes, and terminal nodes. Decision nodes represent points where choices are made, chance nodes encapsulate uncertain outcomes, and terminal nodes signify results or endpoints.

1.3.2 *Analysis and Modeling*

Value-focused thinking centers around decision objectives, creating clear goals and aligning actions to achieve creative solutions. Uncertainty and Risk Analysis address unknowns by using probabilities and simulations to guide optimal choices. Decision Analysis Models, such as decision trees and influence diagrams, represent complex decisions, visualize scenarios, and calculate values for informed decision-making. Real Options theory enhances decision analysis by introducing flexibility, treating decisions as opportunities like financial options, while accounting for future uncertainties. Portfolio Decision Analysis evaluates multiple decisions simultaneously, maximizing value and managing risk across the entire portfolio, thus promoting strategic decision-making. (Parnell, 2013).

1.3.3 Organizational Capability

Organizational capability emphasizes the need for dynamic skills to handle complex decision-making to have a competitive edge in the market. (Konopik, et al., 2022). Implementation of Decision Analysis allows the organization to implement a framework which helps define decision issues, compare alternatives, and synthesize data while accounting for uncertainties. This strategy ensures systematic evaluation and stakeholder participation, which improves intervention planning and execution through evidence-based interventions. (Smith, et al., 2022). Training and Development focuses on the importance of a structured training program for the purpose of allowing engineers to develop continuously which will allow them to adapt to the volatile and highly competitive industry standards. (Tannenbaum, 1992). Embedded Decision Analysis is important for handling complex problems. Embedded decision analysis techniques are used when decisions are made based on vague and contradictory assumptions. (Taherdoost, 2023)

1.3.4 Additional Topics of the SDP Framework

Cognitive biases are systematic thinking errors that affect decisions and judgments. Some examples are overconfidence, confirmation bias, and the availability heuristic. These biases twist how we perceive and interpret information, leading to poor decision-making. (Hayes, n.d.) Game theory looks at interactions where individual outcomes depend on the actions of others. It deals with dilemmas like the prisoner's dilemma and the Nash equilibrium, which are key for predicting behavior in decision-making. (Caputo, 2013) Societal decisions are made by groups or communities and impact the broader public. These choices often require balancing competing interests and values, dealing with issues like collective welfare, resource allocation, and policy creation. (Society of Decision Professionals, n.d.) Personal and life choice decisions involve personal or family matters, involving risk assessment, long-term planning, and emotional influences. Decisions such as career changes, marriage, or investments combine rational analysis with personal values and can be affected by present and projection biases. (Ozdemir, 2018)

1.4 Problem Statement

Building on current literature, this study, the second phase of a larger class project used Monte

Carlo simulations in a Project-Based Learning framework to enhance undergraduate engineering education. It aimed to increase students' curiosity (C1) in financial knowledge while strengthening connections (C2), {i.e., foster teamwork} within teams, extending beyond the traditional engineering boundaries of designing, building, and testing.

1.5 Research Question (RQ)

RQ1: How can Monte Carlo simulations sensitivity analysis of financial statement enhance engineering students' understanding of financial decisions in a project-based learning course?

1.6 Contribution

This study is expected to contribute to engineering education by demonstrating the effectiveness of Monte Carlo simulations in teaching financial decision-making. It aims to enhance students' understanding of sensitivity analysis, improve collaboration skills, and prepare them for real-world financial challenges in engineering projects.

1.7 Structure

The remaining sections of this study explore Methods & Materials (Section 2.0); the Results & Analysis (Section 3.0), and the Discussion, Implications, Limitations, and Conclusions (Section 4.0).

2. Methodology

2.1 Participants

The participants in this research study were undergraduate engineering students enrolled in the "Analysis of Decision Processes" course. The cohort consisted of approximately 20 undergraduate students. The objective was to immerse these students, who primarily had non-financial backgrounds, into the process of economic modeling and decision analysis using the Society of Decision Professionals (SDP) framework. (Society of Decision Professionals, n.d.). The project was subject to a schedule of 4 months.

2.2 Evaluators

This research was supported by a professor who is both an industry expert and entrepreneur. In addition, four industry professionals, currently enrolled as students, contributed to the evaluation process. Their combined practical experience and academic involvement provided key insights into the application of economic modeling and decision analysis within the context of the SDP framework.

2.3 Research Framework and Tools

The SDP framework was selected as the foundational methodology due to its comprehensive approach to decision-making processes and its applicability to real-world scenarios. The framework is well-documented and can be accessed through the Society of Decision Professionals' online library, specifically DecisionPedia. (Society of Decision Professionals, n.d.) To facilitate economic modeling and analysis, Microsoft Excel was utilized extensively. Resources from the Corporate Finance Institute were incorporated to supplement the students' learning and application of financial modeling techniques. These tools provided necessary training and support to the students, helping bridge the gap between their engineering knowledge and financial analysis skills. (corporatefinanceinstitute.com. n.d.).

2.4 Study Design

The study was divided into two distinct phases: Phase 1: Preliminary Economic Modeling: This initial phase involved the creation of a 3-Statement Financial Model, focusing on the basics of financial statements—income statement, balance sheet, and cash flow statement. The details of this phase have been comprehensively documented in a separate journal article and will not be elaborated upon in this section. Phase 2: Advanced Economic Modeling and Analysis: The second phase, which is the primary focus of this study, required each student team to significantly expand the size, scope, and complexity of their initial economic models. This phase was designed to challenge the students to apply and extend their learning to complex, real-world business scenarios.

2.5 Analytical Procedures

Discrete Scenario Analysis: Each student team conducted a detailed Discrete Scenario Analysis. This involved creating "Optimistic (Best Case), “Pessimistic (Worst Case)," and "Most Likely Case" options for key variables across all three financial statements (Income statement, balance sheet, statement of cash flows). The variables analyzed included decisions related to land location, building type, machinery, and personnel requirements. This analysis allowed students to explore different strategic outcomes based on different assumptions and conditions. Probabilistic Sensitivity Analysis (Monte Carlo Simulation): Besides the discrete scenario analysis, each team modified their economic model to incorporate Monte Carlo simulation. This statistical technique enabled the teams to perform thousands of iterations, thereby analyzing the impact of uncertainty and variability on their economic models. Monte Carlo simulations were valuable in understanding the range of outcomes and the probability distributions of key financial metrics.

2.6 Verification and Validation

To ensure the accuracy and reliability of the models, a thorough verification process was conducted. Graduate students, along with the course professor, reviewed the models to check for logical consistency and computational accuracy. Validation was carried out by the individual team members, who scrutinized the assumptions and risks previously determined during the scenario analysis. This dual-layered approach helped in maintaining the integrity of the economic models.

2.7 Repeatability and Reproducibility

The repeatability of the models was tested through the thousands of Monte Carlo iterations conducted by each team. This simulation process demonstrated that the models could consistently produce reliable results under different conditions. Reproducibility was ensured by the standardized use of tools and methods across different teams. Despite each team working on business-specific values, the consistent application of the SDP framework and financial modeling techniques ensured that the analytical processes were consistent and replicable.

3. Results

Monte Carlo simulations are a powerful tool used to understand the impact of risk and uncertainty in financial forecasting and decision-making. In this study, Monte Carlo simulations were employed to extend the initial financial models created by the student teams. The simulations provided a probabilistic approach to assess the potential outcomes of various financial decisions, enhancing the robustness and reliability of the economic models.

The simulations were integrated into the three-statement financial models—comprising the Income Statement, Balance Sheet, and Cash Flow Statement. Each simulation involved thousands of iterations in Microsoft excel, with each iteration representing an outcome based on a set of input variables. These input variables included key financial drivers such as revenue growth rates, cost of goods sold (COGS), operating expenses, capital expenditures, and working capital changes.

3.1 Expected Results

Before running the Monte Carlo simulations, the expected results were based on deterministic scenarios—'Good,' 'Better,' and 'Best'—that provided a range of potential outcomes. These scenarios helped establish a baseline for comparison with the probabilistic outcomes generated by the Monte Carlo simulations. For instance, in the deterministic scenario analysis: **Good Scenario**: Assumed conservative estimates for revenue growth, moderate cost increases, and average operational efficiency. **Better Scenario**: Assumed moderate revenue growth, stable costs, and slight improvements in operational efficiency. **Best Scenario**: Assumed optimistic revenue growth, cost reductions, and high operational efficiency.

3.2 Results from Monte Carlo Simulations

The results from the Monte Carlo simulations provided Expected Values of outcomes for key financial metrics for both the Income Statement and Balance Sheet measures. While each team generated their own unique value relative to their three-statement financial model (Income Statement, Balance Sheet, Statement of Cash Flows), below we show the results from the data of a student team whose project was on the manufacturing expansion of an existing regional business. The results presented below are from Monte Carlo simulations of 1,000 iterations using real historical values as well as proforma financial projections for various elements selected financial statements and related financial ratios.

Metric	Expected Value
Net Sales	2,987,545
Gross Profit	1,606,132
Operating Income	839,563
Net Profit	629,698

Figure 1. Result of Monte Carlo Analysis for Income Statement

Metric	Expected Value
Current Assets	2,119,863
Property, Plant, and Equipment	2,210,056
Current Liabilities	1,937,534
Long Term Liabilities	999,754
Equity	2,063,572

Figure2. Result of Monte Carlo Analysis for Balance Sheet

Profitability

Ratio	Expected Value
Return on Equity	30.9%
Return on Assets	10.0%
Return on Capital Employed	26.9%

Leverage

Ratio	Expected Value
Debt-to-Equity Ratio	141.9%
Equity Ratio	34.3%
Debt Ratio	48.8%

Efficiency

Ratio	Expected Value
Accounts Receivable Turnover Ratio	9.00
Inventory Turnover Ratio	4.91

Liquidity

Ratio	Expected Value
Current Ratio	1.10
Quick Ratio	0.71
Cash Ratio	0.64

Figure 4. Result of Monte Carlo Analysis for Financial Ratios

4. Discussion

4.1 Interpretation of Results

The sample output above illustrates the range of potential financial outcomes over a five-year period. The mean and median values provide a central estimate, while the standard deviation indicates the variability and risk associated with each financial metric. The results highlight the importance of probabilistic analysis in understanding the full spectrum of outcomes and making informed decisions under uncertainty. By comparing the deterministic scenarios with the Monte Carlo simulation results, students gained a deeper understanding of the potential variability in their financial projections. This comparison also underscored the importance of considering a wide range of outcomes in financial decision-making, rather than relying solely on deterministic models.

4.2 Implications

This study highlights the significant benefits of integrating Monte Carlo simulations and financial modeling into the engineering curriculum. It promotes interdisciplinary learning, enhancing students' decision-making and practical skills by bridging engineering and finance. The team-based approach fosters collaboration, preparing students for real-world professional environments. For academic research, the study provides a valuable case for advancing pedagogical methods, assessing learning outcomes, and fostering interdisciplinary research. It contributes to decision science by demonstrating the effective teaching of complex analytical tools. Scalable and adaptable methodology can be applied across various disciplines, making it a valuable resource for educators and researchers aiming to enhance their curricula (RQ1). This research can inform government policy by demonstrating the importance of integrating advanced financial modeling and decision analysis into educational curricula. Policymakers could support initiatives that enhance interdisciplinary learning, preparing a workforce adept at managing complex economic and technical challenges. The use of Monte Carlo simulations and decision frameworks can also be applied in the public sector projects to enhance policy impact evaluations, improve risk management, and promote data-driven decision-making, leading to effective and resilient public policies.

4.3 Limitations of the Study

Confirmation bias Our inherent tendency is to notice, focus on, and give more weight to evidence that aligns with our preexisting beliefs. Hyperbolic discounting is our tendency to prefer immediate, smaller rewards over larger rewards that are delayed into the future.

4.4 Suggestions for Future Work

The authors plan to continue research on the application of the principles noted in this research study, specifically more topics from the Society of Decision Processes, such as “Framing Tools,” “Real Options,” and “Cognitive Biases.”

5. Conclusion

This research study demonstrates the significant benefits of integrating advanced financial modeling and decision analysis into the engineering curriculum (RQ1). By employing the Society of Decision Professionals framework and tools such as Monte Carlo simulations, students gained practical skills in economic modeling and risk management, bridging the gap between engineering and finance. The interdisciplinary approach fostered collaboration and enhanced decision-making abilities, preparing students for real-world challenges, and shaping the engineering entrepreneurs of the future. The study's methodology offers a scalable and adaptable template for various educational settings, contributing to both academic pedagogy and industry practices. Additionally, the findings underscore the value of experiential learning and the importance of interdisciplinary education in shaping a proficient and adaptable workforce. These insights can inform government policy, promoting data-driven decision-making and risk assessment in public sector projects, leading to more effective and resilient policies.

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