Design of a Flight School Decision Support System

Final Report

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1. Context

1.1 Pilot Shortage

In the United States, aircraft pilots are people who have been authorized to operate aircraft by the United States Government through the Federal Aviation Administration (FAA) or through the Armed Services. Under the FAA, civilian pilots are categorized by certificates which assign limitations to their holders. These certificates, in order from most limited to least, are for student, recreational, light sport, private, commercial, and airline transport pilots (ATP). One significant difference between commercial licenses or airline transport licenses and the ones preceding them is that a commercial license allows pilots to get paid for flight, as do airline transport licenses. Additionally, in order for pilots to be able to command an aircraft for airlines, they need an ATP license.

Pilots are essential to quick and efficient transportation of people around the world. Unfortunately, a large portion of today’s commercial pilot force is approaching the mandatory retirement age and there aren’t enough younger pilots to replace them. In 2007, the U.S. government took action to slow the pilot shortage by passing the “age 65 rule.” House Bill H.R. 4343 extended the mandatory retirement age from the previous age of 60 to the age of 65, granting senior commercial pilots more time to work [27].

New FAA regulations also require 1500 hours of flying experience, three times the previous amount, further reducing the number of qualified pilots available for hire. As stricter regulations for career pilots begin to take effect, the probability is high that university and collegiate flight institutions will become the preferred method of flight training, as they will be able to offer students accredited curricula which could decrease the number of flight hours a candidate needs in order to be considered for employment [27].

One trend that has already been noted is a decrease in the total number pilots as well as of new pilot licenses being issued. In 1999, the total number of active pilot certificates in the United States was 635,465. As of 2013, the number of active certificates had dropped to 599,086 – a decline of 6% [28]. The number of original certificates being issued per year at the student level has also decreased since 1990. Less student pilot certificates are being issued which indicates a shrinking pool of individuals looking to earn private certificates. Because earning a private certificate is required in the process to earning an airline transport pilot certificate, this also indicates a shrinking quantity of pilots able to earn the latter.

The Certificated Flight Instructors (CFIs) are also in decline, with the certificate following the trend of decreasing issuance. There exists a 38% drop in the number of CFIs being certified from 1990 to 2009 [27].

Fewer people are becoming certificated pilots and pursuing advanced pilot certificates and ratings. There is not only a declining number of pilots overall, but a dramatic decrease in pilots who are specifically qualified for employment in commercial aviation operations. According to the FAA Civil Airmen Statistics data [28], the total number of new licenses issued for student, recreational, private, commercial, airline transport, rotorcraft, and glider pilots in
1990 was about 157,000. In the year 2013, the total of number of new licenses issued, now including sport pilots to the already mentioned list, reached around 85,000. This was an overall decline of over 45% in the course of 23 years.

Figure 1 represents the number of new certificates issued for student, private, and airline transport pilots between 1990 and 2013 [28]. The rate of issuance for both student and private certificates has been declining over the 23 year interval. In 2004, the sport pilot license was introduced with the aim of lowering the barriers of entry into aviation and making flying more affordable and accessible. This may be the cause of the small peak in the number of student pilot certificates issued between 2005 and 2008. The decrease is concerning because although right now the number of ATP pilots is stable, it takes several years to move from a student pilot to an ATP pilot so with a decrease in student and private licenses it is expected that in the near future the number of ATP pilots will also decrease.

**Figure 1:** Pilot Throughput is Decreasing

As the number of new pilots decreases, the average age of pilots is increasing. Figure 2 [28] depicts the age distribution for all pilot license holders, from students to ATP, in 1999 and 2013. As shown in Figure 2, the age group with the most pilots in 1999 was 40-44, marked in polka dots. In 2013, over a decade later, the age group with the most pilots was 55-59, marked in stripes. After running a significance test at a 95% confidence interval, it was found that the mean age in 2013 had increased to 44.88 years over the mean of 43.59 years in 1999. With a sample size in excess of 600,000 pilots each for both years, this was determined to be a significant result. Additionally, the total number of pilots decreased from 635,465 in 1999 to 599,086 in 2013 which totaled in a 6% decline of pilots. A concern here is that the younger group of pilots does not contain as many individuals as it did in 1999. This suggests that after retirement and other
attrition in current pilots, there may not be enough pilots to satisfy future demand. Since there is already a decline in the number of new pilot licenses being issued and in the total number of pilot license holders, it is likely that the average age of pilots will continue to increase.

**Figure 2: License Holders are Aging**

To further support this point, current estimates for future demand in the aviation industry combined with estimates for supply (in Figure 3) show that there is a gap growing between the actual number of pilots and the needed number of pilots [30].
1.2 Flight Schools

Flight schools are the mechanism by which individuals become pilots. They come in three categories: private, university, and military. A private flight school is an entity owned and operated as a for-profit organization. A university flight school is attached to an accredited university program. A military flight school is a center where the armed forces train recruits in aircraft operations.

Figure 4 below shows the benefits and drawbacks of each of these options. For private schools, one benefit is that students can learn at their own pace, however, the cost and duration in private schools is not fixed. For university students one positive is the monetary assistance they have access to. One negative is going through the admission process of the school. For military, one positive is not paying to fly the aircraft but a negative is the rigid military schedule. This project focuses on private flight schools, because these are the schools whose businesses are struggling.
<table>
<thead>
<tr>
<th>Types of Flight Schools</th>
<th>Number of Schools</th>
<th>Advantages</th>
<th>Disadvantages</th>
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</table>
| PRIVATE (Part 141)     | 410              | • Enroll any time without admission requirements  
                          • Learn at your own pace  
                          • Cost and duration not fixed  
                          • Own a certificate rather than a degree  | |
| UNIVERSITY             | 113              | • Earn a degree  
                          • Receive governmental assistance (scholarships, grants, loans, G.I. Bill etc.)  
                          • Admission process  
                          • Less flexible schedule  | |
| MILITARY               | 11               | • G.I. Bill and other military grants help with costs of school  
                          • Fly aircraft free of charge  
                          • Rigid schedule  
                          • Duty service prior to benefits  | |

Private flight schools come in two types, each labeled for the set of FAA regulations under which they have authority to train pilots: Part 141 and Part 61. Both sets of regulations define minimum requirements for pilot training and certification [29]. Part 61 schools are not FAA accredited schools, but have FAA certificated instructors. A big difference is that Part 61 schools have less FAA oversight and a more relaxed training regimen, which means that they have the flexibility to rearrange flying lesson content. However, the minimum number of hours to earn a license is higher for part 61. This type of school is therefore more flexible and better for students pursuing their license on a less regular schedule. A Part 141 school is both FAA certified and has FAA certificated flight instructors. Greater FAA oversight and more rigorous training criteria afford students the option of earning a certificate in less amount of time than at a Part 61 school [31]. This school is therefore better for full-time students pursuing a career in aviation. Both types of school require potential pilots to meet the same standards of performance.
For more pilots to be created to solve the problem of the pilot shortage, people need to go earn pilot licenses through flight schools. However, currently flight schools are not moving students through the training quick enough to fill this gap. One problem is that flight schools are reporting a shortage of qualified flight instructors [26]. The Certificated Flight Instructor (CFI) certificate follows the trend of declining certificate issuance. There is a roughly 38% drop in the number of CFIs being certificated each year [27].

Figure 6 shows the decreasing trend of people being certified as flight instructors [27]. Figure 7 also shows that the number of people certified as CFIs does not accurately describe the number of active flight instructors [27]. The striped area shows the number of active CFIs, the CFIs that have trained and endorsed students for their practical test in the preceding five years. While the number of total CFIs has remained relatively constant, the number of active CFIs is decreasing.

**Figure 6: Number of new CFIs**

![New CFI Certificates Issued](image)
Employment as a CFI is widely accepted as a stepping-stone to a career as a professional pilot while instructors build time and experience necessary to become marketable candidates for careers with airlines. There are very few CFIs who earn the rating with the intention of spending a career as a flight instructor. 60-80% of flight instructors remain as CFIs within an average time period of 8-12 months, with outliers as short as 4 month periods [27]. This retention problem makes it difficult for flight schools to have consistency with flight instructors. The problem with high turnover is that CFIs will be transitioning out of this role so quickly that there won’t be instructors to train new instructors to take their place. These turnover rates barely allow new instructors to learn how to perform the basics of their job, let alone develop the skills of a good aviation educator.

1.4 Airline Transport Pilot Progression

Figure 8 details the most common path to becoming an ATP for civilians, containing the order in which certificates are obtained and the current delta cost range of each stage in the process [26]. The prices are a range because the cost depends on what part of the country the student is in, whether they are studying at a Part 141 or Part 61 school, and how many hours it takes them to complete the license. To obtain a given certificate, the potential pilot must also obtain each preceding certificate.

First, a student would earn a private license at a minimum requirement of 35 flight hours under Part 141 regulations [29]. Once a pilot has a private certificate, that pilot can obtain an instrument rating, requiring 50 hours of cross-country flight time. Following the instrument rating is the commercial certificate, which authorizes a pilot to be paid to fly. This requires 190 hours for students under 141 regulations. After obtaining a commercial certificate, pilots can
work up to the 1500 hours needed before earning an ATP license. Many pilots choose to earn hours by working as a Certificated Flight Instructor (CFI), training other pilots. A pilot also needs multi-engine and jet engine ratings to become an ATP.

The largest group of fliers has a student certificate. According to the Chief Flight Instructor at Dulles Aviation 80% of students never earn a license. So, after earning all of these licenses, only a fraction of students become ATPs.

**Figure 8: Typical ATP Progression**

The following diagram shows a similar progression as in Figure 8. It also shows a range of prices for each license. It is a range because it depends on location and the type of flight school a student is attending. For a student license, the only cost is a third class medical certificate. The rest of these are delta costs. So it costs $5,000-$12,000 for a private license, then an extra $6,000-$10,000 for an instrument rating and so on. By the time a pilot works up to an ATP license, they would have accumulated costs around $100,000. This diagram also illustrates that the largest group of fliers has a student certificate. According to Tom Adams, the Chief Flight Instructor at Dulles Aviation, about 80% of students never earn a license. After earning all these licenses, only a fraction of students become ATPs.
Figure 9: Typical Costs to Acquire Licenses

![Typical Costs to Acquire Licenses](image)

1.5 Aircraft Operations Cost Model

The cost of obtaining a private pilot certificate has increased uninterrupted since 1990 [24]. There appears to be an approximate correlation in the price of aviation gasoline, typically used to fuel primary training aircraft, which has nearly doubled over 20 years [25]. While the price of obtaining a private pilot certificate seems to follow the trend in aviation gasoline prices, the correlation is not directly proportional, suggesting other factors influencing cost. Such factors include cost of obtaining and maintaining aircraft for student pilots to use. Many of the primary trainers currently used by flight schools are getting older, incurring additional maintenance costs and preventing the planes from flying.

Figure 10 shows an aircraft operations cost model which details the costs associated with acquiring and operating an aircraft. It includes where the fuel price and maintenance would fit into aircraft operations by a flight school. First, flight schools need to acquire the aircraft. When buying the aircraft the principle costs to consider are taxes, price of aircraft, and insurance. Next, flight lessons can be scheduled and then conducted by flight instructors. The costs to consider are fuel and cost of instructors. These aircraft require scheduled and unscheduled maintenance, requiring parts and labor performed by the maintenance technicians. Since some of the costs recur even when the plane is not being flown, such as tie down space to store the aircraft, the more an aircraft is flown the less it costs to keep at the margin. Greater use of the aircraft also spreads use-based recurring costs out over greater revenue streams.
1.6 Flight School Industry Trends

There are several trends occurring in the aviation industry giving insight into the current flight school industry situation. The graph in Figure 12 compares the data for cost of private training in a study by the University of North Dakota [30] to the data for the cost of aviation gasoline obtained from the US Energy Information Administration. As the graph shows, the rise in training costs correlates to the rising cost of aviation gasoline. The graph shows that the price of training is roughly proportional to the price of fuel. Clearly, this is not a one-to-one correlation, as from 1990 to around 1996 the cost of aviation gasoline fluctuates with a minimal range in which there is not significant change in price, while in that same period of time the cost of pilot training keeps increasing. This however, does not disprove a correlation but rather indicates that fuel price is not the only factor influencing the price of training. It is important to note that the aviation gas information is not jet fuel but rather aviation gasoline which is generally used for pilot training.
Another possible contributor to this rise in cost of training is aircraft price. The graph in Figure 13 compares the data for cost of private training to the data for the cost of a Cessna 172 M, which is a very popular primary training aircraft. In 1990 it cost about $175,000 in 2015 dollars to purchase a Cessna 172, and that increased to about $315,000 in 2012. Other costs which are also contributing to a rise include the cost of insurance, which has been mentioned to be between $7,000 and $8,000 per aircraft, and the hourly cost of maintenance for these aircraft. Between 1992 and 2012, there was a 122% increase in Cost of Private training. If we compare this to a 265% change in wholesale aviation gas, a 254% increase in retail aviation gas, and a 266% increase in student loans, we can see that there are multiple contributors to the rise of cost of training.
Figure 13: Cost of Private Training and Cessna 172

Figure 14 shows a downward trend in the number of flight schools between 2005 and 2011, with fluctuations following until 2014. Between 2005 and 2011, the number of establishments dropped by about 150, or about 13% of the total flight schools in 2005 [29]. The reduction in the number of schools could mean fewer options for potential students to choose from and the resulting lower supply combines with the expenses of operating aircraft to drive up the price for obtaining a pilot’s certificate, potentially lowering demand.

Figure 14: Downward Trend in Number of Private Flight Schools
2. Scope

This project is focused on private flight schools, with a focus on the costs associated with flying single-engine primary trainer aircraft. The diagram below shows the life cycle of a primary trainer aircraft. Our project is focused on the costs associated with owning the aircraft, including storage, maintenance, fuel, CFIs, and insurance.

**Figure 15:** Downward Trend in Number of Private Flight Schools

3. Problem and Need

3.1 Problem Statement

As mentioned in earlier sections, the observed decline in total pilots as well as in new licenses being issued in the aviation sector correlates with trends of increased cost of training and increasing cost of potential contributors to training cost. With fewer student licenses being issued, there is a belief that a major hindrance to the new creation of new pilots exists at the level of primary training. The problem, therefore, is that the increased cost of operating aircraft is contributing to higher prices at flight schools which leads to lost customers and struggling businesses. This is represented by the cyclical diagram below.
3.2 Need Statement

With the higher prices of obtaining a license resulting in lower pilot throughput at flight schools, there is a need to assist schools in reducing the costs associated with operating the aircraft used in training new pilots.

4. Stakeholder Analysis

4.1 Stakeholder Introduction

The principal stakeholder within the scope is the flight school and other primary stakeholders are flight students, Certificated Flight Instructors (CFI), and Maintenance Technicians. Outside of our scope, the secondary stakeholders are aircraft manufacturers and airlines.

Our Stakeholder relations are illustrated in Figure 16 below. The blue grid represents the scope. The principal stakeholders, flight schools, are shown in the blue block. Inside the scope grid are also the other primary stakeholders, of which the block labeled “CFI” in the diagram denotes Certificated Flight instructors. Flight schools need students, Flight instructors and maintenance technicians. Flight Instructors and maintenance technicians are employed through flight schools. Students receive instruction from Flight Instructors through Flight School.
On the outer scope, aircraft manufacturers need buyers: primarily airlines or flight schools. Airlines need pilots and need aircraft and this also feeds into flight schools. The project scope focuses on what is inside the blue grid.

**Figure 16: Stakeholder Diagram**

4.2 Flight Schools

In the process of certifying pilots, it is crucial to prepare a student pilot with advanced knowledge and training. The flight schools recruit instructors who are educated and dedicated to instructing student pilots and train them in the field. The school becomes the bridge to build a relationship between the instructors and students and help them interact within given guidelines. The goal of flight schools is to train student pilots and create new pilots and also to maximize their profits.

One challenge flight schools face is that of trying to reduce training costs for students. The flight schools need money to pay their flight instructors and to buy and maintain adequate aircraft. One of the contributing factors to costs for flight schools are the costs associated with operating aircraft. The airlines are also in competition with flight schools for the flight instructors and pilots to close the retirement gap. However, airlines can offer more money and benefits than the flight schools. As a result, lack of financial incentives in the aviation field cause conflicts between the stakeholders.
4.3 Flight Students

Students’ objectives are to earn whichever pilot license certificate they are pursuing. One major challenge that students face is a financial challenge. New regulations require for pilots to have a significantly larger amount of hours in flight before they can earn their ATP license. This involves higher costs for pilots and students aspiring to get and ATP license for several reasons. As students stay at flight schools for a longer period of time to earn their certificate, the cost of training keeps accumulating for them and thus rises [24]. Whenever an instructor is no longer needed to be able to fly and log the required hours, the costs associated with rental or aviation gas still accumulate as flight hours still need to be earned. This provides a deterrent for students, who become dissatisfied that training costs change significantly and reach high prices [24]. The alternatives given to students vary due to cost variations as well. For instance, one option for student pilots to log more hours is to become a Certificated Flight Instructor and build flight hours as he/she trains pilot students. The problem is Certificated Flight Instructor Certificates cost between $6500 and $11100 to earn. If the student only decided to obtain a private pilot license, the cost is about $9500 on average [25]. The expense is significantly higher if the student decided to continue his/her academic education and flight training from a 4-year aviation degree program to obtain up to a commercial pilot certificate with additional ratings necessary to be hired as a pilot for commercial flying, which can exceed over $100,00 [26]. Furthermore, there is lack of financial assistance available to students and offer of aid from the U.S. government [28]. Flight schools and aviation organizations do not give out scholarships and grants to students who are driven to become successful pilots. The U.S. government can help by giving loans and grants for college and university students who are taking flight training as part of their degree curriculum. It would be beneficial for airlines to create innovative methods to compensate pilots’ training expenses and help prospective candidates [28].

Potential financial incentives for students may be a significant reduction in cost of education and training, which would primarily result from a reduction of costs for flight schools that could directly affect the flight instructor and maintenance crew pay. Currently, flight instructors make less than $20,000 per year and further reduction could encourage them to pursue commercial jobs for airlines rather than train new pilots [27]. However, to compete with the higher pay offered by airlines, the schools would have to reduce the budget for utilities, aircraft maintenance and more.

4.4 Certificated Flight Instructors

Certificated flight instructors have the goal of earning wages and commonly another goal is to accumulate flight time needed to qualify for an ATP license certification exam, another objective they have is to train students. One tension that they have is the relatively low pay in comparison to the amount of money they invested to get their certificate.
4.5 Maintenance Technicians

The objective of maintenance technicians is to maintain and repair aircraft and any of the equipment used to operate an aircraft. Tensions include pay as well as availability of parts for aircraft.

4.6 Airlines

The objective of airlines is to recruit pilots who are qualified to operate the aircraft they use to provide their services. Specifically, airlines are looking for ATP licensed pilots. The primary tension they experience is the shortage of ATP pilots.

4.7 Aircraft Manufacturers

Aircraft manufacturers provide aircraft. A tension they have is in the cost of aircraft since it encourages potential buyers to seek used aircraft instead of new aircraft. However, reducing the price of new aircraft would result in a profit loss.

5. Requirements

5.1 Mission Requirements

1. The system shall provide cost-performance curves for a variety of aircraft alternatives
   
   1.1 Aircraft tested shall include the Cessna 172M, Cessna 172S, Cessna 172SP, Cessna 162, Cessna 152, Piper Archer II, Diamond Eclipse, and Van’s RV-12

2. The system shall rank aircraft by utility on a 0-1 scale with 1 being preferable

3. The system shall recommend an optimum aircraft

5.2 Simulation Requirements

1. The simulation shall output results into tables
   
   1.1 The tables shall be in .csv format for universal access
   
   1.2 The tables shall contain 10 columns
      
      1.2.1 Student-Aircraft (S/A) ratio
      1.2.2 Student-Instructor (S/I) ratio
      1.2.3 Aircraft type (i.e. Cessna_172M)
      1.2.4 Yearly total flight time for all aircraft in hours
      1.2.5 Yearly total maintenance time for all aircraft in hours
      1.2.6 Yearly total number of inspections for all aircraft
      1.2.7 Yearly total number of engine overhauls for all aircraft
      1.2.8 Yearly total cost in USD
      1.2.9 Yearly total revenues in USD
1.2.10 Yearly total profit in USD
2. The simulation shall measure results against three variables
   2.1 Type of aircraft
   2.2 S/A ratio
   2.3 S/I ratio
3. The simulation shall use stochastic processes
4. The simulation shall simulate at least 10 years of flight school operations
5. The simulation shall feature at least 100 repetitions

6. Method of Analysis and Simulation

6.1 Simulation

The objective of the simulation is to provide a surrogate for the observation of real-world flight school operations and provide data to determine how time spent flying and time spent in maintenance, as well as associated costs and revenues, are affected by number of available CFI and the type and number of aircraft comprising the school’s fleet.

To fulfill those objectives, the simulation was written in the Java programming language and contains three main models within it: the event scheduling model, the event execution model, each of which are called upon and executed every time the simulation clock advances by one time unit, set equivalent to one hour, and the cost/revenue model, which executes at the end. Code for the project can be found in the Appendix.
6.1.1 Scheduling Sessions

The scheduler takes arriving flight and maintenance sessions, and anchors them to a stochastically position in a list of all the hours remaining in the simulation provided there are sufficient unused resources (aircraft and CFI) to do so. This position is governed by an exponential distribution for mean time between arrivals for flight and maintenance sessions, the profiles of which are shown in Figures 18 and 19.
These distributions were arrived at by observing and analyzing historical data from a real flight school. The R-squared values are 0.97 and 0.96, respectively, providing a satisfactory fit. The number of arriving failures follows a Poisson distribution, with a mean dependent upon the rate of demand expected per-aircraft multiplied by a historically determined ratio between the number of maintenance events and the number of flights:

\[
\text{Mean No. of Maintenance Arrivals} = \frac{\text{Hist.Maintenance}}{\text{Hist.Flights}} \times \left( \frac{\text{Current Rate of Demand}}{\text{Number of Aircraft}} \right) \quad (1)
\]

The duration for a scheduled session is also set during this stage of the simulation. The duration of flight sessions is governed by another exponential function, shown in Figure 20. While having the appearance being exponential, the duration for maintenance is actually governed using a Gaussian distribution, the profile of which can be seen in Figure 21. This was necessary in order to be able to specify a standard deviation from the mean within the program. To prevent a negative value being entered for the duration, the program takes the absolute value of its sampling result to apply as the duration for that session.
The R-squared errors for Figures 4 and 5 are 0.99 and 0.95, respectively, also providing a satisfactory fit.

When placing the incoming session, the program will duplicate the event for the number of hours in its duration and place them adjacent to each other, starting at the arrival point. If all of the resources for a time slot are occupied, an incoming flight session is simply ignored. An incoming maintenance session will, however, overwrite any present flight session because maintenance must take place for a plane to fly. If all of the events in the time slot are already maintenance, the incoming maintenance event is ignored and it is assumed that the new problem will be taken care of during that plane’s already ongoing repair.

6.1.2 Executing Sessions

After any arriving sessions have been scheduled or dropped, the program then looks for any ongoing sessions during the current time slot. If it finds a flight session, it increments the time spent flying by one. If it finds a maintenance session, it increments the time spent in maintenance by one. 

\[
\textit{Flying Time} = T_F
\]

\[
\textit{Unscheduled Maintenance Time} = T_U
\]
6.1.3 Cost Model

The cost model takes the recorded time in flight, time in maintenance, total simulation time, number of inspection, and number of engine overhauls, and applies several unit prices to them:

\[ P_F = \text{price of fuel per gallon} \]
\[ P_I = \text{price of CFI per hour} \]
\[ P_M = \text{price of maintenance per hour} \]
\[ P_H = \text{price of storage per hour} \]

The prices for inspection and engine overhaul are locked to $4000 and $18,000 each. The unit prices above are applied to obtain cost of operations according to the following equations:

\[ C_F = \text{total cost of flying} \]
\[ C_M = \text{total cost of maintenance} \]
\[ C_F = T_F(P_F E_F + 1.3 P_I) \]
\[ C_M = T_S(P_H Q_A) + 4000 Q_{insp} + 18000 Q_{ovr} + P_M T_U \]
\[ \text{Cost} = C_F + C_M \]

Where \( E_F \) is the fuel consumption rate of the tested aircraft, \( Q_A \) is the number of aircraft, \( Q_{insp} \) is the number of inspections, and \( Q_{ovr} \) is the number of engine overhauls. Revenues are calculated using the following equation:

\[ \text{Revenue} = 1.3 T_F(0.3 P_I + P_S) + 195 Q_S \]

Where \( P_S \) is the price per hour of flight charged to students and \( Q_S \) is the number of students. The time flown is multiplied by 1.3 since students are charged according to Hobbs time rather than Tach time, and Hobbs time is roughly equivalent to 1.3 times the displayed Tach time. The price of $195 covers the revenue from instructional supplies sold to students.

6.2 Design of Experiment

The simulation takes as input three primary variables: the type of aircraft used in the fleet, the total number of those aircraft in the fleet, and the total number of CFI available. As such, the experiment was conducted according to a factorial design, as displayed by Figure 22.
Figure 22: Sample of Possible Combinations

<table>
<thead>
<tr>
<th>Case</th>
<th>Aircraft</th>
<th>No. CFI</th>
<th>No. Aircraft</th>
<th>Flight Time (hrs)</th>
<th>Maintenance Time (hrs)</th>
<th>No. of Inspections</th>
<th>No. of Overhauls</th>
<th>Cost ($)</th>
<th>Revenue ($)</th>
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<tbody>
<tr>
<td>1</td>
<td>Cessna 172M</td>
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<td>2</td>
<td>Vans RV-12</td>
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<td>3</td>
<td>Cessna 152</td>
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<td>4</td>
<td>Cessna 172S</td>
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<td>5</td>
<td>Cessna 172SP</td>
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<tr>
<td>6</td>
<td>Piper Archer II</td>
<td>…</td>
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<tr>
<td>7</td>
<td>Diamond</td>
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</table>
The experiment first chooses an aircraft to test, and then a number of instructors to test with, usually starting at one (1). The experiment then sets the number of aircraft, again starting at one (1), and runs the simulation for 100 repetitions under those conditions and records the averaged result into a table. The experiment then increments the size of the aircraft fleet by one (1) aircraft and repeats the process until it has reached the pre-defined upper limit for the number of aircraft to test. For this project, the upper limit is set to 30. After running through 30 aircraft, it then increments the number of CFI by one (1) and begins running the simulation again across the range of aircraft fleet size. After completing the simulation with 30 CFI, the experiment changes the type of aircraft comprising the fleet and begins again with one CFI and one aircraft. The aircraft tested were the Cessna 172M, Cessna 172S, Cessna 172SP, Cessna162, Cessna 152, Piper Archer II, Diamond Eclipse, and the Vans RV-12.

The simulation uses 100 repetitions for time constraints and because an increased number saw diminishing returns. Figure 6 shows five runs with one, ten, one-hundred, and one-thousand repetitions per run.

**Figure 23:** Variance trend in profit margin for Cessna 172M versus number of repetitions

The trend flattens out the more repetitions are performed, but the returns drop off after 100. Figure 24 shows the impact the number of repetitions has on the standard deviation of the results. The spread between the standard deviation at 100 repetitions and the standard deviation at 1000 repetitions is less than $100, with standard deviations of $860 and $770 respectively. Even out to three standard deviations, impact remains less than 5% when profits hover around $55,000.
6.3 Assumptions and Limitations

6.3.1 Assumptions

- The flight school provides its services 24 hours a day, 7 days per year, with no breaks.
- CFI are always available for use, with no unscheduled down-time as a result of sickness, terminated employment, holidays, etc.
- Aircraft are never permanently disabled.
- Rate of demand for flight school services is static.
- Price of maintenance per hour is uniform and static across aircraft types.
- Price of aviation gasoline is static.
- Price of service rendered is static.
- All 100-hour inspections are carried out as annual inspections.

Flight schools are always available because the real school used as the basis for this simulation was similarly always available. Modeling a flight school that only operates during normal business hours is as simple as setting the simulation duration to the number of business hours in the desired time frame rather than setting it to the total number of hours.

CFI are always available because there was no data to construct a distribution to govern stochastic availability. Aircraft are always successfully repaired for the same reason.

The rate of demand for flight school services is static because there was no data correlating the quality or price of service to that rate.

The various prices of services rendered or received by the flight school are static because their fluctuation is small and outside the focus of this project.
The 100-hour inspections are always counted as annual inspections because that is how both of the real flight schools consulted chose to treat them.

6.3.2 Limitations

The simulation has three main limitations. The first of these limitations involves how 100-hour inspections and engine overhauls are factored in. In this program, they are tallied after the simulation has run flights for the entire duration. This means that it is possible to have more hours of total usage, with usage being time in flight and repair, than there are hours in the simulated duration. This is useful, however, because such a result indicates that sustaining the given demand with that particular number of aircraft is infeasible.

The second limitation is the lack of ability to track quality of service. The underlying assumption about demand remaining static is partly based on this limitation, but also governs it. The static rate of demand implies that a student unable to fly during the first chosen time slot will simply choose another time slot at some other point in time.

The final limitation is the small sample size of aircraft. At most, only two real aircraft of a given type were observed, including the Cessna 172M and Cessna 172S. All other aircraft only featured a single airframe determining their behavioral characteristics. A larger, more focused study would be able to gather data on many examples of a single type from many flight schools and generate a more accurate behavioral model.

7. Aircraft Analysis

7.1 Aircraft Alternatives

Figure 25 below details information about each of the eight aircraft alternatives, including the unit prices, engine prices, gross takeoff weight, fuel consumption rate, number of aircraft, the years in production, and the number of seats. Aircraft unit cost and engine price are two very important factors when selecting the fleet for any flight school. Other critical components to consider are number of built aircraft, gross takeoff weight (GTO), number of seats in the aircraft, when the aircraft was in production, and fuel consumption rate. The gross takeoff weight is important for the landing and takeoff. Light aircraft have difficulty taking off, yet heavier aircraft consume more fuel. The number of units built is important for availability purposes.

<table>
<thead>
<tr>
<th>Aircraft</th>
<th>New Unit Price (2015)</th>
<th>Used unit price (range)</th>
<th>Used years considereed (range)</th>
<th>New engine price ($)</th>
<th>Rebuilt engine price ($)</th>
<th>GTO W (lbs)</th>
<th>Fuel consumption rate</th>
<th>Numbeer of built aircraft</th>
<th>Years in Production</th>
<th>Numb er of Seats</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aircraft</td>
<td>Kit Price</td>
<td>Engine Price</td>
<td>Production Period</td>
<td>Engine History</td>
<td>Hours/Year</td>
<td>2008-2014</td>
<td>2008-2014 Hours</td>
<td></td>
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<tr>
<td>Van’s RV-12</td>
<td>$123K</td>
<td>$20K</td>
<td>2008-2014</td>
<td></td>
<td>4</td>
<td>355</td>
<td>2008-2014 Hours</td>
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<tr>
<td>Diamond Eclipse</td>
<td>$100K-12</td>
<td>$27K</td>
<td>1998-2015</td>
<td></td>
<td>5</td>
<td>500</td>
<td>1998-12 Hours</td>
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<tr>
<td>Cessna 172S</td>
<td>$368K</td>
<td>$55K</td>
<td>1999-2015</td>
<td></td>
<td>8</td>
<td>43000</td>
<td>1999-15 Hours</td>
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<td>[15]</td>
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<tr>
<td>Cessna 172M</td>
<td>$42-S100</td>
<td>$55K</td>
<td>1973-1976</td>
<td></td>
<td>8</td>
<td>7306</td>
<td>1973-15 Hours</td>
<td></td>
<td></td>
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<tr>
<td>Cessna 172SP</td>
<td>$100-390K</td>
<td>$55K</td>
<td>2001-2009</td>
<td></td>
<td>4.9</td>
<td>1000</td>
<td>1998-2009 Hours</td>
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*FAA REGISTERED
**ESTIMATED

The Van’s RV-12 is a homebuilt aircraft making it the most compact and affordable aircraft with the kit costing $65,000. The complete aircraft has a base price of $123,000. The kit includes every part except the paint and fluids. The wings can be removed in less than five minutes, making the airplane easy to transport [17]. This feature of the aircraft is useful for flight schools should they need to remove broken parts or send them to the manufacturer [18]. The engine price, both new and rebuilt is very important when considering buying an aircraft. The Van’s RV-12 uses a Rotax engine that has a new price of $20,000 and a rebuilt price of $16,000, making it the most affordable of all of the engine alternatives. Sufficient data was not available about the maintenance history for this aircraft. This aircraft was not designed to be a primary training aircraft; therefore, it is not built as sturdy as most primary trainers. Therefore, it was assumed that it would require more time in maintenance than the Cessna 172 M. It was assumed that it would require twenty percent more time in maintenance than the Cessna 172 M.

Cessna’s 152 is an aircraft primarily used for flight training. It is known for its smooth descents and student-friendly simplicity [2]. Although the aircraft is old, they are good for inexperienced students because the avionics are simple. This aircraft weighs 1670 pounds, making it the second lightest aircraft in the table. In its eight years of production about 7,600 units were produced, making the Cessna 152 one of the most available aircraft for flight training.

The Diamond Eclipse, also known as the DA 20, is a general aviation Canadian aircraft produced since 1994. The plane is known for its easy maneuverability [1]. About 500 of them have been and at least 300 of them are currently used at flight schools. It is still currently being
produced and the manufacturer receives feedback from flight schools and makes changes regarding the utility and reliability of the aircraft[10].

The Cessna 172 M is one of the most produced aircraft by Cessna. This series is known for its low speed handling which is very important in flight training [23]. The production for the M series ended in 1976 at which point the avionics and design were updated and the name was changed to Skyhawk, which is the Cessna 172 S series [IBID]. There have been 43,000 units produced of the Cessna 172 M and 7,000 units of the Cessna 172 S [11]. Production of the Cessna 172 SP began in 1998 but ended in 2009 to return to production of the S series [23]. There are an estimated 1,000 Cessna 172 SPs active [4].

The Piper Archer II is also known as the PA-28-181 Cherokee Archer II. About 5,000 units have been produced [15].

The Cessna 162 Skycatcher was in production from 2007 to 2013. According to the FAA registry, 272 of them are registered as active aircraft. In January 2014, Cessna announced the end of Cessna 162 production and asked buyers to no longer order it. The remaining 80 aircraft of the Cessna 162 will be used as parts [4]. The Cessna 162 did not receive the airworthiness certificate due to an issue regarding the weight of the aircraft. This led to confusion about whether the Cessna 162 was considered to be Light Sport Aircraft or not [30]. There are a few of these aircraft sold in today’s market.

7.2 Real Flight School Case

For the purpose of the simulation it was assumed that all of the aircraft had the same popularity and that the demand for each aircraft was the same. Therefore, the same hourly cost was used for each of the eight aircraft alternatives. However, at real flight schools it is typical that different primary training aircraft have different hourly costs based on the demand of each aircraft.

Results were run for each of the aircraft using the hourly prices at one real flight school. The hourly prices are listed in Figure 26 below.

**Figure 26: Flight Session Pricing**

<table>
<thead>
<tr>
<th>Aircraft Type</th>
<th>Real flight school hourly prices ($)</th>
<th>Simulation hourly price (Control case) ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cessna 172SP</td>
<td>165</td>
<td>150</td>
</tr>
<tr>
<td>Cessna 172S</td>
<td>155</td>
<td>150</td>
</tr>
<tr>
<td>Piper Archer II</td>
<td>145</td>
<td>150</td>
</tr>
<tr>
<td>Cessna 172M</td>
<td>135</td>
<td>150</td>
</tr>
<tr>
<td>Diamond Eclipse</td>
<td>130</td>
<td>150</td>
</tr>
<tr>
<td>Cessna 152</td>
<td>105</td>
<td>150</td>
</tr>
</tbody>
</table>

The yearly profits for each of the aircraft are graphed below. With the new prices only the Cessna 172S, Cessna 172SP, and Piper Archer II are profitable. One reason that they are not profitable is because the number of students used in this simulation is less that the actual number of students at this real flight school. At this school, currently the most popular aircraft are the Cessna 172S, Cessna 172 SP, and the Piper Archer II which is one reason why they are charging the higher price for these aircraft.
Figure 27: Cessna 172 M Profits

![Graph for Cessna 172 M Profits](image1.png)

Figure 28: Cessna 162 Profits

![Graph for Cessna 162 Profits](image2.png)
Figure 31: Cessna 172 SP Profits

Figure 32: Diamond Eclipse Profits
8. Data Analysis

8.1. Results

Figure 34 below displays the results for a Cessna 172M. The Cessna 172 M is a very popular primary training aircraft that although old, is sturdy and for which spare parts are readily available. The vertical axis displays the yearly profit at a flight school. The horizontal axis displays the student-to-aircraft ratio and the depth axis is the student-to-instructor ratio. The student-to-aircraft ratio is a measure of how many students a flight school has per aircraft. This ratio is valuable to flight schools when determining an appropriate fleet size for the size of the school. The student-to-instructor ratio is a measure of how many students a flight school has per Certificated Flight Instructor. This ratio is valuable to flight schools when determining an appropriate number of instructors for the size of the school. The two graphs below this graph display the same information in 2-D graphs to more clearly display the profit trend as the student-to-instructor and student-to-aircraft ratios change.
Figure 34: 3-D Yearly Profit

Figure 35 displays the profit as the student-to-instructor ratio changes. The shape of the line indicates that the student-to-instructor ratio does not greatly affect profit margin. The Certificated Flight Instructor inputs to the simulation assume that the instructors are not paid a base salary; they are only paid when they fly. Also, instructors are not subject to down time like maintenance like the aircraft. Therefore, the number of instructors does not significantly affect the flight school profits.

Figure 35: Student-to-Instructor vs. Margin

Figure 36 below displays the flight school profit as the student-to-aircraft ratio changes. For the Cessna 172M, the profit peaks when the student-to-aircraft ratio is 43. Leading up to this ratio, the profit increased as the student-to-aircraft ratio increased because as utilization of the
aircraft increased the cost of using the aircraft decreased. Beyond the ratio of 43 the profit begins to decrease because the increased usage of the aircraft will cause the aircraft to be in maintenance for much longer periods of time which is expensive and also makes the aircraft unavailable to be flown by the students. Table ____ displays the student-to-aircraft ratio at which each of the aircraft alternatives peaks. Across the aircraft alternatives, the profit peaks at an average student-to-aircraft ratio of 29.

**Figure 36: Student-to-Aircraft Ratio vs. Ratio**

Figure 37 below also displays results for the Cessna 172M. It compares the total hours flown and total hours maintained when the profit is maximized to an increasing student-to-aircraft ratio. When the student-to-aircraft ratio is very low the hours in maintenance is very low because the utilization of the aircraft is low. As the student-to-aircraft ratio increases the time flown decreases as more time in maintenance is required.
Figure 37: Hours Flown and Hours Maintained Line Graph

Figure 38 below shows the same information as the graph above in a different format. At a student-to-aircraft ratio of 20, maintenance accounts for ten percent of the total time. At a student-to-aircraft ratio of 40, maintenance accounts for twenty percent of the total time. At a student-to-aircraft ratio of 128, which is the maximum ratio for the simulation, maintenance accounts for half of the total time. Therefore, when maintenance accounts for a considerable amount of total time, hours flown decreases and profit becomes negative.

Figure 38: Hours Maintained and Hours Flown Total Time

Figure 39 below displays the ratio of income / cost of operations as the student-to-aircraft ratio increases. A ratio of one indicates where profits break even. Therefore, for a Cessna 172M a flight school would not be profitable when the student-to-aircraft ratio is less than ten or greater than one hundred.
**Figure 39:** Income over Cost of Operations

Figure 40 below also displays the cost of operations and income data for a Cessna 172 M. In this format, the intersection points of the cost of operations and income lines indicate where the profit breaks even.

**Figure 40:** Cost of Operations and Income

The yearly profits for the Cessna 152, Cessna 162, Cessna 172 S, Cessna 172 SP, Piper Archer II, Diamond Eclipse, and Van’s RV-12 are below.
Figure 41: Cessna 152 Yearly Profits

Figure 42: Cessna 162 Yearly Profits
Figure 43: Cessna 172 M Yearly Profits

![Cessna 172 M](image)

Figure 44: Cessna 172 S Yearly Profits

![Cessna 172 S](image)
**Figure 45:** Cessna 172 SP Yearly Profits

**Figure 46:** Diamond Eclipse Yearly Profits
8.2 Equations

The equations used to calculate the student-to-aircraft ratio, the student-to-instructor ratio, cost of operations, and revenue of a flight school are listed below.

\[ Q_I = \text{quantity of instructors} \]
\[ Q_A = \text{quantity of aircraft} \]
\[ Q_S = \text{quantity of students} \]
\[ S/A = \text{Student – Aircraft Ratio} = \frac{Q_S}{Q_A} \]
\[ S/I = \text{Student - Instructor Ratio} = \frac{Q_S}{Q_I} \]

\[ Q_{\text{insp}} = \text{total number of inspections} \]

\[ Q_{\text{ovr}} = \text{total number of engine overhauls} \]

\[ T_U = \text{total time spent in unexpected maintenance} \]

\[ T_F = \text{total time in flight} \]

\[ C_F = \text{total cost of flying} \]

\[ C_M = \text{total cost of maintenance} \]

\[ P_F = \text{price of fuel per gallon} \]

\[ P_I = \text{hourly price of CFI} \]

\[ P_M = \text{hourly price of maintenance} \]

\[ P_H = \text{hourly price of tie-downs per aircraft} \]

\[ E_F = \text{fuel consumption rate of aircraft} \]

\[ \text{Cost} = C_F + C_M \]

\[ C_F = T_F(P_F E_F + P_I) \]

\[ C_M = T_S(P_H Q_A) + 4000Q_{\text{insp}} + 18000Q_{\text{ovr}} + P_M T_U \]

\[ P_S = \text{hourly price of flight session to students} \]

\[ \text{Revenue} = 1.3T_F(0.3P_I + P_S) + 195Q_S \]

The total time in flight is multiplied by 1.3 in the revenue equation. Aircraft count time using Tach time which measures engine revolutions. However, students are charged using Hobbs time which starts when the engine starts. Generally, the Hobbs time value is 1.3 times greater than the Tach time.

### 8.3 Quality of Service

Quality of service is one of the most important attributes of a flight school. In this case, quality of service is measured as the total time that a student spends waiting for an available aircraft. As time waiting for an aircraft increases, the quality of service diminishes because customers that have to wait a long period of time for a flight session are more likely to take their business to a different flight school. Figure 49 below shows a student’s total waiting time using the demand rate used in the simulation.
Figure 49: Expected Delay vs. S/A Ratio

![Expected Delay](image)

Figure 50 below displays how the student waiting time changes as the demand rate increases. There is a tension between quality of service and maximizing profits. According to the simulation, the profits from the aircraft alternatives peak at student-to-aircraft ratios ranging between 21 and 43. At these ratios there would be between three to six aircraft for 128 students. At these ratios, the quality of service would be very low. This may cause students to leave the school to find another flight school which would reduce revenues in the long run. Therefore, a given student-to-aircraft ratio may be appealing when looking at the associated profit margin but may actually require a compromised quality of service.

Figure 50: Expected Delay vs. Rate of Arrival

![Expected Delay](image)

One of the assumptions of the model is that demand for service is static. Also, queuing delays are not counted. Therefore, quality of service is not incorporated into the simulation.
results. However, this is a very important attribute to consider when choosing an optimal student-to-aircraft or student-to-instructor ratio.

8.4 Utility Analysis

The performance of the eight primary training aircraft alternatives was measured by scoring them based on the maintenance duration, time between maintenance, and fuel consumption. Maintenance duration is known as mean time to repair or MTTR, and time between maintenance is known as mean time between failures or MTBF. Figure 51 below displays the weights for these three aircraft performance characteristics.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance Duration (MTTR)</td>
<td>0.32</td>
</tr>
<tr>
<td>Time Between Maintenance (MTBF)</td>
<td>0.30</td>
</tr>
<tr>
<td>Fuel Consumption</td>
<td>0.38</td>
</tr>
</tbody>
</table>

The weights were derived by altering the values of the three characteristics by ten percent in the more desirable direction in the simulation while keeping everything else constant. Maintenance duration was reduced by ten percent, the time between maintenance was increased by ten percent, and the fuel consumption was reduced by ten percent. Then, the impact on profits was compared and weights were determined. For example, Figure 52 below displays the yearly profits of a Cessna 172 M when each of the three characteristics were altered ten percent.

<table>
<thead>
<tr>
<th>Characteristic Altered</th>
<th>Yearly Profit Margin ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>55,344.90</td>
</tr>
<tr>
<td>Time Between Maintenance</td>
<td>56,129.90</td>
</tr>
<tr>
<td>Maintenance Duration</td>
<td>59,302.50</td>
</tr>
<tr>
<td>Fuel Consumption</td>
<td>70,534.45</td>
</tr>
</tbody>
</table>

The equation below is the formula used to determine the weights for the three aircraft performance characteristics.

\[ W_a = \frac{M_a}{M_0} \]

\[ \sum_{n=1}^{3} \frac{M_a}{M_0} \]

W = Weight
M = Margin
a = Attribute

Figure 53 below show the results for the eight aircraft alternatives. The Cessna 162 scored the highest with a utility rating of 0.87, and the Cessna 172 SP scoring the lowest with a 0.15.
8.5 Sensitivity Analysis

The graphs below display how the utility of each of the eight aircraft alternatives change as the aircraft performance characteristics’ weights change. The first graph displays the effect of mean time between failure, the middle graphs displays the effect of mean time to repair, and the bottom graph displays the effect of fuel consumption.
**Figure 54: MTBF Weight**

![MTBF Weight Chart](image)

**Figure 55: Fuel Weight**

![Fuel Weight Chart](image)
The graphs below display the same sensitivity analysis results for only the top three scoring aircraft for ease of reading purposes. When fuel consumption is the most important aircraft performance characteristic the Van’s RV-12 scores the highest. When mean time between failures is the most important characteristic the Cessna 162, Van’s RV-12, and the Cessna 152 all have the same utility score. When mean time to repair is the most important characteristic the Cessna 162 scores the highest. At any point on any of the three graphs the Cessna 162 scores either first or second among all of the alternatives.
8.6 Return on Investment

Figure 60 below displays how long it would take to pay off each of the aircraft alternatives. Some of the aircraft alternatives can be bought new or used and some can only be bought used. Therefore, there are many possible prices for each of the aircraft. So there is a calculated time to break even for the best case (lowest price) and worst case (highest price) for each aircraft. The aircraft in this table are listed from highest to lowest utility. For the best case scenario for the top three rated aircraft, the return on investment is less than one year. For the worst case scenario, the return on investment for the Van’s RV-12 is 17 months while the Cessna 162 and Cessna 152 are both less than one year.
### 8.7 Interpretation and Recommendations

From the results, it is clear that large quantities of time spent in maintenance for an aircraft results in lower profits. It is recommended that flight schools place a higher value on tailoring fleet size to fit their demand. However, it is encouraged that schools consider quality of service when making this decision.

The Cessna 162 scored the highest in utility and had the largest profit; however, this aircraft is no longer in production and there are only 272 Cessna 162s registered as active aircraft. Therefore, it is recommended that flight schools use a homogeneous flight of Van’s RV-12s or Cessna 152s. The Van’s RV-12 scored the second highest utility; however, it is currently not a popular choice for a primary trainer so it may be more difficult to get access to spare parts. Also, it is not as sturdy as the Cessna 152 so it may require maintenance more frequently.

### 8.8 Future Work

There has been a large increase in the hourly fee for aircraft maintenance as well as the cost of parts which has caused maintenance to become the highest cost for many flight schools. Therefore, it is recommended that a future study be conducted focusing specifically on the maintenance of a flight school.

### 9. Acknowledgements

We wish to acknowledge the special contributions of Dr. George Donohue.
10. Project Plan

10.1 Work Breakdown Structure

Figure 61: Work Breakdown Structure

10.2 Budget

The budget is based on the rate of $20 per hour with 100% overhead, 10% general and administrative, 6% fees, and 20% fringe benefits. This totals to $48 per hour.

Figure 62: Budget

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct Labor</td>
<td>1,440 hours</td>
</tr>
<tr>
<td>Hourly Rate</td>
<td>$20.00</td>
</tr>
<tr>
<td>GMU Multiplier</td>
<td>$20.00</td>
</tr>
<tr>
<td>G&amp;A</td>
<td>$2.00</td>
</tr>
<tr>
<td>Fringe</td>
<td>$4.00</td>
</tr>
<tr>
<td>-----------</td>
<td>-------</td>
</tr>
<tr>
<td>Fee</td>
<td>$2.00</td>
</tr>
<tr>
<td>Multiplied Rate</td>
<td>$48.00</td>
</tr>
<tr>
<td>Fully Burdened</td>
<td>$69,120.00</td>
</tr>
</tbody>
</table>

10.3 Cost Performance Index and Schedule Performance Index

Figure 63: Earned Value

![Earned Value Graph](image1)

Figure 64: CPI vs. SPI

![CPI vs. SPI Graph](image2)
10.4 Schedule

The figures below show the project schedule from its beginning in August of 2014 until its conclusion at the end of April 2015. The critical path is highlighted in red.

**Figure 65: August-February Tasks**

**Figure 66: February-April Tasks**
10.5 Risk

The figure below describes the primary risks associated with this project. For each of these risks, the main effect is a simulation model that is inaccurate and that cannot be validated. If we are unable to acquire the information that we need to calculate these values then we will use the data we do have access to to manually determine the values.

**Figure 67: Risk**

<table>
<thead>
<tr>
<th>Likelihood</th>
<th>Item</th>
<th>Effects</th>
<th>Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>19</td>
<td>Failure to obtain flight school earnings</td>
<td>Failure to validate model</td>
<td>Determine revenues manually given qualitative information</td>
</tr>
<tr>
<td>17</td>
<td>Failure to obtain flight school expenditures</td>
<td>Inaccurate simulation model</td>
<td>Determine costs manually using given qualitative information</td>
</tr>
<tr>
<td>12</td>
<td>Failure to obtain aircraft utilization rates</td>
<td>Inaccurate simulation model</td>
<td>Determine utilization rates manually from given maintenance records</td>
</tr>
</tbody>
</table>

![Risk Table](image-url)
11. References

Appendix A: Simulation Code

Event class

public class Event
{
    // Attributes
    private String name;
    private boolean isMaintenance;
    private int duration;

    // Maintenance stuff
    private int hoursFlown;

    // Customer stuff
    private int totalAttempts;
    private int rejectedAttempts;

    private static int customerCount = 1;
    private static int maintenanceCount = 1;

    // Constructors
    public Event(boolean isMaintenance)
    {
        this.isMaintenance = isMaintenance;
        if(isMaintenance == true)
        {
            this.name = "Maintenance" + maintenanceCount;
            maintenanceCount++;
        }
        else if (isMaintenance == false)
        {
            this.name = "Customer" + customerCount;
            customerCount++;
        }

        this.hoursFlown = 0;
        this.totalAttempts = 0;
        this.rejectedAttempts = 0;
    }
// Getters
public boolean getType()
{
    return isMaintenance;
}

gpublic String getName()
{
    return name;
}

gpublic float getRejection()
{
    float percentage;
    percentage = (rejectedAttempts/totalAttempts);
    return percentage;
}

// Setters
public void addHour()
{
    this.hoursFlown = hoursFlown + 1;
}

public void addAttempt()
{
    totalAttempts++;
}

public void addRejection()
{
    rejectedAttempts++;
}


Executable class

import java.util.Scanner;

//This is the primary class from which to run the program, providing the user
public class Executable {
    public static void main(String[] args) {
        System.out.println("n\n****************************");
        System.out.println("** Aircraft Operations Simulator **");
        System.out.println("*****************************");

        boolean run = true;

        while (run == true) {
            System.out.println("n*******************");
            System.out.println("** Main Menu **");
            System.out.println("*******************");

            Scanner userInput = new Scanner(System.in);

            System.out.println("nWould you like to proceed [y/n]?");
            System.out.print("n>> ");
            String input = userInput.next().toLowerCase();

            if (input.compareTo("n") == 0) {
                run = false;
                userInput.close();
            } else {
                System.out.print("n");
                OutputWriter newOutput = new OutputWriter();
                newOutput.initialize();
                userInput.close();
            }
        }

        System.out.println("nProgram terminated!");
    }
}
public class OutputWriter
{
    // Attributes
    // General resources
    private int quantityAircraft;
    private int quantityInstructors;
    private int quantityStudents;
    private double flightsPerYear;
    private double fuelPrice;
    private double hangarPrice;
    private double instructorPrice;
    private double sessionIncome;

    // Aircraft specifics
    private String aircraftName;
    private double expectedMaintenanceCost;
    private double expectedMaintenanceArrivalInterval;
    private double expectedMaintenanceDuration;
    private double expectedFuelConsumption;
    private double maintenanceRatio;

    // Simulation parameters
    private int simulationLength;
    private int repetitions;
    private int iterationSize;

    // Settings containers
    private Object[] generalResources = new Object[8];
    private Object[] aircraftSettings = new Object[6];
    private int[] simulationSettings = new int[3];

    // Constructor
    public OutputWriter()
    {
        //
    }
}
public void initialize()
{
    // Simulation inputs

    // **********************************************************
    // Get initialization inputs from user
    //
    // Default case
    //
    // General resources
    quantityAircraft = 1;
    quantityInstructors = 30;
    quantityStudents = 126; //2190/(365/21); // # of students = (0.25 *24 *365)/(365
    days/21 days between sessions)
    flightsPerYear = 2190;
    fuelPrice = 5.50;
    hangarPrice = 0.13;
    instructorPrice = 70.00;
    sessionIncome = 135.00 + (0.3*instructorPrice);

    // Aircraft settings
    aircraftName = "Cessna 172M";
    expectedMaintenanceCost = 90;
    expectedMaintenanceArrivalInterval = 573; //734.4; // this value is arrival rate
    expectedMaintenanceDuration = 45; // this value is the mean (Default 22)
    expectedFuelConsumption = 8.6;
    maintenanceRatio = 0.039;

    // Simulation Parameters
    simulationLength = 3652 * 24;
    repetitions = 100;
    iterationSize = 29;

    // sessionDuration = new GaussianGenerator(1.55, 2, seed); // mean = 1.55
    StdDev = 2
    // sessionInterval = new ExponentialGenerator(686.4, seed); // mean = 686.4
    // maintenanceDuration = new GaussianGenerator(expectedMaintenanceDuration,
    24, seed); StdDev = 24
    // maintenanceInterval = new
    ExponentialGenerator(expectedMaintenanceArrivalInterval, seed);
    // arrivals = new PoissonGenerator(3, seed); lambda = 3
    // maintenanceArrivals = new PoissonGenerator(0.05, seed); lambda = 0.05
Scanner userInputs = new Scanner(System.in);
/*
// General resource inputs
// Get number of aircraft
System.out.println("nInput number of current aircraft: ");
System.out.print("n>> ");
this.quantityAircraft = userInputs.nextInt();

// Get number of instructors
System.out.println("nInput number of current instructors:");
System.out.print("n>> ");
this.quantityInstructors = userInputs.nextInt();

// Get number of students
System.out.println("nInput number of current students:");
System.out.println("n>> ");
this.quantityStudents = userInputs.nextInt();

// Get price of fuel
System.out.println("nInput current cost of fuel (per gallon): ");
System.out.println("n>> ");
this.fuelPrice = userInputs.nextDouble();

// Get hangar/tie-down price
System.out.println("nInput hourly cost of tie-down space:");
System.out.println("n>> ");
this.hangarPrice = userInputs.nextDouble();

// Get instructor salary
System.out.println("nInput hourly cost of instructor: ");
System.out.println("n>> ");
this.instructorPrice = userInputs.nextDouble();
*/

// Aircraft Specifics
// Get aircraft type/name
System.out.println("nInput aircraft name:");
System.out.print("\n>> ");
this.aircraftName = userInputs.next();

/*
// Get average cost of maintenance
System.out.println("\nInput average hourly cost of maintenance:");
System.out.print("\n>> ");
this.expectedMaintenanceCost = userInputs.nextDouble();
*/

// Get maintenance arrival rate
System.out.println("\nInput average hours between maintenance events:");
System.out.print("\n>> ");
this.expectedMaintenanceArrivalInterval = userInputs.nextInt();

// Get maintenance duration
System.out.println("\nInput average duration of unscheduled maintenance in hours:");
System.out.print("\n>> ");
this.expectedMaintenanceDuration = userInputs.nextDouble();

// Get fuel consumption rate
System.out.println("\nInput fuel consumption rate for this aircraft in gal/hr:");
System.out.print("\n>> ");
this.expectedFuelConsumption = userInputs.nextDouble();

// Get maintenance-to-flights ratio
System.out.println("\nInput the ratio of unscheduled maintenance to flight sessions:");
System.out.print("\n>> ");
this.maintenanceRatio = userInputs.nextDouble();

// Get amount charged by school to students per hour
System.out.println("\nInput hourly cost to students for this aircraft:");
System.out.print("\n>> ");
this.sessionIncome = userInputs.nextDouble();

///
******************************************************************************
// Simulation parameters
/*
// Get number of days to simulate and convert to hours
System.out.println("\nInput number of days to simulate:");
System.out.print("\n>> ");
this.simulationLength = 24 * userInputs.nextInt();
*/
// Get number of repetitions for each iteration
System.out.println("\nInput number of repetitions:");
System.out.print("\n>> ");
this.repetitions = userInputs.nextInt();
*

// Get length of iteration for inputs
System.out.println("\nInput number of iterations:");
System.out.print("\n>> ");
this.iterationSize = userInputs.nextInt();

userInputs.close();

// Initialize containers
geneneralResources[0] = quantityAircraft;
geneneralResources[1] = quantityInstructors;
generalResources[2] = quantityStudents;
generalResources[3] = flightsPerYear;
generalResources[4] = fuelPrice;
generalResources[5] = hangarPrice;
generalResources[6] = instructorPrice;
generalResources[7] = sessionIncome;

aircraftSettings[0] = aircraftName;
aircraftSettings[1] = expectedMaintenanceCost;
aircraftSettings[2] = expectedMaintenanceArrivalInterval;
aircraftSettings[3] = expectedMaintenanceDuration;
aircraftSettings[5] = maintenanceRatio;

simulationSettings[0] = simulationLength;
simulationSettings[1] = repetitions;
simulationSettings[2] = iterationSize;

getOutput();
}

private void getOutput()
{
    String fileName;
    FileWriter writer = null;
    SimulationModel simulation;
int startingValueA = (int)generalResources[1];
int startingValueB = (int)generalResources[0];

int i;
for(i = 0; i <= 0; i++)
{
    
    generalResources[1] = startingValueA + i;

    // Creates multiple output files every time an input experimental value is iterated.

    fileName = "Output" + (i+1) + ".csv";
    try
    {
        writer = new FileWriter(fileName);

        writer.write("Students-to-Aircraft, Students-to-
Instructors,Aircraft Type, Hours Flown," + "Hours Maintained, Inspections per Aircraft, Overhauls per Aircraft, Cost of Operations, Income, Margin\n");

        int j;
        for(j = 0; j <= iterationSize; j++)
        {
            generalResources[0] = startingValueB + j;

            // Logs the repetitions of a particular experimental value iteration

            simulation = new SimulationModel(generalResources, aircraftSettings, simulationSettings);
            writer.write(simulation.execute());
        }
    }
    catch(IOException e)
    {
        // Could not write to file
    }

    finally
    {
        try
        {
            writer.flush();
            writer.close();
        }
        catch(Exception e)
public class Schedule {
    // Attributes
    private int aircraftPoolSize;
    private int instructorPoolSize;
    private int aircraftAvailable;
    private int instructorsAvailable;
    private ArrayList<Event> eventsList;
    private static float totalAttempts;
    private static float failedAttempts;
    private static float WLRatio;

    // Constructor
    public Schedule(int totalAircraft, int totalInstructors) {
        this.aircraftPoolSize = totalAircraft;
        this.instructorPoolSize = totalInstructors;
        this.aircraftAvailable = aircraftPoolSize;
        this.instructorsAvailable = instructorPoolSize;
        this.eventsList = new ArrayList<Event>();
        this.totalAttempts = 0;
        this.failedAttempts = 0;
    }
}
// Getters
public int remainingAircraft()
{
    return aircraftPoolSize;
}

public int remainingInstructors()
{
    return instructorPoolSize;
}

public ArrayList<Event> getEvents()
{
    return eventsList;
}

public static float getFailureRate()
{
    return WLRatio;
}

// Setters
public static void flushHistory()
{
    totalAttempts = 0;
    failedAttempts = 0;
}

public void addEvent(Event newEvent)
{
    totalAttempts ++;

    if(newEvent.getType() == false)
    {
        if(aircraftAvailable > 0)
        {
            if(instructorsAvailable > 0)
            {
                eventsList.add(newEvent);
                aircraftAvailable = aircraftAvailable - 1;
                instructorsAvailable = instructorsAvailable - 1;
            }
        }
    }
    else
    {

failedAttempts ++;

else
{
    failedAttempts ++;
}
else
{
    if(aircraftAvailable > 0)
    {
        eventsList.add(newEvent);
        aircraftAvailable = aircraftAvailable - 1;
    }
    else if (aircraftAvailable == 0)
    {
        for(int listIndex = 0; listIndex < eventsList.size();)
        {
            if(eventsList.get(listIndex).getType() == false)
            {
                eventsList.remove(listIndex);
                eventsList.add(newEvent);
                instructorsAvailable = instructorsAvailable + 1;
                listIndex = eventsList.size();
                failedAttempts ++;
            }
            else
            {
                listIndex++;
            }
        }
    }
}

Simulation Model

import java.util.*;
//import java.security.*;
import org.uncommons.maths.random.*;

public class SimulationModel {
    // General resources
    private int quantityAircraft;
    private int quantityInstructors;
    private int quantityStudents;
    private double flightsPerHour;
    private double fuelPrice;
    private double hangarPrice;
    private double instructorPrice;
    private double sessionIncome;

    // Aircraft specifics
    private String aircraftName;
    private double expectedMaintenanceCost;
    private double expectedMaintenanceArrivalInterval;
    private double expectedMaintenanceDuration;
    private double expectedFuelConsumption;
    private double maintenanceRatio;

    // Simulation parameters
    private int simulationLength;
    private int repetitions;
    private int iterationSize;

    // Scheduler
    private Schedule[] simulatedHours;

    // Customer list
    private Event[] customerList;

    // Dependent variables
    private int hoursFlown;
    private int hoursMaintained;
    private float avgRejectionPrcnt;

    // Randomizers
    Random seed = new Random();
    GaussianGenerator sessionDuration;
    GaussianGenerator maintenanceDuration;
    ExponentialGenerator sessionInterval;
    ExponentialGenerator maintenanceInterval;
    PoissonGenerator sessionArrivals;
PoissonGenerator maintenanceArrivals;

// Screw variables
private float totalAircraft;
private float totalInstructors;
private float totalStudents;

// Constructor
public SimulationModel(Object[] generalResources, Object[] aircraftSettings, int[] simulationSettings)
{
    // Set the general inputs
    this.quantityAircraft = (int)generalResources[0];
    this.quantityInstructors = (int)generalResources[1];
    this.quantityStudents = (int)generalResources[2];
    this.flightsPerHour = ((double)generalResources[3] / 8760); // Also equivalent to (504 hrs between flights/126 students)
    this.fuelPrice = (double)generalResources[4];
    this.hangarPrice = (double)generalResources[5];
    this.instructorPrice = (double)generalResources[6];
    this.sessionIncome = (double)generalResources[7];

    // Set the aircraft-specific inputs
    this.aircraftName = (String)aircraftSettings[0];
    this.expectedMaintenanceCost = (double)aircraftSettings[1];
    this.expectedMaintenanceArrivalInterval = (double)aircraftSettings[2];
    this.expectedMaintenanceDuration = (double)aircraftSettings[3];
    this.expectedFuelConsumption = (double)aircraftSettings[4];
    this.maintenanceRatio = (double)aircraftSettings[5];

    // Set the simulation parameters
    this.simulationLength = simulationSettings[0];
    this.repetitions = simulationSettings[1];
    this.iterationSize = simulationSettings[2];

    // Initialize schedule to iterate through
    this.simulatedHours = new Schedule[simulationLength];

    // Initialize size of customer base
    this.customerList = new Event[(int)quantityStudents];

    // Initialize outputs
    this.hoursFlown = 0;
    this.hoursMaintained = 0;
    this.avgRejectionPrcnt = 0;
sessionDuration = new GaussianGenerator(1.55, 2, seed);
sessionInterval = new ExponentialGenerator(504, seed);
maintenanceDuration = new GaussianGenerator(expectedMaintenanceDuration, 4, seed);
maintenanceInterval = new ExponentialGenerator(expectedMaintenanceArrivalInterval, seed);
sessionArrivals = new PoissonGenerator(flightsPerHour, seed);
maintenanceArrivals = new PoissonGenerator(maintenanceRatio*(flightsPerHour/quantityAircraft), seed);

//
this.totalAircraft = quantityAircraft;
this.totalInstructors = quantityInstructors;
this.totalStudents = quantityStudents;
}

//******************************************************************************
**************
// Execute model
public String execute()
{
    // Output components
    String output;
    float ratioAircraftStudent;
    float ratioInstructorStudent;
    float cost;
    float income;
    float margin;
    float avgMissPercentage;

    int[] recordedFlightHours = new int[repetitions];
    int[] recordedMaintHours = new int[repetitions];
    double[] missPercentage = new double[repetitions];
    float recordedAttempts = 0;
    float avgFlightHours = 0;
    float avgMaintHours = 0;
    float avgMisses = 0;

    int currentRepetition;
    for(currentRepetition = 0; currentRepetition < repetitions; currentRepetition ++)
    {
        Schedule.flushHistory();

        hoursFlown = 0;
hoursMaintained = 0;

// Initialize schedule
int currentTime;
for(currentTime = 0; currentTime < simulationLength; currentTime++)
{
    simulatedHours[currentTime] = new Schedule((int)quantityAircraft, (int)quantityInstructors);
}

// Initialize customer list
int currentCustomerNumber;
for(currentCustomerNumber = 0; currentCustomerNumber < customerList.length; currentCustomerNumber++)
{
    customerList[currentCustomerNumber] = new Event(false);
}

//******************************************************************************
******

// Working items
int quantityArrived;
Event newEvent;
int eventDate;
int scheduleDistance;
int eventDuration;
int currentEventIndex;
Event currentEvent;

// Begin simulation
for(currentTime = 0; currentTime < simulationLength; currentTime++)
{
    // First schedule incoming events
    quantityArrived = sessionArrivals.nextValue().intValue();

    int currentArrival;
    for(currentArrival = 0; currentArrival < quantityArrived; currentArrival++)
    {
        int maintenanceEvents = maintenanceArrivals.nextValue().intValue();
        //System.out.println(trigger);
        if(maintenanceEvents > 0)
```java
int currentMaintenance;
for(currentMaintenance = 0; currentMaintenance < maintenanceEvents; currentMaintenance++)
{
    newEvent = new Event(true);
    scheduleDistance = maintenanceInterval.nextValue().intValue();
    if(scheduleDistance < 0)
    {
        scheduleDistance = scheduleDistance * -1;
    }
    eventDate = currentTime + scheduleDistance;
    eventDuration = maintenanceDuration.nextValue().intValue();
    if(eventDuration < 0)
    {
        eventDuration = eventDuration * -1;
    }
    int i;
    for(i = 0; i < eventDuration; i++)
    {
        eventDate = eventDate + i;
        if(eventDate < simulationLength)
        {
            simulatedHours[eventDate].addEvent(newEvent);
        }
    }
}
else
{
    newEvent = customerList[seed.nextInt((int)quantityStudents)];
    eventDate = currentTime + sessionInterval.nextValue().intValue();
    eventDuration = sessionDuration.nextValue().intValue();
    if(eventDuration < 0)
    {
        eventDuration = eventDuration * -1;
    }
    int i;
    for(i = 0; i < eventDuration; i++)
    {
        eventDate = eventDate + i;
        if(eventDate < simulationLength)
        {
            simulatedHours[eventDate].addEvent(newEvent);
        }
    }
}
```
{ 
    eventDuration = eventDuration * -1;
}

int i;
for(i = 0; i < eventDuration; i++)
{
    eventDate = eventDate + i;

    if(eventDate < simulationLength)
    {
        simulatedHours[eventDate].addEvent(newEvent);
    }
}

// Execute events
for(currentEventIndex = 0; currentEventIndex <
simulatedHours[currentTime].getEvents().size();
currentEventIndex++)
{
    currentEventIndex++
    currentEvent =
simulatedHours[currentTime].getEvents().get(currentEventIndex);

    if(currentEvent != null)
    {
        if(currentEvent.getType() == false)
        {
            hoursFlown += 1;
            simulatedHours[currentTime].getEvents().get(currentEventIndex).addHour();
        }
        else
        {
            hoursMaintained += 1;
        }
    }
}

avgRejectionPrcnt = Schedule.getFailureRate();

missPercentage[currentRepetition] = avgRejectionPrcnt;
recordedFlightHours[currentRepetition] = hoursFlown;
recordedMaintHours[currentRepetition] = hoursMaintained;

// System.out.println(hoursFlown);
// System.out.println(hoursMaintained);
}

int i;
for(i = 0; i < repetitions; i++)
{
    avgMisses += missPercentage[i];
    avgFlightHours += recordedFlightHours[i];
    avgMaintHours += recordedMaintHours[i];
}

avgMisses = (avgMisses/repetitions);
avgFlightHours = (avgFlightHours/repetitions);
avgMaintHours = (avgMaintHours/repetitions);

int overhauls = (int)(((avgFlightHours/totalAircraft)/2000)*totalAircraft);
double inspections = (((avgFlightHours/totalAircraft)/100)*totalAircraft) - overhauls;

int overhauls = (int)(avgFlightHours/(totalAircraft*2000));
int inspections = (int)(avgFlightHours/(totalAircraft*100));

// Generate output
double years = (simulationLength/8760);
ratioAircraftStudent = (totalStudents/totalAircraft);
ratioInstructorStudent = (totalStudents/totalInstructors);
avgMissPercentage = (float)(avgMisses*100);
cost = (float) (((quantityAircraft*hangarPrice*simulationLength) +
(avgFlightHours*instructorPrice) +
(avgMaintHours*expectedFuelConsumption*fuelPrice) +
(avgMaintHours*expectedMaintenanceCost)) +
(overhauls*totalAircraft*18000) +
(inspections*totalAircraft*4000)+(0.85*simulationLength*totalAircraft));
income = (float)(avgFlightHours*1.3*sessionIncome)+(totalStudents*195);
margin = income - cost;

// Format output values for table
output = ratioAircraftStudent + "," + ratioInstructorStudent + "," + aircraftName + "," + (avgFlightHours/years) +
"", + (avgMaintHours + (overhauls*504) + 
(inspections*24))/years) + "," + (inspections/years) + "," + 
(overhauls/years) + "," + (cost/years) + "," + (income/years) + "," + 
(margin/years) + "\n";

    System.out.print(">> " + (avgMissPercentage) + "\r");
    //System.out.println((avgMaintHours/totalAircraft));

    return output;

}