Spring 2009

A Sensitivity Analysis of Scheduling Changes on Flight Training Resource Utilization Using Discrete Event Simulation

Melissa A. Findlay
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A Sensitivity Analysis of Scheduling Changes on Flight Training Resource Utilization
Using Discrete Event Simulation

by

Melissa A. Findlay
B.S., University of Waterloo, 2005

A Graduate Thesis Submitted to the
Department of Human Factors and Systems
in Partial Fulfillment of the Requirements for the Degree of
Master of Science in Human Factors and Systems

Embry-Riddle Aeronautical University
Daytona Beach Florida
Spring 2009
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A SENSITIVITY ANALYSIS OF SCHEDULING CHANGES ON FLIGHT TRAINING RESOURCE UTILIZATION USING DISCRETE EVENT SIMULATION

by

Melissa A. Findlay

This thesis was prepared under the direction of the candidate’s thesis committee chair, Dahai Liu, Ph.D., Department of Human Factors and Systems, and has been approved by the members of the thesis committee. It was submitted to the Department of Human Factors and Systems and has been accepted in partial fulfillment of the requirements for the degree of Master of Science in Human Factors and Systems.

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Abstract

This study presented a scheduling model of the Flight Training Department at Embry Riddle Aeronautical University’s Daytona Beach Campus built using ARENA 12.0. The purpose of the study was to determine if the Flight Training Department system was sensitive to changes in the resources available to students in Flight Training Device (FTD) course modules. Historical data from the Flight Training Department was used to build the model. As no significant difference was found between the actual real world system and the model for the number of active students and for the time it took students to complete the program, the model was determined to be valid for this study. On average, students who had more resources available to them during FTD modules completed the training program 1 day earlier than those in the current system. As well, Cessna 172 and PA44 Aircraft average daily utilization increased while Cessna 172 S and PA44 FTD average daily utilization decreased. These results are discussed and conclusions are given at the end of this paper.
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Introduction

ERAU Flight Training Department, Daytona Beach Campus

The Flight Training Department at Embry-Riddle Aeronautical University (ERAU) provides hands-on flight training to students in the four year Bachelor of Science in Aeronautical Science (professional pilot) program (ERAU, 2007). During the period of January 2, 2006 to July 3, 2006 there were between 206 and 775 active flight students (fluctuations in the number of active students are due to a number of factors, including time of year and voluntary and involuntary holds).

The Flight Training Program at Embry-Riddle recently changed from the Federal Aviation Administration (FAA) Part 141 curriculum to the Part 142 curriculum. The Part 142 Curriculum allows students to graduate as Commercial Multi-Engine pilots in a total of 140 hours. One major difference between the Part 141 and the Part 142 curriculum is that the 142 curriculum allows students to complete some of their training time in Flight Training Devices (FTD’s). The FTD’s allow students to spend less time in actual aircraft, thus reducing the cost of flight training (ERAU, 2007).

Students in the Flight Training Program have a choice between a Single Engine Track and a Multi Engine Track. The Single Engine Track is the less expensive of the two tracks and allows students to obtain the prerequisites required for the Certified Flight Instructor Course sooner. The Multi Engine Track provides students with multi engine pilot in command flight time, making the student more marketable for airline hiring (Byrnes, 2007). Figure 1 outlines the flow of students through the Flight Training curriculum.
At the beginning of each semester, flight students register for a flight block (a block of time when they are allowed to schedule flight activities). There are 7 flight blocks available per day and students can register for blocks on either Mondays, Wednesdays and Fridays or Tuesdays, Thursdays and Saturdays (Sundays are reserved for make-up activities that may have been grounded or cancelled through the week). Each student is assigned to a Certified Flight Instructor (CFI) and the CFIs are divided into 5 teams. Each team has a separate launch time within each flight block (i.e., during the first flight block of the day, Team 1 will launch at 5:45, Team 3 will launch at 6:00, Team 4 will launch at 6:15, Team 5 will launch at 6:30, and Team 6 will launch at 6:45) (Byrnes, 2007). Figure 2 graphically displays the flight blocks (each a different color) and shows how each team is assigned a different launch time to keep the aircraft staggered on the runway and in the airspace.
Figure 1. Flow Chart of the Flight Training Curriculum

Figure 2. Flight Block Schedule and Team Launch Times
The first five flight blocks are during daylight hours. The majority (75%) of the training is completed during these flight blocks. The last 2 evening flight blocks are reserved for students completing instrument training (Byrnes, 2007).

Each flight training course is divided into modules. During each module, the student tries to accomplish a set of specific tasks. The resources required vary from module to module. Figure 3 outlines each flight training course in the 142 curriculum and each of the modules within each course.

![Figure 3. Flight Course Modules](image)

**Resource Constraints**

The Flight Training Department has a limited number of resources available to students. These resources include CFI’s, aircraft, and FTD’s. The number of aircraft and FTD’s possessed by Embry-Riddle’s Daytona Beach Campus are listed below in Table 1. Students are limited to the resources that they are able to use depending on their current course and module.

The Flight Training Department tries to keep a ratio of students to CFI’s at 8:1. During the period of January 2, 2006 to July 3, 2006, there were between 55 and 98 CFI’s employed by the department (Flight Training Dept., 2006).
Due to the limited availability of resources, not all students are actively assigned to flight blocks every semester. Many students need to be placed on hold until space becomes available. Long waiting times on the part of the students results in loss of students to other local flight schools (Bazargan-Lari, 2004).

Table 1

Number of Aircraft Possessed by ERAU (Daytona Beach)

<table>
<thead>
<tr>
<th>Type</th>
<th>Number Possessed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cessna 172</td>
<td>41</td>
</tr>
<tr>
<td>Decathlon</td>
<td>1</td>
</tr>
<tr>
<td>PA28R - Arrow</td>
<td>7</td>
</tr>
<tr>
<td>PA44 - Séminole</td>
<td>9</td>
</tr>
<tr>
<td>TOTAL</td>
<td>58</td>
</tr>
<tr>
<td>Cessna 172 S</td>
<td>7</td>
</tr>
<tr>
<td>PA44 - Seminole</td>
<td>3</td>
</tr>
<tr>
<td>CRJ – Canadair Regional Jet</td>
<td>1</td>
</tr>
<tr>
<td>TOTAL</td>
<td>11</td>
</tr>
</tbody>
</table>

Problem Statement

Administrators in the Flight Training Department feel that the 142 Curriculum has led to improved efficiency in the training of flight students, but are still falling short of their goal of having flight students participate in an average of 3 flight activities per week (F. Ayers, personal communication on November 5, 2007). Flight records, kept by the department, recorded that, between the dates of December 27, 2005 and July 2, 2006, their students participated in an average of 1.1 – 3.29 activities per week, with an overall mean of 2.22 activities per week.
A case study by Bazargan-Lari (2004) presented a timetable problem of the Flight Training Department at ERAU. The study initially presented an optimized fixed timetable developed through linear programming. However, the timetable was not sustained after implementation due to the dynamic nature of the Flight Training Department. The author proposed a flexible timetable that allowed CFI’s and students to make their own schedules, but the study did not address the issue of limited resources (aircraft and FTD’s).

Byrnes (2007) conducted a Monte Carlo simulation study on the Flight Training Department at ERAU with the focus of trying to predict the number of FTD’s required by the department based on student demand. One of the challenges found in the study was that the need for resources varied seasonally. The author recommended investigating rewriting the curriculum to place a more balanced demand on the resources.

The situation at the Flight Training Department is that although CFI’s and flight blocks are available, students may not be performing activities because the other resources (aircraft and FTD’s) are not available (students need a combination of resources to complete the training). As well, it appears that some aircraft may be sitting idle while, at the same time, FTD’s are at almost 100% utilization.

A theoretical solution would be difficult to obtain for the Flight Training Department’s resource utilization issue because of the department’s dynamic nature and because of the number of variables that play a role in the system. One technique for analyzing the resource utilization issues that the Flight Training Department experiences is to build a model of the system. Modeling and simulation can provide insight into the system’s behavior, as well as allow testing of alternative solutions.
**Literature Review**

In this section, simulation and modeling will be explained, along with advantages and disadvantages of simulation studies. This will be followed by a review of simulation studies that have been conducted on systems in other service sectors.

*Simulation.* A model is a representation of a system and it may be mathematical, descriptive, logical or some combination of the three (Banks and Carson, 1986). Simulation is the process of modeling and consists of two basic steps: 1) model development and 2) experimentation. Discrete Event Simulation (DES) is a technique for the study of systems whose state changes at discrete points in time. Fundamental concepts in DES are that a system is composed of objects, known as entities, and each entity has unique properties called attributes. The system state is a collection of attributes that represent the entities of the system. An event is an occurrence in time that alters the state of the system (Pollacia, 1989).

According to Seila (1995), all simulations use a model to represent the behavior of a system that may or may not already exist. The main idea for modeling a system is to be able to analyze and understand a system’s behavior under various alternative actions or decisions.

Modeling and simulation is a widely used and increasingly popular method for studying complex systems. Some advantages to simulation that may account for its growing popularity include (Law and Kelton, 2000):

- Mathematical models cannot accurately describe stochastic elements in a system
• Simulation allows the estimation of performance of an existing system under different operating conditions

• Several alternative designs can be compared

• Simulation offers better control over experimental conditions compared to experimenting with the system itself

• Simulation allows the study of a system over a long time frame in compressed time

However, there are also disadvantages to modeling and simulation (Law and Kelton, 2000; Pollacia, 1989):

• Stochastic simulations produce only estimates of how the real system will perform

• Complex simulations can be time consuming and expensive to develop

• The large volume of data that is produced by the simulation can sometimes place greater confidence in the study’s results than justified.

• Simulation modeling can be used to compare alternatives, but not to find the optimal solution to a problem

Types of simulation studies. Law and Kelton (2000) explain that the options available for designing and analyzing a simulation experiment are dependent on the type of simulation. Simulations can be either terminating or nonterminating (steady state). A terminating simulation has a natural event that ends the simulation run and, therefore, specifies the length of each run. A steady state simulation has no distinct event that ends the simulation run and can, in theory, run forever. A model of the Flight Training Department would be an example of a steady state simulation. As long as students enter
the system at the beginning and graduate at the end, the system can run for however long
the experimenter sets it to run.

There are special statistical considerations required for steady state simulations
(Law and Kelton, 2000). A steady state model requires an initial warm up period, “after
which the statistical accumulators are cleared to allow the effect of possibly atypical
initial conditions to wear off” (Kelton, Sadowski & Sturrock, 2004).

A review of published simulation studies. Simulation has been used to model a
variety of complex systems. It is not a method specific to any particular application area
(Seila, 1995). Chin and Sprecher (1990) modeled a customer service center to analyze
“what if” scenarios in order to determine the optimal conditions necessary to meet a goal
of answering calls within the first three rings. Ioannou and Srisuwanrat (2006)
developed a scheduling algorithm to address problems with resource utilization when
scheduling construction crews to repetitive projects with probabilistic activity durations.
Lee, Park and Seo (2006) created a simulation of rail terminals at a port container facility
to determine the number of transshipment lanes and cranes required and the traffic flow
within the rail terminal. They were able to identify a layout of the terminal that most
appropriately met the rail terminal’s needs.

Literature on a simulation model of a system close to the Flight Training
Department’s scheduling process was not found, however, studies on scheduling services
were found on other service sector systems that have various elements that are similar to
the proposed study.

The Flight Training Department at ERAU provides a training service to flight
students. Modeling of a process in the service sector presents unique problems,
compared to modeling a process in manufacturing. The product produced by a service is intangible in nature and cannot be stored as inventory for future use. Services are defined as “something which are produced and consumed more or less simultaneously” (Jeang, 1994). Further complicating service sector models are variations in the type of service required, the arrival rates of the demand, and the amount of time required to provide the service (Jeang and Gonzalez, 1989).

Rossetti, Trzcinski, and Syverud (1999) used ARENA, DES software from Rockwell Automation, to simulate a 24 hour emergency department. The facility treated approximately 165 patients per day. The authors developed the model to look at staffing and utilization of nurses and physicians with the hopes of lowering staffing at slower times of the day/week to save on operating expenses and to increase staff utilization. After validating the model’s 11 performance measures against historical data from the hospital, the authors modeled 4 alternative approaches. They were able to find an approach that performed significantly better than the other approaches including the current practice.

Guo, Wagner, and West (2004) created a model for the scheduling of outpatient appointments at a pediatric ophthalmology center. Factors that made the system complex included the randomness of patient demand, substantial no-show rates in certain population segments, the large number of diagnosis types resulting in different follow-up patterns, and the highly variable nature of the providers’ schedules. The primary goal of the project was to minimize the delays for patients to get an appointment while simultaneously maximizing provider utilization and overall clinic effectiveness. Their model, the Patient Scheduling Simulation Model (PSSM), captured 4 components of the
scheduling system: external demand for appointments, supply of provider time slots, the patient flow logic, and the scheduling algorithm. Variability in their system was attributed to several factors related to the patients. The number of calls from new patients varied from day to day, the desired follow-up intervals were variable, the total number of clinic visits per patient was stochastic and patients had different habits when they scheduled follow-up appointments (some requests were weeks or months in the future). They also found that the overall provider availability was highly variable.

The PSSM was developed using a combination of tools. Arrivals and patient flow logic was implemented using ARENA 8.0, the scheduling process was implemented using a Microsoft Visual Basic module that queried and modified a Microsoft Access database table with the provider schedules. All patient appointments, both realized and only scheduled, were recorded in a table which was built up during the run of the model and contained a complete simulation record which was analyzed.

After the PSSM was set up, Guo et al. (2004) were able to evaluate how successful a given strategy was with respect to the goals of patient flow management. One goal was that 95% of patients should be seen within a week of when they want to be seen. Using their model, they tracked waiting times in the system and graphed maximum and average waiting times for a 2 year period. They observed an increasing trend in waiting times over the 2 year period and were able to implement corrective action into PSSM (they shifted capacity from another, underutilized appointment type). A second measure monitored the number of “busy” days and the number of “quiet” days for each provider. This gave the authors insight into how overbooking affects the day-to-day operations and whether the bottom line of the clinic was affected by low capacity
utilization. The third, and final, measure calculated overall utilization rates for each provider and each appointment type. This allowed a detailed look at the fluctuations in scheduled versus real utilization, enabling them to fine-tune scheduling strategies. Unfortunately, the authors did not outline specific changes that were implemented to their system or how they improved their performance measures as a result of successfully simulating their system.

Sepulveda and Cahoon (1999) developed an ARENA model of a cancer treatment center with the objective to analyze patient flow through the unit and evaluate the impact of alternative floor layouts, alternative scheduling options and requirements of a new building. Their second objective, evaluation of alternative scheduling options, is of main concern to this present study. Their initial simulation showed that there were many idle patient chairs in the center during the morning hours. By allowing more short term patients (appointment length of 4 hours or less) to schedule appointments in the morning, they decreased the number of empty chairs during the morning hours, although, this also increased the number of empty chairs in the afternoon. However, the authors did not look at the empty chairs in the afternoon as a negative effect as the restructuring of appointment scheduling allowed the center to close earlier (even though they closed the doors at 5pm, they have to wait for the last patient to finish treatment before closing for the night).

Weijewickrama and Takakuwa (2005) developed a simulation model using ARENA for an outpatient department at a Japanese hospital. Their goal was to assess different appointment schedules using simulation, with patient wait time as their performance measure. The authors were able to identify 3 efficient appointment
schedules, although, after adding environmental factors, such as no shows, variance in consultation times, and walk in rates, they were unable to identify a dominant appointment schedule for the department.

Holland (1969) developed a model of a company managed hospital facility. The facility consisted of 8 workstations, each utilizing 1 employee, with the exception of the doctor’s station where there were 4 doctors. The author examined utilization of each workstation and developed 5 alternative models that combined some of the lower utilized workstations with higher utilized workstations, thus leveling the workload between the two stations. After running and analyzing the models, the author was able to identify the best combination of workstations that leveled utilization across the facility.

Another study that looked at staffing allocation in a hospital was conducted by Jeang and Gonzales (1989). The authors looked at staffing policies for a respiratory case unit of a large hospital. The performance variables that they measured included; total cost, overtime hours, overstaff hours, incomplete job hours, overstaff frequency and incomplete job frequency. The authors were able to simulate the different policies and determine which policy, for their particular respiratory case unit, worked best at minimizing their performance variables.

The literature reviewed in the above outlines simulation studies that were performed, primarily in the health care sector, in order to level resource utilization, minimize costs or develop staffing strategies to meet variable patient demand. One downfall of most of the studies above is that they failed to outline the verification and validation of their models against real data. It is unknown how well their models of the current or proposed system behave with respect to the expected behavior from the real
system. As well, some of the studies outline the process of modeling the current system, but then only briefly describe the strategies used to develop better, more efficient systems. They rarely compared the model of the current system to the alternative that they thought would best improve their performance measures.

*Steps to a simulation study.* Law (1991) outlines steps in a sound simulation study. Figure 4 outlines these steps. The first step is to formulate the problem and plan the study. Here, the issues that need to be addressed by the model are defined so that the level of detail adequately reaches the model's objectives. The second step is to collect data on the system of interest and determine the model's logic. The third step is very important because this is where the first two steps are reviewed in order to ensure that they are complete, correct and consistent. This step should occur before any coding begins to avoid reprogramming the model. The fourth step is to construct the computer program and verify the model. Next, pilot runs will help to debug the model and produce data for the sixth step. The sixth step is to validate the data from the pilot runs. Statistical analysis that compares the model's output to actual system data will ensure that the model is valid and performs closely to the actual system. The seventh step is to design the experiment. This is where alternative designs are developed. The eighth step is to make production runs of both the model of the current system and of the proposed alternative designs. The ninth step is to analyze the output data from the model of the current system and from the model(s) of the alternative designs. Finally, the results should be documented, presented and implemented.
Current study. Few studies were found that applied discrete event simulation to a training service. That alone called for a need to study the flight training system, as it is a service business, but does not have some of the variation that other service businesses contain (i.e., variable service time). The current study was unique in that instead of
manipulating supply to accommodate a highly variable demand, it will approach the
problem by trying to level demand in order to more evenly utilize resources over time.

One requirement set by the Flight Training Department for this study dictate that it cannot require a change in the total number of resources available. The study must try to increase throughput of students and the number of weekly activities without purchasing or hiring more resources.

Hypotheses

The study proposed manipulating the types of resources available to the FTD modules. It was believed that the FTD's are a bottleneck in the system and that the system would respond to allowing a larger set of resources for the FTD modules (i.e., allowing aircraft to be used when no FTD's are available for FTD modules).

The first hypothesis was that by allowing a larger set of resources for the FTD modules, it was believed that students would progress through the system more quickly and that more activities would be performed each week.

The second hypothesis was that by allowing a larger set of resources for the FTD modules, it was believed that the Cessna 172 S and PA44 FTD utilization would decrease.

The third hypothesis was that by allowing a larger set of resources for the FTD modules, it was believed that the Cessna 172 and PA44 Aircraft utilization would increase.
Method

In this section, the ARENA Modeling Software is described, and a high level structure for the Flight Training Department model is given. As well, all input, independent and performance variables used are discussed. The end of the section outlines the statistical methods used to remove initialization bias, used to validate the model and used to compare the experimental results.

**ARENA Modeling Software**

The model of the Flight Training Department was created using the modeling software ARENA 12.0., developed by Rockwell Automation®.

ARENA is built on the SIMAN simulation language and employs an object-oriented design for an entirely graphical model development. Users develop their models creating a flowchart of the system they are modeling. The user selects the appropriate graphical modules and places them on the ARENA layout. The user can then connect the modules in the appropriate order (Markovitch and Profozick, 1996).

The ARENA software package includes an Input Analyzer that is useful for taking raw data and determining the appropriate statistical distribution that fits the data (Markovitch and Profozick, 1996).

An Output Analyzer is also included and is used to display and analyze model data after the simulation run(s). Options include plots, histograms, and other charts. It provides analysis features such as confidence intervals, one way ANOVA’s, and comparisons of multiple systems (Markovitch and Profozick, 1996).
Model Structure

Figure 5 is a very simplified, high level diagram of the ARENA model for the Flight Training Department. The model creates the arrival of new students once per year. New students are assigned attributes defining them as private pilot students and defining their track choice. Each student is assigned to a flight block and is held in a queue until an opening in their flight block becomes available. Once released, they are held until a signal is received that it is their flight block time. Once their flight block time signal is received, the system routes them to the appropriate activity, given the module sequence for their particular course. The activity holds both the student and all related resources (i.e., CFI and FTD or aircraft) for the duration of the activity. Once released, they pass through a decide block that determines if the student has met the criteria to complete the course. If the student has not completed the course, they will be routed back to the hold block until they can be released during their next flight block time. If the student has completed the course, they will be moved to another decide block that will determine if they have completed the entire flight training program. If they have not completed the entire program, they will be routed back to the assign block to be assigned to their next course. If they have completed the program, they will be disposed from the system.
Input Data Analysis

All input data used to build the model was obtained from the Flight Training Department’s records and ETA (Education and Training Administration; ERAU’s online flight training management system). Table 2 outlines the types of input data used from the Flight Training Department.
Table 2

Input Data

<table>
<thead>
<tr>
<th>Input Data Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aircraft</td>
<td>The number of each type of aircraft available.</td>
</tr>
<tr>
<td>CFI</td>
<td>The number of CFI’s available during each flight block.</td>
</tr>
<tr>
<td>FTD</td>
<td>The number of each type of FTD available.</td>
</tr>
<tr>
<td>Flight Block Assignment</td>
<td>The percentage (%) of students allocated to each flight block.</td>
</tr>
<tr>
<td>Flight Block Start Time</td>
<td>The start times for each flight block.</td>
</tr>
<tr>
<td>Module Sequence</td>
<td>The sequence of the modules for each training course.</td>
</tr>
<tr>
<td>New Students</td>
<td>The number of new students arriving each year.</td>
</tr>
<tr>
<td>Student Hold Time</td>
<td>The time (days) that students remain grounded/on hold.</td>
</tr>
<tr>
<td>Students on Hold</td>
<td>The percentage (%) of students that are grounded/on hold.</td>
</tr>
<tr>
<td>Track Choice</td>
<td>The percentage (%) of students choosing Single or Multi Tracks.</td>
</tr>
<tr>
<td>Withdraw / No-Starts</td>
<td>The percentage of students that withdraw or don’t start a course.</td>
</tr>
</tbody>
</table>

The number of aircraft and FTD’s available remained constant throughout the entire simulation. The types of aircraft and FTD’s available and the number used in the simulation is based on the current number of each available to students at the Daytona Beach Campus. Table 1 in the Introduction section outlined the type of each aircraft and FTD’s available and the number currently possessed by ERAU’s Daytona Beach Campus.

The number of CFI’s available varies throughout the day. In order to keep the model as simple as possible for the situations being considered, the number of both full time and part time CFI’s available during the Fall 2007 semester was used. A schedule was built in the model for CFI’s. Table 3 outlines a typical CFI daily schedule.
Table 3

CFI Daily Schedule

<table>
<thead>
<tr>
<th>Time Slot</th>
<th>Number of CFI's Scheduled</th>
</tr>
</thead>
<tbody>
<tr>
<td>00:00 – 06:00</td>
<td>0</td>
</tr>
<tr>
<td>06:00 – 08:00</td>
<td>29</td>
</tr>
<tr>
<td>08:00 – 16:00</td>
<td>43</td>
</tr>
<tr>
<td>16:00 – 18:00</td>
<td>26</td>
</tr>
<tr>
<td>18:00 – 00:00</td>
<td>16</td>
</tr>
</tbody>
</table>

The model was designed so that the last two flight blocks of the evening are reserved for instrument students. All instrument course students were routed evenly between the instrument flight blocks. All non-instrument course students were routed evenly between the remaining flight blocks.

The start of each flight block was preceded by a flight block signal. The current flight block start times used by the Flight Training Department were used in the model. Figure 2 in the Introduction section outlines the flight block schedule. The Flight Training Department staggers flight block times for each team to avoid congestion in the airspace and on the taxi ways and runways. In order to keep the model simple, flight block times were not staggered between teams. Flight block times are the same for the Monday, Wednesday, Friday flight blocks as they are for the Tuesday, Thursday, Saturday flight blocks.

Each course in the flight training department has a specific set of modules that are performed in a specific sequence. Each course and module sequence was used in the
model. Students in the model followed the same course and module sequence as in the
actual system. See Figure 3 in the Introduction section for module sequences.

The Input Analyzer fits probability distributions to observed real world data.
Distributions fall into two main types: theoretical and empirical. Theoretical distributions
use mathematical formulas to generate samples while empirical distributions simply
divide the actual data into groupings and calculate the proportion of values in each group.
(Kelton et al., 2004).

Law and Kelton (2000) explain that if a theoretical distribution can be found to fit
the actual data reasonable well, it is preferable to using an empirical distribution for the
following reasons:

- Theoretical distributions “smooth out” irregularities found in empirical
distributions
- It is not possible to generate values outside of the range of the observed data
  in the simulation using an empirical distribution
- The theoretical distribution is a more compact way of representing a set of
data values
- A theoretical distribution is easier to change

The Input Analyzer includes goodness of fit tests (a chi square test for large
samples or a Kolmogorov-Smirnov test for small samples) to test how adequately a
theoretical distribution explains the data points. These tests are standard statistical
hypothesis tests where the null hypothesis is that the theoretical distribution is a good fit
for the actual data (there is no difference between the actual and proposed distributions).
A larger corresponding p-value for the goodness of fit tests indicates a better fit. A rule
of thumb is that the p-value should be 0.15 or higher for a theoretical distribution to be used. If it is less than 0.15, the empirical distribution should be used (Kelton et al., 2004).

Historical data for the number of new students each Fall semester, the number of days a student was grounded or on hold and the percentage of students on hold were all analyzed with the Input Analyzer. First, the theoretical distribution was selected and the goodness of fit tests were computed. For the data that did not present adequate p-values for the goodness of fit tests, the empirical distributions were used.

According to Byrnes (2007), 75% of flight training students at ERAU choose the Single Engine Track. This percentage was used in the model for students choosing the Single Engine Track.

The percentage of students withdrawing or not starting a course varies by the course. Historical data was analyzed to determine the percentage of students withdrawing or not starting a course they had registered for. Table 4 outlines the percentage of withdraws and no-starts for each course.

Table 4

Percentage of Withdraws and No Starts for Each Course

<table>
<thead>
<tr>
<th>Course</th>
<th>Percentage of Students that Withdraw or No Start (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Private</td>
<td>14</td>
</tr>
<tr>
<td>Single Track, Multi Commercial</td>
<td>0</td>
</tr>
<tr>
<td>Single Track, Single Commercial</td>
<td>6</td>
</tr>
<tr>
<td>Single Track, Single Instrument</td>
<td>7</td>
</tr>
<tr>
<td>Multi Track, Single Commercial</td>
<td>6</td>
</tr>
<tr>
<td>Multi Track, Multi Commercial</td>
<td>0</td>
</tr>
<tr>
<td>Multi Track, Multi Instrument</td>
<td>7</td>
</tr>
<tr>
<td>Multi Track, Multi Private</td>
<td>0</td>
</tr>
</tbody>
</table>
Independent Variable

Each module type within each of the courses has a specific set of resources available to the students. The resources available to students in each module are referred to as a Resource Set. The CFI’s are not included in the resource set, as their availability is based on a schedule. All oral activities use only the CFI as a resource. The resource sets for each of the module types are listed in Table 5.

Table 5

<table>
<thead>
<tr>
<th>Module Type</th>
<th>Resource Set</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Private Flight</td>
<td>Cessna 172 Aircraft</td>
</tr>
<tr>
<td>Single Private FTD</td>
<td>Cessna 172 S FTD</td>
</tr>
<tr>
<td>Single Track, Single Instrument FTD</td>
<td>PA28R – Arrow Aircraft</td>
</tr>
<tr>
<td>Single Track, Single Instrument FTD</td>
<td>Cessna 172 S FTD</td>
</tr>
<tr>
<td>Single Track, Single Commercial FTD</td>
<td>PA44 Seminole Aircraft</td>
</tr>
<tr>
<td>Single Track, Single Commercial Flight</td>
<td>PA44 Seminole FTD</td>
</tr>
<tr>
<td>Multi Track, Multi Private Flight</td>
<td>Cessna 172 S FTD</td>
</tr>
<tr>
<td>Multi Track, Multi Instrument Flight</td>
<td>PA44 Seminole Aircraft</td>
</tr>
<tr>
<td>Multi Track, Multi Instrument FTD</td>
<td>Cessna 172 S FTD</td>
</tr>
<tr>
<td>Multi Track, Multi Commercial Flight</td>
<td>PA44 Seminole Aircraft</td>
</tr>
<tr>
<td>Multi Track, Multi Commercial FTD</td>
<td>PA44 Seminole FTD</td>
</tr>
<tr>
<td>Multi Track, Single Commercial Flight</td>
<td>Cessna 172 S FTD</td>
</tr>
</tbody>
</table>
Two situations were modeled in this study. The first situation is the current state of the Flight Training Department. The second, experimental situation provided additional resources to the FTD course modules. Rather than having just the particular FTD’s available to the students, the appropriate aircraft will also be available for use. The resource sets for each module type in the experimental situation are listed in Table 6.

Table 6
Resource Sets for Each Module Type in the Experimental Situation

<table>
<thead>
<tr>
<th>Module Type</th>
<th>Resource Set</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Private Flight</td>
<td>Cessna 172 Aircraft</td>
</tr>
<tr>
<td>Single Private FTD</td>
<td>Cessna 172 S FTD</td>
</tr>
<tr>
<td>Single Track, Single Instrument Flight</td>
<td>Cessna 172 Aircraft</td>
</tr>
<tr>
<td>Single Track, Single Instrument FTD</td>
<td>Cessna 172 S FTD</td>
</tr>
<tr>
<td>Single Track, Single Commercial Flight</td>
<td>Cessna 172 Aircraft</td>
</tr>
<tr>
<td>Single Track, Single Commercial FTD</td>
<td>PA28R – Arrow Aircraft</td>
</tr>
<tr>
<td>Single Track, Multi Commercial Flight</td>
<td>PA44 Seminole Aircraft</td>
</tr>
<tr>
<td>Single Track, Multi Commercial FTD</td>
<td>PA44 Seminole FTD</td>
</tr>
<tr>
<td>Multi Track, Multi Private Flight</td>
<td>Cessna 172 Aircraft</td>
</tr>
<tr>
<td>Multi Track, Multi Private FTD</td>
<td>Cessna 172 S FTD</td>
</tr>
<tr>
<td>Multi Track, Multi Instrument Flight</td>
<td>Cessna 172 Aircraft</td>
</tr>
<tr>
<td>Multi Track, Multi Instrument FTD</td>
<td>PA44 Seminole Aircraft</td>
</tr>
<tr>
<td>Multi Track, Multi Commercial Flight</td>
<td>Cessna 172 Aircraft</td>
</tr>
<tr>
<td>Multi Track, Multi Commercial FTD</td>
<td>PA44 Seminole FTD</td>
</tr>
<tr>
<td>Multi Track, Single Commercial Flight</td>
<td>Cessna 172 Aircraft</td>
</tr>
<tr>
<td>Multi Track, Single Commercial FTD</td>
<td>Cessna 172 S FTD</td>
</tr>
</tbody>
</table>
Output / Performance Measures

The goal of a sensitivity analysis is to determine how changes in input parameters affect the output parameters (Law and Kelton, 2000). Table 7 outlines the performance collected in this study.

Table 7
Performance Measures

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time to Complete Training</td>
<td>Time (days) for each student to complete the entire training curriculum.</td>
</tr>
<tr>
<td>Number of Active Students</td>
<td>The total number of active students.</td>
</tr>
<tr>
<td>Activities per Week</td>
<td>The number of activities that are performed each week.</td>
</tr>
<tr>
<td>Resource Utilization</td>
<td>Average daily utilization (%) of each resource.</td>
</tr>
</tbody>
</table>

Model Assumptions

The following assumptions were used to keep the model as simple as possible:

- Resources were available 100% of their scheduled time. Scheduled and unscheduled downtime was not modeled. This assumption was made to eliminate the affect of downtime on resource utilization.

- The total number of resources remained constant throughout the simulations. This assumption was made to eliminate the affect of fluctuations in the number of resources on resource utilization.
• Holidays and breaks in training were not modeled. The effect of this assumption is that number of days reported from the model cannot be considered consecutive calendar days. Since the assumption was made above to keep resources constant throughout the simulations, holidays and breaks were not modeled as this usually includes a decrease in the number of CFI’s scheduled.

• Extra training activities were not modeled. The students followed the course modules as outlined in Figure 2 of the Introduction section. This assumption was made to eliminate any affect extra training could have on the time to complete the program.

• Flight block start times were not staggered between teams in the model. Flight blocks are staggered to reduce congestion on the taxi ways, runways and in the airspace. It was believed to have no impact on the resource utilization.

Statistical Analysis

Removal of initialization bias. One of the more difficult issues in steady state simulations is the removal of any initialization bias. Since the current model starts with no students in the system, it takes a period of time for the system to warm up and reach a steady state number of students in the system (the first number of years of students need time to work through the system and graduate in order to present true system behavior). Allowing the warm up period to remain as part of the simulation can improperly affect the results, especially when the model data is compared to actual historical data. One way to remove the bias in a steady state simulation study is to identify the initialization period
and truncate those observations. The Welch graphical method involves plotting the moving average of the steady state parameter (output measure) and visually selecting the point at which to truncate the initialization period (Banks, 1998).

The Welch graphical method was used to select the warm up period in the Flight Training Department model. The Output Analyzer was used to plot the moving average of the number of active students for 10 replications of 30 years each.

**Validation of the model.** The model was built using actual historical input data from the Flight Training department, enabling comparison of the output measures to corresponding actual historical data. The actual number of active students and the actual number of activities completed per week were compared to the model’s output of number of active students and number of activities completed per week, respectively. A Welch’s t confidence interval (independent samples t confidence interval for unequal sample size and unequal variance) was used to compare actual data to model data. Welch’s t was recommended by Law and Kelton (2000) to account for the large difference in sample size between the actual data and the model data.

**Experimentation.** The ARENA software includes a random number generator, which is “the source of all randomness in simulations” (Kelton et al., 2004). The issue with random numbers and comparing two alternative simulations is that ARENA, like most other simulation software, is set up to use the same default stream of random numbers every time a simulation is run. This means that independent observations between the two alternatives cannot be guaranteed. One method to address this issue is to explicitly assign a stream of random numbers to each area that uses random numbers in each alternative simulation. The other method is to use common random numbers in both
situations and use a paired t confidence interval to compare them. The common set of random numbers also needs to be explicitly set, especially in large simulations, because as the simulation runs on in time the default stream of random numbers may not remain synchronized between the two situations (Law and Kelton, 2004). The first method was chosen for this simulation and an explicit stream of random numbers was assigned to each area of the model where random numbers were used.

The number of activities completed per week, the time for students to complete the flight training program, and average daily resource utilization from the current situation and the experimental situation were compared using a Welch’s t confidence interval because the random number streams were explicitly assigned to each area that used random numbers, enabling the assumption that the observations were independent. The effect size was computed for each comparison using Cohen’s $d$. 

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Results

Model Development

The model was built in 4 sections. The first section, shown in Figure 6, creates signals at the start time of each flight block. The signals are received by the hold blocks that are holding students that are waiting for their flight block time. When the signal matches their flight block time, the students are released from the hold block.

Figure 6. Screen Shot of Flight Block Signals
The second section, shown in Figure 7, is where the students perform their activities after they are released from the hold block. They “pick up” their appropriate resources and seize them for the duration of their flight block.

*Figure 7. Screen Shot of Activity Types and Activity Process Blocks*

The third section, shown in Figure 8, runs once per week and collects data on the number of active students in the system and the number of activities performed that week. It is reset to zero at the end of each week so that new data can be collected during the next week.
The fourth section, shown in Figure 9, is the main section of the model. It takes care of creating new students each fall, assigns attributes to the students (i.e., track decision), routes students to flight blocks and determines whether or not the student has met the requirements to complete their current course and whether or not the student has met the requirements to complete the Flight Training program. It also determines withdraws and no starts and grounds and holds based on the input data.
Figure 9. Assign, Allocate and Route Students through Flight Training Program

Removal of Initialization Bias

Figure 10 is a screen shot of the plot of the moving average for the number of active students taken from the Output Analyzer. A window length (w) of 365 days was used to smooth the moving average plot. Visually, it appeared that the initialization period could be truncated at ~3500 days. The warm up period was set for 3650 days (10 years) to ensure that all of the initialization bias was removed.
Input Data Analysis

Using the Input Analyzer, the theoretical distribution for the number of students that arrived each year in the model was: $524 + 100 \times \text{BETA}(0.299, 0.279)$. However, the goodness of fit for this distribution was not reported due to the small sample size ($n=5$). Therefore, the empirical distribution was used to generate the number of students that arrived each year. See Appendix A for the empirical distribution.

The Input Analyzer presented: $-0.5 + \text{WEIB}(13.7, 0.846)$, as the theoretical distribution for the number of days that a student is grounded or on hold. However, the goodness of fit test for the distribution was statistically significant ($\chi^2(3, n=38) = 22.8$,
p < 0.005). Therefore, the empirical distribution, in Appendix A, was used to generate the number of days a student is grounded or on hold.

The Input Analyzer presented: 1 + 60 * BETA(0.433, 1.27) as the theoretical distribution for the percentage of students grounded or placed on hold. However, the goodness of fit test for the theoretical distribution was found to be statistically significant ($\chi^2(5, n=174) = 17.0, p < 0.005$). Therefore, the empirical distribution, in Appendix A, was used to generate the percentage of students grounded or placed on hold.

**Model Validation**

The model was run 100 times for a length of 10 years each time. There was a 10 year warm up period before each replication.

The number of active students at the end of each week and the total number of activities completed each week recorded during each replication of the model were compared to the actual historical data from the Flight Training Department.

There was no significant difference for the number of active students at the end of each week between the model data and the actual historical data ($t(148) = 1.59, p = 0.11$). The 95% Welch confidence interval for the mean difference was [-69.41, 7.51].

There was also no significant difference for the number of activities completed each week between the model data and the actual historical data ($t(165) = 0.55, p = 0.60$). The 95% Welch confidence interval for the mean difference was [-96.68, 51.38]. See Table 8 for the descriptive statistics for the model validation.
Table 8

Descriptive Statistics for Model Validation

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual Number of Activities Completed Per Week</td>
<td>1156.85</td>
<td>480.70</td>
<td>165</td>
</tr>
<tr>
<td>Simulated Number of Activities Per Week</td>
<td>1179.50</td>
<td>529.94</td>
<td>52200</td>
</tr>
<tr>
<td>Actual Number of Active Students Per Week</td>
<td>592.97</td>
<td>237.38</td>
<td>148</td>
</tr>
<tr>
<td>Simulated Number of Active Students Per Week</td>
<td>623.92</td>
<td>163.75</td>
<td>52200</td>
</tr>
</tbody>
</table>

Experimentation

The current and experimental situations were run and the performance measures recorded. See Table 9 for the descriptive statistics of the output measures.

Table 9

Descriptive Statistics for Model Experimentation

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current Number of Activities Completed Per Week</td>
<td>1179.50</td>
<td>529.94</td>
<td>52200</td>
</tr>
<tr>
<td>Experimental Number of Activities Completed Per Week</td>
<td>1181.82</td>
<td>531.33</td>
<td>52200</td>
</tr>
<tr>
<td>Current Time for Students to Complete Flight Training Program (Days)</td>
<td>509.00</td>
<td>132.42</td>
<td>335000</td>
</tr>
<tr>
<td>Experimental Time for Students to Complete Flight Training Program (Days)</td>
<td>507.68</td>
<td>133.34</td>
<td>335000</td>
</tr>
<tr>
<td>Current Cessna 172 Aircraft Utilization (Average Daily Utilization)</td>
<td>0.03</td>
<td>0.11</td>
<td>365100</td>
</tr>
<tr>
<td>Experimental Cessna 172 Aircraft Utilization (Average Daily Utilization)</td>
<td>0.04</td>
<td>0.14</td>
<td>365100</td>
</tr>
<tr>
<td>Current Cessna 172 S FTD Utilization (Average Daily Utilization)</td>
<td>0.29</td>
<td>0.44</td>
<td>365100</td>
</tr>
<tr>
<td>Experimental Cessna 172 S FTD Utilization (Average Daily Utilization)</td>
<td>0.09</td>
<td>0.26</td>
<td>365100</td>
</tr>
<tr>
<td>Current PA44 Aircraft Utilization (Average Daily Utilization)</td>
<td>0.01</td>
<td>0.05</td>
<td>365100</td>
</tr>
<tr>
<td>Experimental PA44 Aircraft Utilization (Average Daily Utilization)</td>
<td>0.02</td>
<td>0.08</td>
<td>365100</td>
</tr>
<tr>
<td>Current PA44 FTD Utilization (Average Daily Utilization)</td>
<td>0.08</td>
<td>0.26</td>
<td>365100</td>
</tr>
<tr>
<td>Experimental PA44 FTD Utilization (Average Daily Utilization)</td>
<td>0.03</td>
<td>0.13</td>
<td>365100</td>
</tr>
</tbody>
</table>
There was no significant difference for the number of activities completed per week between the current and experimental situations ($t(104397) = 0.71, p = 0.48$). The 95% Welch confidence interval for the mean difference was $[-8.77, 4.13]$. Figure 11 shows the average number of activities completed per week for both conditions.

![Figure 11. Average Number of Activities Completed Per Week](image)

There was a significant decrease in the number of days it took for students to complete the flight training program ($t(669965) = 4.07, p < 0.0001$). The 95% Welch confidence interval for the mean difference was $[0.68, 1.96]$. On average, students took approximately 509 days to complete the program in the current situation and only approximately 508 days to complete the program in the experimental situation. The effect size $d$ of 0.01 indicates a small effect. The small effect indicated that only 1% of
the samples from the experimental situation are different from the current situation. Note that this is the cumulative number of days. The model did not account for holidays or breaks in training, so it should not be considered consecutive calendar days. Figure 12 shows the average time to complete the program.

![Bar graph showing average time to complete program](image)

Figure 12. Average Time to Complete Program

There was a significant decrease in the average daily utilization of the Cessna 172 S FTD’s ($t(543521) = 226.49, p<0.0001$). The 95% Welch confidence interval for the mean difference was [0.198, 0.201]. On average, the daily average utilization for the Cessna 172 S FTD’s was 29% in the current situation and 9% in the experimental situation. The effect size $d$ of 0.61 indicated a medium effect.
There was a significant increase in the average daily utilization of the Cessna 172 Aircraft ($t(634482) = 32.51, p < 0.0001$). The 95% Welch confidence interval for the mean difference was [-0.010, -0.009]. On average, the daily average utilization for the Cessna 172 Aircraft was 3% in the current situation and 4% in the experimental situation. The effect size $d$ of 0.08 indicated a small effect.

There was a significant decrease in the average daily utilization of the PA44 FTD’s ($t(492645) = 99.56, p<0.0001$). The 95% Welch confidence interval for the mean difference was [0.0490, 0.0510]. On average, the daily average utilization for the PA44 Aircraft was 8% in the current situation and 3% in the experimental situation. The effect size $d$ of 0.28 indicated a medium effect.

There was a significant increase in the average daily utilization of the PA44 Aircraft ($t(562068) = 61.35, p<0.0001$). The 95% Welch confidence interval for the mean difference was [-0.0103, -0.0097]. On average, the daily average utilization for the PA44 Aircraft was 1% in the current situation and 2% in the experimental situation. The effect size $d$ of 0.16 indicated a small effect.

Figure 13 summarizes the average daily utilization for each of the resources measured.
Discussion

In this section, the findings from the model and related issues were further investigated and discussed.

Removal of Initialization Bias

The Welch graphical method was used to remove 3650 days of data from the beginning of each replication. The removal of this data allowed the model to warm up to a steady state, eliminating the affect of any initialization bias on the output measures.

According to Law and Kelton (2000), Welch’s technique is the most general and simplest for determining the warm up length. However, it is the only technique that
requires more than 1 replication (Law and Kelton (2000) recommend more than 5) to determine the warm up length. As well, it not very precise and a large margin of error must be given by the experimenter to ensure no residual initialization bias remains.

**Input Data Analysis**

The Input Analyzer was used to fit probability distributions to the historical data for the number of new students each year, the number of days a student is placed on hold or grounded and the percentage of students on hold or grounded. The goodness of fit tests (chi square) for all three theoretical distributions showed that they really did not adequately fit the historical data points. Therefore, the empirical distributions were used to generate values for each of the three data inputs.

**Model Validation**

The model was validated using the number of active students at the end of each week and the total number of activities completed each week. Data from the model was compared to actual data from the Flight Training Department using the Welch’s t confidence interval method. The Welch’s method was chosen because of the large difference in sample size between the historical data and the simulation data.

The lack of significant difference for both the number of active students and the number of activities completed each week between the model data and the actual historical data indicated that the model is a valid representation of the Flight Training Department for the purpose of this study.
Experimentation

As stated in the hypothesis 1, it was expected that an increase in the number of resources available to the FTD modules would have an significant affect on the number of activities performed each week and the on the time it takes students to complete the flight training program.

Using Welch’s t confidence interval method, the analysis of performance measures between the current and the experimental situations showed that by adding aircraft to the resource set available to the FTD modules had a significant affect on the time it took students to complete the flight training program and on the Cessna 172 Aircraft, Cessna 172 S FTD, PA44 Aircraft and PA44 FTD resources. It did not, however, significantly affect the average number of activities that the Flight Training Department could complete in a week.

The decrease in time for students to complete the program of approximately 1 day on average was considered a small effect. Given this small effect, plus the fact that there was not a significant difference in the number of activities completed each week, the results of the study do not appear to support a recommendation to implement the proposed changes on the basis of increased throughput.

In hypothesis 2, it was believed that a larger set of resources for the FTD modules would decrease FTD utilization. A significant decrease (medium effects) in Cessna 172 S FTD and PA44 FTD average daily utilization was observed.
In hypothesis 3, it was believed that a larger set of resources for the FTD modules would increase aircraft utilization. A significant increase (small effects) in Cessna 172 Aircraft and PA44 Aircraft was observed.

The changes in both FTD and aircraft utilization indicate that the change in the resource set for the FTD modules may be the first step towards leveling resource utilization, so that there are not queues of students waiting for a particular resource when other resources are sitting idle.

Since this study was tasked to use only resources already available at ERAU’s Daytona Beach Campus, implementing the experimental condition would be only a matter of administratively changing the courses to allow use of Cessna 172 Aircraft when Cessna 172 S FTD’s are allowed and to allow use of PA44 Aircraft when PA44 FTD’s are allowed. However, this study did not look at the trade offs that exist outside of the model for implementing the experimental conditions. One of the benefits to the Part 142 curriculum is that it allows flight training to be completed in the FTD’s. Training in an FTD is less costly to the student and provides a safer training environment than an actual aircraft, especially during particular course modules. As well, FTD activities are not cancelled due to weather (in most cases) and require fewer personnel to maintain. Further analysis is required before any recommendation is made to the Flight Training Department.
Conclusions

This study applied a discrete event simulation (DES) based on ARENA to determine whether the Flight Training Department system is sensitive to changes in resource scheduling. A model was built based on the current scheduling model and historical data were obtained to verify and validate the model. From the results, it can be found that changes to the resource sets available to the FTD course modules yielded significant differences in the amount of time it took students to complete the flight training program and in the daily average utilization of the Cessna 172 Aircraft, Cessna 172 S FTD's, PA44 Aircraft and the PA44 FTD's. Thus, only part of the hypothesis was accepted based on the results as the changes to the resource set available to FTD course modules did not yield significant differences for the number of activities performed each week.

One of the goals of the Flight Training Department is to have students participate in an average of 3.0 activities per week. Currently, they are participating in an average of 2.2 activities per week. Given that this study did not present a significant difference in the number of activities completed each week with the changes in resources available to the FTD course modules, further investigation and analysis will need to be performed to improve throughput.

This study provided a working model of the Flight Training Department and the statistical analysis showed that the model was valid for the purpose of this study. Data from 100 replications, each ran for 10 years, was collected in a matter of hours. This
model can be used or modified to look more closely at the Flight Training Department, particularly other proposals that may affect throughput.

Experimentation with a model is relatively easy, once the current system is modeled and validated. What-if scenarios can be investigated before any large changes or investments are made. Yet, models are only a simplified version of the complex real system. Assumptions are made and the level of detail modeled depends on the question being answered. A particular model may be valid for one study, but not for another on the same system.

This study is limited by the number of assumptions made to keep the model as simple as possible. The assumptions may have made a difference in the analysis had they been relaxed. The study is also limited by the independent variable manipulated. The decision to manipulate the resources available to the FTD course modules was not based on a systematic approach. Other variables may be more critical to than the FTD resource set. The study did not provide, nor did it try to provide, the optimal solution for leveling resource utilization at the Daytona Beach Campus.

Input data quality is also a limitation. The historical data analyzed using the Input Analyzer, did not fit well to any of the theoretical distributions. As well, the Flight Training Department has only recently changed to a Part 142 curriculum, leaving only a small amount of historical data available for analysis. The Flight Training Department is continually working to improve the service they provide. Any changes implemented, yet not indicated in the historical data pose a possible threat of affecting the performance measures of the study.
Any future study using this, or a similar model should pursue other independent variables for manipulation. Changes to the resource sets can be expanded to the other types of course modules, as appropriate.

As well, CFI availability should be examined more closely, as they are a required resource for every module except for solo flights. The number of CFI’s available is an important factor in determining the number of activities that can be performed in a given week. This study kept the number of CFI’s constant in order to isolate the effect of the FTD module resources, however, CFI schedules are not fixed throughout the year in the actual system.

The model assumptions should be relaxed to address uncertain events, like weather, extra training and scheduled and unscheduled equipment maintenance. As the Part 142 curriculum ages, more historical data will become available and data quality will improve.

One of the benefits of using DES for a complex system, like the Flight Training Department, is that it can be analyzed under a specific set of operating conditions. As seen with this study, another benefit is that alternative conditions can be proposed and tested. Making assumptions in the model allowed control over variables not normally controlled in the real world. Finally, DES allowed the study to collect data over a period of 10 years in a matter of minutes. DES can provide the Flight Training Department visibility and information for decision making before ever making changes that will impact their operation.
References


Appendix A

The empirical distribution for the number of students arriving each year is:

CONT (0.0048, 523.500, 0.0096, 524.500, 0.0144, 525.500, 0.0192, 526.500, 0.024, 527.500, 0.0288, 528.500, 0.0336, 529.500, 0.0384, 530.500, 0.0432, 531.500, 0.048, 532.500, 0.0528, 533.500, 0.0576, 534.500, 0.0624, 535.500, 0.0672, 536.500, 0.072, 537.500, 0.0768, 538.500, 0.0816, 539.500, 0.0864, 540.500, 0.0912, 541.500, 0.096, 542.500, 0.1008, 543.500, 0.1056, 544.500, 0.1104, 545.500, 0.1152, 546.500, 0.12, 547.500, 0.1248, 548.500, 0.1296, 549.500, 0.1344, 550.500, 0.1392, 551.500, 0.144, 552.500, 0.1488, 553.500, 0.1536, 554.500, 0.1584, 555.500, 0.1632, 556.500, 0.168, 557.500, 0.1728, 558.500, 0.1776, 559.500, 0.1824, 560.500, 0.1872, 561.500, 0.192, 562.500, 0.1968, 563.500, 0.2016, 564.500, 0.2064, 565.500, 0.2112, 566.500, 0.216, 567.500, 0.2208, 568.500, 0.2256, 569.500, 0.2304, 570.500, 0.2352, 571.500, 0.24, 572.500, 0.2448, 573.500, 0.2496, 574.500, 0.2544, 575.500, 0.2592, 576.500, 0.264, 577.500, 0.2688, 578.500, 0.2736, 579.500, 0.2784, 580.500, 0.2832, 581.500, 0.288, 582.500, 0.2928, 583.500, 0.2976, 584.500, 0.3024, 585.500, 0.3072, 586.500, 0.312, 587.500, 0.3168, 588.500, 0.3216, 589.500, 0.3264, 590.500, 0.3312, 591.500, 0.3612, 592.500, 0.3912, 593.500, 0.4212, 594.500, 0.4512, 595.500, 0.4812, 596.500, 0.5112, 597.500, 0.5412, 598.500, 0.5712, 599.500, 0.6012, 600.500, 0.6312, 601.500, 0.6612, 602.500, 0.6912, 603.500, 0.7212, 604.500, 0.7512, 605.500, 0.7812, 606.500, 0.8112, 607.500, 0.8412, 608.500, 0.8712, 609.500, 0.9012, 610.500, 0.9312, 611.500, 0.9612, 612.500, 0.9912, 613.500, 1.0, 614.500)

The empirical distribution for the percentage of students grounded or on hold is:

CONT (0.000, 1.000, 0.402, 5.615, 0.557, 10.231, 0.598, 14.846, 0.644, 19.462, 0.713, 24.077, 0.793, 28.692, 0.851, 33.308, 0.874, 37.923, 0.885, 42.538, 0.931, 47.154, 0.966, 51.769, 0.989, 56.385, 1.0, 61.000)

The empirical distribution for the number of days a student is grounded or on hold is:

CONT (0.000, 0.999, 0.588, 25.899, 0.915, 50.799, 0.930, 75.699, 0.941, 100.599, 0.962, 125.499, 0.969, 150.399, 0.972, 175.299, 0.974, 200.199, 0.979, 225.099, 0.979, 249.999, 0.982, 274.900, 0.985, 299.800, 0.986, 324.700, 0.987, 349.600, 0.990, 374.500, 0.991, 399.400, 0.991, 424.300, 0.991, 449.200, 0.991, 474.100, 0.992, 499.000, 0.992, 523.900, 0.992, 548.800, 0.992, 573.700, 0.992, 598.600, 0.992, 623.500, 0.993, 648.400, 0.994, 673.300, 0.994, 698.200, 0.995, 723.100, 0.996, 748.000, 0.996, 772.901, 0.996, 797.801, 0.997, 822.701, 0.998, 847.601, 0.998, 872.501, 0.998, 897.401, 0.999, 922.301, 0.999, 947.201, 0.999, 972.101, 1.0, 997.001)