



**A Simulation Approach to Address MQ-9 Flying
Training Unit Manning Shortfalls**

THESIS

Erika E. Gilts, Captain, USAF

AFIT-ENS-MS-19-M-116

**DEPARTMENT OF THE AIR FORCE
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MANNING SHORTFALLS

THESIS

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Degree of Master of Science in Operations Research

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Abstract

Increased use of unmanned aerial vehicles (UAV) by the United States Air Force (USAF) has put a strain on the flying training units responsible for producing aircrew. An increase in student quotas, coupled with new training requirements stemming from a transition to the MQ-9 airframe, impact the resources needed to meet the desired level of student throughput. This research uses historical data of a UAV flying training unit to develop a simulation model of daily operations within a training squadron. Current requirements, operations, and instructor manning levels are used to provide a baseline assessment of the relationship between unit manning and aircrew production. Subsequent analysis investigates the effects of course frequency, class size, and quantity of instructors on student throughput. Results from this research recommend novel approaches in course execution to more fully utilize instructor capacity and inform UAV flying training units on appropriate manning levels required to meet USAF needs.

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Erika E. Gilts

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A SIMULATION APPROACH TO ADDRESS MQ-9 FLYING TRAINING UNIT MANNING SHORTFALLS

I. Introduction

1.1 Background

The 9 Attack Squadron (ATKS), located at Holloman Air Force Base, New Mexico, is responsible for training aircrew for the MQ-9 Reaper. The MQ-9 Reaper, a remotely piloted aircraft, is operated by two crews with differing roles. A pilot and sensor operator serve as the launch and recovery crew that perform takeoffs and landings. An in-flight crew consisting of a sensor operator and pilot conduct operations in flight. The MQ-9 serves a multitude of operational roles ranging from air interdiction to combat search and rescue assistance. The 9 ATKS implements five different training courses to prepare operators for all aspects of MQ-9 operations.

The largest training course is the Basic Initial Qualification Course, also referred to as the Requalification/Transition Track 1 (IQT). The IQT course trains new pilots and sensor operators as well as pilots that are transitioning from other aircraft. The IQT track consists of 93 training days with 61 academic days and 32 flight days. The Requalification/Transition Track 2 (TX-2) is mandatory training for pilots and sensor operators that have been unqualified on the MQ-9 for more than 39 months. This course consists of 71 training days with 49 academic days and 22 flight days. The Requalification/Transition Track 3 (TX-3) is similar to the TX-2 track but is required for pilots and sensor operators that have been unqualified in the MQ-9 for less than 39 months. The TX-3 track consists of 43 academic days and 16 flight days

for a total of 59 training days. Transition Track 4 (TX-4) is for training qualified MQ-9/MQ-1 pilots or sensor operators to be qualified in the MQ-9 major weapons system. The TX-4 track is 44 training days with 28 academic days and 16 flight days. The final training track offered by the 9 ATKS is the Formal Training Unit (FTU) Instructor Upgrade Training (FIUT) course, which is used to upgrade crew members to instructor status. The course runs for 22 days, consisting of seven academic days and 15 flying days. All five of the training tracks are run concurrently by the 9 ATKS year-round, excluding holidays, weekends, and MAJCOM family days.

The 9 ATKS has 15 contractor pilots who are responsible for all of the academic portions of each course, with the exclusion of one academic day on the FIUT syllabus. This allows the 34 assigned pilots, 15 attached pilots, and five reserve pilots to serve as instructors for the flight portions of the course. The number of flying events each pilot is able to instruct per week is determined by their position availability. If a pilot does not have additional squadron requirements, they are able to instruct five flying events per week while maintaining appropriate crew rest and quality of life expectations. Each pilot has a different skill set that determines which portion of each course they can instruct. The 9 ATKS pilots are also responsible for daily manning of an operations supervisor, the supervisor of flight, and a launch and recovery crew. These additional positions require particular skill sets that limit the number of pilots that are able to serve in each position. Although the pilots are frequently flying as instructors, they also must maintain currency on the MQ-9 by flying once a month as the primary pilot.

Table 1. 9 ATKS Manning

Type	Pilots	Sensor Operators
Assigned	34	30
Attached	15	9
Reserve	5	6
Contractor	15	18

Similarly, the sensor operators are limited on what they are able to instruct based on their position and availability. As depicted in Table 1, the 9 ATKS has 30 assigned sensor operators, nine attached sensor operators, six reservist sensor operators, and 18 contract sensor operators. The contract sensor operators facilitate all classroom coursework allowing the other sensor operators to instruct five flying events per week. The sensor operators are also responsible for manning launch and recovery crews daily. Unless dictated by a certain position in the squadron, the sensor operators do not otherwise serve in other capacities.

Basic crew equivalence (BCE) is a measure used by the 9 ATKS to capture annual crew production. The 9 ATKS is expected to produce at least 120 BCE per year under normal operations. The BCE factor is weighted by syllabus type with the IQT syllabus being the most heavily weighted. Each crew, a pilot and sensor operator, that completes the IQT syllabus is valued at 1 BCE. Each TX-2 crew is 0.76 BCE; TX-3 is 0.63 BCE; TX-4 is 0.45 BCE; and the FIUT crew is valued at 0.46 BCE, as displayed in Table 2.

In fiscal year 2018 the 9 ATKS was able to produce 140 BCE by implementing a surge level of effort. Because of the surge effort level, the squadron is unable to support exercises, but can require instructors to complete two flights in one day (double turns). Additionally, under surge efforts members fly more frequently each week preventing administration duties from being accomplished. Prior to 2018, the 9 ATKS produced 107 BCE on average over the course of three years.

1.2 Problem Statement

Currently, the 9 ATKS is finding difficulty in three areas: supporting administrative tasks, maintaining flight proficiency for the permanent party aircrew, and

Table 2. BCE Weights

Syllabus	BCE
IQT	1.00
TX-2	0.76
TX-3	0.63
TX-4	0.45
FIUT	0.46

providing appropriate crew rest to meet the demands of the current number of students in training. The 9 ATKS anticipates an influx of additional students for the IQT syllabus in the coming years and are unsure of the number of instructor pilots needed to maintain coursework flow so that students graduate on time. Other factors that affect the ability to meet training requirements are: weather conditions, permanent party deployments, temporary duty assignments (TDY), maintenance, flying status, and leave.

Currently, the 9 ATKS falls under Air Combat Command (ACC), but will be transitioning to Air Education and Training Command (AETC) in the near future. Prior to transitioning to AETC, the 9 ATKS would like insight into optimizing the current flying operations to meet all squadron needs and determining the number of instructor aircrew needed as class sizes fluctuate. A manning assessment had not been completed since the MQ-9 Reaper replaced the MQ-1, nor had one been conducted with the multiple changes in course syllabi. The purpose of this analysis was to determine the number of operators the 9 ATKS can train annually with their current manning, as well as to determine the number of instructors required for the anticipated increase in student operators training on the MQ-9.

1.3 Research Objectives

The objectives of this manning study are to answer the following questions for the 9 ATKS:

1. Will current manning allow student production needs to be met without over-tasking instructors?
2. What is the appropriate instructor-student ratio to produce a certain number of students in a specified time frame?
3. What aspects of the training create delays?
4. Given changes in Air Force (AF) demand, how many instructors are projected to be needed in the future?

1.4 Summary

This document first reviews differing approaches to solving a scheduling problem of this nature in Chapter 2. In Chapter 3, the method in which the manning analysis was completed is presented, followed by the analysis and results from the study in Chapter 4. Finally, conclusions and recommendations on how to proceed are addressed in Chapter 5.

II. Literature Review

2.1 Overview

This chapter explores the different methods of schedule optimization when multiple constraints exist. Scheduling optimization problems are common, thus there are many approaches for discovering a near-optimal solution. The methods discussed provide insight into approaches used for differing scheduling situations. All of the methods are considered as potential applications to provide insight to the 9 ATKs.

2.2 Linear Programming

The most basic employee scheduling problems can be addressed with linear programming techniques. The general form has an objective function which minimizes the number of employees working constrained by the number of individuals required to be on shift each day. This approach typically yields a non-integer solution that users ultimately end up rounding or truncating to meet the needs of the problem and to simplify the means to solving [1]. Although linear programming is a good starting point, other math programming methods are more effective and realistic for the scheduling situation under analysis.

2.3 Integer Programming

Billionnet [2] showed that integer programming can be used to solve a scheduling problem with a hierarchical workforce for a seven day work week. His simple model can be extended to other scheduling situations, such as employees receiving a certain number of off days.

A real-world example of integer programming techniques applied to a New Zealand metropolitan bus operation schedule was completed by Ryan and Foster [3], where

subproblems were formed in order to obtain optimal solutions. The bus operation schedule was quite complex in comparison to the simple models presented by Billionnet, illustrating the wide application of integer programming to scheduling scenarios. Some traditional scheduling integer programming problems use a branch-and-bound procedure to find the optimal solution. This solution method discards schedules by showing that the objective values found are better than a provable lower bound that was previously obtained in the same manner[4].

Another method that has been used for solving optimization problems is the coordinate decent technique. The algorithm minimizes the function along each coordinate axis and eventually converges to the global optimal solution[5]. Miller, Pierskall, and Rath [6] discuss how to use a cyclic coordinate descent algorithm to find optimal solutions for a hospital unit scheduling problem. Their problem is to balance the trade-off between schedule preferences and shift coverage. The balance treats the nurse dissatisfaction as a cost balanced against the cost of staffing. There is a similar factor in the scheduling of instructor pilots when considering both the crew rest and quality of life aspects. The problem also has a number of constraints, such as number of days on/off, individual staffing constraints, and differing schedules by ward. This required the split of constraints into two classes, feasibility constraints and non-binding constraints. The non-binding constraints have a cost associated with them to penalize not meeting the desired goal. The results found that the cyclic coordinate descent algorithm produced a near-optimal solution more quickly than a branch-and-bound algorithm that gave the optimal solution.

Not having sufficient instructor pilots to meet the flight hour demands while satisfying office hours suggests potential binding constraint issues that may lead to infeasible solutions. Beck [7] states that “since scheduling problems are often over constrained, relaxation is sometimes needed to find any solution, not just optimized

solutions”. Generally, when constraints are relaxed, a weight or cost is used to penalize not meeting the constraint. In applying this concept to the training group, the weight could reflect the negative impact on the unit for loss of administrative time or quality of life factors. Relaxation also allows for trade-offs involved with the problem constraint.

Although integer programming has been used to solve many scheduling problems successfully, it is not the best method to use for our manning assessment. Some of the factors to consider for the 9 ATKS are dynamic, and would not properly be captured using an integer programming approach. The only way to apply integer programming to the problem at hand would require assumptions that would create unrealistic and potentially unachievable solutions for the 9 ATKS.

2.4 Simulation

Simulation has been used in application for scheduling optimization. Simulations allow for factors to be represented with distributions that more closely resemble the real-world problem opposed to a constant value. Banks, et al. [8] highlight that often a model of the system can be developed which can be solved with mathematical methods, but the complexity of the real-world system isn’t captured as well as it can with a computer-based simulation. A simulation of the system allows for study and analysis of aspects that can change over time with multiple runs providing insight to the expected outcomes and their distributions. Once a simulation model is constructed, the user can alter multiple factors and predict system performance with those changes. Analysis of the output of a simulation based on changes in the input provides valuable information on the impact of the differing variables. The insights gained from a simulation can help identify areas that can be improved in the real-world system.

A simulation was used to improve the process in a cancer treatment center by Sepulveda, et al. [9]. Four different types of patients were under consideration in the system. They visit two different locations for medical consultation, followed by treatment if required. At the first location, each type of patient is treated specific to their condition and visited by different hospital staff. The service times for each patient differ according to their type. A simulation model was created considering all of the factors and 20 replications were run to obtain reliable system estimates. Three objectives were considered in the simulation, the one of interest being a comparison of scheduling alternatives. The simulation identified that chairs were idle in the morning, and with a change in scheduling procedure, a 30% increase in patients serviced was observed with the same level of staffing.

Our manning assessment has similar aspects to the cancer treatment center case. Each student has a number of different flights to complete in their training plan where the instructors are limited by their skill set similar to the patient type requiring different medical professionals to treat them. Additionally, the syllabus each student follows determines which flights are required comparable to the alternate service times of each patient type.

Another scheduling application using simulation was presented by Kumar and Kapur on emergency room scheduling [10]. The objective of the simulation analysis was to evaluate the effect of staffing level by shift length on the quality of service while optimizing the patient turnaround time and minimizing cost. A simulation was used in order to capture the dynamic types of workload and to experiment with alternate staffing options as they impacted patient service. The emergency room had five levels of emergency and each level is treated in a different way. The staff is used for each level of emergency in alternate ways and is constrained by the length of shift they are working. An optimal schedule was determined by running three alternative schedules

to identify which best decreased wait time in relation to staff utilization.

The five levels of emergency in this problem are comparable to the different syllabus tracks that the 9th ATKS is responsible for instructing. The instructors are responsible for teaching all of the syllabus tracks which are running simultaneously with differing number of students and flights for each syllabus. The 9th ATKS wishes to optimize the use of their instructors in a way to maximize the number of students completing each syllabus. Running multiple combinations of factors that are changeable is one method to identify an optimal scheduling scheme as was demonstrated in the emergency room problem.

Sequin and Hunter [11] used a resource allocation planning tool to simulate the training operations for the Canadian Forces Flying Training School to analyze potential alterations to the training program. The simulation accounts for weather, aircraft, simulators, different instructor types, as well as student performance. The objective of the study was to identify which of three alternatives would minimize delays for course completion. The simulation allowed them to identify causes of delays and the impact of different scheduling options. Based on their simulation results from the different scenarios, Sequin and Hunter determined the availability of simulators to be the biggest factor in delays. They also were able to identify that block scheduling format to be the best scheduling alternative to expedite course completion. The Canadian Forces Flying Training Schools operations are similar to that of the 9th ATKS and further support the use of a simulation for this analysis.

With the use of a simulation, each 9 ATKS instructor can be modeled with their specific skill set and applicable time available to instruct. A simulation will also capture the effect of maintenance down time and weather cancellations in a manner that more realistically represents real life. In comparison, a constant rate does not properly capture seasonal differences as would be used with an integer programming

approach.

2.5 Optimizing Simulation

A simulation provides valuable information regarding performance measures for different system combinations, but it is not an immediate optimization tool. As explained by Jun, Jacobson, and Swisher [12], a multi-criteria objective function is created when there are multiple output measures from the simulation to optimize. They further argue that while there are advantages and disadvantages to both, combining a simulation with optimization methods will “capitalize on the advantages of using both techniques simultaneously.”

Rather than manually change input parameters, run the simulation, and compare results, modern simulation software provides features that can systematically optimize a simulation. April, et al. [13] state that nearly all modern software simulation packages provide a search for optimal values of input parameters as opposed to just completing a pure statistical estimation. They further state that most optimization software uses evolutionary approaches, which “search the solution space by building and then evolving a population of solutions.” The simulation software program available for this study, Simio, offers the optimizer OptQuest; an evolutionary approach according to April et al. [13].

According to Wan and Kleijnen [14], OptQuest assesses the inputs and outputs of the simulation. The user provides a starting point for the parameters as well as precision level, stopping criteria, and the objective to optimize. If a solution does not meet the parameter constraints, OptQuest explores other candidate values. Wan and Kleijnen used OptQuest to optimize an inventory management system where the objective was to minimize the inventory cost. They found that OptQuest provided an output that was the best estimate of the true optimum when compared to a modified

response surface methodology, or a combination of perturbation analysis and feasible direction method. Creating a simulation to represent the 9 ATKS scheduling scenario with the implementation of OptQuest can provide a means to assess optimal schedule options for the unit.

2.6 Conclusion

The methods presented are only a few common ways to address the constrained scheduling problem. With the complexity of the flight training scheduling for the MQ-9 community, one method will not be sufficient in addressing the unit concerns. Therefore, a combination of model simulation and optimization will be utilized via Simios OptQuest feature to analyze the scheduling scenario at the 9 ATKS.

III. Methodology

3.1 Overview

This chapter discusses the formulation and construction of a simulation model representing the 9 ATKS operations. First, the software being used is described followed by a description of how the model was built to represent real life operations. Assumptions used to create the model are presented. Data sources, model metrics, as well as, validation and verification processes are discussed. The chapter concludes with the description of the experiments conducted, which were used to gather information for the 9 ATKS and to best inform their future manning decisions.

3.2 Software

To best address the research objectives, a simulation was built using Simio simulation software. This represents the real-life operations of the 9 ATKS. It would be both impractical, and for some scenarios, impossible, to test the different manning configurations directly in the squadron. The use of Simio simulation software by Simio LLC provides a means to create a simulation representing the squadron functions. Simio simulation software is a graphical object-oriented modeling program. The software allows users to build the model step-by-step using intelligent objects that are able to interact with one another. This simulation tool has built-in features that simplified building a simulation. Simio provides the capability to run experiments as well as generate multiple types of output data, allowing for intuitive analysis of results [15]. Users do not require extensive simulation software engineering experience to exhibit vast control over simulation models. Coupled with the wide variety of tools provided in the framework, Simio software provides a solid platform upon which a model was created to represent the operations of the 9 ATKS.

3.3 Model Overview

The model represents key aspects of the day-to-day operations of the 9 ATKS. Each instructor that was assigned, attached, reservist, or a contractor is represented in the simulation as a resource. The number of pilots and sensor operators associated with the 9 ATKS in October of 2018 was used as the representative number of members the 9 ATKS typically maintains. No two instructors in the 9 ATKS hold the same skill set or job requirements.

With a total of 132 instructors, modeling individualized schedules was impractical, and such granularity is not necessitated. Based upon historical averages provided by the unit, an average number of flying duties capable of being completed in a week was applied to each type of instructor: assigned, attached, reserve, and contractor. This allows assigned instructors to complete five events per week, attached instructors two events, active reservists four events, and contractors five events. Additionally, the traditional reserve pilots that fly one event per month were removed from the model altogether.

Under normal operations, once considerations are made for pre-brief, post-brief and administrative requirements that are involved, instructors are only able to complete one flying event per day. Flying more than one event would violate crew rest requirements. Therefore, the simulation seizes an instructor for the entirety of the eight-hour day for one flying event.

Instructors can also be seized for specialty daily assignments which prevents them from instructing that day. Four sensor operators and four pilots are used daily for launch and recovery of the MQ-9. One experienced pilot is assigned to operations supervisor along with one pilot captain. The 9 ATKS mans a supervisor of flight (SOF) position which prevents those qualified to serve as SOF from instructing twice a week, on average. Also, all instructors must maintain currency on their certifications.

This requires a skilled pilot and sensor operator to oversee a certification maintenance flight. This is captured in the model by seizing the appropriate instructors once a week.

There are 14 different skill sets each instructor can possess which determines what flights or academic courses they can instruct. For both the sensor operators and the pilots, 14 different lists were created from which to pull when selecting instructors in the model. Model selection of instructors reflects the sourcing prioritization schedule of the 9 ATKS and is accordingly captured in the resource list order. The 9 ATKS prefers to use contractors first, followed by reserve and attached members, and assigned members last. A few of the instructors are limited to flights that are taught in a simulator. This required an additional five lists to differentiate when a flight can only be taught in the MQ-9 aircraft.

The 9 ATKS also identifies a few select pilots and sensor operators for classroom instruction. Currently, they use only contractors to fill the in-class instructor role. This was represented with a resource list identifying the appropriate instructors. As experienced in the real world, instructors are not always available due to TDYs, leave, illness, and other military duties. Based on the historical data provided by the 9 ATKS, 12% of instructors are unavailable each duty day. This was modeled by having an additional entity seize 16 instructors at random each day, so they cannot be used for any other tasks.

The 9 ATKS uses both MQ-9 aircraft and MQ-9 simulators for training purposes. They have four aircraft and four simulators on hand for daily use. These are modeled as resources that are seized by students as they commence each training task. On a normal day in the 9 ATKS, each aircraft completes four flights and each simulator completes five flights. For simplification purposes, the number of daily flights the aircraft or simulator can complete is captured with a capacity placed on each equipment

resource. Availability of aircraft is limited by both weather conditions and necessary aircraft maintenance, and simulator availability is limited by downtime for maintenance and software updates. Based on historical data, the average operational time aircraft lost due to weather and maintenance is 23.6% and 3.5%, respectively. The simulators are not affected by weather, but are down 0.3% of the time for maintenance and software updates. The effect of weather is modeled by seizing all aircraft on days when the weather would prevent flight. This is captured in the model by a process that uses a Bernoulli distribution with probability of success equal to 23.6%, which upon a success seizes all aircraft from use for the day. Additionally, the maintenance of each type of aircraft is an individual reliability factor attached to each equipment resource. The failure is based on a usage count and the count between failures follows a uniform distribution for both aircraft and simulators. Each downtime is modeled as a full day, which makes the equipment inoperable for four flights on an aircraft and five flights on a simulator. To simulate the 3.5% downtime on the aircraft as four flights, the uptime per aircraft is 114 flights, and was modeled as a uniform distribution with a minimum of 104 and max of 124. The simulators have an uptime of 1,600 flights for 0.3% to be modeled as five flights of down time and was captured in the model as a uniform distribution with a max of 1,800 and minimum of 1,400.

There are a total of five different syllabi in the MQ-9 Initial Qualification and Requalification Training Courses. In both Initial Qualification and Requalification Training, each syllabus is broken down by events with the time in hours that each event takes to complete. These events consist of academic courses, simulation flights, and flights in the aircraft. All syllabi in the MQ-9 Initial Qualification and Requalification Training documentation list each training day for the syllabus with the event that is completed on that day [16]. Instead of individually addressing all academic courses, the training days that consisted solely of academic courses were modeled as

an entire training day of academics. Both types of flying events are broken down into mission support time and flight time. With the requirements for pre-brief/post-brief, as well as paperwork, students are only able to complete one flying event per day under normal operations. To simplify the initial model, flights were modeled as lasting the duration of the day, since the same students and crew complete these portions together.

The five different courses are represented as servers that process entities. Within each server is a task table that lists all of the events required for that syllabus in the order in which the tasks need to be completed. The task tables were constructed based on the MQ-9 Initial Qualification and Requalification Training manual along with consultation with members of the 9 ATKS. A flow chart was created as a visual representation of the task list to capture the different routes students can take to complete the syllabus. In Figure 1, the IQT syllabus flow chart depicts the progression of the syllabus. The remaining four course flow charts are located in Appendix A.



Figure 1. Flowchart of IQT Syllabus

Each task table representing a syllabus contains columns representing the different aspects of each training event. The table contains the following information: task name, processing time, predecessor tasks, probability of student failure, pilot resource requirement, sensor operator resource requirement, equipment requirement, starting task process, and a finish task process. All task processing times are set to eight hours, as they normally take a student an entire day to complete. The predecessor tasks are determined by the course flow, as listed in the MQ-9 Initial Qualification and Requalification Training manual.

A few tasks can be completed in differing order, dependent on their prerequisite requirements. The predecessor component allows the students to complete the tasks in a variety of patterns, dependent on instructor and equipment availability. The probability of student failure is listed for each event as provided by 9 ATKS historical data. The pilot, sensor operator, and equipment requirements contain the list of applicable instructors or equipment (aircraft or simulator) for that particular event. For some events, only an in-class instructor is required, and a dummy resource is used as a filler for the other instructor requirement. Also, some academic days are strictly computer-based and do not require any resources.

The starting task for each training event is either an individual process completed by each student, a event completed as a set of two students (super-sortie), or an academic course that is completed as a class of students. The individual process checks that the resources are available for that student, and that the student is not currently completing other tasks. If both those criteria are met, the student seizes the appropriate resources for the duration of the task. If one of those criteria is not met, the student waits until both criteria are met. For the super-sorties and academic class tasks, the start task process has student entities wait to complete the task until the appropriate number of students are available. For super-sorties, there must be

two students to complete the task. For the academic classes, the entire class must be available to complete the tasks.

Once the appropriate number of students are in the queue for the task, the resource requirements are checked, as well as ensuring the students are not also completing other tasks. If all resources are available, only one student seizes them for the entire group of students to represent that only one instructor is needed for either the whole class or pair of students. After the processing time has passed in the simulation, the finish task process is implemented. The finish task process is similar for all events; the student releases the resources seized for the task.

To determine if the student failed the course, a random number is generated and compared to the probability of failure for that event. If the random number is larger than the probability of failure, the student passes the event and the task is saved as complete without failing for that student. If the student fails the event, it is marked as complete with a failure for the student. If the student fails, they have not met the predecessor requirement for the next task and will repeat the task until passed. An example of the task table for the IQT Syllabus is listed below in Figure 2.

Task_Number	Task_Name	Process_Time (Hours)	Predecessor_Job_Number	Prob_Failure	IP_Resource	ISO_Resource	Equipment_Required	Starting_Task	Finished_Task
1	Acad1	8		0	DummyResourceList	DummyResourceList	DummyResourceList	Batch_Task_Started	Batch_Task_Finished
2	Acad2	8	1	0	PilotClass1	SensorClass1	DummyResourceList	Batch_Task_Started	Batch_Task_Finished
3	FAM_1S	8	2	0	Pilots_IP_SO	Sensors_ISO_SO	Simulators	Task_Started	Task_Finished
4	Acad4	8	3	0	PilotClass1	SensorClass1	DummyResourceList	Batch_Task_Started	Batch_Task_Finished
5	Acad5	8	4	0	PilotClass1	DummyResourceList	DummyResourceList	Batch_Task_Started	Batch_Task_Finished
6	Acad6	8	5	0	DummyResourceList	DummyResourceList	DummyResourceList	Batch_Task_Started	Batch_Task_Finished
7	Acad7	8	6	0	DummyResourceList	SensorClass1	DummyResourceList	Batch_Task_Started	Batch_Task_Finished
8	Acad8	8	7	0	DummyResourceList	DummyResourceList	DummyResourceList	Batch_Task_Started	Batch_Task_Finished
9	Acad9	8	8	0	PilotClass1	DummyResourceList	DummyResourceList	Batch_Task_Started	Batch_Task_Finished
10	Acad10	8	9	0	DummyResourceList	DummyResourceList	DummyResourceList	Batch_Task_Started	Batch_Task_Finished
11	Acad11	8	10	0	PilotClass1	DummyResourceList	DummyResourceList	Batch_Task_Started	Batch_Task_Finished
12	Acad12	8	11	0	PilotClass1	DummyResourceList	DummyResourceList	Batch_Task_Started	Batch_Task_Finished
13	TR_1S	8	12	0	Pilots_IP_SO	Sensors_ISO_SO	Simulators	SS_Task_Started	SS_Task_Finished
14	TR_2S	8	13	0	Pilots_IP_SO	Sensors_ISO_SO	Simulators	SS_Task_Started	SS_Task_Finished
15	EP_1S	8	14	0	Pilots_IP_SO	Sensors_ISO_SO	Simulators	SS_Task_Started	SS_Task_Finished

Figure 2. Portion of Task Table for IQT Syllabus

The students flowing through the events in each course are represented as entities in the simulation. Each student entity represents a pair of students, or crew, comprised of a student pilot and student sensor operator, representative of how the 9 ATKS trains all of their students. For the initial model, student arrivals are determined by the historical average number of classes taught in the last two years for each course.

The 9 ATKS did not begin using the most current IQT syllabus until October of 2018. However, the 9 ATKS sister squadron, the 6th Attack Squadron (6 ATKS), has been using the new syllabus for a longer period of time. Historical data from the 6 ATKS was therefore used for validation purposes. For the most current IQT syllabus, the 6 ATKS facilitated nine courses with an average class size of 10 students. In the model, the IQT classes are modeled as arriving every 41 days to ensure nine IQT classes are carried out in the simulated year.

In the 2016-2018 time frame the 9 ATKS facilitated two TX-2 courses, three TX-3 courses, four TX-4 courses, and 20 FIUT courses. This was represented in the model as students for the TX-2 course arriving every 365 days, every 219 days for the TX-3 course, every 183 days for the TX-3 course, and every 37 days for the FIUT track. The historical average class size for the TX-4 course was six students and the remaining courses (TX-2, TX-3 and FIUT) all had an average class size of two.

In addition to instruction, pilots and sensor operator instructors have additional duties that must be completed. To capture these additional duties in the model, an additional entity is used to seize the instructor resources. For every day in the simulation model, an additional duty entity arrives and seizes the instructor resources that are needed for squadron operations outside of instruction, as is the case in real world operations. This same method is used to seize the 12% of instructors that are unavailable for instruction each day. Derivation of how this 12% was derived is

further discussed in section 3.4. Similarly, an entity is used to represent bad weather, where all four aircraft are seized due to cancellation of flight operations.

3.4 Assumptions

Model assumptions are necessary to properly capture the real world aspects of the 9 ATKS that cannot be recreated in the simulation. Members of the 9 ATKS are unavailable to complete their duty when they are TDY, duties not to include flight (DNIF) status, on leave, or attending other Air Force mandated events. The 9 ATKS data provides the unavailability of instructors but does not decompose it by reason. Therefore, the percentage of instructors unavailable, as provided by the unit, was implemented as a per-day proportion of the entire instructor bank. This rate was represented in the model with an entity completing a process that seized 12% of instructors for the duration of the duty day. This approach captures the effect of instructor unavailability as required.

Weather also inhibits the ability to complete training for the 9 ATKS. During the rainy season (July to September) many scheduled flights are either completed as a simulation or are cancelled. Rather than implement the seasonal effect of weather, the model implements an overall average rate of flight cancellation due to weather. Aircraft were seized by a weather entity to represent their inability to be used for a flight. The entity seizes all MQ-9 aircraft 23.6% of the time, as reported by the 9 ATKS. This ensures all aircraft are unavailable for the day, instead of applying an independent weather cancellation probability for each aircraft.

Maintenance on the aircraft and on simulators also causes delays in training for the 9 ATKS. The maintenance on the simulators is rare compared to the aircraft, with simulators only being down 0.3% of the time. The aircraft maintenance is captured at a steady rate of 3.5%, as has been documented by the 9 ATKS for MQ-9

reliability. This reliability factor is built into each equipment resource, as there is no interdependence between aircraft reliability. For both the simulators and MQ-9 aircraft, the uptime between failures is captured with a uniform distribution with a down time of one day. It was assumed that maintenance on an aircraft would remove it from use for the entirety of the day.

The FIUT course is used to train students to become instructors of the other four courses taught in the 9 ATKS. All of the flights required for the course are reliant on the IQT syllabus flow. The FIUT students instruct the IQT students as part of their course requirements. This aspect of the FIUT training was not modeled due to the complexity of the real-world training situation. The delays that have been experienced in the 9 ATKS due to this reliance have been built into the FIUT course task table to represent the time delay. These delays are assumed to be representative of the actual delays caused by the FIUT students waiting on IQT course flights to instruct.

3.5 Data Source and Model Inputs

All data used for model input was provided by the 9 ATKS and 16th Training Squadron (16 TRS). The assistant director of operations of the 16 TRS oversees the 9 ATKS operations and maintains historical data on the number of students flowing through courses for all three squadrons that train MQ-9 pilots and sensor operators. The 16 TRS also provided flight cancellation rates due to weather and maintenance issues. Data were collected on the number of 9 ATKS members unavailable for duty due to leave, TDYs, appointments, volunteering, training, and morale events from July to December of 2018. This information was used to determine the number of instructors unavailable on a daily basis. Information on the number of instructors and their skill sets was provided by the 9 ATKS Director of Staff which guided

creation of the resource lists, as well as the number of resources representative of the current operations in the 9 ATKS. The preferences of instructor selection was provided by the 9 ATKS scheduler, who has been managing scheduling for five years. The scheduler also provided guidance on the average instructor utilization for additional duties, helping to create a more realistic model. The scheduler also provided the mean number of flights each type of instructor completed weekly and how frequently members must fly recertification flights.

3.6 Model Metrics

The focus of this study is to provide insight to the 9 ATKS on the number of instructors required to achieve a desired number of students completing training in a specified amount of time. To capture data from the simulation, the instructor utilization and time to complete each course for the students was recorded. Additionally, for model validation and further insights on 9 ATKS operations, the aircraft utilization, simulator utilization, and instructor utilization were recorded for analysis. In order to provide guidance on where the syllabi could potentially be improved, the time waiting to complete each task was recorded to identify which events in each syllabi were causing delays.

3.7 Verification and Validation

Verification and validation are necessary steps in developing a simulation to ensure the model is representative of the operations of the 9 ATKS. Throughout the construction of the model, members of the 9 ATKS that were most familiar with the squadron functions were consulted to confirm the representations in the model were accurate. Initially, a test model was constructed with only a few students completing a few tasks to verify that the processes created to simulate the course flow were func-

tioning appropriately. The test model was also used to verify proper implementation of the logic for student failure. Additionally, a visual was added to follow the student flow through each task in the syllabus to provide further verification of proper course completion in the simulation.

Once the processes proved to be representative of the course tasks in the test model, they were applied to the full model of the 9 ATKS unit. In the complete model of the 9 ATKS operations, the student count was monitored with a visual display during test runs, showing the number of students currently in the course and the number that completed the course. This allowed for verification that classes were starting and ending together and that students were successfully completing the entire syllabus. Also, to establish a baseline, the number of days to complete the syllabus was recorded under perfect conditions, with no weather or maintenance cancellations and all instructors available. The time to complete the syllabus for each class of students directly matched the MQ-9 Initial Qualification and Requalification Training Course syllabus projection, further verifying that the model was representing the 9 ATKS functions accurately.

The model was validated by comparing the length of time to complete each syllabi with the historical results provided by the 9 ATKS. The simulation was run with the same number of students as had historically gone through the different training courses. The simulation completed twenty runs with a warm up period of 365 days and then recorded the completion time and number of students completing each syllabi in the systems' steady state for 365 days. The real-world average number of days it took to complete each syllabi was compared to the average number of days it took for the simulated students to complete each syllabi as depicted in Table 3. A modified two-sample- t confidence interval was used to assess the difference between the simulated mean completion time and the historical completion time, which indicated that the

two are not statistically significantly different.

Table 3. Real-World Completion Time vs Simulation

Syllabus	Mean Completion Time	Simulation Mean Time	95% CI Mean Difference
IQT	151.9	153.0	(-13.8, 11.6)
TX-2	122.0	102.4	(-246.4, 286.6)
TX-3	114.7	91.0	(-108.5, 155.8)
TX-4	64.0	69.1	(-19.0, 8.9)
FIUT	83.0	81.9	(-12.8, 14.8)

Additionally, the historical number of students that completed each syllabus in 2017-2018 was compared to the number of students completing each syllabus as shown in Table 4. The syllabus of most interest is the IQT syllabus, in which the difference in the student completion numbers between simulated data and historical data was only one student. The remaining syllabi student throughput is very similar to real world, with the FIUT syllabus throughput being the furthest from historically observed by four students.

Table 4. Real-World Student Throughput vs Simulation

Syllabus	Mean Throughput	Simulation Mean Throughput
IQT	87	86
TX-2	2	2
TX-3	1	2
TX-4	35	36
FIUT	14	10

3.8 Experiments

The 9 ATKs anticipates an increased demand for trained MQ-9 crews and, therefore, larger class sizes as the MQ-9 platform is being utilized more frequently in Air Force operations. To capture the impact of increased class size on the squadron, experiments were run with differing levels of students flowing into the system. With a

current class size for the IQT syllabus of 16 students, experiments were run testing a range of 10 to 18 students per class.

Furthermore, the 9 ATKS was interested in knowing the impact on student flow with an increase of instructors, leading to an experiment increasing the current instructors by up to 18 additional instructors to both the pilot and sensor operator instructor set to simulate 100% of authorized levels. Another alternative under consideration is an increase in class frequency. As such, an additional experiment was run with class arrival decreasing from every 50 days to 40 and 30 days between class arrivals, while holding instructor levels constant and varying class size ranging from 10 to 18 students. The results of the experiments are used to inform the 9 ATKS of the impacts of any of the potential changes on their capability to train MQ-9 aircrew.

3.9 Summary

The model built to simulate the operations of the 9 ATKS took into account the key components in student completion of courses. The nuances of day-to-day operations in the squadron are not captured, but the discrete event simulation was thoroughly and meticulously created to simulate normal daily operations in the 9 ATKS. The simulation provides validated results that can inform 9 ATKS decision-makers on current manning and training shortfalls. The simulation also allows for adjustments representative of changes the 9 ATKS could experience, which can guide future decisions on manning, student class size, and course scheduling.

IV. Analysis

4.1 Overview

In this chapter, the baseline model is analyzed to understand current operations in the 9 ATKS. A design of experiments approach is used to explore the solution space of possible class size and instructor levels as they relate to student throughput and course completion for the IQT syllabus. Additional experiments are completed to assess the impact of frequency of IQT course offerings with class size variations on student throughput and course completion. The results of these experiments allowed a response surface to be mapped and used to identify optimal levels for operating based upon the desired student throughput and course completion time. Additionally, the simulation is optimized using the OptQuest feature in Simio to further inform the optimal operating levels to achieve desired throughput and completion time.

4.2 Baseline Analysis

After validation, the model was updated with the typical class size the 9 ATKS experiences for the IQT syllabus, with seven classes being taught annually. Twenty replications of the updated model reflecting normal 9 ATKS operations was run for 730 days, with a warm-up period of 365 days. The input parameters for the baseline model are listed below in Table 5.

Table 5. Baseline Parameter Settings

Syllabus	Class Size	Arrival Frequency(days)
IQT	16	50
TX-2	2	365
TX-3	2	219
TX-4	6	183
FIUT	2	37

The output data were analyzed to determine the utilization rates of differing resources in the squadron under normal operations with the new IQT syllabus. The aircraft and simulator utilization rates listed in Table 6 illustrate the lack of randomization for equipment selection, showing a higher utilization for the equipment listed first. This is purely a limitation of the simulation environment and not reflective of the interchangeability within each type of equipment, as there is no preferred order in which the equipment is used. The focus, therefore, is on the overall utilization rate by equipment type. Under normal operations, aircraft and simulators are only being utilized 50% and 58% of the available time, respectively. This indicates that under normal operations, availability of aircraft and/or simulators is not a limiting factor on student throughput.

Table 6. Equipment Utilization

Equipment	Average Utilization
AC1	63.9
AC2	54.9
AC3	45.1
AC4	36.7
Overall AC	50.2
SIM1	87.8
SIM2	69.1
SIM3	50.4
SIM4	29.6
Overall Sim	57.9

The utilization rate of instructors with particular skill sets was also collected when running the baseline model to best understand how the pilots are being used under normal operations. These rates include the 12% of the time that the simulation is seizing them for tasks outside of instruction (TDY/Leave/DNIF). The values listed in Table 7 are the average utilization rates for all instructors by listed skill set. Instructor pilots that are qualified as Operations Supervisor (TOP 3), Additional Duty

Flight Evaluator/Flight Evaluator (ADFE/FE) , Launch and Recovery (LR) and all advanced skills are being utilized over 90% of the time. The Designated Instructors (DI), whom are used most heavily for the FIUT courses, have a utilization rate of nearly 86%. The instructors qualified to only instruct in the simulators are used 77%, but are only represented by the contractor pilots. The SOF is utilized the least, with nearly 70% utilization. The sensor operator utilization rates are lower than pilot utilization rates due to the smaller number of additional duties they have to fulfill. Many of the instructors hold multiple qualifications, and therefore the utilization rates are not mutually exclusive.

Table 7. Baseline Instructor Utilization

Pilot		Sensor Operator	
Overall	88.6%	Overall	74.9%
TOP3	94.2%	LR	92.1%
ADFE/FE	94.2%	ADFE/FE	75.3%
LR	93.0%	Sim Only	71.9%
Advanced	90.3%	DI	75.1%
DI	85.7%	Advanced	59.9%
Sim Only	77.2%		
SOF	69.6%		

The baseline model was used to analyze the effect of adding additional instructors on student throughput for the IQT syllabus. Instructors were added six at a time, with three pilots and three sensor operators, per increase. The three pilots added to the pool of the instructors are of varying skill sets; a pilot with LR and SOF qualifications, one with ADFE and TOP 3 qualifications, and one that possesses the SOF and DI designators were added with each increase of instructors. The added sensor operators had designators of LR, LR and ADFE, and DI and ADFE. In Table 8, the number of students completing the IQT in 365 days appears to increase with additional instructors, as well as decrease the number of days it takes to complete the IQT syllabus.

Table 8. Simulation Mean Student Completion and Completion Time

Instructor Level	Mean Students Complete	Mean Completion Time (days)
Baseline	108	190.5
Add 3 Each	111	174.4
Add 6 Each	115	171.9
Add 9 Each	115	168.5
Add 12 Each	114	167.9
Add 15 Each	117	168.0
Add 18 Each	117	168.0
Add 21 Each	117	166.8

A paired- t confidence interval was used to verify that the changes in the average number of students completing the IQT syllabus in a year and the average completion time were statistically different from the baseline values and from one another. The baseline model was analyzed against each increase of instructor, as well as each pairwise comparisons between each increase in instructors. The baseline model versus the other scenarios, seen in Table 9, shows a statistically significant difference in both the average number of students complete and the average completion time when six or more instructors are added. When only three instructors are added, there is no statistical difference from the baseline on the average number of students complete, but a significant difference in completion time is observed.

Adding more than six instructors does not result in a statistically larger number of students completing the syllabus in a year, but does significantly reduce the time needed to complete the syllabus. Addition of more than nine instructors does not result in a significant decrease in time needed to complete the syllabus when compared to adding more than nine instructors. Thus, in order to see a statistically significant change in both student completion numbers and time, at least six instructors would be needed, but adding more than nine yields no benefit. As more instructors are added, it is reasonable to assume that the lack of significant improvement can be attributed to instructors no longer being the limiting factor in student throughput.

Table 9. Instructor Increase Comparisons

	95% CI Student Complete	95% CI Completion Time
BL vs Add 3	(-7.3, 1.3)	(9.2, 14.8)
BL vs Add 6	(-12.3, -2.3)	(16.3, 20.8)
BL vs Add 9	(-11.9, -1.9)	(19.1, 24.9)
BL vs Add 12	(-10.5, -0.6)	(19.8, 25.4)
BL vs Add 15	(-13.1, -3.8)	(19.7, 26.7)
BL vs Add 18	(-12.5, -4.9)	(20.1, 24.9)
BL vs Add 21	(-12.2, -2.0)	(20.9, 26.4)
Add 3 vs Add 6	(-11.5, -2.8)	(8.4, 13.9)
Add 3 vs Add 9	(-7.2, -0.7)	(7.8, 12.1)
Add 3 vs Add 12	(-4.3, -0.03)	(10.6, 15.3)
Add 3 vs Add 15	(-10.3, -0.6)	(8.6, 13.7)
Add 3 vs Add 18	(-10.5, -0.9)	(8.0, 12.9)
Add 3 vs Add 21	(-8.4, -0.2)	(8.5, 14.8)
Add 6 vs Add 9	(-4.4, 5.1)	(1.4, 5.4)
Add 6 vs Add 12	(-4.1, 7.6)	(1.9, 6.1)
Add 6 vs Add 15	(-5.0, 2.7)	(2.7, 6.6)
Add 6 vs Add 18	(-4.9, 2.2)	(2.8, 5.0)
Add 6 vs Add 21	(-4.1, 4.5)	(3.4, 6.8)
Add 9 vs Add 12	(-1.0, 3.8)	(-0.9, 2.1)
Add 9 vs Add 15	(-6.7, 3.7)	(-0.7, 3.2)
Add 9 vs Add 18	(-6.3, 2.8)	(-1.1, 2.2)
Add 9 vs Add 21	(-4.5, 4.2)	(-0.6, 4.0)
Add 12 vs Add 15	(-8.7, 2.9)	(-1.3, 2.6)
Add 12 vs Add 18	(-7.7, 1.5)	(-1.8, 1.6)
Add 12 vs Add 21	(-6.8, 3.7)	(-1.5, 3.7)
Add 15 vs Add 18	(-4.4, 3.9)	(-2.5, 1.0)
Add 15 vs Add 21	(-2.7, 5.4)	(-2.2, 3.1)
Add 18 vs Add 21	(-2.6, 5.8)	(-0.6, 3.0)

The IQT syllabus has 72 tasks that each student must complete to successfully finish the course. These tasks can be seen in Appendix B. The flights, whether completed in an aircraft or simulator, are completed independently or in pairs, depending on the task. The academic portions of the syllabus require the entire class to be taught together. This requires students to wait until all their peers finish the prerequisite tasks before the course can be taught. The wait time for each student for each task was collected while running the baseline model. In Table 10 below, the

mean wait in days for each task that exceed one day is listed, along with the longest wait experienced for that task. The full list of wait times for each task is located in Appendix E.

Table 10. IQT Tasks with Mean Wait Time Exceeding One Day

Task	Type	Mean Wait	Longest	Task	Type	Mean Wait	Longest
4	Academic	2.34	6	45	Sim	1.07	4
7	Academic	1.24	3	48	Flight	1.16	6
10	Academic	1.26	5	49	Flight	1.40	5
16	Flight	1.73	5	50	Academic	3.29	7
21	Flight	1.06	7	51	Academic	2.32	6
22	Academic	3.80	17	56	Academic	3.42	10
23	Academic	1.14	5	57	Academic	2.41	6
24	Academic	1.28	5	58	Academic	2.46	6
30	Academic	3.43	8	60	Flight	1.31	7
35	Sim	1.20	6	63	Flight	1.19	5
36	Sim	2.13	7	64	Academic	3.45	14
37	Flight	2.77	7	65	Academic	2.15	7
38	Flight	1.16	6	70	Flight	1.95	5
39	Academic	5.60	18	71	Flight	1.65	7
40	Academic	1.7	4	72	Flight	1.64	7
41	Academic	1.69	5				

Of the 33 tasks that have a mean wait time that exceeds one day, 19 are academic courses that require the entire class to complete together. The task with the longest mean wait time, task 39, follows a series of seven flights, two of which have the highest failure rate for the entire syllabus. When considering all 72 tasks, the academic courses account for 55.1% of the waits experienced, while flights in an aircraft account for only 24.2% of wait time, and simulator flights contribute to 20.7% of the wait time. A majority of the delay in training for the IQT syllabus occurs for the academic courses that require the class to complete the course simultaneously.

Under normal effort level, the 9 ATKS is expected to produce 120 BCE annually. In the baseline simulation, the throughput for each syllabus is listed in Table 11, with the BCE weight and the total BCE the simulation achieves in a year. Under normal

operations, with the current military and contractor manning levels, and historic class sizes and frequency, the goal of 120 BCE is achievable.

Table 11. Baseline BCE

Syllabus	Mean Throughput	Weight	BCE
IQT	108	1.00	108
TX-2	2	0.76	1.52
TX-3	4	0.63	2.52
TX-4	12	0.45	5.40
FIUT	18	0.46	8.28
		Total BCE	125.72

Currently, the 9 ATKS has 15 contractor pilots and 18 contractor sensor operators. Of the contractors, eight of the pilots and seven of the sensor operators are certified to instruct only in the simulators. The simulation model was run for 730 days, with a warm up period of 365 days, for 20 replications of each scenario using only the non-contractor instructors. Each scenario increased the number of pilot and sensor operator instructors by three up to an addition of 24 of each type of instructor being added to the model. In Table 12, the mean number of students completing the IQT course and the mean number of days to complete the IQT course are displayed, as well as the results from the baseline model where contractors were included. From the baseline scenario without any contractors, it is obvious that the contractor force has an impact on the student throughput.

A paired-*t* confidence interval was computed to identify what increase of assigned pilots and sensor operators would bring average student throughput to the level achieved with the contractor instructors. The mean number of students completing the IQT syllabus is not statistically significantly different from the baseline model when adding both twelve and fifteen instructors to both the pilot and sensor operator pool, as highlighted in Table 13. The mean completion time is not statistically significantly different from the baseline model when twelve of each type of instruc-

Table 12. Simulation Mean Output without Contractors

Instructor Level	Mean Students Complete	Mean Completion Time (days)
Baseline	108	190.5
Baseline w/o Ctr	56	390.7
Add 3 Inst w/o Ctr	77	317.3
Add 6 Inst w/o Ctr	94	253.1
Add 9 Inst w/o Ctr	102	218.5
Add 12 Inst w/o Ctr	108	193.9
Add 15 Inst w/o Ctr	111	178.8
Add 18 Inst w/o Ctr	115	169.1
Add 21 Inst w/o Ctr	113	165.0
Add 24 Inst w/o Ctr	113	162.7

tor is added to the list of 9 ATKS instructors. When the contractor instructors are not included in the model, the number of students complete is statistically significantly higher and the student completion time shorter with the addition of 18 or more assigned instructors.

Table 13. Baseline Instructor Increase Comparison Without Contractors

Comparison	95% CI Student Complete	95% CI Completion Time
BL vs BL w/o Ctr	(48.9, 55.7)	(-206.6, 193.9)
BL vs Add 9 w/o Ctr	(1.8, 9.4)	(-31.0, -25.0)
BL vs Add 12 w/o Ctr	(-1.1, 1.9)	(-6.9, 0.002)
BL vs Add 15 w/o Ctr	(-7.9, 1.5)	(8.4, 15.2)
BL vs Add 18 w/o Ctr	(-11.5, -2.4)	(18.3, 24.2)

When comparing adding 12 instructors to adding 15 instructors, as shown in Table 14, the mean number of students complete is not statistically significantly different. Based on these results, the 15 contractor pilots and 18 contractor sensor operators could be replaced with 12 assigned pilots and 12 assigned sensor operators while still producing the same number of students in a year.

Table 14. Instructor Increase Comparison Without Contractors

	95% CI Student Complete Complete	95% CI Completion Time
Add 12 w/o Ctr vs Add 9 w/o Ctr	(1.2, 9.4)	(-227.6, -21.6)
Add 12 w/o Ctr vs Add 15 w/o Ctr	(-8.2, 1.0)	(10.9, 19.4)

4.3 Experiments

The 9 ATKS is most interested in increasing their student throughput for the IQT syllabus. The two response factors that best indicate student throughput are the number of students completing the syllabus in a year and the time it takes to complete the entire course. Two controllable factors that impact the student throughput are an changes to the number of instructors and class size. To best inform the 9 ATKS, an experimental design was implemented to identify the levels of instructor increase and class size that would have the largest impact on student throughput.

The two factors under analysis are assigned instructor increase and the class size for the IQT syllabus. The range of class sizes, from 10 to 18, was determined by the 9 ATKS historical experience, as well as anticipated for future classes. Based on the 9 ATKS self-assessment, they are currently manned at 67% for assigned pilots and 62% for assigned sensor operators. An addition of 18 instructors to both the pilot and sensor operator set would bring assigned manning to above 100% for each type of instructor. The baseline analysis also informed the choice to range the increase of instructors from none to 18. The levels selected for each factor are listed below in Table 15. A central composite design with axial points on the face and an additional center point was used to analyze the different levels of instructor and student class size. The experimental design developed can be referenced in Appendix D.

Using JMP, the statistical analysis tool from SAS Institute Inc., to analyze the ten scenarios, results from the simulation yielded a significant model for both responses.

Table 15. Factor Levels for Design of Experiments

Factors	Levels		
Codes	-1	0	1
Class Size	10	14	18
Instructor Increase	0	9	18

The coded variables were analyzed against the responses recorded from the model. A second order model was analyzed for the response of student number complete. Initial analysis showed a lack of consistency in variation, as well as a lack of normally distributed studentized residuals. To mitigate these issues, the Box-Cox method of transformation depicted in Equation 1 was applied to the number of students complete response.

$$y^\lambda = \frac{y^{\lambda-1}}{\lambda \ln^{-1}\left(\frac{1}{n} \sum_{i=1}^n \ln y_i\right)^{\lambda-1}} = \frac{y^{-1.6} - 1}{-0.00001225} \quad (1)$$

All regressors excluding the second order instructor increase were significant and the defined model had both an R^2 and R^2 adjusted of 0.96. With the transformation, the residuals met the necessary assumptions of independence, normality, and constant variance. However, there was a lack of fit with the transformed model. The inclusion of interactions between the second order regressors and the remaining regressor assisted in capturing the aspect of the model that was not properly fitting. The terms that were not significant were removed from the model which again produced both an R^2 and R^2 adjusted of 0.96, and no issues with lack of fit or residuals. The final response surface model in coded space for the number of students complete is seen in

Equation 2.

$$\begin{aligned}
 \text{Students Complete} &= 81570.49 + 28.75 \times \text{Class Size} - 12.53 \times (\text{Class Size})^2 \\
 &+ 1.30 \times (\text{Class Size})(\text{Instructor Increase}) \\
 &+ 1.91 \times (\text{Class Size})^2(\text{Instructor Increase})
 \end{aligned} \tag{2}$$

For analysis of the time for students to complete the IQT syllabus, all terms in the second order model were significant. Although the residuals were normally distributed, they did not have a constant variance, and the Box-Cox method of transformation depicted in Equation 3 was applied to the student completion time response.

$$y^\lambda = \frac{y^{\lambda-1}}{\lambda \ln^{-1}\left(\frac{1}{n} \sum_{i=1}^n \ln y_i\right)^{\lambda-1}} = \frac{y^{-2} - 1}{-0.0000005} \tag{3}$$

After applying the transformation to the response, the residuals of the new model have a more constant spread across the observations. Both the R^2 and adjusted R^2 with the transformation improved, increasing to 0.93 from the 0.86 R^2 and adjusted R^2 of the model prior to transformation. The lack of fit test shows that the second order model is not accurately capturing the behavior of the data. The interaction between the second order regressors and all other regressors was added to the model. With the addition of the second order interactions, the model no longer has a lack of fit issue and both the R^2 and adjusted R^2 value increases to 0.96. The only term that was not significant was the interaction between instructor increase and the second order class size regressor. Equation 4 provides the transformed response surface in

coded space for student completion time with all significant regressors:

$$\begin{aligned}
 \text{Completion Time} = & 2211259.27 + 24.93 \times \text{Class Size} \\
 & - 5.94 \times \text{Instructor Increase} \\
 & + 5.91 \times (\text{Class Size})^2 + 6.52 \times (\text{Instructor Increase})^2 \\
 & - 3.67 \times (\text{Class Size})(\text{Instructor Increase}) \\
 & + 2.11 \times (\text{Instructor Increase})^2(\text{Class Size}) \\
 & - 2.62 \times (\text{Class Size})^2(\text{Instructor Increase})^2
 \end{aligned} \tag{4}$$

To determine the best class size and number of instructors by which to increase, each regression equation was analyzed using Microsoft Excel's Generalized Reduced Gradient (GRG) nonlinear solver function. To maximize student throughput in one year for the IQT syllabus, the number of instructors and class size should be at the highest levels, with class sizes of 18 and an additional 18 instructors. This yields a throughput of 126 students annually with a completion time of 186.3 days. To minimize the completion time of the IQT syllabus, the class size should be smallest, with 10 students, and the addition of 15 instructors. This results in a completion time of 141.3 days but only pushes 68 students through the syllabus in one year's time.

To assess the optimal solution for both objectives simultaneously, the difference between the normalized student throughput objective and the normalized course length objective was analyzed. Using Excel's GRG nonlinear solver to identify the maximum solution, results yielded an average completion time of 178.3 days with an average of 121 students completing the course in a year. This was achieved by adding 18 instructors with a class size of 17. This solution was only five students from the best throughput for students achievable and 37 days from the optimal completion time. As displayed in Table 16, when comparing these results to the baseline model of class

sizes of 16 with no added instructors, both responses were statistically significantly different for all three optimal scenarios. For testing purposes, the recommended class size of 17 for the multi-objective solution was lowered to 16 in order to properly process through the model.

Table 16. Baseline Comparisons to Optimal

	Class Size	Instructor Increase	95% CI Student Complete	95% CI Completion Time
BL vs Stu Num Opt	18	18	(-20.3, -13.9)	(0.04, 5.5)
BL vs Comp Time Opt	10	15	(13.0, 68.8)	(45.8, 51.5)
BL vs Both Opt	16	18	(-12.5, -4.9)	(20.1, 24.9)

Using each prediction equation, heat maps were created with a range of possible combinations the 9 ATKs can experience. In Figure 3, the shortest completion times are highlighted in green and achieved when class sizes are smaller and more instructors are added to the 9 ATKs. The student throughput is maximized when the class sizes are largest, but are not drastically impacted by increases in instructors, as depicted in Figure 4.

Completion Time		Instructor Increase																		
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Class Size	10	144.5	144.1	143.7	143.3	143.0	142.7	142.4	142.2	142.0	141.8	141.6	141.5	141.4	141.4	141.3	141.3	141.4	141.4	141.5
	11	148.9	148.1	147.4	146.8	146.2	145.6	145.2	144.8	144.5	144.2	144.0	143.8	143.7	143.7	143.7	143.8	143.9	144.1	144.4
	12	154.2	153.0	151.9	150.9	150.1	149.3	148.7	148.1	147.6	147.3	147.0	146.8	146.7	146.6	146.7	146.8	147.1	147.4	147.8
	13	160.4	158.7	157.3	156.0	154.8	153.8	153.0	152.2	151.6	151.1	150.7	150.5	150.3	150.3	150.3	150.5	150.8	151.2	151.8
	14	167.8	165.7	163.8	162.1	160.7	159.4	158.3	157.3	156.5	155.9	155.4	155.1	154.8	154.8	154.8	155.0	155.3	155.8	156.4
	15	177.0	174.3	171.9	169.8	167.9	166.3	164.9	163.7	162.7	161.9	161.2	160.8	160.5	160.3	160.3	160.5	160.8	161.3	161.9
	16	188.4	185.0	182.0	179.3	177.0	175.0	173.3	171.8	170.5	169.4	168.6	167.9	167.5	167.2	167.1	167.2	167.4	167.9	168.5
	17	203.1	198.8	195.0	191.7	188.7	186.2	184.0	182.1	180.5	179.1	177.9	177.0	176.3	175.9	175.6	175.5	175.6	175.9	176.5
	18	222.9	217.3	212.4	208.1	204.4	201.1	198.3	195.8	193.6	191.8	190.2	188.9	187.8	187.0	186.4	186.1	185.9	186.0	186.3

Figure 3. Completion Time Heat Map

Weights were added to this objective function to analyze the impact of prioritizing one objective over the other. The combined weighted objective was maximized with incremented weighting to identify an optimal solution given the level of importance placed on each objective. The resulting optimal settings using this method for class size and instructor increase is shown below in Table 17. From the heat map tables

Students Complete		Instructor Increase																			
Class Size		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
	10	67	67	67	67	67	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68
	11	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74
	12	81	81	81	81	81	81	81	81	81	81	81	81	81	81	81	81	81	81	81	81
	13	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88
	14	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96
	15	103	103	103	103	103	103	103	104	104	104	104	104	104	104	104	104	104	104	104	104
	16	109	109	109	110	110	110	110	110	111	111	111	111	111	111	112	112	112	112	112	113
	17	113	113	113	114	114	115	115	115	116	116	117	117	117	117	118	118	119	119	120	120
	18	114	114	115	115	116	117	117	118	119	119	120	121	121	122	122	123	124	124	125	126

Figure 4. Student Throughput Heat Map

of complete combinations, it is apparent that multiple combinations yield similar course completion time and student throughput due to the complexity of the response surfaces. Therefore, the table of weighted objective results in Table17 is only an example of combinations yielding those results, as deemed optimal by Excel’s GRG nonlinear solution method.

Table 17. Class Size and Instructor Increase Weighted Multi-Objective Solutions

Time Weight	Student Comp	Time Output	Time Diff from Optimal	Student Output	Student Diff from Optimal	Class Size	Instructor Increase
1	0	141.3	0.0	68	-58	10	15
0.9	0.1	141.3	0.0	68	-58	10	15
0.8	0.2	141.3	0.0	68	-58	10	15
0.7	0.3	153.8	12.4	94	-32	14	13
0.6	0.4	165.5	24.2	110	-16	16	15
0.5	0.5	178.3	36.9	121	-5	17	18
0.4	0.6	185.2	43.9	126	0	18	18
0.3	0.7	186.3	44.9	126	0	18	18
0.2	0.8	186.3	44.9	126	0	18	18
0.1	0.9	186.3	44.9	126	0	18	18
0	1	186.3	44.9	126	0	18	18

To further analyze the relationship between class size, instructors, student throughput and time to complete the IQT syllabus, the OptQuest add-in feature was utilized in Simio. The class size was set to increment in twos, as required to properly process in the model, while the increase of instructors was set to increments of three. Each scenario that OptQuest developed was run a minimum of ten times to produce an average student throughput and syllabus completion time. Each objective was individually optimized. When maximizing the student throughput as the single objective,

the student throughput was 125 in 186.7 days with 18 additional instructors and class sizes of 18. Minimizing the course completion time yielded a completion time of 140.6 days with 68 students completing the IQT course in a year. This was achieved with class sizes of 10 and an additional 12 instructors. These results were compared to the baseline model of class sizes of 16 with no added instructors and both responses were statistically significantly different for all three scenarios as shown in Table 18.

Table 18. Baseline Comparisons to OptQuest Optimal

	Class Size	Instructor Increase	95% Student Complete	95% CI Completion Time
BL vs OptQuest Stu Num Opt	18	18	(-20.3, -13.9)	(0.04, 5.5)
BL vs OptQuest Comp Time Opt	10	12	(39.1, 41.4)	(46.3, 52.1)
BL vs OptQuest Both Opt	16	15	(-13.1, -3.8)	(19.7, 26.7)
Both Opt vs OptQuest Both Opt	16/16	18/15	(-3.9, 4.4)	(-1.0, 2.5)

The two objectives were normalized and equally weighted to implement the multi-objective feature of OptQuest. All possible scenarios were run and terminated with class size of 16 and increase of instructors by 15 as the optimal solution. Those variable values produced an average student throughput of 116 and average student completion time of 167.3 days. At this optimal solution, the deviation in the number of students complete is ten students from the best throughput of 126, while the completion time shows a deviation of 26 days from the best completion time of 141.3 days.

The solutions found using the response surface prediction equations were very similar when assessing the individual objectives. When completing a multi-objective approach with weights, the results differ from those found using OptQuest. This highlights the different solution methods being utilized within software suites, and the variation that the regression equation was unable to capture. Using OptQuest, only scenarios that are capable of being processed by the model are run, which limits the solution space to only include even class sizes and the addition of instructors in

increments of three. Again, for model testing purposes, the optimal suggested class size of 17 as identified by the GRG nonlinear solution method was lowered to 16 for proper processing. When comparing the student throughput and completion time for both suggested optimum, they were found to not be statistically significantly different as displayed in Table 18. This also highlights that student throughput and course completion time are not significantly impacted by the addition of 18 instructors versus adding 15 instructors.

The responses of student completion time and number of students completing the IQT syllabus are correlated as expected. However, the relationship is not linear when comparing the effect of student number on student completion time. The initial plot of student number versus completion time shows a variation from linear past the 100 students, as depicted in Figure 5. This suggests that beyond a 100 student throughput, the variation in completion time ranges with the increased student load.

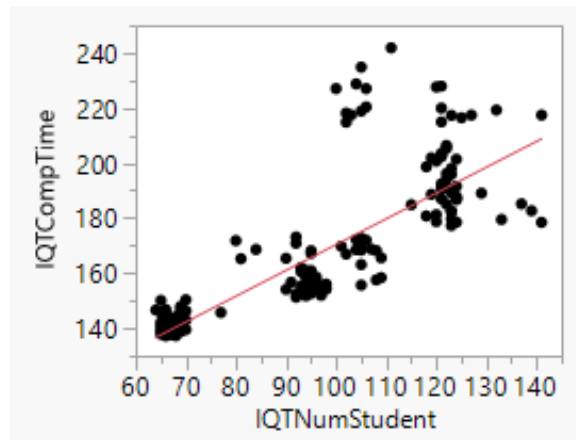


Figure 5. Student Throughput vs Completion Time

During surge efforts, the 9 ATKs is expected to produce 140 BCE annually. With the other four course factors held constant, this requires 125 students to complete the IQT syllabus in the year. As seen in Figure 4, the only way to achieve above 125 student completion rate is with a class size of 18 and instructor increase of 17 or 18.

With current manning, when class sizes are increased to 18 in the base model, only an average of 114 students complete the syllabus annually with an average completion time of 222.4 days. This increased class size increases the scheduled utilization rate by 3% from the baseline class size of 16 for both pilots and sensor operators. Another factor that may allow the 140 BCE demands to be met with current manning is increasing the number of IQT classes taught per year. To explore the possibility of additional classes being taught with varying class size, a design of experiments was completed to identify the frequency of classes and class size that would have the largest impact on student throughput.

The two factors under analysis are the frequency of class arrival and the class size for the IQT syllabus. The range of class size from 10 to 18 was again used for the experiments. Currently, the 9 ATKS teaches seven sections of the IQT syllabus per year. An increase up to 12 sections per year was analyzed. This equates to a range of class arrivals from 30 days to 50 days. The levels selected for each factor are listed below in Table 19. A central composite design with axial points on the face and two center points was used to analyze the different arrival rate and student class size. The developed experimental design can be referenced in Appendix D.

Table 19. Factor Levels for DOE

Factors	Levels		
Codes	-1	0	1
Class Size	10	14	18
Arrival	30	40	50

The second order model with all possible interactions, to include the interactions between second order regressors, was analyzed with the response of student throughput. Only the interaction of the second order regressor of class size with arrival rate was not statistically significant and removed from the model. The residuals met assumptions of independence, normality, and constant variance. The R^2 was 0.80

with an adjusted R^2 of 0.79, and there was no indication of lack of fit . Equation 5 shows the response surface in coded space for numbers of students complete with all significant regressors.

$$\begin{aligned}
 \text{Students Complete} = & 117.24 + 17.86 \times \text{Class Size} - 12.08 \times \text{Arrival Rate} \\
 & - 10.95 \times (\text{Class Size})^2 - 3.61 \times (\text{Arrival Rate})^2 \\
 & + 11.91 \times (\text{Class Size})(\text{Arrival Rate}) \\
 & - 5.82 \times (\text{Arrival Rate})^2(\text{Class Size})
 \end{aligned} \tag{5}$$

The response of student completion time was also analyzed with a second order model including all possible interactions, to include the interactions between second order regressors. All regressors were statistically significant and a review of the residuals showed they met assumptions of independence, normality, and constant variance. There was no indication of lack of fit and the R^2 and adjusted R^2 was 0.98. Equation 6 shows the response surface in coded space for student completion time with all significant regressors.

$$\begin{aligned}
 \text{Completion Time} = & 206.35 + 56.77 \times \text{Class Size} - 51.82 \times \text{Arrival Rate} \\
 & + 5.88 \times \text{Class Size}^2 + 13.36 \times (\text{Arrival Rate})^2 \\
 & - 25.56 \times (\text{Class Size})(\text{Arrival Rate}) \\
 & + 3.95 \times (\text{Arrival Rate})^2(\text{Class Size}) \\
 & + 9.48 \times (\text{Class Size})^2(\text{Arrival Rate})
 \end{aligned} \tag{6}$$

To determine the best class size and arrival rate, each regression equation was analyzed using Excel's GRG nonlinear solver function. To maximize student throughput in one year for the IQT syllabus, the arrival rate should be every 30 days with class sizes of 14. This yields a throughput of 126 students annually, with a completion

time of 272.1 days. To minimize the completion time of the IQT syllabus, the class size should be smallest with ten students arriving every 49 days. This results in a completion time of 145.0 days but only pushes 69 students through the course in one year’s time. When compared to the baseline model, which has class sizes of 16 arriving every 50 days, the optimal levels produce a statistically significantly different mean throughput and completion time as show in Table 20.

Table 20. Baseline Comparisons to Optimal

	Class Size	Arrival Rate (days)	95% CI Student Complete	95% CI Completion Time
BL vs Stu Num Opt	14	30	(-20.5, -3.1)	(-80.8, -69.6)
BL vs Comp Time Opt	10	49	(35.8, 40.7)	(42.6, 48.3)
BL vs Both Opt	10	30	(-10.9, -6.5)	(11.5, 16.1)

Using each prediction equation, heat maps were created with a range of possible combinations the 9 ATKs can experience. In Figure 6 the shortest completion times are highlighted in green and achieved when class sizes are smaller and arrival times are further apart. The student throughput is maximized when the class sizes are moderate and arrival times are shorter, as depicted in Figure 7. This also shows that with current manning, the 9 ATKs can have 125 students complete the IQT course in a year by increasing the frequency with which courses are taught.

The difference between the normalized student throughput objective and the normalized course length objective was analyzed to assess objectives simultaneously. Using Excel’s GRG nonlinear solver to identify the maximum solution, a completion time of 178.6 days was yielded with 115 students completing the course in a year. This was achieved with class sizes of ten arriving every 30 days. Weights were added to this objective function to analyze the impact of prioritizing one objective over the other. The combined weighted objective was maximized with incremented weighting to identify an optimal solution given the level of importance placed on each objec-

Completion Time						
		Arrival Rate				
		30	35	40	45	50
Class Size	10	178.6	163.2	152.5	146.4	145.1
	11	202.5	181.1	164.8	153.8	147.9
	12	226.0	199.1	177.9	162.4	152.6
	13	249.0	217.3	191.8	172.4	159.3
	14	271.5	235.6	206.3	183.8	167.9
	15	293.6	254.1	221.7	196.4	178.4
	16	315.3	272.7	237.7	210.4	190.8
	17	336.5	291.4	254.5	225.7	205.1
	18	357.2	310.3	272.0	242.4	221.4

Figure 6. Completion Time Heat Map

Students Complete						
		Arrival Rate				
		30	35	40	45	50
Class Size	10	115	101	88	77	67
	11	119	108	98	87	77
	12	123	114	106	96	87
	13	125	119	112	104	95
	14	126	122	117	110	102
	15	125	124	121	115	107
	16	123	125	123	119	111
	17	120	124	125	121	113
	18	115	122	124	122	115

Figure 7. Student Throughput Heat Map

tive. The resulting optimal settings for class size and instructor increase is shown in Table 21. Again, the response surfaces are complex and the weighted Table 21 is only one combination that produces the desired outcomes listed. Other combinations are possible to achieve similar results as apparent in the heat map tables.

Based on these results, the unit will be able to achieve 140 BCE, or a throughput of 125 students with multiple different combinations of class size and arrival rate, as depicted in Figures 6 and 7. Since the largest throughput identified was 126 students,

Table 21. Class Size and Arrival Weighted Multi-Objective Solutions

Time Weight	Student Completion Weight	Time Output	Time Diff from Optimal	Student Completion Output	Student Diff from Optimal	Class Size	Arrival Rate
1	0	145.0	0.0	69	-57	10	49
0.9	0.1	147.1	2.1	79	-47	10	44
0.8	0.2	158.8	13.9	96	-30	10	37
0.7	0.3	178.6	33.7	115	-11	10	30
0.6	0.4	178.6	33.7	115	-11	10	30
0.5	0.5	178.6	33.7	115	-11	10	30
0.4	0.6	198.0	53.0	119	-7	11	30
0.3	0.7	226.1	81.1	123	-3	12	30
0.2	0.8	245.9	100.9	125	-1	13	30
0.1	0.9	260.7	115.7	126	0	14	30
0	1	272.1	127.1	126	0	14	30

with the combination of class size of 14 arriving every 30 days, this scenario was further analyzed in the simulation. When implementing these parameters, the overall pilot utilization is 94.1% and sensor operator utilization is 77.8% which includes the 12% that instructors are unavailable. This is an increase of utilization by 5.5% for pilots and 2.9% for sensor operators from the current baseline operations. However, with the change in class size and arrival rate, the same number of instructors is able to produce 18 more MQ-9 crews per year on average.

To further analyze the relationship between class size, class arrivals, student throughput and time to complete the IQT syllabus, the OptQuest add-in feature was utilized in Simio. The class size was set to increment in twos, as required to properly process in the model, while the arrival rate was set to increments of five. All scenario combinations were developed in Optquest and run a minimum of ten times to produce an average student throughput and syllabus completion time. Each objective was individually optimized. When maximizing the student throughput as the single objective, the student throughput was 129 students in 271.3 days with class sizes of 18 arriving every 40 days. Minimizing the course completion time yielded a completion time of 144.8 days with 68 students completing the IQT course in a year. This was achieved with class sizes of 10 arriving every 50 days. Again, the difference

in means for the student throughput and course completion time were statistically significantly different when compared to the baseline model as displayed in Table 22.

Table 22. Baseline Comparisons to OptQuest Optimal

	Class Size	Arrival Rate (days)	95% CI Student Complete	95% CI Completion Time
BL vs OQ Stu Opt	18	40	(-24.9,-10.6)	(-84.9, -76.9)
BL vs OQ Comp Opt	10	50	(39.6, 41.5)	(43.2, 49.1)
BL vs OQ Both	10	30	(-10.9, -6.5)	(11.5,16.1)

The two objectives were normalized and equally weighted to implement the multi-objective feature of OptQuest. All possible scenarios were created, and OptQuest terminated with class size of ten and class arrival rate of every 30 days as the optimal solution. Those variable values produced an average student throughput of 121 and average student completion time of 175.9 days. At this optimal solution, the number of students complete is a deviation of eight students from the best throughput of 129 achieved by Optquest, while the completion time is a deviation of 31.1 days from the best completion time of 144.8 days. Both the optimal solution found using the prediction equation and the one identified by OptQuest were the same with class size of ten arriving every 30 days.

4.4 Summary

The analysis provides insight to the operations of the 9 ATKS and lends itself to informing the unit of manning and training concerns. The exploration into potential changes the unit could implement or experience provides a foundation for understanding where alterations can be made to meet AF expectations of MQ-9 crew production. From the analysis, it is clear that class size, student completion time, and class arrival rate affect the student throughput for the IQT course. While careful considerations have been made to provide a valid model, results from the simulation should be used

as a tool to inform decisions for the 9 ATKS operations, as implementing changes in the real world may not necessarily be realized with the same results as in the simulated environment.

V. Conclusions and Future Research

5.1 Overview

In this chapter, the results of the analysis are described and applied to the initial manning questions the 9 ATKS provided. Each question is addressed and expanded on with details on implications to the squadron. The chapter closes with recommendations for future research using the simulation already constructed, as well as ways to improve the simulation to better capture the real-world system.

5.2 Conclusions of Research

The purpose of this research was to address questions regarding manning for the 9 ATKS. From the analysis completed, the following insights were gained to inform the unit:

1. Will current manning allow student production needs to be met without over-tasking instructors?

In the analysis of the baseline model, which represents the current manning of the 9 ATKS, the student throughput is 125.72 BCE which exceeds the normal operations expectation of 120 BCE. However, to achieve that student throughput the most qualified pilots are being utilized more than 90%. This group of skilled pilots accounts for two-thirds of the pilot force in the 9 ATKS. Of the entire pilot force, 26 of the 69, or 37% of pilots have a utilization rate of 100%. Even though the model did not allow pilots to facilitate more than one flying event a day, over a third of the 9 ATKS pilots are being used to the max. Additionally, the model accounted for some events that removed them from their ability to instruct, but does not capture other time filled tasks outside of instruction that could also be time demanding of the instructors. Many of the pilots are being used to the extreme and most likely have a

higher rate of utilization than being observed in this model.

2. What is the appropriate instructor-student ratio to produce a certain number of students in a specified time frame?

The factors that the 9 ATKS has control over will determine what instructor-student ratio is most appropriate. The 9 ATKS is able to meet the 120 BCE requirement with their current manning based on the analysis of the baseline model. The unit currently has a student to instructor ratio of roughly 1:4 for both student to sensor operator instructors and student to pilot instructors.

If a surge effort is put into effect and the arrival rate of the IQT syllabus is held constant, the addition of 18 instructors to both the sensor operator instructors and pilot instructors would be necessary to meet the goal of 125 IQT students completing the course annually. This would also require class sizes to be 18 for each IQT class. In that scenario, the student to instructor ratio is roughly 1:5 for both student to sensor operator instructors and student to pilot instructors. However, that ratio does not remain constant for other student throughput goals. When considering factors of class size and number of instructors, analysis determined that class size was more influential on student throughput than the number of instructors.

If the number of instructors in the 9 ATKS remains constant, and the class sizes and arrival rates are adjustable, then class sizes ranging from 14 to 18 can meet the 140 BCE goal, depending on the arrival time. In that scenario, the ratio of student to instructor for a class size of 14, is 1:5 for both sets of instructors. When class size is 18, the student to instructor ratio is roughly 1:4 for both student to sensor operator instructors and student to pilot instructors.

3. What aspects of the training creates delays?

In analyzing the baseline model of current operations in the 9 ATKS, the delays in training were identified. Although, in the simulation, students were occasionally

delayed due to course flights on either the aircraft or in the simulator, the largest cause of delay was academics. The requirement of having students take academic courses as a class created over 50% of the delays in training.

4. How many instructors are projected to be needed in the future given changes in Air Force demand?

Under surge operations, which requires 140 BCE to be produced by the 9 ATKs, they= squadron would need to be 100% manned to meet demand, if arrival time of classes does not change. With the assumption that class sizes are at a max of 18, the unit would need to add 34 to 36 instructors total, adding 17 or 18 to both the sensor operators and to the pilot instructors. This also assumes the instructors being added are assigned to the 9 ATKs, as was simulated in the model, and not contractor instructors.

5.3 Recommendations for Future Research

The discrete event model created addresses daily operations of the 9 ATKs. To more accurately capture the operations of the unit, an hourly model would be more appropriate. That would provide a more accurate assessment of utilization of instructors. It also would allow instructors to complete more than one flying event each day, as can occur in the 9 ATKs, when necessary. Additionally, that would allow the individual academic courses to be modeled using the specific instructors for each lesson.

With continued collection of data in the 9 ATKs, fidelity can be added to the model. With increased and continual data collection on failure rates per syllabus event, as well as overall failure rates, the model can gain further accuracy projecting overall student completion. Also, with the 9 ATKs implementing the new IQT syllabus, more data will be available and can be used to ensure the model is valid,

as the 6 ATKS historical data was used for initial model validation. More specific data collection on the time instructors are unavailable could allow for the use of an availability rate on each instructor in the model with appropriate down times as experienced with leave, TDY, and DNIF events in the squadron. Additionally, more courses will be held overtime and an arrival distribution could be determined for use in the model to more accurately capture the variation in class arrivals.

With additional time and resources, the model could be improved by adding additional logic and details. Currently, the model has limitations in the logic that do not allow for every scenario to be simulated. Adding logic to allow the model to handle odd class sizes would be more realistic and representative of the real-world system. The model was simplified to require two students to complete a super-sortie, whereas, in the real-world, if another student is not available, the flight would still occur. Updating the model to allow a super-sortie solo or in pairs would increase the fidelity of the model.

In the 9 ATKS, the FIUT flights are dependent on the IQT syllabus, which was not captured in the simulation. The addition of the reliance of FIUT course completion on the IQT course timeline would improve the validity of the completion time and student throughput of the FIUT students. Although every instructor is individually represented in the model, blanket schedules are applied to them based on their type (assigned, attached, reserve, contractor). To gain more fidelity, each instructors individual schedule could be attached to them to gain the variety of availability the 9 ATKS experiences.

The focus of this analysis was on the IQT syllabus which facilitates the most students trained by the 9 ATKS complete. Further studies could assess the impact of changes on class size, instructors, and arrival rate on the remaining four courses. This would provide even more information to the 9 ATKS on how to properly meet

their BCE annual requirements.

5.4 Summary

Overall, the simulation successfully provided the means to analyze the 9 ATKS operations without disrupting their system. From the scenarios tested in the simulation, multiple regression equations were developed that can be used to provide predictions on student throughput and course completion time. Insight into the real-world system was gained by analyzing different aspects of the simulation when settings were representative of current manning and operations in the 9 ATKS. Assumptions and simplifications were necessary to represent the real-world system in the discrete event simulation, and therefore the results are reliable, but not precise, due to these modifications. The analysis and results are valuable to the 9 ATKS decision makers as they may need to adjust multiple factors in the unit to meet AF demand for MQ-9 crews.

Appendix A. Course Syllabi

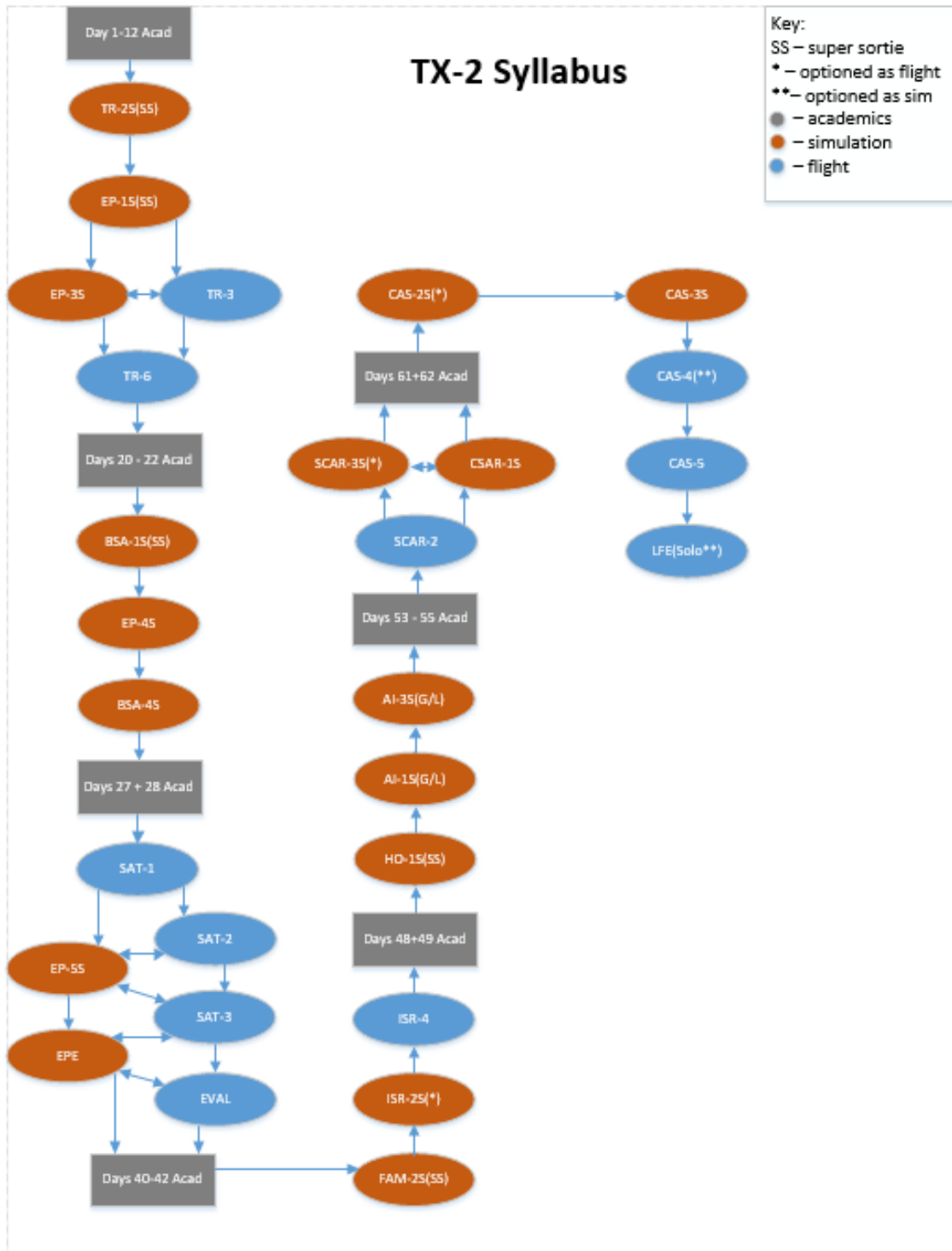


Figure 8. TX-2 Course Flow

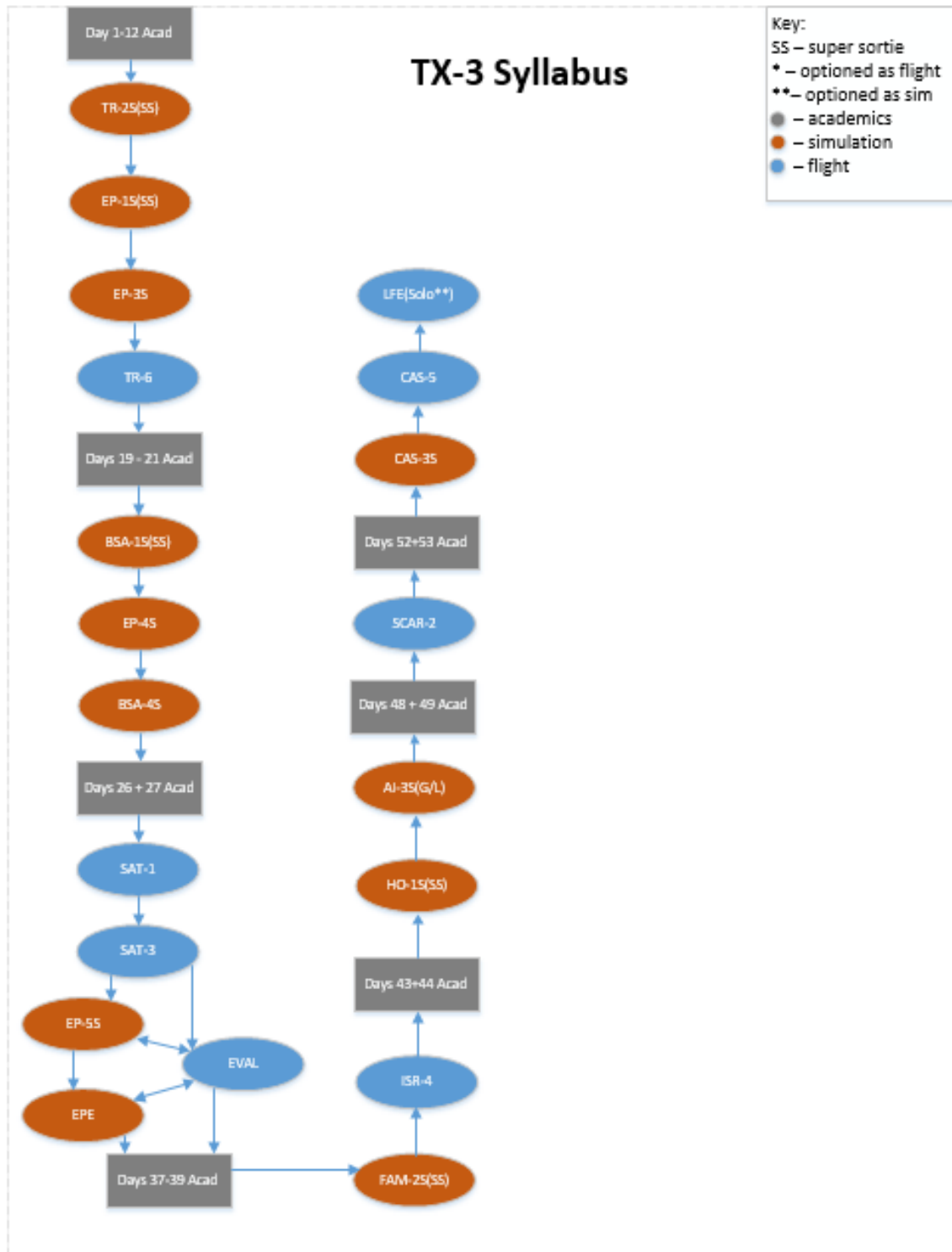


Figure 9. TX-3 Course Flow

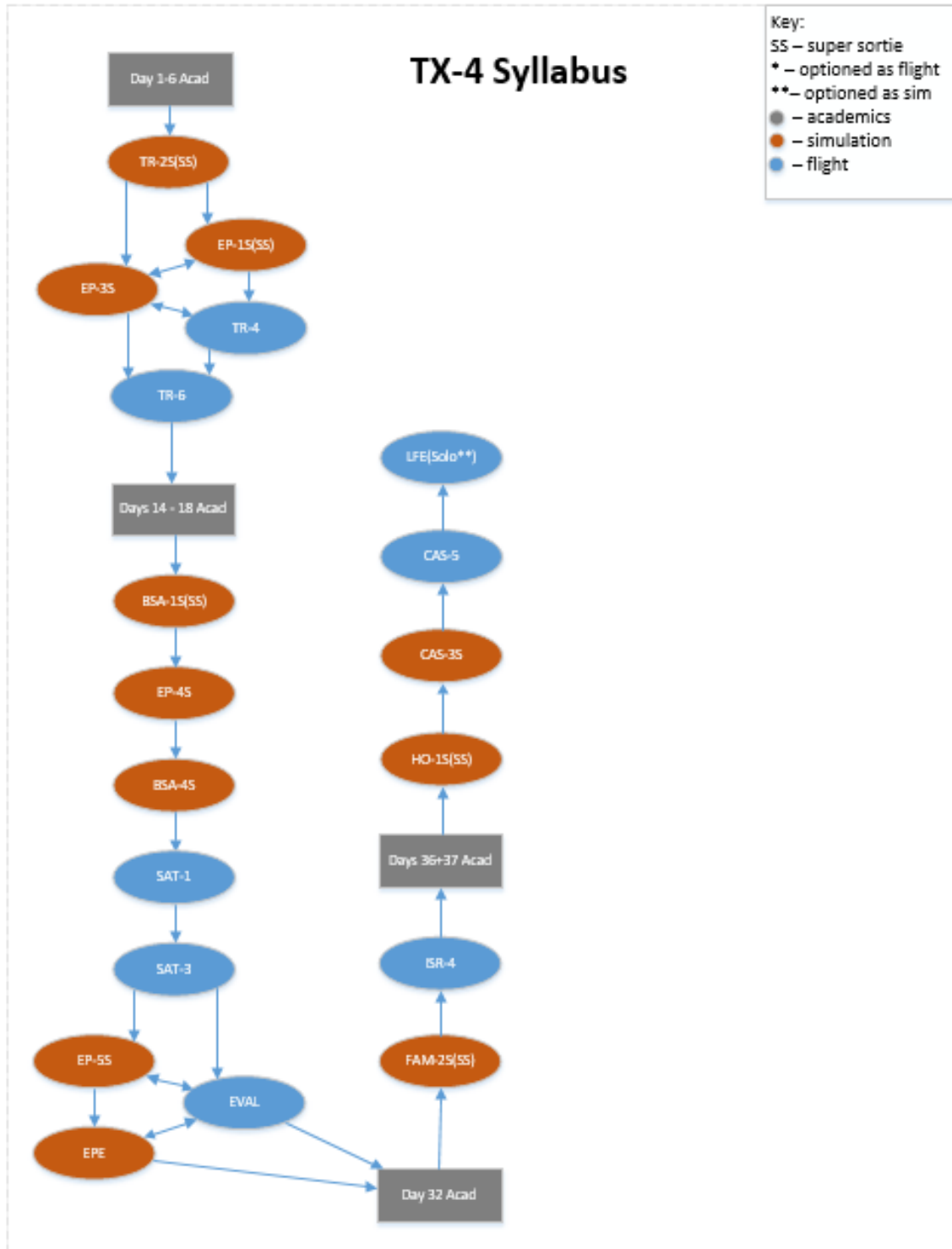


Figure 10. TX-4 Course Flow

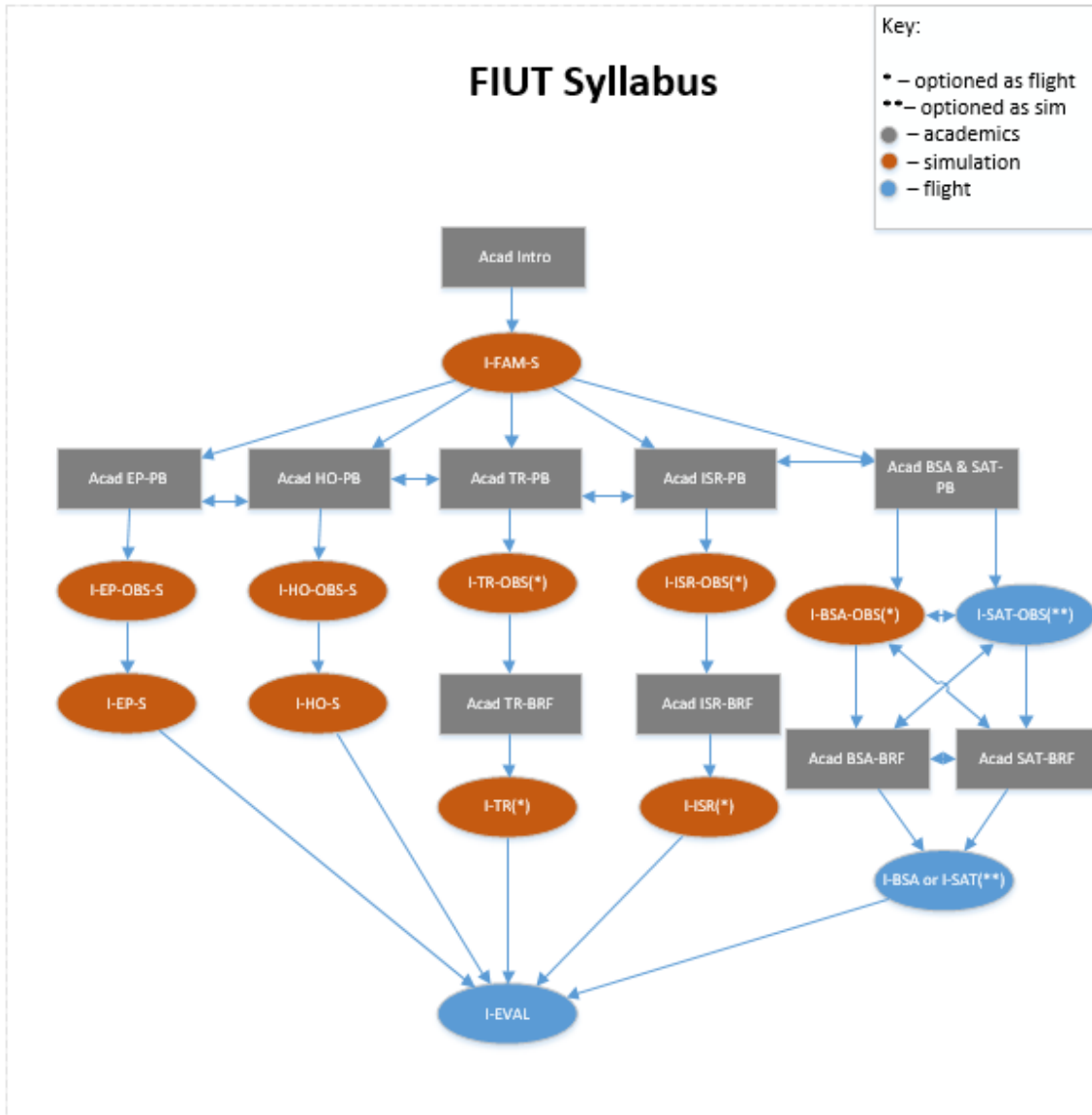


Figure 11. FIUT Course Flow

Appendix B. Course Task Tables

Task_Number	Task_Name	Process_Time	Predecessor_Job_Number	Prob_Failure	IP_Resource	ISO_Resource	Equipment_Required	Starting_Task	Finished_Task
1	Acad1	8		0	DummyResourceList	DummyResourceList	DummyResourceList	Batch_Task_Started	Batch_Task_Finished
2	Acad2	8	1	0	PilotClass1	SensorClass1	DummyResourceList	Batch_Task_Started	Batch_Task_Finished
3	FAM_1S	8	2	0	Pilots_IP_SO	Sensors_ISO_SO	Simulators	Task_Started	Task_Finished
4	Acad4	8	3	0	PilotClass1	SensorClass1	DummyResourceList	Batch_Task_Started	Batch_Task_Finished
5	Acad5	8	4	0	PilotClass1	DummyResourceList	DummyResourceList	Batch_Task_Started	Batch_Task_Finished
6	Acad6	8	5	0	Pilots_OR_Sensors	DummyResourceList	DummyResourceList	Batch_Task_Started	Batch_Task_Finished
7	Acad7	8	6	0	Pilots_IP_SO	SensorClass1	DummyResourceList	Batch_Task_Started	Batch_Task_Finished
8	Acad8	8	7	0	Pilots_IP_SO	Sensors_ISO_SO	DummyResourceList	Batch_Task_Started	Batch_Task_Finished
9	Acad9	8	8	0	Pilots_OR_Sensors	DummyResourceList	DummyResourceList	Batch_Task_Started	Batch_Task_Finished
10	Acad10	8	9	0	PilotClass1	DummyResourceList	DummyResourceList	Batch_Task_Started	Batch_Task_Finished
11	Acad11	8	10	0	PilotClass1	Pilots_OR_Sensors	DummyResourceList	Batch_Task_Started	Batch_Task_Finished
12	Acad12	8	11	0	PilotClass1	Pilots_OR_Sensors	DummyResourceList	Batch_Task_Started	Batch_Task_Finished
13	TR_1S	8	12	0	Pilots_IP_SO	Sensors_ISO_SO	Simulators	SS_Task_Started	SS_Task_Finished
14	TR_2S	8	13	0	Pilots_IP_SO	Sensors_ISO_SO	Simulators	SS_Task_Started	SS_Task_Finished
15	EP_1S	8	14	0	Pilots_IP_SO	Sensors_ISO_SO	Simulators	SS_Task_Started	SS_Task_Finished
16	TR_3	8	15	0	Pilots_IP	Sensors_ISO	Aircrafts	Task_Started	Task_Finished
17	TR_4	8	16	0	Pilots_IP	Sensors_ISO	Aircrafts	Task_Started	Task_Finished
18	EP_2S	8	17	0	Pilots_IP	Sensors_ISO	Simulators	SS_Task_Started	SS_Task_Finished
19	EP_3S	8	18	0	Pilots_IP	Sensors_ISO	Simulators	Task_Started	Task_Finished
20	TR_5S	8	16,17,18,19	0.03	Pilots_IP_SO	Sensors_ISO_SO	Simulators	Task_Started	Task_Finished
21	TR_6	8	20	0.03	Pilots_IP	Sensors_ISO	Aircrafts	Task_Started	Task_Finished
22	Acad25	8	21	0	PilotClass2	SensorClass2	DummyResourceList	Batch_Task_Started	Batch_Task_Finished
23	Acad26	8	22	0	PilotClass2	DummyResourceList	DummyResourceList	Batch_Task_Started	Batch_Task_Finished
24	Acad27	8	23	0	PilotClass2	DummyResourceList	DummyResourceList	Batch_Task_Started	Batch_Task_Finished
25	BSA_1S	8	24	0	Pilots_IP_SO	Sensors_ISO_SO	Simulators	SS_Task_Started	SS_Task_Finished
26	BSA_2S	8	25	0.1	Pilots_IP	Sensors_ISO	SimthenAC	Task_Started	Task_Finished
27	EP_4S	8	26	0.1	Pilots_IP_SO	Sensors_ISO_SO	Simulators	Task_Started	Task_Finished
28	BSA_3S	8	27	0	Pilots_IP	Sensors_ISO	SimthenAC	Task_Started	Task_Finished
29	BSA_4S	8	27,28	0	Pilots_IP_SO	Sensors_ISO_SO	Simulators	Task_Started	Task_Finished
30	Acad35	8	29	0	PilotClass2	DummyResourceList	DummyResourceList	Batch_Task_Started	Batch_Task_Finished
31	Acad36	8	30	0	PilotClass2	DummyResourceList	DummyResourceList	Batch_Task_Started	Batch_Task_Finished
32	SAT_1	8	31	0	Pilots_IP	Sensors_ISO	Aircrafts	Task_Started	Task_Finished
33	SAT_2	8	32	0.03	Pilots_IP	Sensors_ISO	Aircrafts	Task_Started	Task_Finished
34	SAT_3	8	33	0.17	Pilots_IP	Sensors_ISO	Aircrafts	Task_Started	Task_Finished
35	EP_5S	8	33	0.27	Pilots_IP_SO	Sensors_ISO_SO	Simulators	Task_Started	Task_Finished
36	EPE	8	35	0.03	Pilots_ADFE_FE	Sensors_ADFE_FE	Simulators	Task_Started	Task_Finished
37	EVAL	8	34	0.07	Pilots_ADFE_FE	Sensors_ADFE_FE	Aircrafts	Task_Started	Task_Finished
38	SAT_4	8	34,35,36,37	0.03	Pilots_IP	Sensors_ISO	Aircrafts	Task_Started	Task_Finished
39	Acad50	8	38	0	PilotClass2	SensorClass2	DummyResourceList	Batch_Task_Started	Batch_Task_Finished
40	Acad51	8	39	0	DummyResourceList	SensorClass2	DummyResourceList	Batch_Task_Started	Batch_Task_Finished
41	Acad52	8	40	0	PilotClass2	SensorClass2	DummyResourceList	Batch_Task_Started	Batch_Task_Finished
42	Acad53	8	41	0	PilotClass2	SensorClass2	DummyResourceList	Batch_Task_Started	Batch_Task_Finished
43	Acad54	8	42	0	DummyResourceList	DummyResourceList	DummyResourceList	Batch_Task_Started	Batch_Task_Finished
44	FAM_2S	8	43	0	Pilots_IP_SO	Sensors_ISO_SO	Simulators	SS_Task_Started	SS_Task_Finished
45	ISR_1S	8	44	0	Pilots_IP_SO	Sensors_ISO_SO	Simulators	Task_Started	Task_Finished
46	ISR_2S	8	45	0	Pilots_IP	Sensors_ISO	SimthenAC	Task_Started	Task_Finished
47	ISR_3S	8	46	0	Pilots_IP	Sensors_ISO	SimthenAC	Task_Started	Task_Finished
48	ISR_4	8	47	0	Pilots_IP	Sensors_ISO	Aircrafts	Task_Started	Task_Finished
49	ISR_5	8	48	0	Pilots_IP	Sensors_ISO	Aircrafts	Task_Started	Task_Finished
50	Acad63	8	49	0	PilotClass3	DummyResourceList	DummyResourceList	Batch_Task_Started	Batch_Task_Finished
51	Acad64	8	50	0	PilotClass3	SensorClass2	DummyResourceList	Batch_Task_Started	Batch_Task_Finished
52	HO_1S	8	51	0	Pilots_IP_SO	Sensors_ISO_SO	Simulators	SS_Task_Started	SS_Task_Finished
53	AI_1S	8	52	0	Pilots_AI_SO	Sensors_AI_SO	Simulators	Task_Started	Task_Finished
54	AI_2S	8	53	0	Pilots_AI_SO	Sensors_AI_SO	Simulators	Task_Started	Task_Finished
55	AI_3S	8	54	0	Pilots_AI_SO	Sensors_AI_SO	Simulators	Task_Started	Task_Finished
56	Acad69	8	55	0	PilotClass3	DummyResourceList	DummyResourceList	Batch_Task_Started	Batch_Task_Finished
57	Acad70	8	56	0	PilotClass3	DummyResourceList	DummyResourceList	Batch_Task_Started	Batch_Task_Finished
58	Acad71	8	57	0	PilotClass3	DummyResourceList	DummyResourceList	Batch_Task_Started	Batch_Task_Finished
59	SCAR_1S	8	58	0	Pilots_SCAR_SO	Sensors_SCAR_SO	Simulators	Task_Started	Task_Finished
60	SCAR_2	8	59	0	Pilots_SCAR	Sensors_SCAR	Aircrafts	Task_Started	Task_Finished
61	SCAR_3S	8	60	0	Pilots_SCAR	Sensors_SCAR	SimthenAC	Task_Started	Task_Finished
62	CSAR_1S	8	61	0	Pilots_CSAR_SO	Sensors_CSAR_SO	Simulators	Task_Started	Task_Finished
63	SCAR_4	8	60,61,62	0	Pilots_SCAR	Sensors_SCAR	Aircrafts	Task_Started	Task_Finished
64	Acad80	8	63	0	PilotClass3	DummyResourceList	DummyResourceList	Batch_Task_Started	Batch_Task_Finished
65	Acad81	8	64	0	PilotClass3	DummyResourceList	DummyResourceList	Batch_Task_Started	Batch_Task_Finished
66	CAS_1S	8	65	0	Pilots_CAS_SO	Sensors_CAS_SO	Simulators	Task_Started	Task_Finished
67	CAS_2S	8	66	0	Pilots_CAS	Sensors_CAS	SimthenAC	Task_Started	Task_Finished
68	CAS_3S	8	67	0	Pilots_CAS_SO	Sensors_CAS_SO	Simulators	Task_Started	Task_Finished
69	CAS_4	8	68	0	Pilots_CAS	Sensors_CAS	AthenSim	Task_Started	Task_Finished
70	CAS_5	8	69	0	Pilots_CAS	Sensors_CAS	Aircrafts	Task_Started	Task_Finished
71	CAS_6	8	70	0	Pilots_CAS	Sensors_CAS	Aircrafts	Task_Started	Task_Finished
72	LFE	8	71	0	Pilots_Advanced	Sensors_Advanced	Aircrafts	Task_Started	Task_Finished

Figure 12. IQT Task Table

Task_Number	Task_Name	Process_Time	Predecessor_Job_Number	Prob_Failure	IP_Resource	ISO_Resource	Equipment_Required	Starting_Task	Finished_Task
1	Acad1	8		0	DummyResourceList	DummyResourceList	DummyResourceList	SS_Task_Started_TX2	SS_Task_Finished_TX2
2	Acad2	8	1	0	PilotClass1	DummyResourceList	DummyResourceList	SS_Task_Started_TX2	SS_Task_Finished_TX2
3	Acad3	8	2	0	DummyResourceList	DummyResourceList	DummyResourceList	SS_Task_Started_TX2	SS_Task_Finished_TX2
4	Acad4	8	3	0	PilotClass1	SensorClass1	DummyResourceList	SS_Task_Started_TX2	SS_Task_Finished_TX2
5	Acad5	8	4	0	PilotClass1	DummyResourceList	DummyResourceList	SS_Task_Started_TX2	SS_Task_Finished_TX2
6	Acad6	8	5	0	Pilots_OR_Sensors	DummyResourceList	DummyResourceList	SS_Task_Started_TX2	SS_Task_Finished_TX2
7	Acad7	8	6	0	DummyResourceList	SensorClass1	DummyResourceList	SS_Task_Started_TX2	SS_Task_Finished_TX2
8	Acad8	8	7	0	Pilots_IP	Sensors_ISO	DummyResourceList	SS_Task_Started_TX2	SS_Task_Finished_TX2
9	Acad9	8	8	0	Pilots_OR_Sensors	DummyResourceList	DummyResourceList	SS_Task_Started_TX2	SS_Task_Finished_TX2
10	Acad10	8	9	0	Pilots_IP_SO	Sensors_ISO_SO	DummyResourceList	SS_Task_Started_TX2	SS_Task_Finished_TX2
11	Acad11	8	10	0	PilotClass1	Pilots_OR_Sensors	DummyResourceList	SS_Task_Started_TX2	SS_Task_Finished_TX2
12	Acad12	8	11	0	PilotClass1	DummyResourceList	DummyResourceList	SS_Task_Started_TX2	SS_Task_Finished_TX2
13	TR_2S	8	12	0	Pilots_IP_SO	Sensors_ISO_SO	Simulators	SS_Task_Started_TX2	SS_Task_Finished_TX2
14	EP_1S	8	13	0	Pilots_IP_SO	Sensors_ISO_SO	Simulators	SS_Task_Started_TX2	SS_Task_Finished_TX2
15	EP_3S	8	14	0	Pilots_IP_SO	Sensors_ISO_SO	Simulators	Task_Started_TX2	Task_Finished_TX2
16	TR_3	8	14	0	Pilots_IP	Sensors_ISO	Aircrafts	Task_Started_TX2	Task_Finished_TX2
17	TR_6	8	15,16	0	Pilots_IP	Sensors_ISO	Aircrafts	Task_Started_TX2	Task_Finished_TX2
18	Acad20	8	17	0	PilotClass2	SensorClass2	DummyResourceList	SS_Task_Started_TX2	SS_Task_Finished_TX2
19	Acad21	8	18	0	PilotClass2	DummyResourceList	DummyResourceList	SS_Task_Started_TX2	SS_Task_Finished_TX2
20	Acad22	8	19	0	PilotClass2	DummyResourceList	DummyResourceList	SS_Task_Started_TX2	SS_Task_Finished_TX2
21	BSA_1S	8	20	0	Pilots_IP_SO	Sensors_ISO_SO	Simulators	SS_Task_Started_TX2	SS_Task_Finished_TX2
22	EP_4s	8	21	0	Pilots_IP_SO	Sensors_ISO_SO	Simulators	Task_Started_TX2	Task_Finished_TX2
23	BSA_4S	8	22	0	Pilots_IP_SO	Sensors_ISO_SO	Simulators	Task_Started_TX2	Task_Finished_TX2
24	Acad27	8	23	0	PilotClass2	SensorClass2	DummyResourceList	SS_Task_Started_TX2	SS_Task_Finished_TX2
25	Acad28	8	24	0	PilotClass2	DummyResourceList	DummyResourceList	SS_Task_Started_TX2	SS_Task_Finished_TX2
26	SAT_1	8	25	0	Pilots_IP	Sensors_ISO	Aircrafts	Task_Started_TX2	Task_Finished_TX2
27	SAT_2	8	26	0	Pilots_IP	Sensors_ISO	Aircrafts	Task_Started_TX2	Task_Finished_TX2
28	SAT_3	8	27	0	Pilots_IP	Sensors_ISO	Aircrafts	Task_Started_TX2	Task_Finished_TX2
29	EVAL	8	28	0	Pilots_ADFF_FE	Sensors_ADFF_FE	Aircrafts	Task_Started_TX2	Task_Finished_TX2
30	EP_5S	8	26	0	Pilots_IP_SO	Sensors_ISO_SO	Simulators	Task_Started_TX2	Task_Finished_TX2
31	EPE	8	30	0	Pilots_ADFF_FE	Sensors_ADFF_FE	Simulators	Task_Started_TX2	Task_Finished_TX2
32	Acad40	8	27,28,29,30,31	0	DummyResourceList	SensorClass2	DummyResourceList	SS_Task_Started_TX2	SS_Task_Finished_TX2
33	Acad41	8	32	0	PilotClass2	SensorClass2	DummyResourceList	SS_Task_Started_TX2	SS_Task_Finished_TX2
34	Acad42	8	33	0	PilotClass2	SensorClass2	DummyResourceList	SS_Task_Started_TX2	SS_Task_Finished_TX2
35	FAM_2S	8	34	0	Pilots_IP_SO	Sensors_ISO_SO	Simulators	SS_Task_Started_TX2	SS_Task_Finished_TX2
36	ISR_2S	8	35	0	Pilots_IP	Sensors_ISO	SimthenAC	Task_Started_TX2	Task_Finished_TX2
37	ISR_4	8	36	0	Pilots_IP	Sensors_ISO	Aircrafts	Task_Started_TX2	Task_Finished_TX2
38	Acad48	8	37	0	PilotClass3	SensorClass2	DummyResourceList	SS_Task_Started_TX2	SS_Task_Finished_TX2
39	Acad49	8	38	0	PilotClass3	DummyResourceList	DummyResourceList	SS_Task_Started_TX2	SS_Task_Finished_TX2
40	HQ_1S	8	39	0	Pilots_IP_SO	Sensors_ISO_SO	Simulators	Task_Started_TX2	Task_Finished_TX2
41	AI_1S	8	40	0	Pilots_AI_SO	Sensors_AI_SO	Simulators	Task_Started_TX2	Task_Finished_TX2
42	AI_3S	8	41	0	Pilots_AI_SO	Sensors_AI_SO	Simulators	Task_Started_TX2	Task_Finished_TX2
43	Acad53	8	42	0	PilotClass3	DummyResourceList	DummyResourceList	SS_Task_Started_TX2	SS_Task_Finished_TX2
44	Acad54	8	43	0	PilotClass3	DummyResourceList	DummyResourceList	SS_Task_Started_TX2	SS_Task_Finished_TX2
45	Acad55	8	44	0	PilotClass3	DummyResourceList	DummyResourceList	SS_Task_Started_TX2	SS_Task_Finished_TX2
46	SCAR_2	8	45	0	Pilots_SCAR	Sensors_SCAR	Aircrafts	Task_Started_TX2	Task_Finished_TX2
47	SCAR_3S	8	46	0	Pilots_SCAR	Sensors_SCAR	SimthenAC	Task_Started_TX2	Task_Finished_TX2
48	CSAR_1S	8	46	0	Pilots_CSAR_SO	Sensors_CSAR_SO	Simulators	Task_Started_TX2	Task_Finished_TX2
49	Acad61	8	47,48	0	PilotClass3	DummyResourceList	DummyResourceList	SS_Task_Started_TX2	SS_Task_Finished_TX2
50	Acad62	8	49	0	PilotClass3	DummyResourceList	DummyResourceList	SS_Task_Started_TX2	SS_Task_Finished_TX2
51	CAS_2S	8	50	0	Pilots_CAS	Sensors_CAS	SimthenAC	Task_Started_TX2	Task_Finished_TX2
52	CAS_3S	8	51	0	Pilots_CAS_SO	Sensors_CAS_SO	Simulators	Task_Started_TX2	Task_Finished_TX2
53	CAS_4	8	52	0	Pilots_CAS	Sensors_CAS	ACthenSim	Task_Started_TX2	Task_Finished_TX2
54	CAS_5	8	53	0	Pilots_CAS	Sensors_CAS	Aircrafts	Task_Started_TX2	Task_Finished_TX2
55	LFE	8	54	0	Pilots_Advanced	Sensors_Advanced	ACthenSim	Task_Started_TX2	Task_Finished_TX2

Figure 13. TX-2 Task Table

Task_Number	Task_Name	Process_Time	Predecessor_Job_Number	Prob_Failure	IP_Resource	ISO_Resource	Equipment_Required	Starting_Task	Finished_Task
1	Acad1	8		0	DummyResourceList	DummyResourceList	DummyResourceList	Batch_Task_Started_TX3	Batch_Task_Finished_TX3
2	Acad2	8	1	0	PilotClass1	DummyResourceList	DummyResourceList	Batch_Task_Started_TX3	Batch_Task_Finished_TX3
3	Acad3	8	2	0	DummyResourceList	DummyResourceList	DummyResourceList	Batch_Task_Started_TX3	Batch_Task_Finished_TX3
4	Acad4	8	3	0	PilotClass1	SensorClass1	DummyResourceList	Batch_Task_Started_TX3	Batch_Task_Finished_TX3
5	Acad5	8	4	0	PilotClass1	DummyResourceList	DummyResourceList	Batch_Task_Started_TX3	Batch_Task_Finished_TX3
6	Acad6	8	5	0	Pilots_OR_Sensors	DummyResourceList	DummyResourceList	Batch_Task_Started_TX3	Batch_Task_Finished_TX3
7	Acad7	8	6	0	Pilots_IP_SO	SensorClass1	DummyResourceList	Batch_Task_Started_TX3	Batch_Task_Finished_TX3
8	Acad8	8	7	0	Pilots_IP_SO	Sensors_ISO_SO	DummyResourceList	Batch_Task_Started_TX3	Batch_Task_Finished_TX3
9	Acad9	8	8	0	Pilots_OR_Sensors	DummyResourceList	DummyResourceList	Batch_Task_Started_TX3	Batch_Task_Finished_TX3
10	Acad10	8	9	0	Pilots_IP_SO	Sensors_ISO_SO	DummyResourceList	Batch_Task_Started_TX3	Batch_Task_Finished_TX3
11	Acad11	8	10	0	PilotClass1	Sensors_ISO_SO	DummyResourceList	Batch_Task_Started_TX3	Batch_Task_Finished_TX3
12	Acad12	8	11	0	PilotClass1	Sensors_ISO_SO	DummyResourceList	Batch_Task_Started_TX3	Batch_Task_Finished_TX3
13	TR_2S	8	12	0	Pilots_IP_SO	Sensors_ISO_SO	Simulators	SS_Task_Started_TX3	SS_Task_Finished_TX3
14	EP_1S	8	13	0	Pilots_IP_SO	Sensors_ISO_SO	Simulators	SS_Task_Started_TX3	SS_Task_Finished_TX3
15	EP_3S	8	14	0	Pilots_IP_SO	Sensors_ISO_SO	Simulators	Task_Started_TX3	Task_Finished_TX3
16	TR_6	8	15	0	Pilots_IP	Sensors_ISO	Aircrafts	Task_Started_TX3	Task_Finished_TX3
17	Acad19	8	16	0	PilotClass2	SensorClass2	DummyResourceList	Batch_Task_Started_TX3	Batch_Task_Finished_TX3
18	Acad20	8	17	0	PilotClass2	DummyResourceList	DummyResourceList	Batch_Task_Started_TX3	Batch_Task_Finished_TX3
19	Acad21	8	18	0	PilotClass2	DummyResourceList	DummyResourceList	Batch_Task_Started_TX3	Batch_Task_Finished_TX3
20	BSA_1S	8	19	0	Pilots_IP_SO	Sensors_ISO_SO	Simulators	SS_Task_Started_TX3	SS_Task_Finished_TX3
21	EP_4s	8	20	0	Pilots_IP_SO	Sensors_ISO_SO	Simulators	Task_Started_TX3	Task_Finished_TX3
22	BSA_4S	8	21	0	Pilots_IP_SO	Sensors_ISO_SO	Simulators	Task_Started_TX3	Task_Finished_TX3
23	Acad26	8	22	0	PilotClass2	SensorClass2	DummyResourceList	Batch_Task_Started_TX3	Batch_Task_Finished_TX3
24	Acad27	8	23	0	PilotClass2	DummyResourceList	DummyResourceList	Batch_Task_Started_TX3	Batch_Task_Finished_TX3
25	SAT_1	8	24	0	Pilots_IP	Sensors_ISO	Aircrafts	Task_Started_TX3	Task_Finished_TX3
26	SAT_3	8	25	0	Pilots_IP	Sensors_ISO	Aircrafts	Task_Started_TX3	Task_Finished_TX3
27	EVAL	8	26	0	Pilots_ADFE_FE	Sensors_ADFE_FE	Aircrafts	Task_Started_TX3	Task_Finished_TX3
28	EP_5S	8	26	0	Pilots_IP_SO	Sensors_ISO_SO	Simulators	Task_Started_TX3	Task_Finished_TX3
29	EPE	8	28	0	Pilots_ADFE_FE	Sensors_ADFE_FE	Simulators	Task_Started_TX3	Task_Finished_TX3
30	Acad37	8	27,28,29	0	DummyResourceList	SensorClass2	DummyResourceList	Batch_Task_Started_TX3	Batch_Task_Finished_TX3
31	Acad38	8	30	0	PilotClass2	SensorClass2	DummyResourceList	Batch_Task_Started_TX3	Batch_Task_Finished_TX3
32	Acad39	8	31	0	PilotClass2	SensorClass2	DummyResourceList	Batch_Task_Started_TX3	Batch_Task_Finished_TX3
33	FAM_2S	8	32	0	Pilots_IP_SO	Sensors_ISO_SO	Simulators	SS_Task_Started_TX3	SS_Task_Finished_TX3
34	ISR_4	8	33	0	Pilots_IP	Sensors_ISO	Aircrafts	Task_Started_TX3	Task_Finished_TX3
35	Acad43	8	34	0	PilotClass3	SensorClass2	DummyResourceList	Batch_Task_Started_TX3	Batch_Task_Finished_TX3
36	Acad44	8	35	0	PilotClass3	DummyResourceList	DummyResourceList	Batch_Task_Started_TX3	Batch_Task_Finished_TX3
37	HO_1S	8	36	0	Pilots_IP_SO	Sensors_ISO_SO	Simulators	SS_Task_Started_TX3	SS_Task_Finished_TX3
38	AI_3S	8	37	0	Pilots_AI_SO	Sensors_AI_SO	Simulators	Task_Started_TX3	Task_Finished_TX3
39	Acad48	8	38	0	PilotClass3	DummyResourceList	DummyResourceList	Batch_Task_Started_TX3	Batch_Task_Finished_TX3
40	Acad49	8	39	0	PilotClass3	DummyResourceList	DummyResourceList	Batch_Task_Started_TX3	Batch_Task_Finished_TX3
41	SCAR_2	8	40	0	Pilots_SCAR	Sensors_SCAR	Aircrafts	Task_Started_TX3	Task_Finished_TX3
42	Acad52	8	41	0	PilotClass3	DummyResourceList	DummyResourceList	Batch_Task_Started_TX3	Batch_Task_Finished_TX3
43	Acad53	8	42	0	PilotClass3	DummyResourceList	DummyResourceList	Batch_Task_Started_TX3	Batch_Task_Finished_TX3
44	CAS_3S	8	43	0	Pilots_CAS_SO	Sensors_CAS_SO	Simulators	Task_Started_TX3	Task_Finished_TX3
45	CAS_5	8	44	0	Pilots_CAS	Sensors_CAS	Aircrafts	Task_Started_TX3	Task_Finished_TX3
46	LFE	8	45	0	Pilots_Advanced	Sensors_Advanced	ACthenSim	Task_Started_TX3	Task_Finished_TX3

Figure 14. TX-3 Task Table

Task_Number	Task_Name	Process_Time	Predecessor_Job_Number	Prob_Failure	IP_Resource	ISO_Resource	Equipment_Required	Starting_Task	Finished_Task
1	Acad1	8		0	PilotClass1	SensorClass1	DummyResourceList	Batch_Task_Started_TX4	Batch_Task_Finished_TX4
2	Acad2	8	1	0	PilotClass1	DummyResourceList	DummyResourceList	Batch_Task_Started_TX4	Batch_Task_Finished_TX4
3	Acad3	8	2	0	DummyResourceList	SensorClass1	DummyResourceList	Batch_Task_Started_TX4	Batch_Task_Finished_TX4
4	Acad4	8	3	0	Pilots_IP_SO	Sensors_ISO_SO	DummyResourceList	Batch_Task_Started_TX4	Batch_Task_Finished_TX4
5	Acad5	8	4	0	PilotClass1	Sensors_ISO_SO	DummyResourceList	Batch_Task_Started_TX4	Batch_Task_Finished_TX4
6	Acad6	8	5	0	PilotClass1	Sensors_ISO_SO	DummyResourceList	Batch_Task_Started_TX4	Batch_Task_Finished_TX4
7	TR_2S	8	6	0	Pilots_IP_SO	Sensors_ISO_SO	Simulators	SS_Task_Started_TX4	SS_Task_Finished_TX4
8	EP_1S	8	7	0	Pilots_IP_SO	Sensors_ISO_SO	Simulators	SS_Task_Started_TX4	SS_Task_Finished_TX4
9	EP_3S	8	7	0	Pilots_IP_SO	Sensors_ISO_SO	Simulators	Task_Started_TX4	Task_Finished_TX4
10	TR_4	8	8	0	Pilots_IP	Sensors_ISO	Aircrafts	Task_Started_TX4	Task_Finished_TX4
11	TR_6	8	8,9,10	0	Pilots_IP	Sensors_ISO	Aircrafts	Task_Started_TX4	Task_Finished_TX4
12	Acad14	8	11	0	DummyResourceList	DummyResourceList	DummyResourceList	Batch_Task_Started_TX4	Batch_Task_Finished_TX4
13	Acad15	8	12	0	PilotClass2	SensorClass2	DummyResourceList	Batch_Task_Started_TX4	Batch_Task_Finished_TX4
14	Acad16	8	13	0	PilotClass2	DummyResourceList	DummyResourceList	Batch_Task_Started_TX4	Batch_Task_Finished_TX4
15	Acad17	8	14	0	PilotClass2	DummyResourceList	DummyResourceList	Batch_Task_Started_TX4	Batch_Task_Finished_TX4
16	Acad18	8	15	0	PilotClass2	DummyResourceList	DummyResourceList	Batch_Task_Started_TX4	Batch_Task_Finished_TX4
17	BSA_1S	8	16	0	Pilots_IP_SO	Sensors_ISO_SO	Simulators	SS_Task_Started_TX4	SS_Task_Finished_TX4
18	EP_4s	8	17	0	Pilots_IP_SO	Sensors_ISO_SO	Simulators	Task_Started_TX4	Task_Finished_TX4
19	BSA_4S	8	18	0	Pilots_IP_SO	Sensors_ISO_SO	Simulators	Task_Started_TX4	Task_Finished_TX4
20	SAT_1	8	19	0	Pilots_IP	Sensors_ISO	Aircrafts	Task_Started_TX4	Task_Finished_TX4
21	SAT_3	8	20	0	Pilots_IP	Sensors_ISO	Aircrafts	Task_Started_TX4	Task_Finished_TX4
22	EVAL	8	21	0	Pilots_ADFE_FE	Sensors_ADFE_FE	Aircrafts	Task_Started_TX4	Task_Finished_TX4
23	EP_5S	8	21	0	Pilots_IP_SO	Sensors_ISO_SO	Simulators	Task_Started_TX4	Task_Finished_TX4
24	EPE	8	23	0	Pilots_ADFE_FE	Sensors_ADFE_FE	Simulators	Task_Started_TX4	Task_Finished_TX4
25	Acad32	8	22,23,24	0	PilotClass2	SensorClass2	DummyResourceList	Batch_Task_Started_TX4	Batch_Task_Finished_TX4
26	FAM_2S	8	25	0	Pilots_IP_SO	Sensors_ISO_SO	Simulators	SS_Task_Started_TX4	SS_Task_Finished_TX4
27	ISR_4	8	26	0	Pilots_IP	Sensors_ISO	Aircrafts	Task_Started_TX4	Task_Finished_TX4
28	Acad36	8	27	0	PilotClass3	SensorClass2	DummyResourceList	Batch_Task_Started_TX4	Batch_Task_Finished_TX4
29	Acad37	8	28	0	PilotClass3	SensorClass2	DummyResourceList	Batch_Task_Started_TX4	Batch_Task_Finished_TX4
30	HO_1S	8	29	0	Pilots_IP_SO	Sensors_ISO_SO	Simulators	SS_Task_Started_TX4	SS_Task_Finished_TX4
31	CAS_3S	8	30	0	Pilots_CAS_SO	Sensors_CAS_SO	Simulators	Task_Started_TX4	Task_Finished_TX4
32	CAS_5	8	31	0	Pilots_CAS	Sensors_CAS	Aircrafts	Task_Started_TX4	Task_Finished_TX4
33	LFE	8	32	0	Pilots_Advanced	Sensors_Advanced	ACthenSim	Task_Started_TX4	Task_Finished_TX4

Figure 15. TX-4 Task Table

Task_Number	Task_Name	Process_Time	Predecessor_Job_Number	Prob_Failure	IP_Resource	ISO_Resource	Equipment_Required	Starting_Task	Finished_Task
1	Acad1	8		0	Patch	DummyResourceList	DummyResourceList	SS_Task_Started_FIUT	SS_Task_Finished_FIUT
2	I_FAM_S	8	1	0	Pilots_DI	Sensors_DI	DummyResourceList	Task_Started_FIUT	Task_Finished_FIUT
3	DD1	48	2	0	DummyResourceList	DummyResourceList	DummyResourceList	DummyTask_StartedFIUT	DummyTask_Finished_FIUT
4	I_EP_PB	8	3	0	Pilots_DI	Sensors_DI	DummyResourceList	Task_Started_FIUT	Task_Finished_FIUT
5	I_HO_PB	8	3	0	Pilots_DI	Sensors_DI	DummyResourceList	Task_Started_FIUT	Task_Finished_FIUT
6	I_TR_PB	8	3	0	Pilots_DI	Sensors_DI	DummyResourceList	Task_Started_FIUT	Task_Finished_FIUT
7	I_ISR_PB	8	3	0	Pilots_DI	Sensors_DI	DummyResourceList	Task_Started_FIUT	Task_Finished_FIUT
8	I_BSA&SAT_PB	8	3	0	Pilots_DI	Sensors_DI	DummyResourceList	Task_Started_FIUT	Task_Finished_FIUT
9	DD2	48	4	0	DummyResourceList	DummyResourceList	DummyResourceList	DummyTask_StartedFIUT	DummyTask_Finished_FIUT
10	DD3	48	5	0	DummyResourceList	DummyResourceList	DummyResourceList	DummyTask_StartedFIUT	DummyTask_Finished_FIUT
11	DD4	24	6	0	DummyResourceList	DummyResourceList	DummyResourceList	DummyTask_StartedFIUT	DummyTask_Finished_FIUT
12	DD5	48	7	0	DummyResourceList	DummyResourceList	DummyResourceList	DummyTask_StartedFIUT	DummyTask_Finished_FIUT
13	DD6	48	8	0	DummyResourceList	DummyResourceList	DummyResourceList	DummyTask_StartedFIUT	DummyTask_Finished_FIUT
14	I_EP_OBS_S	8	9	0	Pilots_DI	Sensors_DI	DummyResourceList	Task_Started_FIUT	Task_Finished_FIUT
15	I_HO_OBS_S	8	10	0	Pilots_DI	Sensors_DI	DummyResourceList	Task_Started_FIUT	Task_Finished_FIUT
16	I_TR_OBS	8	11	0	Pilots_DI	Sensors_DI	DummyResourceList	Task_Started_FIUT	Task_Finished_FIUT
17	I_ISR_OBS	8	12	0	Pilots_DI	Sensors_DI	DummyResourceList	Task_Started_FIUT	Task_Finished_FIUT
18	I_BSA_OBS	8	13	0	Pilots_DI	Sensors_DI	DummyResourceList	Task_Started_FIUT	Task_Finished_FIUT
19	I_SAT_OBS	8	13	0	Pilots_DI	Sensors_DI	DummyResourceList	Task_Started_FIUT	Task_Finished_FIUT
20	DD7	48	14	0	DummyResourceList	DummyResourceList	DummyResourceList	DummyTask_StartedFIUT	DummyTask_Finished_FIUT
21	DD8	48	15	0	DummyResourceList	DummyResourceList	DummyResourceList	DummyTask_StartedFIUT	DummyTask_Finished_FIUT
22	DD9	48	16	0	DummyResourceList	DummyResourceList	DummyResourceList	DummyTask_StartedFIUT	DummyTask_Finished_FIUT
23	DD10	48	17	0	DummyResourceList	DummyResourceList	DummyResourceList	DummyTask_StartedFIUT	DummyTask_Finished_FIUT
24	DD11	24	18	0	DummyResourceList	DummyResourceList	DummyResourceList	DummyTask_StartedFIUT	DummyTask_Finished_FIUT
25	DD12	48	19	0	DummyResourceList	DummyResourceList	DummyResourceList	DummyTask_StartedFIUT	DummyTask_Finished_FIUT
26	I_EP_S	8	20	0	Pilots_DI	Sensors_DI	DummyResourceList	Task_Started_FIUT	Task_Finished_FIUT
27	I_HO_S	8	21	0	Pilots_DI	Sensors_DI	DummyResourceList	Task_Started_FIUT	Task_Finished_FIUT
28	I_TR_BRF1	8	22	0	Pilots_DI	Sensors_DI	DummyResourceList	Task_Started_FIUT	Task_Finished_FIUT
29	I_TR_BRF2	8	28	0	Pilots_DI	Sensors_DI	DummyResourceList	Task_Started_FIUT	Task_Finished_FIUT
30	I_ISR_BRF1	8	23	0	Pilots_DI	Sensors_DI	DummyResourceList	Task_Started_FIUT	Task_Finished_FIUT
31	I_ISR_BRF2	8	30	0	Pilots_DI	Sensors_DI	DummyResourceList	Task_Started_FIUT	Task_Finished_FIUT
32	I_BSA_BRF1	8	24	0	Pilots_DI	Sensors_DI	DummyResourceList	Task_Started_FIUT	Task_Finished_FIUT
33	I_BSA_BRF2	8	32	0	Pilots_DI	Sensors_DI	DummyResourceList	Task_Started_FIUT	Task_Finished_FIUT
34	I_SAT_BRF1	8	25	0	Pilots_DI	Sensors_DI	DummyResourceList	Task_Started_FIUT	Task_Finished_FIUT
35	I_SAT_BRF2	8	34	0	Pilots_DI	Sensors_DI	DummyResourceList	Task_Started_FIUT	Task_Finished_FIUT
36	DD13	48	29	0	DummyResourceList	DummyResourceList	DummyResourceList	DummyTask_StartedFIUT	DummyTask_Finished_FIUT
37	DD14	48	31	0	DummyResourceList	DummyResourceList	DummyResourceList	DummyTask_StartedFIUT	DummyTask_Finished_FIUT
38	DD15	48	33	0	DummyResourceList	DummyResourceList	DummyResourceList	DummyTask_StartedFIUT	DummyTask_Finished_FIUT
39	DD16	48	35	0	DummyResourceList	DummyResourceList	DummyResourceList	DummyTask_StartedFIUT	DummyTask_Finished_FIUT
40	I_TR	8	36	0	Pilots_DI	Sensors_DI	DummyResourceList	Task_Started_FIUT	Task_Finished_FIUT
41	I_ISR	8	37	0	Pilots_DI	Sensors_DI	DummyResourceList	Task_Started_FIUT	Task_Finished_FIUT
42	I_BSA	8	38,39	0	Pilots_DI	Sensors_DI	DummyResourceList	Task_Started_FIUT	Task_Finished_FIUT
43	DD17	48	40	0	DummyResourceList	DummyResourceList	DummyResourceList	DummyTask_StartedFIUT	DummyTask_Finished_FIUT
44	DD18	48	41	0	DummyResourceList	DummyResourceList	DummyResourceList	DummyTask_StartedFIUT	DummyTask_Finished_FIUT
45	DD19	48	42	0	DummyResourceList	DummyResourceList	DummyResourceList	DummyTask_StartedFIUT	DummyTask_Finished_FIUT
46	I_EVAL	8	26,27,40,41,42	0	Pilots_ADFE_FE	Sensors_ADFE_FE	DummyResourceList	Task_Started_FIUT	Task_Finished_FIUT

Figure 16. FIUT Task Table

Appendix C. Instructor Qualifications

	Rank	Role	BMC	MCE	ISO	LR	LRI/F	ADFE	FE	DI	AI	SCAR	CSAR	CAS
1	MSgt	Assigned	X	X	X				X					
2	MSgt	Assigned	X	X	X	X			X		X	X	X	X
3	MSgt	Assigned	X	X	X			X			X	X	X	X
4	SSgt	Assigned	X	X	X							X		X
5	TSgt	Assigned	X	X	X	X								
6	SSgt	Assigned	X	X	X						X	X	X	X
7	SSgt	Assigned	X	X	X						X	X	X	X
8	SSgt	Assigned	X	X	X	X	X	X			X	X	X	X
9	TSgt	Assigned	X	X										
10	SSgt	Assigned	X	X	X	X					X	X	X	X
11	SSgt	Assigned	X	X	X	X								
12	SSgt	Assigned	X	X	X			X		X	X	X	X	X
13	SSgt	Assigned	X	X	X					X	X	X	X	X
14	MSgt	Assigned	X											
15	MSgt	Assigned	X	X	X						X	X		
16	TSgt	Assigned	X	X	X			X		X	X	X	X	X
17	TSgt	Assigned	X	X	X			X		X	X	X	X	X
18	SSgt	Assigned	X	X	X				X	X	X	X	X	X
19	TSgt	Assigned	X	X	X			X			X	X	X	X
20	SSgt	Assigned	X	X	X						X	X	X	X
21	SSgt	Assigned	X	X	X			X		X	X	X	X	X
22	SSgt	Assigned	X	X	X						X	X	X	X
23	TSgt	Assigned	X	X	X				X	X	X	X	X	X
24	SSgt	Assigned	X	X										
25	SSgt	Assigned	X	X	X			X			X	X	X	X
26	TSgt	Assigned	X	X	X						X	X	X	X
27	TSgt	Assigned	X	X										
28	SSgt	Assigned	X	X										
29	SSgt	Assigned	X	X	X	X	X	X			X	X	X	X
30	TSgt	Assigned	X	X	X						X	X	X	X
31	MSgt	Attached	X	X	X			X		X	X	X	X	X
32	TSgt	Attached	X	X	X	X					X	X	X	
33	OMSgt	Attached	X	X	X					X				X
34	MSgt	Attached	X	X	X						X			X
35	SSgt	Attached	X	X	X			X		X	X	X	X	X
36	SSgt	Attached	X											
37	TSgt	Attached	X	X	X				X	X	X	X	X	X
38	SSgt	Attached	X	X	X									
39	TSgt	Attached	X	X	X	X	X		X	X	X	X	X	X
40	SSgt	Reserve	X	X	X						X	X	X	X
41	SSgt	Reserve	X	X	X						X	X	X	X
42	TSgt	Reserve	X	X	X	X		X	X	X	X	X	X	X
43	MSgt	Reserve	X	X	X	X		X	X	X	X	X	X	X
44	SMSgt	Reserve	X	X	X	X	X	X			X	X	X	X
45	SSgt	Reserve	X	X	X	X		X			X	X	X	X
46	Civ	Contractor	X	X	X						X	X	X	X
47	Civ	Contractor			X						X	X	X	X
48	Civ	Contractor	X	X	X	X	X				X	X	X	X
49	Civ	Contractor	X	X	X					X	X	X	X	X
50	Civ	Contractor	X	X	X						X	X	X	X
51	Civ	Contractor	X	X	X					X	X	X	X	X
52	Civ	Contractor	X	X	X						X	X	X	X
53	Civ	Contractor	X	X	X					X	X	X	X	X
54	Civ	Contractor	X	X	X	X	X				X	X	X	X
55	Civ	Contractor			X						X	X	X	X
56	Civ	Contractor	X	X	X						X	X	X	X
57	Civ	Contractor	X	X	X						X	X	X	X
58	Civ	Contractor			X						X	X	X	X
59	Civ	Contractor	X	X	X						X	X	X	X
60	Civ	Contractor			X						X	X	X	X
61	Civ	Contractor	X	X	X						X	X	X	X
62	Civ	Contractor			X						X	X	X	X
63	Civ	Contractor	X	X	X						X	X	X	X

Figure 17. Sensor Operator List of Qualifications

	Rank	Type	BMC	MCE	IP	LR	LR/F	SOF	TOP3	ADFE	FE	DI	SAR	AI	SCAR	CSAR	CAS
1	LTC (CC)	Assigned	X	X	X						X	X	X	X	X	X	X
2	LTC (DO)	Assigned	X	X	X				X		X		X	X	X	X	X
3	CAPT	Assigned	X	X	X			X		X			X	X	X	X	X
4	CAPT	Assigned	X	X	X			X			X	X	X	X	X	X	X
5	CAPT	Assigned	X	X	X			X		X		X	X	X	X	X	X
6	CAPT	Assigned	X	X	X	X	X	X			X	X	X	X	X	X	X
7	CAPT	Assigned	X	X	X			X		X		X	X	X	X	X	X
8	CAPT	Assigned	X	X	X								X	X	X	X	X
9	CAPT	Assigned	X	X	X	X		X					X	X	X	X	X
10	CAPT	Assigned	X	X									X		X	X	X
11	MAJ	Assigned	X	X	X	X			X				X	X	X	X	X
12	CAPT	Assigned	X	X	X								X	X	X	X	X
13	CAPT	Assigned	X	X	X												
14	CAPT	Assigned	X										X	X	X	X	X
15	MAJ	Assigned	X	X	X				X								X
16	CAPT	Assigned	X	X	X	X	X	X			X		X				X
17	MAJ	Assigned	X	X	X	X			X								
18	CAPT	Assigned	X										X	X	X	X	X
19	CAPT	Assigned	X	X	X			X			X	X		X	X	X	X
20	CAPT	Assigned	X	X	X	X								X	X	X	X
21	MAJ	Assigned	X	X	X	X	X		X		X						
22	1LT	Assigned	X	X									X	X	X	X	X
23	CAPT	Assigned	X	X	X					X							
24	CAPT	Assigned	X	X								X	X	X	X	X	X
25	CAPT	Assigned	X	X	X							X	X	X	X	X	X
26	CAPT	Assigned	X	X	X								X	X			
27	CAPT	Assigned	X	X	X							X	X	X	X	X	X
28	CAPT	Assigned	X	X									X	X	X	X	X
29	MAJ	Assigned	X	X	X				X				X	X	X	X	X
30	MAJ	Assigned	X	X	X				X		X		X	X	X	X	X
31	CAPT	Assigned	X	X	X			X	X	X			X	X	X	X	X
32	CAPT	Assigned	X	X	X			X		X		X	X	X	X	X	X
33	CAPT	Assigned	X	X	X							X	X	X	X	X	X
34	MAJ	Assigned	X	X	X	X			X	X			X	X	X	X	X
35	CAPT	Attached	X	X	X						X			X	X		X
36	CAPT	Attached	X	X	X					X			X	X	X	X	X
37	CAPT	Attached	X	X	X								X	X	X	X	X
38	MAJ	Attached	X	X	X	X	X				X						X
39	CAPT	Attached	X	X	X									X			X
40	MAJ	Attached	X	X	X						X	X	X	X	X	X	X
41	MAJ	Attached	X	X	X	X	X		X		X	X	X	X	X	X	X
42	MAJ	Attached	X	X	X									X	X	X	X
43	CAPT	Attached	X	X	X									X	X		X
44	MAJ	Attached	X	X	X				X				X	X	X	X	X
45	CAPT	Attached	X	X	X						X	X	X	X	X	X	X
46	MAJ	Attached	X	X	X				X				X	X	X	X	X
47	MAJ	Attached	X	X	X				X	X			X	X	X	X	X
48	MAJ	Attached	X	X	X	X			X				X	X	X	X	X
49	MAJ	Attached	X	X	X						X	X	X	X	X	X	X
50	LTC	Reserve	X	X	X								X	X	X	X	X
51	MAJ	Reserve	X	X	X	X	X		X		X		X	X	X	X	X
52	MAJ	Reserve	X	X	X	X	X				X		X	X	X	X	X
53	MAJ	Reserve	X	X	X					X			X	X	X	X	X
54	MAJ	Reserve	X	X	X								X	X	X	X	X
55	Civ	Contractor	X	X	X							X	X	X	X	X	X
56	Civ	Contractor	X	X	X	X	X					X	X	X	X	X	X
57	Civ	Contractor											X	X	X	X	X
58	Civ	Contractor	X										X	X	X	X	X
59	Civ	Contractor												X	X	X	X
60	Civ	Contractor	X	X	X								X	X	X	X	X
61	Civ	Contractor	X	X	X								X	X	X	X	X
62	Civ	Contractor											X	X	X	X	X
63	Civ	Contractor	X		X								X	X	X	X	X
64	Civ	Contractor											X	X	X	X	X
65	Civ	Contractor	X	X	X	X	X					X	X	X	X	X	X
66	Civ	Contractor											X	X	X	X	X
67	Civ	Contractor	X	X	X								X	X	X	X	X
68	Civ	Contractor	X	X	X								X	X	X	X	X
69	Civ	Contractor	X		X							X	X	X	X	X	X

Figure 18. Pilot List of Qualifications

Appendix D. Test Designs

Table 23. Two Factor Central Composite Design with Class Size and Instructor Increase

Scenario	Class Size	Instructor Increase
1	14	0
2	10	18
3	18	0
4	18	9
5	10	9
6	14	9
7	18	18
8	14	18
9	14	9
10	10	0

Table 24. Two Factor Central Composite Design with Class Size and Arrival Rate

Scenario	Class Size	Arrival Rate
1	14	30
2	18	50
3	10	50
4	14	50
5	18	30
6	10	30
7	10	40
8	14	40
9	14	40
10	18	40

Appendix E. Baseline Wait Log

Table 25. Baseline Wait Log by IQT Task

IQT Task	Mean Wait (days)	IQT Task	Mean Wait (days)
1	0.004	36	2.131
2	1.196	37	2.767
3	0.356	38	1.157
4	2.341	39	5.600
5	0.812	40	1.173
6	0.060	41	1.688
7	1.238	42	1.158
8	0.440	43	0.223
9	0.045	44	0.529
10	1.260	45	1.069
11	0.797	46	0.648
12	0.859	47	0.738
13	0.424	48	1.158
14	0.508	49	1.404
15	0.447	50	3.290
16	1.725	51	2.323
17	0.983	52	0.424
18	0.689	53	0.495
19	0.508	54	0.576
20	0.339	55	0.712
21	1.060	56	3.417
22	3.803	57	2.407
23	1.139	58	2.464
24	1.276	59	0.210
25	0.441	60	1.308
26	0.610	61	0.508
27	0.838	62	0.763
28	0.682	63	1.190
29	0.458	64	3.447
30	3.434	65	2.149
31	0.983	66	0.342
32	0.955	67	0.993
33	0.849	68	0.763
34	0.803	69	0.878
35	1.201	70	1.954
36	2.131	71	1.648
37	2.767	72	1.636

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