



SORTIE GENERATION SIMULATION OF A FIGHTER SQUADRON

THESIS

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AFIT-ENS-MS-16-M-127

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THESIS

Presented to the Faculty

Department of Operational Sciences

Graduate School of Engineering and Management

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the
Degree of Master of Science in Operations Research

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Major, TURAF

March 2016

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THESIS

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Abstract

The Turkish Air Force utilizes several fighter squadrons to enhance its military capabilities. One of the most critical challenges for these squadrons is generating sorties to meet the currency and demand during both peacetime and wartime. This sortie generation process directly affects the success of both training and operations. In this study, this process is assessed using a discrete event simulation.

Air Force decision makers require a simulation tool to conduct “what-if” analysis on how potential changes in the environment affect an F-16 fighter squadron’s sortie generation process. Creating a usable simulation provides decision makers with a flexible tool to analyze and evaluate the possible scenarios. The model assists in determining new concepts to provide benefits over current systems. These benefits may include increased operational availability and better system performance.

To my wife and son for their loving support, patience, and for understanding of the long hours I spent working and to Family for their encouragement and love – Thank you all.

Acknowledgments

I would like to express my sincere appreciation to my advisor Dr. J.O.Miller who has supported me throughout my thesis with his patience. I appreciate his vast knowledge and skill in many areas. Without him, I would not have been able to complete this thesis effort. I would also like to extend my gratitude to Dr. Carl R.Parson who has been reviewed my thesis as a reader. My special thanks are for my friends Capt. Changsung Kim, Lt.James Park and Lt.Bahadir Aykiri for their support during the whole thesis work.

Abdurrahman Sevimli

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SORTIE GENERATION SIMULATION OF A FIGHTER SQUADRON

I. Introduction

1.1. General Issue

Turkey is a strong member of NATO with its significant military superiority. Aviation is the leading factor to keep this current military presence strong. Aviation technology is the pioneer of the advanced technologies. Rapidly advancing aircraft technologies both increase mission effectiveness and require advanced planning. To support the technological advancement, planning tools must also be considered. The Air Force needs tools allowing analysis and evaluation of the sortie generation process.

Turkish Air Forces have several fighter squadrons including F-16s. During peace and war all the squadrons need to generate sorties to meet the currency and requirements. The sortie generation process directly affects the success of both training and operations. To better assess the sortie generation process requires a model and a simulation program. A simulation provides decision makers with a flexible tool to analyze and evaluate the sortie generation process. This thesis builds a discrete event simulation tool of the current sortie generation process. This tool allows decision makers to perform what-if analyses to determine new concepts to provide benefits over current systems. These benefits may include increased operational availability and better system performance.

1.2. Problem Statement

Air Force decision makers need a simulation tool to study the effects of what-if analyses emerging with the change of the current sortie generation process on an F-16

fighter squadron. The simulation model developed in this research provides the capability to analyze and evaluate changes in operating policy, available aircraft, available pilots, and other factors affecting the sortie generation process for a typical F-16 squadron.

1.3. Research Objectives

Our model is built in Simio which is an object oriented simulation tool. We start with 100% availability of modeled resources to see the maximum sortie generation. Then we modify our baseline model to evaluate different scenarios and check the change in the number of generated sorties and other performance metrics. Simio simulation software enables better decisions by providing decision makers the impact of proposed changes before they are implemented.

1.4. Research Focus

This study focuses on the sortie generation process modeled in Simio. After getting the results, Simio allows us to analyze and remove risk from our sortie generation process. Our simulation provides insight to improve process performance by maximizing sortie generation for our scenarios by intelligent use of critical resources and risk reduction associated with operational decisions.

1.5. Investigative Questions

All countries make operational plans with taking the threats' targets into account. Missions planned for killing and defending the targets must be executed with the needed resources. Therefore, the resources must be determined and the flight schedules must be generated. In this study we generate fixed flight schedules using a Decision Support

Software (DSS) and random flight schedules in terms of the resources. We used these flight schedules in our sortie generation process model created in Simio. In this study we look for answers to the following questions:

- **Question 1:** Given a baseline sortie generation process in Simio with fixed flight schedules and defined resources, how do ground, air, and weather abort rates affect sortie generation?
- **Question 2:** Given a sortie generation process in Simio with random flight schedules and defined resources, how do ground, air, and weather abort rates affect sortie generation? How does removal of the mission planning affect sortie generation process?
- **Question 3:** How does a reduction in pilots at different ratings affect the sortie generation process?

1.6. Thesis Organization

This thesis is organized in five chapters. In this chapter we describe the problem statement along with our research objectives and scope. Three different questions were formed to analyze the change in sortie generation using our simulation created in Simio. Chapter two reviews the previous research regarding the sortie generation process with a focus on flight scheduling and simulation. Chapter three defines the structure of the model, how it is built in Simio, and gives some detailed information of the model. In chapter four, model results and conclusions are presented. The last chapter pulls together highlights from all chapters and makes some conclusions and recommendations for future research.

II. Literature Review

2.1 Chapter Overview

The sortie generation process is driven by the sortie schedule. The process of scheduling aircraft is an iterative process which includes annual, quarterly, monthly, and weekly scheduling meetings. This chapter summarizes the literature on flight scheduling and sortie generation to learn how to implement similar applications to the sortie generation process. The literature review includes the following areas: the sortie generation process, recent research on flight scheduling, and other simulation projects in the area of sortie generation.

2.2 Sortie generation process

The complexity of computing sortie rates is more than a mere spreadsheet task, and to collect an abundance of data for large models reduces the commander's flexibility, responsiveness, and ability to create alternative options. Thus, a requirement for a generic sortie model with simple operational input and quick turnaround will help the entire Air Force and contribute significant operational insights that add realism to the planning process. This was the motivation for developing a generic sortie generation rate model (Harris, 2002). The process is cyclical in nature; Figure 1 shows the typical process.

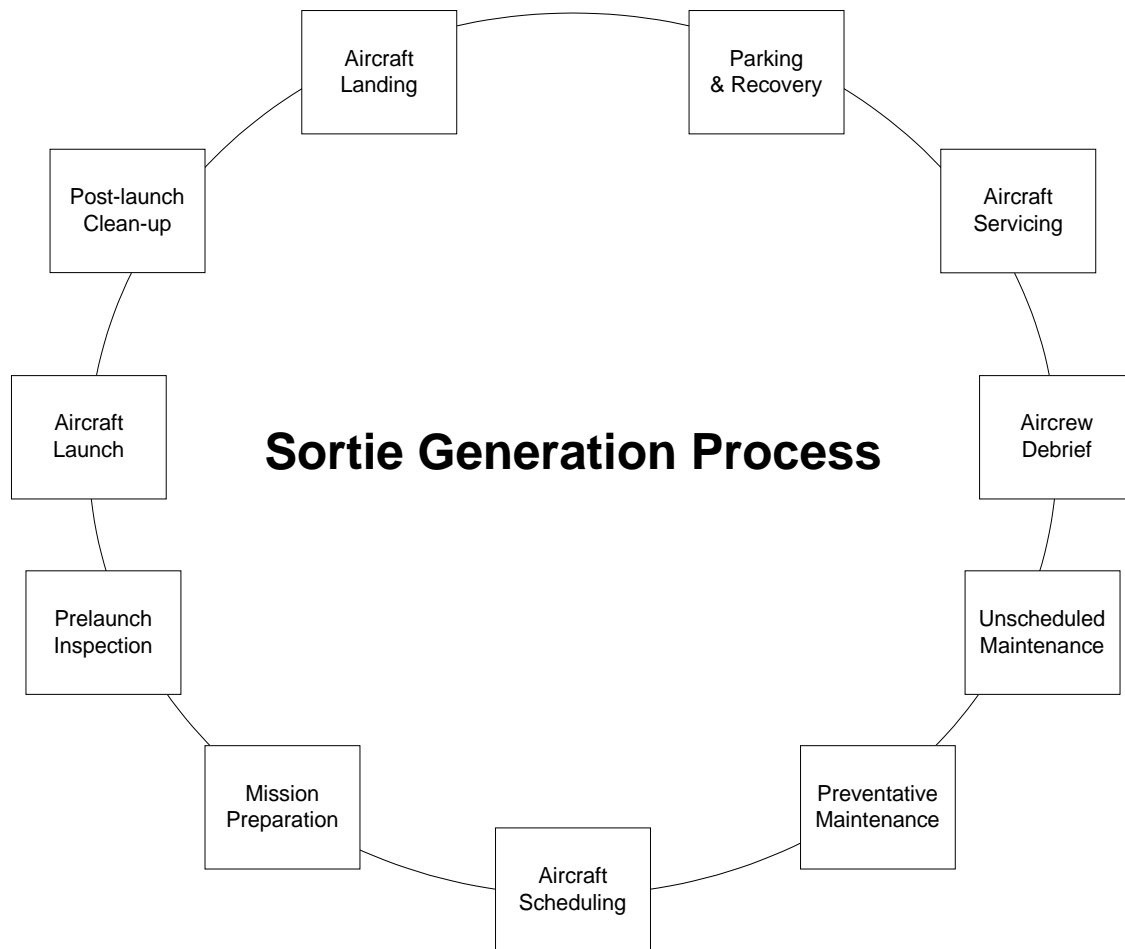


Figure 1. Sortie Generation Process (Faas, 2003)

The starting point is generally considered to be the aircraft landing. After moving to the parking location and engine shutdown, post flight servicing is conducted, while the aircrew conducts their debriefings to the maintenance crew. Numerous routine maintenance functions are required to ready the jet for the next mission, followed by any unscheduled maintenance derived from the recorded faults collected during the flight. The aircraft are prepared for flight by the ground crews; the pilots then load the assigned mission, take-off, perform the mission, and land to complete the cycle (Faas, 2003).

2.3 Recent Research on Flight Scheduling

Multiple studies on squadron flight schedules have been done by past researchers. Most of the research observed in this literature review focuses on training squadrons instead of fighter squadrons. It is important to understand the differences in personnel and requirements between the two different types of squadrons. Overall, the complexity and difficulty of scheduling issues for training squadrons is less than fighter squadrons. In order to properly understand the flight scheduling problem, it is crucial to understand these differences and how they change the problem. This section presents a thorough overview on past research efforts to improve flight scheduling.

2.3.1 Nguyen's research

Nguyen's (2002) research attempts to solve the flight scheduling problem by creating a Microsoft Excel VBA tool to maximize the number of sorties while meeting training requirements for a training squadron. His Squadron Scheduling Decision Tool (SSDT) utilizes previous work by Belton and Elder (1996) by implementing a heuristic engine to influence search, preference, and performance criteria. Nguyen's tool gives the scheduler the ability to interact with generated schedules until a satisfactory schedule is built. In addition, the tool was an updated version of previous scheduling tools which removed the need for new training. Finally, the tool allows the scheduler to manually prioritize specific flights over other flights depending on training requirements (Nguyen, 2002).

2.3.2 Aslan's research

Another interesting study on flight scheduling is Aslan's (2003) research focusing on an F-16 training squadron. Similar to Nguyen's (2002) study, Aslan also developed a

tool to improve daily training schedules. Moreover, the tool is based on a bottleneck heuristic and also allows the user to edit the schedule based on their preferences. The main disadvantage of this method is that the scheduler is not allowed to make any arrangements after the schedule is built (Aslan, 2003).

2.3.3 Boyd, Cunningham, Gray, and Parker's Research

These authors (Boyd et al., 2006) attempted to solve the flight scheduling problem using a network flow model to set up the weekly flight schedule for a fighter squadron in Germany. The main strategy was to split each workday as morning scheduled flight windows (AM GOs) and afternoon scheduled flight windows (PM GOs). The researchers found that splitting into these additional sections increases the number of variables dramatically, pushing the Premium Solver Platform software past its limit. The main finding from this study understands the complexity and constraints in flight scheduling for fighter squadrons (Boyd et al., 2006).

2.3.4 Newlon 's Research

Newlon's (2007) research attempts to go where Boyd et al. (2006) left off in creating a mathematical model of the scheduling process for fighter squadrons. While Boyd et al. (2006) aimed to split the workday into two sections, Newlon (2007) partitions the workday into hourly sections by taking these constraints as sub problems of the overall problem. Due to having a less complex problem and relatively lower number of variables, an optimal solution can be found using standard optimization software. However, there are many occurrences where the tool presents an infeasible solution and does not take into account pilot availability and unavailability. Finally, unlike the other tools discussed in this literature review, Newlon's (2007) research does not consider

manual inputs from the scheduler because of the fighter squadron's nature and need for operational flexibility.

2.3.5 Gokcen 's Research

Gokcen's (2008) research is another study on scheduling which generates robust flight schedules for fighter squadrons. Gokcen tries to develop a weekly schedule by producing multiple schedules and comparing these generated schedules according to the expected number of real-time updates to capture the potential daily changes. Following the comparison phase, candidate schedules are sorted with respect to the number of updates and the schedule with the minimum number of updates is accepted as the best schedule (Gokcen, 2008).

Gokcen's (2008) primary objective is developing a schedule that has the smallest probability of being re-arranged or the smallest probability of assigning alternate pilots. To achieve this goal, he introduces some simplifying assumptions to reduce the scope of the problem that have practical implications. For instance, the number of flown sorties is limited to six flights. Since Gokcen (2007) divides workday into morning (AM), afternoon (PM), and Night GO sections, assuming a maximum of six flights is not realistic for a fighter squadron. Furthermore, all of the flight leads are assumed to be four-ship leaders and two-ship leaders are not included in his model. In most of the fighter squadrons the number of four-ship leaders is almost the same as the number of two-ship leaders. As a result, the number of scheduled two-ship missions is high in the flight schedule. Moreover, Gokcen (2008) assumes that the squadron does not have any D model (two-seated) aircraft. However, as he stated in this study, every squadron has two-seated aircraft to keep the training level as high as possible and scheduling two-

seated aircraft is the most difficult part of the schedule. If a scheduler can decide two-seated aircraft assignments, the remaining sections of the schedule do not take much time (Gokcen, 2008).

2.3.6 Yavuz 's Research

Yavuz (2010) worked on automating weekly flight schedules for fighter squadrons, focusing on the Turkish Air Force. His research answers the question of which pilots to assign to predetermined missions. Data of predetermined missions include take-off time, landing time, and pilots in which category to assign to each mission. With this approach the flight scheduler selects pilots by name to fill mission slots. Therefore, Yavuz focuses on the pilot assignment portion of flight schedule (Yavuz, 2010).

2.3.7 Durkan 's Research

Following Yavuz's (2010) research on establishing a decision analysis model to evaluate pilot-mission matches, Durkan (2011) looks for a way to save additional time on building a flight schedule. He applies a Value Focused Thinking approach to his model to speed up the flight scheduling process with the support of experienced schedulers and decision makers. Durkan (2011) uses his value model to rank order pilot-mission matches at the end of his evaluation phase. His approach considers the evaluation of pilot-mission matches as a multi-objective assignment problem and claims that the decision analysis model in his research presents a relatively new solution technique (Durkan, 2011).

Durkan's (2011) model helps the scheduler to manually build flight schedules with the focus on a specific time frame like a block or a day. He summarizes the process of the model in three steps and sets his goal to achieve the first two steps. These three steps are:

- i. Building an evaluation model using VFT (Defining objectives and values).
- ii. Using the evaluation model structure to aid the scheduler in manually building schedules (Decision Support System).
- iii. Automating the process of pilot-mission assignment with the help of defined values and objectives.

Durkan (2011) asks the question of “What is the value of a pilot-mission match in a specific block of time?” to start his methodology. The value of a particular pilot-mission match comes from the four major measures shown in Figure 2 (Durkan, 2011).

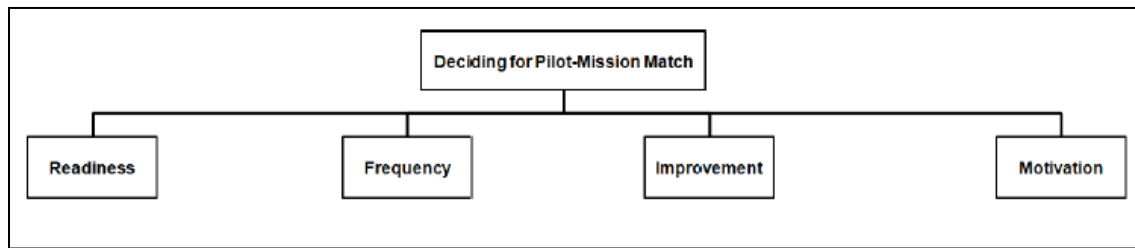


Figure 2. Four Major Values for Pilot-Mission Match (Durkan, 2011)

He cites measures for each major value branch and their value functions for evaluation. Preferences of decision makers and subject matter experts are considered to construct value functions to get results close to real life. In the construction phase of his value functions, Durkan uses a software tool (Hierarchy Builder 2.0, Weir, J. 2008) to build the value hierarchy (Durkan, 2011).

2.3.8 Erdemir ‘s Research

In Erdemir’s (2014) research, the main objective is to build a Decision Support System (DSS) to assist the schedulers in fighter squadrons. Scheduling in fighter squadrons is complex and time consuming due to the combination of the large number of constraints and limited number of schedulers. Also, the dynamic environment of the

operations area increases the uncertainty of the problem. For this reason, building flight schedules without any supplementary tools takes a large amount of time. Thus, air forces are in need of an automated decision support system for flight scheduling (Erdemir, 2014).

In his thesis, Erdemir (2014) develops the required DSS using Microsoft Excel Visual Basic to produce flight schedules which are now made manually. To generate feasible schedules, Greedy Randomized Adaptive Search Procedures are implemented and generated schedules are scored to attain the best solution. Resulting solutions are then analyzed to evaluate performance of the DSS and scoring method (Erdemir, 2014).

In our modeling of the sortie generation process, the needed flight schedules are created via Erdemir's (2014) DSS. His tool generates the monthly schedules which are then transferred into our simulation program. More details on this process are discussed in Chapter 3.

2.4 Other simulation studies of the sortie generation process

This section highlights other simulation studies that have been conducted in the area of sortie generation. These simulation projects come from academia, small businesses, larger companies, and the government. The purpose of this section is to identify different simulation and programming techniques in order to enrich the simulation model built for this research with the most useful techniques.

2.4.1 Simulation of Autonomic Logistics System (ALS) Sortie Generation

Faas (2003) modeled a sortie generation system in Arena, focusing on the impact of an Autonomic Logistics System (ALS) with various measures of effectiveness (MOE).

As MOEs he used the Mission Capable Rate, Not-mission Capable for Maintenance and Supply, and Flying Scheduling Effectiveness. He felt that these rates would offer the best way to observe the differences between the baseline system and the ALS, and also the differences between the various ALS levels that were set-up. He analyzed the impact of ALS to the MOEs by performing a full factorial design of experiments.

2.4.2 *SIMFORCE*

SIMFORCE (Scalable Integration Model for Objective Resource Capability Evaluations) is a desktop decision support tool that predicts resource utilization using simulation and modeling technology (Kelley Logistics Support Systems, 2002). It calculates probable maintenance resource (people, equipment, vehicles, facilities, and parts) needs based on an Air Force Wing's operational tasking. SIMFORCE also determines the effects of reduced or increased levels of resources on sortie capability. The user can adjust operations tempo, tasking, resources and failure rates. The model captures the information on the logistics and maintenance operation and provides the output as spreadsheets and charts via Microsoft Excel. Users familiar with Excel can use the raw data to create their own unique graphs to examine different views or answer different questions.

2.4.3 *LogSAM*

The Logistics Simulation and Analysis Model (LogSAM) (Smiley, 1997) is built by Synergy Inc. LogSAM also simulates the aircraft sortie generation process. The model is broken down into several modules: aircraft generation, sortie generation, preflight and launch, and post flight evaluation. Added features include its ability to schedule sorties based on the Air Tasking Orders (ATOs). These ATOs describe what targets to attack

along with numbers and types of aircraft to use. Synergy has also expanded LogSAM to include a module called LogBase, which simulates enemy attacks and the effect of those attacks on sortie generation capability. Both LogSAM and LogBase are interesting applications but are more applicable for a wartime scenario.

2.4.4 Simulation Model for Military Aircraft Maintenance and Availability

The Helsinki University of Technology constructed a simulation model for the use of a fleet of Bae Hawk MK51 aircraft during their normal operational use (Raivio et al., 2001). The model describes the flight policy and the main factors of the maintenance, failure, and repair processes. The model aims at a better understanding of the critical paths in the normal service activity, and thus helps to determine ways to shorten the turnaround times in the maintenance process. Model implementation with graphical simulation software allows rapid what-if analysis for maintenance designers. The authors then conducted sensitivity analysis with respect to the most important model parameters, like the average duration of the maintenance operations and the manpower capacities of the repair facilities (Raivio et al., 2001). The model was also built in Arena®.

2.4.5 Useful Approaches and Techniques

Based on the information provided above regarding other simulation studies of the sortie generation process, the following approaches and techniques were included in the development of our simulation. The first is that most of the simulation studies of the sortie generation process were built using a commercial Discrete Event Simulation (DES) tool such as Arena. This demonstrates that a tool such as Arena (Simio in our case) provides a flexible simulation environment for modeling the sortie generation process. Secondly the graphical process flow for model construction and animation features of

such a tool were highlighted for ease of use and key in verification and validation efforts. Many studies also used some type of Graphical User Interface (GUI) or other feature for ease of changing model parameters for different system configurations such as setting levels of factors for a Design of Experiment. In addition, a number of studies took advantage of features for importing or exporting data to external tools such as Microsoft Excel for analysis. The Simio DES tool we are using has import and export capabilities as well as powerful analysis tools included within Simio, for ease of performing a variety of different types of output analysis.

2.5 Summary

In building a model to study the sortie generation process we begin by reviewing previous research regarding the sortie generation process with a focus on flight scheduling and simulation. The literature review in this chapter covers material on the sortie generation process, a number of recent research efforts in flight scheduling, and a closer look at previous simulation studies of this process, highlighting approaches and techniques incorporated with our research described in detail in Chapter 3.

III. Methodology

3.1. Chapter Overview

Understanding the sortie generation process significantly aids decision makers in properly executing a flight schedule to meet mission requirements. Once information is gathered for a typical fighter squadron regarding system entities and resources, we can create a model of the sortie generation process to assess and improve the execution of a flight schedule. In this study we create a simulation for the sortie generation process and use a DSS for generating flight schedules. This chapter discusses details of the sortie generation process and assumptions made in developing our simulation in Simio.

3.2. Sortie Generation Process Model

Our model simulates all of the processes a pilot is required to perform before and after a scheduled flight. Before processing a flight in our model, the resources (aircraft and pilots) and the entities (scheduled missions) must be determined. The sortie generation process consists of scheduling, mission planning, briefing, flight and debriefing phases. With the needed data gathered we built our simulation in SIMIO. The model logic is presented in Figure 3 and each of the processes and data are described in further detail below.

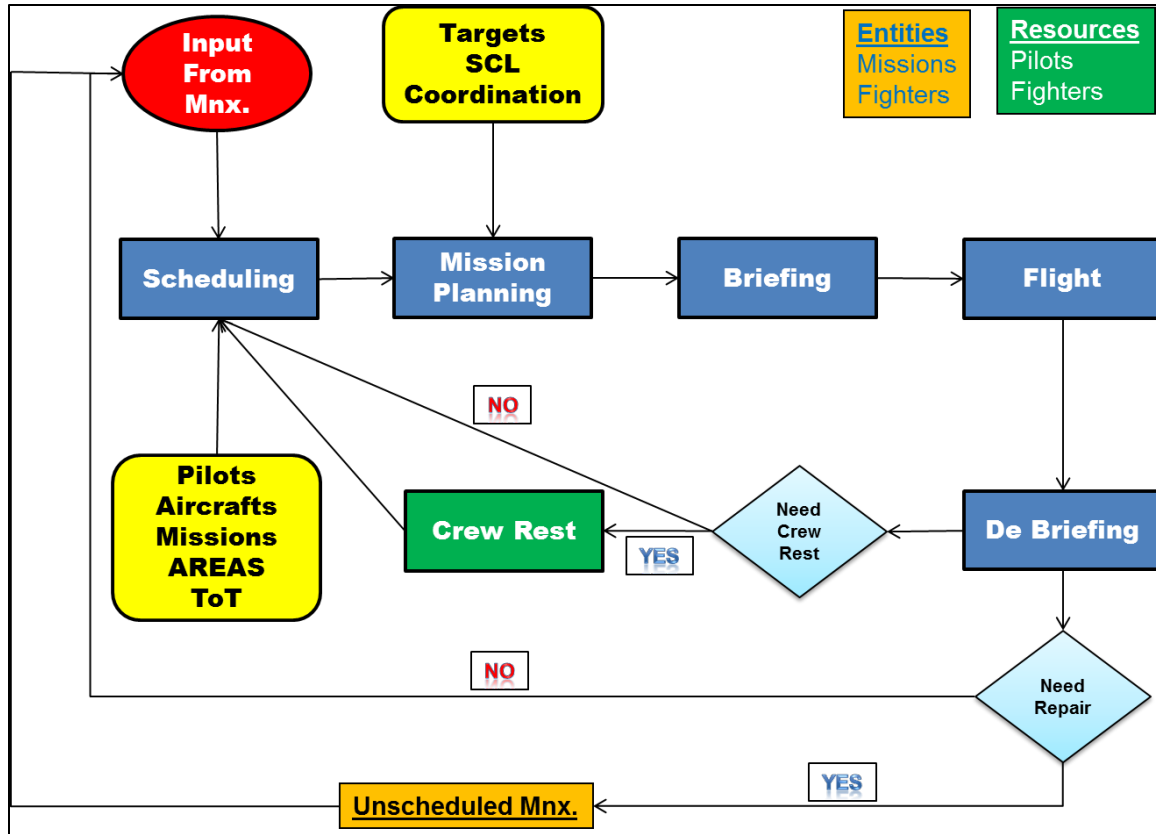


Figure 3. The Sortie Generation Process

3.2.1. Scheduling

The first requirement is generating the flight schedules. In this model we generate flight schedules both randomly and with the use of a DSS. This DSS was created in Erdemir's (2014) research. We generate monthly schedules and transfer them into Simio for creating the mission entities. The DSS includes the information that the schedulers need before generating the schedules. To illustrate what a scheduler does in producing a flight schedule, we first present some definitions regarding fighter squadron schedules. These definitions help in providing a better understanding of the DSS.

3.2.1.1. Erdemir's (2014) DSS Definitions

The definitions highlighted in Figure 4 are explained in the following sections.

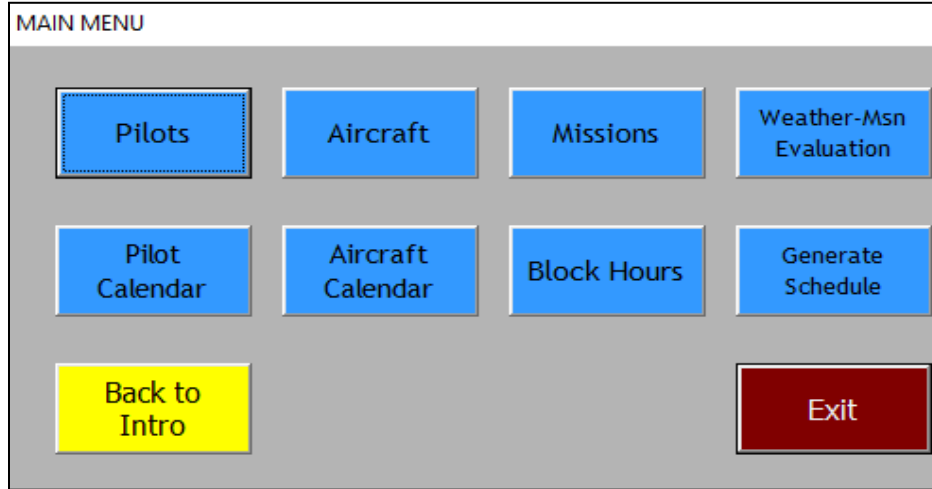


Figure 4. The Main Menu of Erdemir's DSS

3.2.1.2 Pilots

This research focuses on a typical fighter squadron. The number of pilots assigned to a squadron is determined according to the crew ratio (AFI 65-503, 2015), which is 1.25 for F-16 C/D. In fighter squadrons the total number of aircraft typically falls in the range of 15-25. For this study, we assume that the squadron has 20 aircraft for executing the missions along with 25 pilots based on the given crew ratio.

In fighter squadrons, there are four main pilot ratings determined according to flight hours and pilot skills. From the lowest to highest qualifications, these are Wingman, Two-Ship Leader, Four-Ship Leader, and Instructor Pilot. The number of pilots according to their ratings varies for each year. The menu coming from the initial DSS's window when we hit the pilots' button is shown in Table 1.

Table 1. Pilot List with Ratings

INSTRUCTOR	4-SHIP LEADER	2-SHIP LEADER	WINGMAN
LUNDAY	BRADSHAW	DAVIS	BOARDMAN
MILLER	LUCAS	KIM	CLISBY
SHALLCROSS	YILDIZ	PARK	GUNDUZ
	SEVIMLI	MCDONALD	TETRAUT
		MCLEAN	PALCO
			SALGADO
			KEVIN
			ERHAN
			AYKIRI
			YASIN
			DWYER
			AMIE
			GUZMAN

The pilots, categorized by their ratings, are shown in Table 1 which includes three Instructor Pilots, four Four-Ship Leaders, five Two-Ship Leaders and thirteen Wingmen.

Each pilot rating has a list of suitable cockpits in which that pilot can be assigned. The list of the suitable cockpits for each pilot rating is shown in Table 2 which depicts that only instructor pilots are allowed to fly D Model back cockpits.

Table 2. Pilot Ratings and Suitable Cockpits

PILOT STATUS		INSTRUCTOR	4-SHIP LEADER	2-SHIP LEADER	WINGMAN
4-SHIP MISSIONS	NUMBER 1	YES	YES	NO	NO
	NUMBER 2	YES	YES	YES	YES
	NUMBER 3	YES	YES	YES	NO
	NUMBER 4	YES	YES	YES	YES
3-SHIP MISSIONS	NUMBER 1	YES	YES	NO	NO
	NUMBER 2	YES	YES	YES	YES
	NUMBER 3	YES	YES	YES	NO
2-SHIP MISSIONS	NUMBER 1	YES	YES	YES	NO
	NUMBER 2	YES	YES	YES	YES
1-SHIP MISSIONS	FRONT SEAT	YES	YES	YES	YES
ALL MISSIONS	BACK SEAT	YES	NO	NO	NO

3.2.1.3 Aircraft

Most of the fighter squadrons (except special role squadrons) consist of one type of fighter aircraft, such as the F-16, F-22, or any other jet. These squadrons usually have two different aircraft models such as one-seated and two-seated models. In this research, one-seated and two-seated aircraft are called C and D Model aircraft, respectively. To significantly simplify our aircraft scheduling logic, we restrict our model to only one-seated aircraft and therefore have 20 F-16C fighters assigned as listed by tail number in the aircraft DSS window shown in Table 3.

Table 3. Aircraft List

AIRCRAFT LIST				
F-16C				
0001	0005	0009	0013	0017
0002	0006	0010	0014	0018
0003	0007	0011	0015	0019
0004	0008	0012	0016	0020

3.2.1.4 Missions

In general, there are two types of missions, day-time and night-time, with two sub-categories; each includes Air to Air (AA) and Air to Ground (AG) missions. The mission button on the initial DSS window leads to the menu of the missions determined for this research as shown in Table 4. Mission acronyms are defined in Table 5.

Table 4. Mission List

DAY MISSIONS		NIGHT MISSIONS	
A-A Missions	A-G Missions	A-A Missions	A-G Missions
1V1 INT	SA	1V1 NI	NSA
2V2 INT	SAT	2V2 NI	
AAR	CAS	NAAR	
ACM		NCAP	
ACT		NESC	
BFM			
CAP			
ESC			
HVAAP			

Table 5. Mission Acronyms

Acronyms	Description
AAR	Air to Air Refueling
ACM	Air Combat Maneuver
ACT	Air Combat Training
BFM	Basic Flight Maneuver
CAP	Combat Air Patrol
CAS	Close Air Support
ESC	Escort
HVAAP	High Value Airborne Asset Protection
INT	Intercept
IF	Instrument Flight
NAAR	Night Air to Air Refueling
NCAP	Night Combat Air Patrol
NESC	Night Escort
NI	Night Intercept
NSA	Night Surface Attack
SA	Surface Attack
SAT	Surface Attack Tactics

While some missions require four aircraft, some missions need three, two, or one aircraft to be able to be flown. Missions and the required number of aircrafts are depicted in Table 6.

Table 6. Mission-Aircraft Requirements

MISSION	AIRCRAFT REQUIREMENT			
	4-SHIP	3-SHIP	2-SHIP	1-SHIP
ACT	YES	NO	NO	NO
INT	YES	NO	YES	NO
CAP	YES	NO	YES	NO
ESC	YES	NO	YES	NO
HVAA	YES	NO	YES	NO
CAS	YES	NO	YES	NO
AREC	YES	NO	YES	NO
AAR	YES	NO	YES	NO
NI	YES	NO	YES	NO
NCAP	YES	NO	YES	NO
NESC	YES	NO	YES	NO
NAAR	YES	NO	YES	NO
ACM	NO	YES	NO	NO
BFM	NO	NO	YES	NO
IF	NO	NO	NO	YES

3.2.1.5 Blocks

Block time period is used to partition a day into segments in which several flights are executed. Blocks are preferred to be four or five hour time intervals. In Erdemir's DSS, there are four potential different day-blocks and three night-blocks. Hitting the blocks menu on the initial window shows us the blocks as depicted in Table 7.

Table 7. Flight Block Hours

Day Time Block Hours

1st Block

2nd Block

3rd Block

4th Block

First T/O

07:00

12:30

00:00

00:00

Last Land

12:00

17:30

00:00

00:00

Duty

☒ SOF
 ☒ RSU
 ☐ BO
 ☐ SIM

☐ SOF
 ☐ RSU
 ☐ BO
 ☐ SIM

☐ SOF
 ☐ RSU
 ☐ BO
 ☐ SIM

☐ SOF
 ☐ RSU
 ☐ BO
 ☐ SIM

Night Time Block Hours

1st Block

2nd Block

3rd Block

First T/O

18:00

00:00

00:00

Last Land

23:00

00:00

00:00

Duty

☒ SOF
 ☒ RSU
 ☐ BO
 ☐ SIM

☐ SOF
 ☐ RSU
 ☐ BO
 ☐ SIM

☐ SOF
 ☐ RSU
 ☐ BO
 ☐ SIM

Cancel

Save

We classify the five flying days per week into two different categories labeled even and odd, with three even days and two odd days in a week. Even days have only two day blocks, on the other hand odd days have three blocks including one night block. The weekly flight schedule is shown in Table 8.

Table 8. Weekly Flight Schedule

Weekly Flight Schedule Fighter Squadron				
WEEK # 1				
Day	AM GOs	PM GOs	NIGHT GOs	DAY TYPE
Monday	√	√	X	EVEN
Tuesday	√	√	√	ODD
Wednesday	√	√	X	EVEN
Thursday	√	√	√	ODD
Friday	√	√	X	EVEN

All the flight blocks necessitate five hours for our study. The crew rest is twelve hours. So, a pilot can only fly two consecutive flight blocks under these circumstances, otherwise they would violate the crew rest time. The scheduled AM/PM/NIGHT GOs Time Table is depicted in Table 9 below.

Table 9. AM/PM/NIGHT GOs Time Table

 AM/PM/NIGHT GOs TIME TABLE Fighter Squadron			
TIME	AM GOs	PM GOs	NIGHT GOs
0700-0800	Mission Planning		
0800-1000	Briefing		
1000-1130	Flight		
1130-1200	De Briefing		
1230-1330		Mission Planning	
1330-1530		Briefing	
1530-1700		Flight	
1700-1730		De Briefing	
1800-1900			Mission Planning
1900-2100			Briefing
2100-2230			Flight
2230-2300			De Briefing

3.2.1.6 Ground Duties

Ground duties are additional responsibilities requiring an assigned pilot to check activities which may violate flight and/or ground safety. The pilot on duty must assure that all activities inside his/her responsibility area are performed without any unsafe practices. The main duties are Supervisory of Flight (SOF), Runway Supervisory Unit (RSU), Base Operation (BO), and Simulator (SIM). Since there is no need for RSU or BO duty in certain bases, SOF is the only mandatory ground duty slot in flight schedule

for some squadrons (Erdemir, 2014). We only model RSU and SOF duties in our simulations however; we have included BO and SIM duties in the duty-pilot rating table shown in Table 10.

Table 10. Ground Duty-Pilot Rating

PILOT STATUS	INSTRUCTOR	4-SHIP LEADER	2-SHIP LEADER	WINGMAN
SOF	YES	YES	NO	NO
RSU	YES*	YES*	YES	YES
BO	YES*	YES*	YES	YES
SIM	YES*	YES*	YES	YES
YES* : Pilot can be assigned to duty but not preferable				

3.2.1.7 Flight Schedule

By using the definitions above, we generate the flight schedule. During this phase, all the pilots and aircraft are available. The availability of resources change dynamically as the simulation is run. We also change initial resource numbers in Simio for some of our analysis in the next chapter. The flight schedule generated from the initial window is shown in Table 11.

Table 11. The Flight Schedule

12TH SQUADRON WEEKLY FLIGHT SCHEDULE																							
MONDAY		1/11/2016		TUESDAY		2/11/2016		WEDNESDAY		3/11/2016		THURSDAY		4/11/2016		FRIDAY		5/11/2016					
NUMBER	BLOCK/MISSION	ACFT	PILOTS	TAKE OFF/LAND	NUMBER	BLOCK/MISSION	ACFT	PILOTS	TAKE OFF/LAND	NUMBER	BLOCK/MISSION	ACFT	PILOTS	TAKE OFF/LAND	NUMBER	BLOCK/MISSION	ACFT	PILOTS	TAKE OFF/LAND				
1	1 ACT	KF-16C	SEVIMU	1000 1130	1	1 SA	KF-16C/D	YLDZ	1000 1130	1	1 ACT	KF-16C/D	SEVIMU	1000 1130	1	1 SA	KF-16C/D	YLDZ	1000 1130				
			ATKRI PARK YASIN				ATKRI KIM AMIE					ATKRI PARK YASIN					ATKRI KIM AMIE						
2	1 BFM	ZNF16C/D	LUNDAY	1000 1130	2	1 AAR	KF-16C/D	BRASSO/HAM	1000 1130	2	1 BFM	ZNF16C/D	ERHAN	1000 1130	2	1 AAR	KF-16C/D	BRASSO/HAM	1000 1130				
			ERHAN				GUNDUZ DAVIS GUZMAN					LUNDAY GUNDUZ MILLER					ERHAN DAVIS GUZMAN						
3	1 TXI INT	ZNF16C/D	CUSBY	1000 1130						3	1 TXI INT	ZNF16C/D	CUSBY	1000 1130									
			YASIN				MILLER CUSBY					CUSBY					MILLER CUSBY						
4	1 AAR	KF-16C/D	BRASSO/HAM	1000 1130	3	2 STA	KF-16C/D	MILLER	1530 1700	4	1 AAR	KF-16C/D	BRASSO/HAM	1000 1130	3	2 STA	KF-16C/D	MILLER	1530 1700				
			GUNDUZ				CUSBY					CUSBY					GUNDUZ						
			DAVIS				MCDONALD					DAVIS					DAVIS						
			TETRAUT				SALGADO					TETRAUT					TETRAUT						
5	2 TXI INT	ZNF16C/D	MCGLEN	1000 1130	4	2 CAS	ZNF16C/D	LUNDAY	1530 1700	5	1 TXI INT	ZNF16C/D	MCGLEN	1000 1130	4	2 CAS	ZNF16C/D	LUNDAY	1530 1700				
			PAUKO				ERHAN					PAUKO					ERHAN						
6	1 CAP	ZNF16C/D	MCDONALD	1000 1130	5	2 HVAAR	KF-16C/D	LUCAS	1530 1700	6	1 CAP	ZNF16C/D	MCDONALD	1000 1130	5	2 HVAAR	KF-16C/D	LUCAS	1530 1700				
			SALGADO				KEVIN					SALGADO					KEVIN						
7	1 ESC	ZNF16C/D	LUCAS	1000 1130						7	1 ESC	ZNF16C/D	LUCAS	1000 1130									
			KEVIN				DWYER					KEVIN					DWYER						
8	1 BFM	ZNF16C/D	SHALLCROSS	1000 1130	6	2 ESC	ZNF16C/D	MCGLEN	1530 1700	8	1 BFM	ZNF16C/D	SHALLCROSS	1000 1130	6	2 ESC	ZNF16C/D	MCGLEN	1530 1700				
			DWYER				PAUKO					DWYER					PAUKO						
9	2 TXI INT	KF-16C/D	SEVIMU	1530 1700	7	2 SA	KF-16C/D	BRASSO/HAM	1530 1700	9	2 TXI INT	KF-16C/D	SEVIMU	1530 1700	7	2 SA	KF-16C/D	BRASSO/HAM	1530 1700				
			ATKRI				GUNDUZ					ATKRI					GUNDUZ						
			PARK				DAVIS					PARK					DAVIS						
			YASIN				YLDZ					YASIN					YLDZ						
10	2 ACT	KF-16C/D	BRASSO/HAM	1530 1700	8	2 AAR	KF-16C/D	YLDZ	1530 1700	10	2 ACT	KF-16C/D	BRASSO/HAM	1530 1700	8	2 AAR	KF-16C/D	YLDZ	1530 1700				
			GUNDUZ				ATKRI					GUNDUZ					GUNDUZ						
			DAVIS				KIM					DAVIS					DAVIS						
			TETRAUT				AMIE					TETRAUT					TETRAUT						
11	2 CAP	ZNF16C/D	LUNDAY	1530 1700	9	3 NCAP	KF-16C/D	MILLER	2100 2230	11	2 CAP	ZNF16C/D	LUNDAY	1530 1700	9	3 NCAP	KF-16C/D	MILLER	2100 2230				
			ERHAN				CUSBY					ERHAN					ERHAN						
12	2 TXI INT	ZNF16C/D	MILLER	1530 1700						12	2 TXI INT	ZNF16C/D	MILLER	1530 1700									
			CUSBY				MCDONALD					CUSBY					CUSBY						
13	2 BFM	ZNF16C/D	MCDONALD	1530 1700	10	3 TXI INT	ZNF16C/D	LUNDAY	2100 2230	13	2 BFM	ZNF16C/D	MCDONALD	1530 1700	10	3 TXI INT	ZNF16C/D	LUNDAY	2100 2230				
			SALGADO				ERHAN					SALGADO					ERHAN						
14	2 BFM	ZNF16C/D	LUCAS	1530 1700	11	3 TXI INT	KF-16C/D	LUCAS	2100 2230	14	2 BFM	ZNF16C/D	LUCAS	1530 1700	11	3 TXI INT	KF-16C/D	LUCAS	2100 2230				
			KEVIN				KEVIN					KEVIN					KEVIN						
15	2 ESC	ZNF16C/D	SHALLCROSS	1530 1700						15	2 ESC	ZNF16C/D	SHALLCROSS	1530 1700									
			DWYER				PARK					DWYER					DWYER						
16	2 ESC	ZNF16C/D	MCGLEN	1530 1700	11	3 NESC	ZNF16C/D	MCGLEN	2100 2230	16	2 ESC	ZNF16C/D	MCGLEN	1530 1700	11	3 NESC	ZNF16C/D	MCGLEN	2100 2230				
			PAUKO				PAUKO					PAUKO					PAUKO						
SIM 0900 - 1000 KIM					SIM 0900 - 1000 YASIN					SIM 0900 - 1000 KIM					SIM 0900 - 1000 YASIN					SIM 0900 - 1000 KIM			
SIM 1000 - 1100 AMIE					SIM 1000 - 1100 BOARDMAN					SIM 1000 - 1100 AMIE					SIM 1000 - 1100 BOARDMAN					SIM 1000 - 1100 AMIE			
RSU-1		SOF - 1			RSU-1		SOF - 1			RSU-1		SOF - 1			RSU-1		SOF - 1			RSU-1		SOF - 1	
GUZMAN		YLDZ			TETRAUT		SEVIMU			GUZMAN		YLDZ			TETRAUT		SEVIMU			GUZMAN		YLDZ	
SIM 1500 - 1600 KIM					SIM 1500 - 1600 YASIN					SIM 1500 - 1600 KIM					SIM 1500 - 1600 YASIN					SIM 1500 - 1600 KIM			
SIM 1600 - 1700 AMIE					SIM 1600 - 1700 BOARDMAN					SIM 1600 - 1700 AMIE					SIM 1600 - 1700 BOARDMAN					SIM 1600 - 1700 AMIE			
RSU-2		SOF - 2			RSU-2		SOF - 2			RSU-2		SOF - 2			RSU-2		SOF - 2			RSU-2		SOF - 2	
GUZMAN		YLDZ			TETRAUT		SEVIMU			GUZMAN		YLDZ			TETRAUT		SEVIMU			GUZMAN		YLDZ	
SIM 2000 - 2100 YASIN					SIM 2000 - 2100 YASIN					SIM 2000 - 2100 YASIN					SIM 2000 - 2100 YASIN					SIM 2000 - 2100 YASIN			
SIM 2100 - 2200 PARK					SIM 2100 - 2200 PARK					SIM 2100 - 2200 PARK					SIM 2100 - 2200 PARK					SIM 2100 - 2200 PARK			
RSU-3		SOF - 3			RSU-3		SOF - 3			RSU-3		SOF - 3			RSU-3		SOF - 3			RSU-3		SOF - 3	
BOARDMAN		SHALLCROSS			BOARDMAN		SHALLCROSS			BOARDMAN		SHALLCROSS			BOARDMAN		SHALLCROSS			BOARDMAN		SHALLCROSS	

3.2.2. Mission Planning

Mission planning phase starts after scheduling. When the flight schedule is generated, pilots start to plan their missions. Mission planning requires the pilots to get the needed information about the missions, weapons, and coordination. In fighter squadrons the mission planning is done by the pilots. We use the pilots in our baseline model to perform mission planning. As an alternative approach, we consider an operation cell with a route planner, target expert, weapon expert, and intelligence personnel. This operation cell is not explicitly modeled, but allows us to remove the mission planning task from the pilots executing the flying schedule. At most the mission planning phase needs one or two hours. In our study we use one hour for each mission.

3.2.3. Briefing

In this phase, the pilots brief the mission requirements in respect with the route, target information, coordination, weapon planning, and intelligence. In flight operations, the briefing typically starts two hours prior to the take-off time, which is how we model it for this study.

3.2.4. Flight

We conduct different missions of a Multi Role F-16 Fighter Squadron in this study. The average time of these missions is modeled deterministically as one and a half hours. The flight starts with the take-off time and ends with the landing time. Our simulation model checks the availability of the required resources according to the fixed schedules and flies all supportable sorties. The number of completed sorties over a selected time period produces a sortie rate.

3.2.5. Debriefing

The sortie generation process finishes with the debriefing phase which we model as thirty minutes for an F-16 squadron. We expect this phase to be removed with the use of advanced technology in fifth generation aircraft such as F-35 and F-22. Removal of the debriefing phase may affect the sortie generation rate and must be checked with our simulation. After the debriefing phase, the pilots are released for the next mission, ground duty, or crew rest, and the maintenance division releases the aircraft if it does not need a repair. If the aircraft needs unscheduled maintenance, the release occurs at the end of the maintenance.

3.3. Description of Models

In our study, we investigated ten different model configurations with different features in order to answer the research questions presented in this study. The first model represents a baseline scenario where a fixed flight schedule is generated and abort rates are not considered. From here, the baseline scenario is modified to capture various situations of interest proposed by the researcher. These configurations allow thorough analysis on the behavior and impact of certain features on sortie generation of a fighter squadron. Each model's unique features can be referenced in Table 12.

Table 12. Model Features

Model Number	Fixed Flight Schedule	Abort Rates Considered	Set Abort Rates	Set Pilot Numbers	Mission Planning Present
1	YES	NO	NO	NO	YES
2	YES	YES	NO	NO	YES
3	NO	YES	NO	NO	YES
4	NO	YES	NO	NO	NO
5a	YES	YES	YES	NO	YES
5p	YES	YES	NO	YES	YES
6a	NO	YES	YES	NO	YES
6p	NO	YES	NO	YES	YES
7a	NO	YES	YES	NO	NO
7p	NO	YES	NO	YES	NO

The baseline model utilizes a fixed flight schedule with zero abort rates. Whenever a fixed flight schedule is not used, the models use random flight schedules generated by Simio. Fixed flight schedules represent times of peace whereas random schedules model times of conflict where there is a higher level of operational variability. Excluding the baseline model, all other models incorporate abort rates. In addition, some models go step further and apply a stochastic element to the abort rates. For example, model 5a includes abort rates in its experiments but it also implements multiple

combinations of abort rates to represent dynamic aspect of abort rates. Lastly, in models 4, 7a and 7p, the mission planning function was removed to observe the impact on the number of sorties generated.

In models 5-7, ground, air, and weather abort rates are varied by increments to represent real life changes in the sortie generation process. In addition, models 5-7 also utilize mixed combination of pilot numbers for the instructor and four ship leader to capture potential personnel shortages and manning constraint. The Abort Rates and Pilot Numbers are depicted in Table 13 and 14. Pilot numbers are the instructors and four ship leaders available in a squadron to carry out missions in each respective scenario. Increments show the level of deviation from the baseline.

Table 13. Abort Rates

Abort Rates (%)				
Scenario	Ground	Air	Weather	Increments
1	3	2	3	0
2	2	1	2	-1
3	1	0	1	-2
4	0	0	0	-3
5	4	3	4	+1
6	5	4	5	+2
7	6	5	6	+3

Table 14. Pilot Numbers

Pilot Numbers				
Scenario	Instructors	Inst. Incr.	Four Ship Leaders	FShipLdr Incr.
1	3	0	4	0
2	2	-1	4	0
3	1	-2	4	0
4	3	0	3	-1
5	3	0	2	-2
6	3	0	1	-3
7	2	-1	3	-1
8	1	-2	2	-2

3.4. Model Development

The sortie generation process is modeled using Simio Simulation Software. In this section we provide a brief discussion of some key Simio features and how they were used in building our simulation.

3.4.1. Standard Library

We used the standard library included with Simio to provide a set of modeling features. Model construction began with dragging an object into the facility view and connecting it to other objects. Each object has a comprehensive set of properties to allow

Table 15. Simio Standard Library Objects

Object	Description
Source	Generates entity objects of a specified type and arrival pattern.
Sink	Destroys entities that have completed processing in the model.
Server	Represents a capacitated process such as a machine or service operation.
Workstation	Includes setup, processing, and teardown and secondary resource and material requirements.
Combiner	Combines multiple entities together with a parent entity (e.g. a pallet).
Separator	Splits a batched group of entities or makes copies of a single entity.
Resource	A generic object that can be seized and released by other objects.
Worker	A moveable resource that may be seized for tasks as well as used to transport entities.
Vehicle	A transporter that can follow a fixed route or perform on demand pickups/drop offs.
BasicNode	Models a simple intersection between multiple links
TransferNode	Models a complex intersection for changing destination and travel mode.
Connector	A simple zero-time travel link between two nodes. Path
Path	A link over which entities may independently move at their own speeds.
TimePath	A link that has a specified travel time for all entities.
Conveyor	A link that models both accumulating and non-accumulating conveyor devices.

customizing its behavior. In addition, the behavior of each object can be extended by taking advantage of add-on processes to define extra logic specific to our application. Finally, all of the objects in the standard library have been defined using processes. The standard library objects are illustrated in Table 15 (Sturrock & Pegden, 2010).

3.4.2. Processes

Object-based tools such as Simio are very good for rapidly building models. We simply drag objects into the workspace, set the properties for those objects, and our model is ready to run. However, the traditional problem with this approach is modeling flexibility. It's extremely difficult to design a set of objects that work in all situations across multiple and disparate application areas without making the objects overly complicated and difficult to learn and use. The Simio Standard Library addresses this problem through the concept of add-on processes (Sturrock & Pegden, 2010). In our sortie generation process we created different processes to represent ground duties, four ship flight, three ship flight, and two ship flight.

3.4.2.1. Ground Duties Process

We transfer the flight schedules generated with the use of DSS or randomly into Simio. Our sortie generation process scheduling starts with assigning the pilots for SOF and RSU duties.

This process respectively checks the availability of the four ship leader and instructor for the SOF and assigns the first available. If there are no pilots of appropriate skill available, the flight block is canceled.

After assigning the SOF it assigns the RSU with the similar logic across all pilot ratings. It respectively checks the availability of pilots starting at lowest skill level

(wingman) up to instructor pilot. If no pilot is available the flight block is canceled. After the ground duties are assigned, the generation of the flights in the schedule starts. The ground duties process is shown in Figure 5.

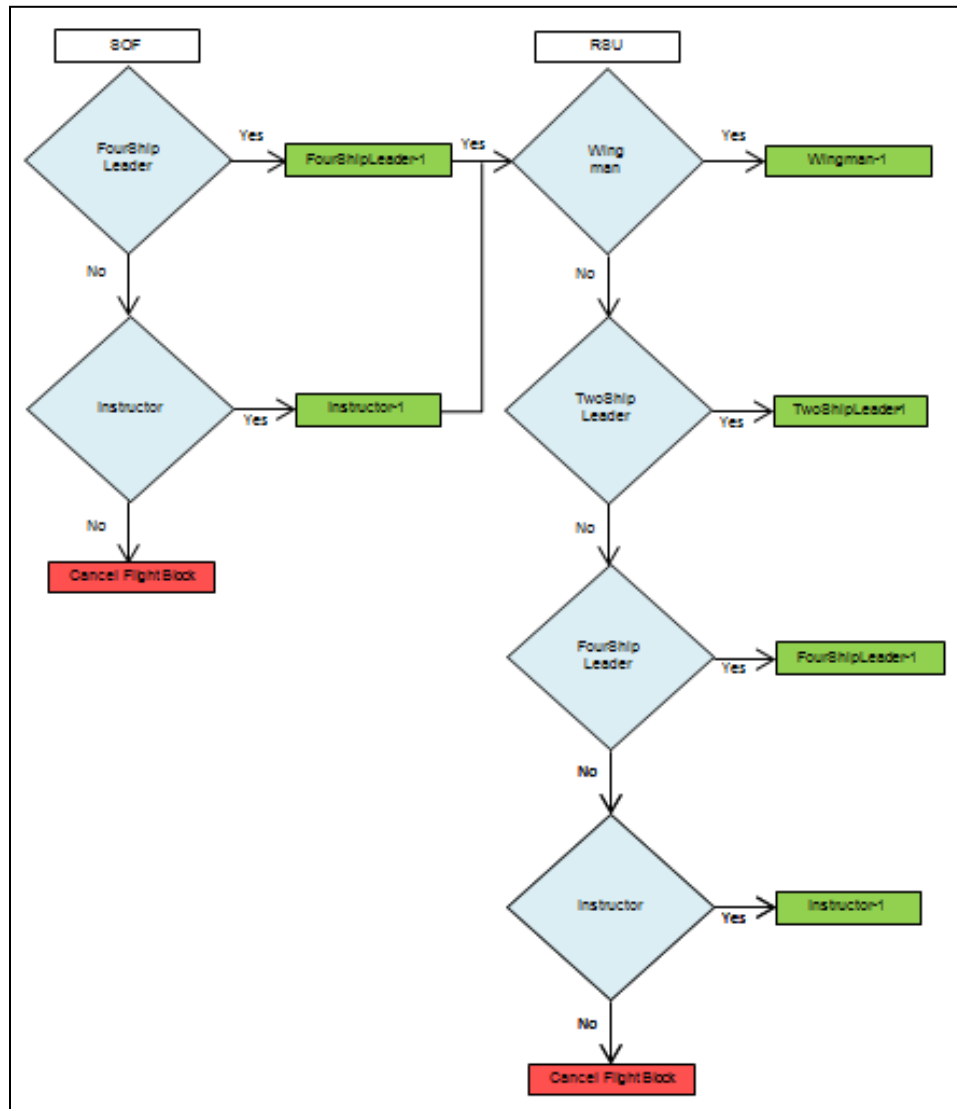


Figure 5. The Ground Duties Process

3.4.2.2. Four Ship Flight Process

This process starts when a scheduled mission requires four aircraft. It respectively checks the availability of the four ship leader and instructor, then assigns the first

available to the first aircraft. For all other aircraft, available pilots are checked starting at the lowest skill level qualified up to instructor pilot. If qualified pilots are not available for all four aircraft, the mission is canceled. The four ship flight process is shown in Figure 6.

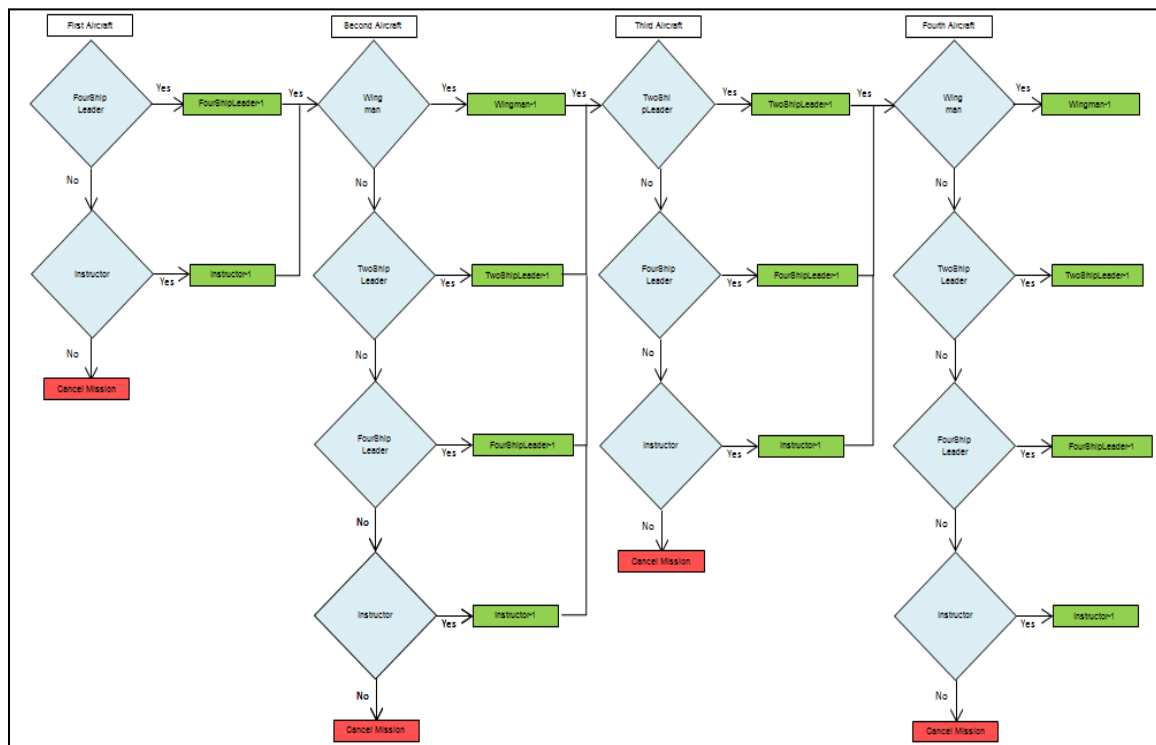


Figure 6. The Four Ship Process

3.4.2.3. Three Ship Flight Process

This process starts when a scheduled mission requires three aircraft. It respectively checks the availability of the four ship leader and instructor, then assigns the first available to the first aircraft. For all other aircraft, available pilots are checked starting at the lowest skill level qualified up to instructor pilot. If qualified pilots are not available for all three aircraft, the mission is canceled. The three ship flight process is shown in Figure 7.

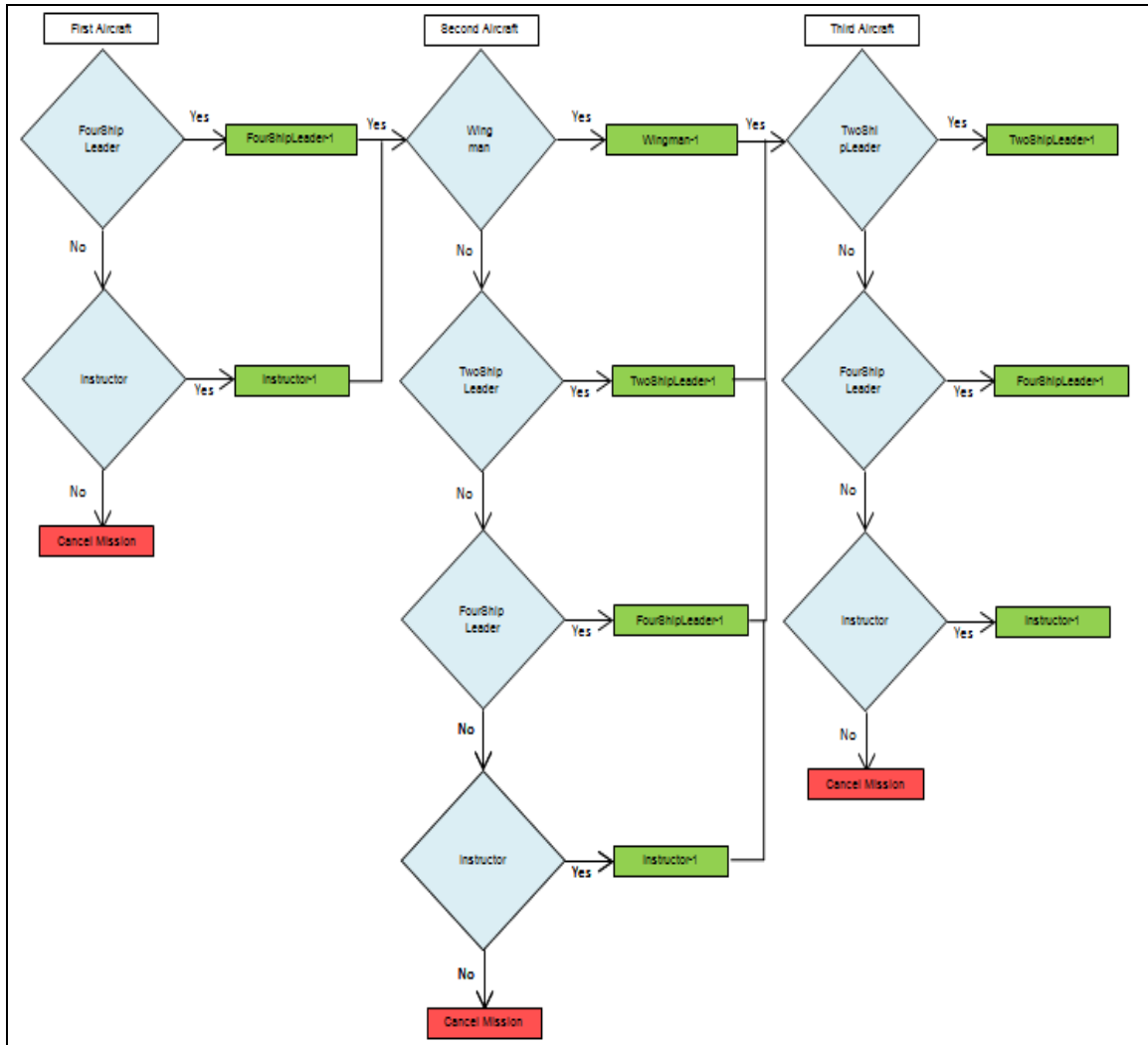


Figure 7. The Three Ship Flight

3.4.2.4. Two Ship Flight Process

This process starts when a scheduled mission requires two aircraft. It respectively checks the availability of the two ship leader, four ship leader and instructor, then assigns the first available to the first aircraft. For all other aircraft, available pilots are checked starting at the lowest skill level qualified up to instructor pilot. If qualified pilots are not available for both aircraft, the mission is canceled. The two ship flight process is shown in Figure 8.

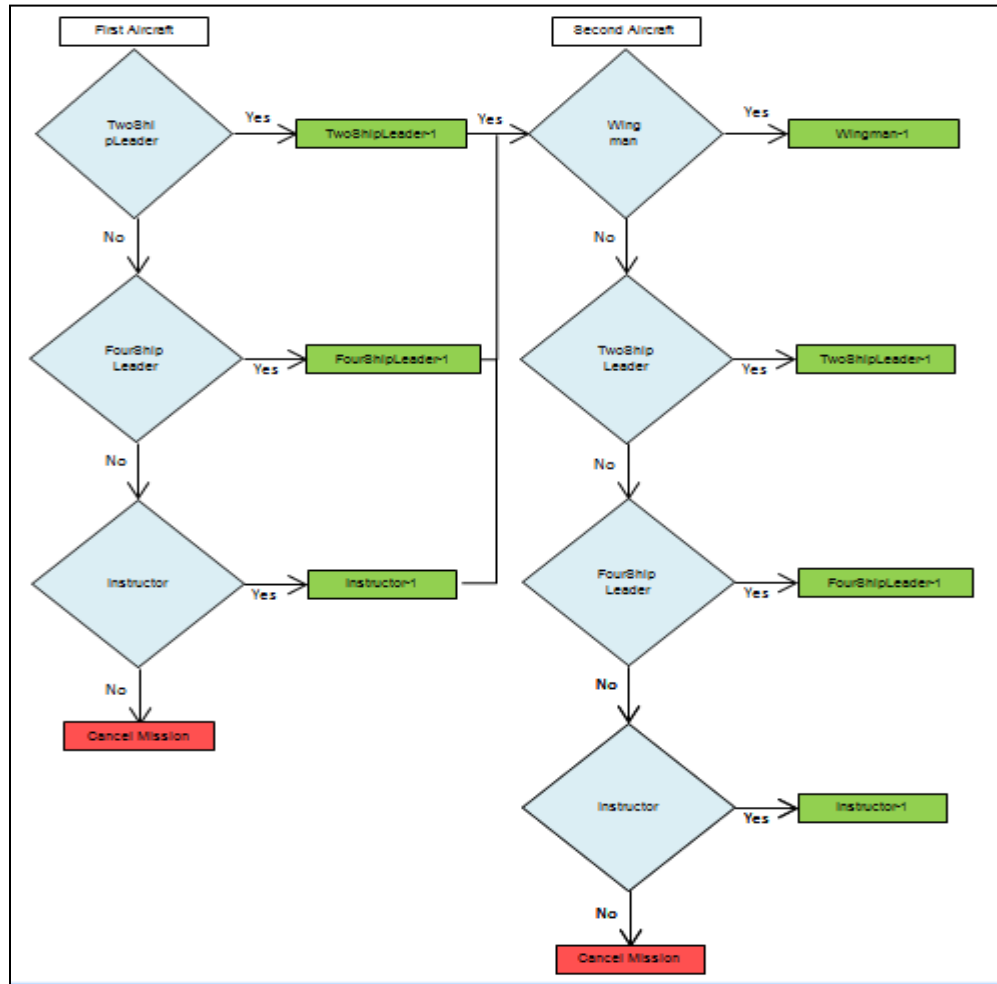


Figure 8. The Two Ship Flight

3.4.3. Experiment Windows

In the experimentation mode we define one or more properties on the model that we can change to see the impact on the system performance. These properties, exposed in the experiment as Controls, might be used to vary things like the number of pilots, the number of aircraft, or the abort percentage. These model properties are then referenced by one or more objects in the model. You may also add Responses; these would generally be your Key Performance Indicators (KPIs) on which you make the primary decision on

“goodness” of the scenario. You may dynamically sort on any column, for example to display the highest daily sorties scenarios first. You can also add Constraints that will automatically be applied before or after a run to prevent running, or to later discard a scenario that violates an input or output constraint. When you run an experiment, it takes full advantage of all processors available (Sturrock & Pegden, 2010). In our model we created an experiment to see the results of our responses for a number of different scenarios defined by varying the values of our parameters. An example of our model’s experiment window is shown in Figure 9.

DesignResponse ResultsPivot GridReportsInput Analysis																		
Scenario			Replications		Controls								Responses					
<input checked="" type="checkbox"/>	Name	Status	...	Compl...	Ground...	Air...	Weather...	NumberOfAircraft	NumberOfinstr...	N...	N...	N...	SortieNumber	Aircraft Utilization	Instructor Pilot	Fourship Leader	Twoship Leader	Wingman
<input checked="" type="checkbox"/>	1a	Canceled	20	4 of 20	3	2	3	20	3	4	5	13	335.5	61.9493	42.3756	68.8132	62.7036	53.1893
<input checked="" type="checkbox"/>	2a	Canceled	20	3 of 20	2	1	2	20	3	4	5	13	349.333	62.8585	42.8263	69.6107	63.2562	53.9771
<input checked="" type="checkbox"/>	3a	Canceled	20	3 of 20	1	0	1	20	3	4	5	13	352.667	63.0431	44.2287	69.4911	63.5221	53.8039
<input checked="" type="checkbox"/>	4a	Canceled	20	3 of 20	0	0	0	20	3	4	5	13	354	63.2143	44.1547	69.7674	63.7874	53.9058
<input checked="" type="checkbox"/>	5a	Canceled	20	3 of 20	4	3	4	20	3	4	5	13	331.333	61.4826	42.2863	68.3849	62.1211	52.8456
<input checked="" type="checkbox"/>	6a	Canceled	20	3 of 20	5	4	5	20	3	4	5	13	327.333	61.0211	41.8937	67.9613	61.7006	52.5311
<input checked="" type="checkbox"/>	7a	Canceled	20	3 of 20	6	4	6	20	3	4	5	13	329	60.9994	42.2992	68.4955	61.3834	52.4171
<input checked="" type="checkbox"/>	1p	Canceled	20	3 of 20	3	2	3	20	3	4	5	13	337.667	61.9075	42.1514	68.7994	62.8069	53.1433
<input checked="" type="checkbox"/>	2p	Canceled	20	3 of 20	3	2	3	20	2	4	5	14	341.333	62.0041	62.6319	68.7442	62.3566	49.6081
<input checked="" type="checkbox"/>	3p	Canceled	20	3 of 20	3	2	3	20	1	4	5	15	301	55.0525	61.9495	68.6157	62.1722	41.4482
<input checked="" type="checkbox"/>	4p	Canceled	20	3 of 20	3	2	3	20	3	3	5	14	341.333	62.0041	62.6869	70.7284	62.3566	49.6081
<input checked="" type="checkbox"/>	5p	Canceled	20	3 of 20	3	2	3	20	3	2	5	15	301	55.0525	62.1221	75.0284	62.1722	41.4482
<input checked="" type="checkbox"/>	6p	Canceled	20	3 of 20	3	2	3	20	3	1	5	16	276.333	49.4008	62.1218	87.7076	62.4898	35.7152
<input checked="" type="checkbox"/>	7p	Canceled	20	3 of 20	3	2	3	20	2	3	5	15	301	55.0525	62.2446	70.6428	62.1722	41.4482
<input checked="" type="checkbox"/>	8p	Canceled	20	3 of 20	3	2	3	20	1	2	5	17	243.333	43.1627	61.9492	75.4341	62.4452	29.8683

Figure 9. The Experiment Window

3.4.4. Simio Measure of Risk and Error (SMORE) Plots

Simio Pivot Tables and Reports provide an estimate of the population mean and confidence interval based on multiple replications. While this is exactly what is needed in some situations, in others it provides an inadequate amount of information required to make a decision while accounting for risk.

The Response Results window of an Experiment creates a SMORE plot using the Response value that is selected in the Response pull down menu. A SMORE plot displays both the estimated expected value of a scenario and multiple levels of variability behind the expected value. The plot displays results across replications, for each scenario.

A SMORE plot consists of a Mean, Confidence Interval for the Mean, Upper Percentile Value, Confidence Interval for the Upper Percentile Value, Lower Percentile Value, Confidence Interval for the Lower Percentile Value, Median, Maximum Value, and Minimum Value (Sturrock & Pegden, 2010). An example of a SMORE plot is depicted in Figure 10.

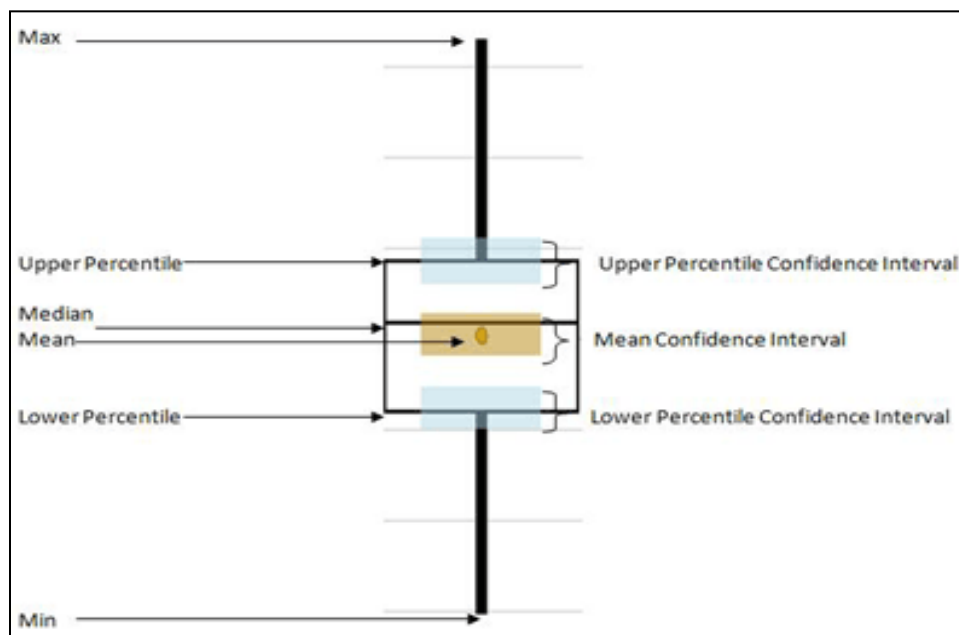


Figure 10. SMORE Plot (Sturrock & Pegden, 2010)

3.5. Verification and Validation of the Model

Verification is the step to check the model and logic to ensure they are implementing what is intended. In this section, our focus is on the application of verification methods for the model. First it is appropriate to mention again that verification should not be considered as a step which is applied once while building a model. It is an ongoing process where a modeler uses various techniques throughout construction of the model. The animation feature in Simio is one of the major techniques used to verify the model. Whenever additional logic or a new sub model is inserted, the simulation is run with animation enabled to check for the proper flow of entities and use of resources. Simio has other useful features such as dynamic variables to count entities at specific points. These counters are embedded into the model to check the results and verify them numerically. For instance, a dynamic variable is inserted for every flight sub phases to collect and check the number of simulator missions accomplished. The numbers from the simulation are compared with numbers obtained analytically or from the actual system. This technique is used in a number of places throughout our model.

Another verification technique is to have someone familiar with the actual system review the model. Our model and sub models were reviewed by pilots who flew more than 1000 hours with F-16 to see whether the sortie generation flow logic is correctly represented. In addition, the sub process created for four ship, three ship, two ship flight and ground duties representing the actual procedures was also reviewed. Based upon feedback from these reviews, the model was modified accordingly.

Face validity is used among the validation techniques. A graduate student in the ENS department simulation track reviewed most of the model's modification as a face validity technique.

3.6. Summary

The model for this research was built to replicate the sortie generation process. This chapter focused on description of the sortie generation system, concepts of building a simulation model and application of steps for building a simulation model. Details of our final model are discussed to include numerous figures depicting the Simio logic. In the following chapter, we discuss the analysis of our simulation output using a variety of techniques.

IV. Analysis and Results

4.1. Chapter Overview

The previous chapter defined the simulation model that was used for this research. This chapter defines the requirements in setting up and performing our analysis. These requirements start by determining the number of replications to produce sufficiently normal output data while meeting a specified confidence interval half width. We discuss the organization of our analysis and the results from our simulation runs.

4.2. Model Results

After models described in the methodology are executed, initial results are presented with their significant explanations.

4.2.1. Model 1 (Baseline)

In this model, we created the baseline model including the fixed scheduled generated in a DSS with no resource failures. Our DSS created 288 different missions while utilizing all the resources. As expected, with deterministic processing times, a single Simio replication produced 288 sorties with baseline utilizations for all resources. Results for model 1 are shown in Table 16.

Table 16. Initial Results for Model 1

Model	Replication	SortieNumber	AircraftUtilization	InstructorPilot	FourshipLeader	TwoshipLeader	Wingman
1	1	288	51.1	16.6	57.9	57.6	43.8

Aircraft utilization is around 50 % because the aircraft are assigned for 12 hours in a whole day. However, instructor pilots only have a utilization percentage of around 16 %. This can be explained by the way the models' process logic is set up. As a reminder,

the sortie generation process assigns instructor pilots last after selecting all other pilots for suitable cockpits. In addition, this model does not take into account back seat flights which require instructor pilots.

The use of this baseline model provides the squadron commander with the needed plan for the next month beforehand. That way he can assess at the end of the month as to how well the squadron did in meeting the planned sorties. This simulation also provides a nice tool to effectively share results of flight line operations with the base commander or headquarters.

Another important aspect of such tools is facilitation in standardization of reporting operations at the Air Force level. This kind of simulation, when used by all squadrons, would make it much easier to collect and present standard operational performance data across appropriate units, providing personnel more time to improve other job requirements.

4.2.2. Model 2

Model 2 is created by adjusting the baseline model to include abort rates. The model is replicated 20 times and there are significant differences between model 2 and model 1 (baseline). Twenty replications were selected since output from all metrics was approximately normal and all standard deviations were reasonable. Averaged results for Model 2 along with the standard deviations are shown in Table 17.

Table 17. Averaged Results for Model 2

Model	Replication	SortieNumber	AircraftUtilization	InstructorPilot	FourshipLeader	TwoshipLeader	Wingman
1	1	288	51.1	16.6	57.9	57.6	43.8
2	20	266±5.35	55.6±0.65	19.3±0.46	63.1±0.71	66.2±0.75	49.3±0.47

First, the results show that the sortie number decreases significantly, both statistically and practically, when compared to the baseline. Also, aircraft and pilots utilization show a statistically significant rise, with little practical difference. These results are confirmed by both a paired student's t test and also a Tukey-Kramer HSD test executed in JMP at the 95% confidence level. In depth analysis can be found in Appendix A. All statistical comparison tests and analysis for the models from this point can be found in the Appendix.

Understanding the impact of various factors on the flying schedule is an important aspect of planning for a squadron commander. The squadron commanders can compare past variations with potential future ones given by the tool. Moreover, it would become very easy for the scheduling officer or squadron commander to make adjustments based on the anticipated impacts from the simulation. In this model the abort rates are given monthly. For future studies, we may want to model using daily aborts instead of monthly aborts. One reason for this is that the forecast for weather is much more accurate for the next day as compared to that of 28 days ahead.

4.2.3. Model 3

Model 3 is almost identical to Model 2 but uses a random flight schedule instead of a fixed flight schedule. Our use of a random flight schedule represents increased operational tempo in time of a conflict. In this model, the results show that the sortie number and instructor utilization increase clearly much larger, both statistically and practically, when compared to the baseline. Also, aircraft and other pilots utilization show a statistically significant rise, but not nearly as much practically. Averaged results for Model 3 along with the standard deviations are shown in Table 18.

Table 18. Averaged Results for Model 3

Model	SortieNumber	AircraftUtilization	InstructorPilot	FourshipLeader	TwoshipLeader	Wingman
2	266±5.35	55.6±0.65	19.3±0.46	63.1±0.71	66.2±0.75	49.3±0.47
3	337.2±6.97	61.8±0.45	42.7±0.91	68.6±0.47	62.4±0.35	53.0±0.45

The Squadron Commander can get a fair idea about the maximum utilization of his assets in this case. This is especially important for wartime scenarios not only for operational planning but also for associated logistics planning at base and headquarter levels. The base commander and headquarter now have better insight into the other resources needed to complete the missions such as weapons and fuel.

4.2.4. Model 4

Model 4 makes further adjustments to Model 3 by removing the mission planning function in the simulation. As mentioned in Chapter 3, we remove the mission planning phase to leave more time for the pilots to actually fly. When we remove it, it provides another block to fly each day. So the sortie number and utilizations increase significantly, both statistically and practically, compared to Model 3. Averaged results for Model 4 along with the standard deviations are shown in Table 19.

Table 19. Averaged Results for Model 4

Model	SortieNumber	AircraftUtilization	InstructorPilot	FourshipLeader	TwoshipLeader	Wingman
3	337.2±6.97	61.8±0.45	42.7±0.91	68.6±0.47	62.4±0.35	53.0±0.45
4	422.9±6.93	77.3±0.44	53.7±1.05	85.8±0.44	77.9±0.50	66.3±0.46

This is a good model to show how many additional sorties we can generate with a minor change to the sortie generation process during a conflict. In this model we

deactivated the mission planning for the pilots. In future studies, the briefing or flight section can be shortened and analyzed.

4.2.5. *Model 5a and 5p*

In Model 5a, seven different scenarios are created using the abort rates shown in Table 13. Averaged results for Model 5a along with the standard deviations are depicted in Table 20. In Abort column the first number represents the ground abort percentage, the second number air abort percentage, and the third number weather abort percentage.

Table 20. Averaged Results for Model 5a

Model	Scenario	Abort Rates	SortieNumber	AircraftUtilization	InstructorPilot	FourshipLeader	TwoshipLeader	Wingman
5a	1	3/2/3	266.5±5.36	55.6±0.65	19.3±0.46	63.1±0.71	66.2±0.75	49.3±0.47
5a	2	2/1/2	275.2±3.76	56.6±0.55	19.4±0.38	64±0.51	67.4±0.70	50.1±0.41
5a	3	1/0/1	283.1±2.06	57.5±0.30	19.8±0.18	64.7±0.39	68.4±0.41	50.8±0.22
5a	4	0/0/0	288	58.1	19.9	65.1	69.1	51.2
5a	5	4/3/4	257.7±6.91	54.7±0.81	18.9±0.59	62.7±1.01	65±0.90	48.7±0.60
5a	6	5/4/5	250.7±6.80	54.2±0.72	18.7±0.82	62.4±0.90	64.4±0.84	48.3±0.55
5a	7	6/5/6	246.6±5.68	53.6±0.66	18.5±0.67	61.7±0.95	63.7±0.83	47.8±0.53

From the analysis of these results, a slight decrease in abort rates lead to a significant rise in the number of sorties generated and utilizations. In contrast, decreases in abort rates result in significant drops in both the number of sorties generated and utilizations. The SMORE plot in Figure 11 illustrates these differences with our baseline scenario as the single point in middle of the plot (Scenario 4). Scenarios to the left of the baseline show a statistically significant increase (non-overlapping confidence intervals- brown rectangles) as the abort rates decrease. On the right side of the baseline scenario, scenarios 5, 6, and 7 show a significant decrease (not statistically significant between scenario 6 and 7 as the abort rates increase).

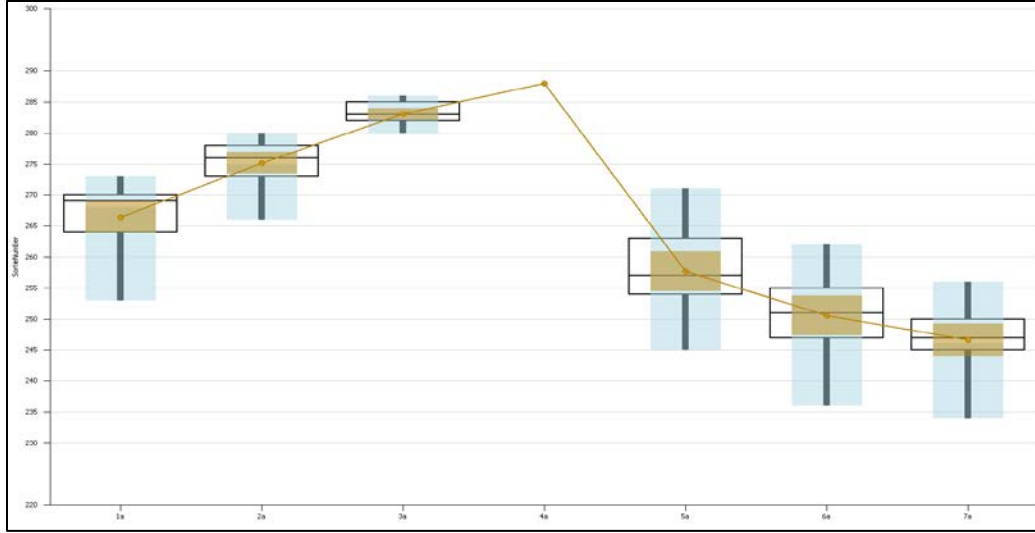


Figure 11. Model 5a Scenarios Comparison Analyses

In Model 5p, eight different scenarios are created using the pilot numbers mentioned in Table 14. Here, instead of manipulating abort rates, pilot numbers are emphasized. Averaged results for Model 5p along with the standard deviations are shown in Table 21 and Figure 12. In Pilots column the first number represents change in instructor pilots and the second number change in four ship leaders.

Table 21. Averaged Results for Model 5p

Model	Scenario	Pilots	SortieNumber	AircraftUtilization	InstructorPilot	FourshipLeader	TwoshipLeader	Wingman
5p	1	3/4	266.5±5.36	55.6±0.65	19.3±0.46	63.1±0.71	66.2±0.75	49.3±0.47
5p	2	2/4	266.3±5.32	55.6±0.64	28.9±0.73	63.1±0.71	66.2±0.73	45.8±0.43
5p	3	1/4	255.5±4.65	53.8±0.57	38.1±1.35	63.4±0.72	66.3±0.66	41.6±0.38
5p	4	3/3	266.5±5.92	55.6±0.65	36.2±0.65	67.2±0.67	66.2±0.84	45.8±0.75
5p	5	3/2	255.5±4.65	53.8±0.57	46.6±0.94	76±0.73	66.3±0.66	41.6±0.38
5p	6	3/1	232.7±3.10	50±0.41	55.5±0.78	87.7±0	66.2±0.54	36.6±0.24
5p	7	2/3	255.5±4.65	53.8±0.57	44.5±1.05	67.6±0.68	66.3±0.66	41.6±0.38
5p	8	1/2	203.4±4.46	44.8±0.55	51.2±1.06	75.8±0.67	66.3±0.79	31.4±0.31

First, we changed the number of instructors while keeping the number of four ship leaders the same. The result was a significant increase in utilizations. However, there was no obvious change in the number of sorties generated. Second, we changed the number of four ship leaders while keeping the number of instructors constant. Again, there was a significant rise in utilizations but, sortie numbers saw a drop. Lastly, we degraded both the number of instructors and four ship leaders. This led to another significant drop in sortie numbers and a jump in utilizations at a fluctuation greater than seen previously. The SMORE plot in Figure 12 illustrates the influence of instructors and four ship leaders can have on sortie numbers. In Scenarios 2p and 3p the number of instructors is decreased by increments of one. Once again, because of the process logic implemented in our simulation and the exclusion of back seat flights, the SMORE plots show no significant changes from scenario 2p. However, a notable drop is observed when a second instructor is absent in scenario 3p. Starting from scenarios 4p to 6p, the SMORE plots represent a constant number of instructors and incremental drop in four ship leaders. Here, there is an immediate significant drop of sorties generated in all three scenarios as the number of four ship leaders go down. Next, in scenario 7p both a single instructor and a single four ship leader are removed from the fighter squadron. Compared to scenario 1p where no personnel are missing, there is a significant drop in sortie numbers. Finally, the SMORE plot from scenario 7p to 8p presents a dramatic drop in sortie numbers. Here, an additional instructor and four ship leader are removed leading to even greater statistical and practical consequences.

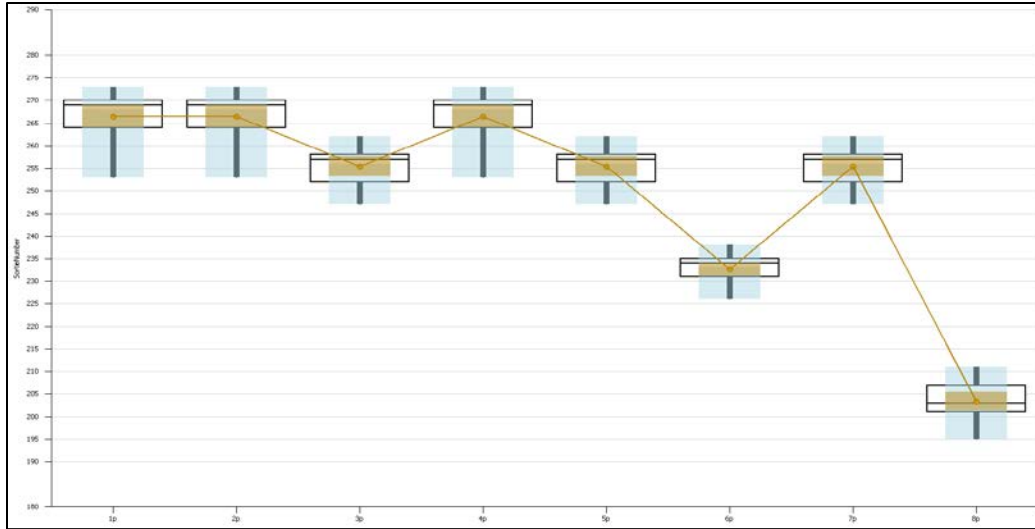


Figure 12. Model 5p Scenarios Comparison Analyses

4.2.6. Model 6a and 6p

In Model 6a, seven different scenarios are created using the abort rates mentioned in Table 13. Averaged results for Model 6a along with the standard deviations are shown in Table 22. In Abort column the first number represents the ground abort percentage, the second number air abort percentage, and the third number weather abort percentage.

Table 22. Averaged Results for Model 6a

Model	Scenario	Abort Rates	Sortie.Number	AircraftUtilization	InstructorPilot	FourshipLeader	TwoshipLeader	Wingman
6a	1	3/2/3	337.2±6.97	61.8±0.45	42.7±0.91	68.6±0.47	62.4±0.35	53.0±0.45
6a	2	2/1/2	344.3±6.51	62.4±0.38	43.2±0.60	69.1±0.37	62.8±0.34	53.5±0.41
6a	3	1/0/1	353.7±6.28	63.0±0.32	43.6±0.73	69.5±0.22	63.4±0.18	53.9±0.34
6a	4	0/0/0	357.3±7.65	63.4±0.28	43.9±0.77	69.8±0	63.8±0	54.2±0.38
6a	5	4/3/4	327.8±5.33	61.0±0.41	42.4±0.70	68.0±0.52	61.6±0.44	52.4±0.46
6a	6	5/4/5	327.0±9.04	60.9±0.66	42.2±0.92	68.0±0.54	61.5±0.64	52.4±0.58
6a	7	6/5/6	326.0±9.91	60.7±0.56	42.1±0.96	68.0±0.60	61.2±0.51	52.2±0.47

The big change in this model is adjusting the abort rates but with a random schedule. Similar to Model 5a, a decrease in abort rates causes a rise in both sortie

numbers and utilizations. The opposite is true for raising abort rates. The SMORE plot in Figure 13 illustrates these differences with our baseline scenario 4a. Scenarios to the left of the baseline show a statistically significant increase (non-overlapping confidence intervals-brown rectangles) as the abort rates decrease. On the right side of the baseline scenario, scenarios 5, 6, and 7 show a significant decrease (not statistically significant between scenarios 5, 6, and 7 as the abort rates increase). Also, range increases in the responses as the abort rate increases.

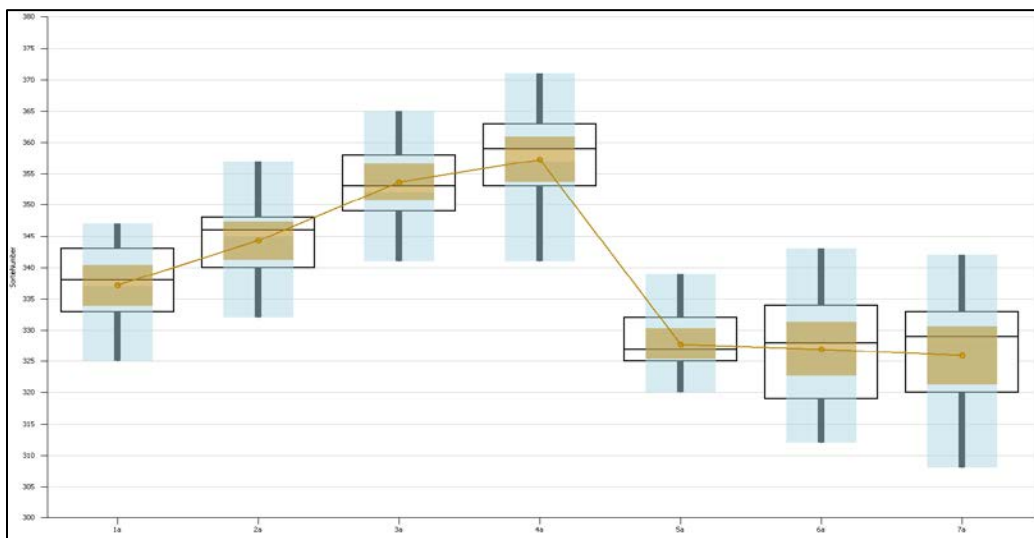


Figure 13. Model 6a Scenarios Comparison Analyses

In Model 6p, eight unique scenarios are generated using the pilot numbers mentioned in Table 14. Here, instead of manipulating abort rates, pilot numbers are altered. Averaged results for Model 6p along with the standard deviations are shown in Table 23. In Pilots column the first number represents change in instructor pilots and the second number change in four ship leaders. We use a random schedule here as in Model 6a.

Table 23. Averaged Results for Model 6p

Model	Scenario	Pilots	SortieNumber	AircraftUtilization	InstructorPilot	FourshipLeader	TwoshipLeader	Wingman
6p	1	3/4	337.2±6.97	61.8±0.45	42.7±0.91	68.6±0.47	62.4±0.35	53.0±0.45
6p	2	2/4	327.4±7.81	59.5±0.63	62.2±0.94	69.3±0.49	62.2±0.51	46.7±0.61
6p	3	1/4	304.8±7.22	55.4±0.47	62.3±0.86	68.7±0.37	62.3±0.43	41.8±0.47
6p	4	3/3	338.7±18.73	61.5±3.13	62.3±0.67	70.7±2.30	62.2±0.47	49.1±3.74
6p	5	3/2	304.8±7.22	55.4±0.47	62.3±0.62	75.1±0.42	62.3±0.43	41.8±0.47
6p	6	3/1	272.6±7.07	49.2±0.52	62.3±0.67	87.7±0	62.3±0.42	35.5±0.44
6p	7	2/3	304.8±7.22	55.4±0.47	62.4±0.67	70.8±0.43	62.3±0.43	41.8±0.47
6p	8	1/2	246.0±5.38	43.2±0.34	62.2±0.69	75.0±0.53	62.4±0.42	30.0±0.27

The logic in these results follows that from Model 5p. First, we changed the number of instructors while keeping the number of four ship leaders the same. As expected, the result was a significant increase in utilizations. However, there was no obvious change in the number of sorties generated. Second, we changed the number of four ship leaders while keeping the number of instructors constant. Again, there was a significant rise in utilizations but, sortie numbers saw a drop. Lastly, we degraded both the number of instructors and four ship leaders. This led to another significant drop in sortie numbers and a jump in utilizations at a fluctuation greater than seen previously. The SMORE plot in Figure 14 illustrates the influence instructors and four ship leaders can have on sortie numbers. In Scenarios 2p and 3p the number of instructors is decreased by increments of one. Once again, because of the process logic implemented in our simulation and the exclusion of back seat flights, the SMORE plots show no significant changes from scenario 2p. However, a notable drop is observed when a second instructor is absent in scenario 3p. Starting from scenarios 4p to 6p, the SMORE plots represent a constant number of instructors and incremental drop in four ship leaders.

Here, there is an immediate significant drop of sorties generated in all three scenarios as the number of four ship leaders go down. Next, in scenario 7p both a single instructor and a single four ship leader are removed from the fighter squadron. Compared to scenario 1p where no personnel are missing, there is a significant drop in sortie numbers. Finally, the SMORE plot from scenario 7p to 8p presents a dramatic drop in sortie numbers. Here, an additional instructor and four ship leader are removed leading to even greater statistical and practical consequences.

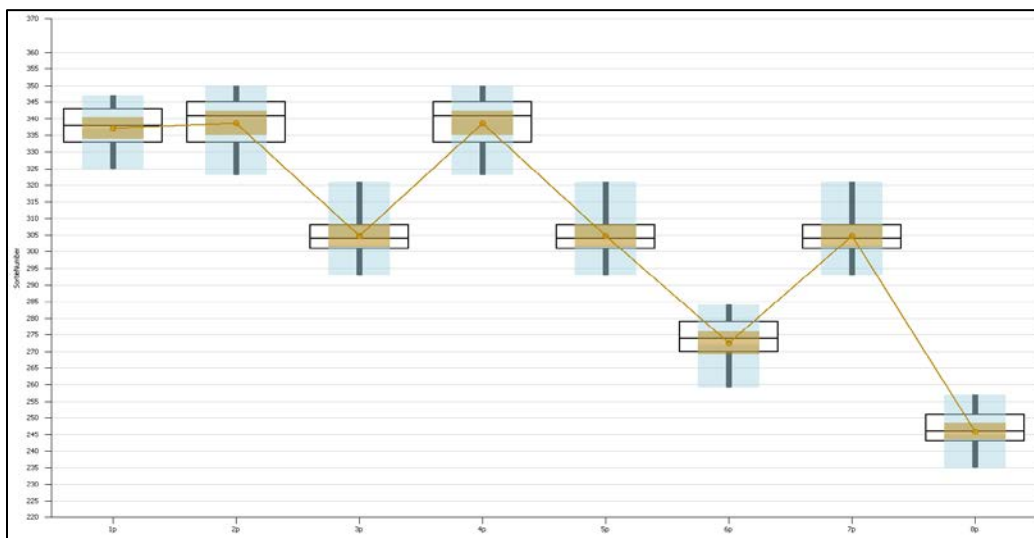


Figure 14. Model 6p Scenarios Comparison Analyses

4.2.7. Model 7a and 7p

Model 7a and 7p are similar to Model 6a and 6p, but the mission planning function has been removed. However, the effects on the results follow trends seen in Model 6a and 6p as expected. The results for these models are summarized in Tables 24 and 25 and the SMORE plots belonging to this analysis are shown in Figure 15 and 16. In Abort column the first number represents the ground abort percentage, the second number air abort percentage, and the third number weather abort percentage. In Pilots

column the first number represents change in instructor pilots and the second number change in four ship leaders.

Table 24. Averaged Results for Model 7a

Model	Scenario	Abort Rates	SortieNumber	AircraftUtilization	InstructorPilot	FourshipLeader	TwoshipLeader	Wingman
7a	1	3/2/3	422.4±8.98	77.3±0.57	53.4±1.01	85.8±0.45	77.9±0.46	66.3±0.54
7a	2	2/1/2	431.5±6.66	78.0±0.39	53.9±0.76	86.3±0.35	78.6±0.36	66.9±0.46
7a	3	1/0/1	442.7±6.38	78.7±0.31	54.3±0.65	86.9±0.21	79.3±0.19	67.4±0.33
7a	4	0/0/0	446.5±7.19	79.2±0.32	54.7±0.78	87.2±0	79.7±0	67.8±0.38
7a	5	4/3/4	411.4±7.71	76.3±0.54	53.0±0.82	85.1±0.56	77.0±0.59	65.5±0.58
7a	6	5/4/5	408.7±11.10	76.2±0.68	52.9±1.07	84.9±0.56	76.8±0.64	65.5±0.59
7a	7	6/5/6	408.6±10.76	75.9±0.60	52.5±1.16	85.0±0.58	76.6±0.50	65.2±0.49

Table 25. Averaged Results for Model 7p

Model	Scenario	Pilots	SortieNumber	AircraftUtilization	InstructorPilot	FourshipLeader	TwoshipLeader	Wingman
7p	1	3/4	422.4±8.98	77.3±0.57	53.4±1.01	85.8±0.45	77.9±0.46	66.3±0.54
7p	2	2/4	421.7±7.88	76.8±0.64	77.9±1.00	85.8±0.47	77.6±0.46	61.4±0.61
7p	3	1/4	380.5±7.73	69.2±0.58	77.9±1.02	85.9±0.42	77.8±0.47	52.2±0.60
7p	4	3/3	421.7±7.88	76.8±0.64	78.0±0.81	88.3±0.52	77.6±0.46	61.4±0.61
7p	5	3/2	380.5±7.73	69.2±0.58	77.9±0.71	93.9±0.49	77.8±0.47	52.2±0.60
7p	6	3/1	341.5±7.32	61.6±0.52	77.9±0.73	93.8±0.51	77.9±0.44	44.4±0.44
7p	7	2/3	380.5±7.73	69.2±0.58	78.0±0.86	88.4±0.44	77.8±0.47	52.2±0.60
7p	8	1/2	307.0±5.49	53.9±0.39	77.5±0.95	93.8±0.58	78.0±0.43	37.4±0.30

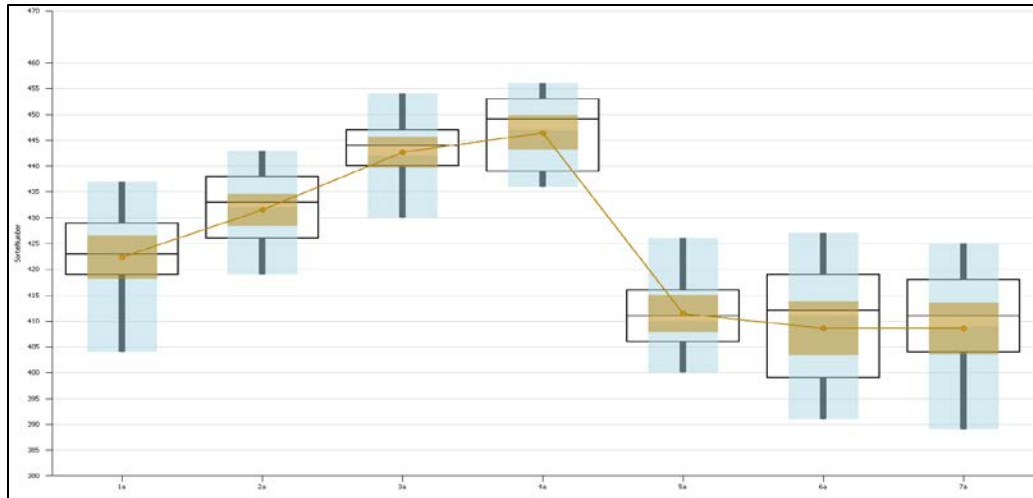


Figure 15. Model 7a Scenarios Comparison Analyses

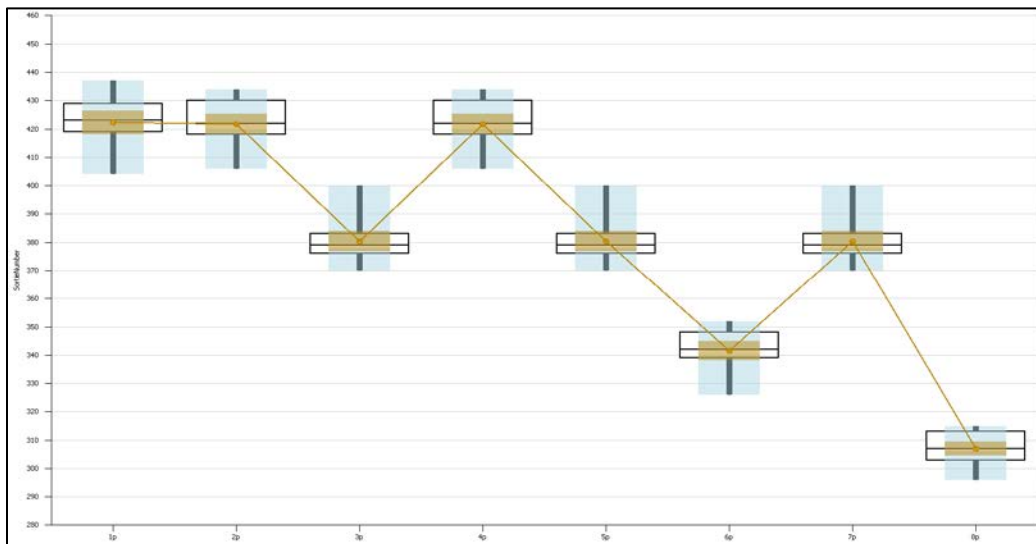


Figure 16. Model 7p Scenarios Comparison Analyses

Models 5a, 6a, and 7a follow similar trends and observations seen in the previous models that explore abort rate effects. Likewise, results from models 5p, 6p, and 7p closely resemble responses found in the previous models that examine the influence of personnel availability. Key insights from this analysis are discussed further in the next summary section of this chapter. Changes in abort rates, personnel availability, and the

usage of mission planning have been explored in these results. As explained in the methodology, each model slightly modifies a specific area of the sortie generation process and investigates the impact. For example, in model 6p1, the mission planning cell is removed for model 7p1 resulting in an increase of around 85 missions. These impacts are further explained in Chapter 5.

4.3. Summary

These models allow decision makers to assess the impact certain situations have on fighter squadrons. By utilizing all of these models which cover various variables in different scenarios, a commander can gain valuable insight on the impact of changes in these factors. They give a basis for planners and schedulers to see how changes in circumstances affect the sortie generation process. For example, a randomized schedule seen in war time scenario forces squadrons to generate more missions. In addition, when the mission planning function is removed in the sortie generation process, pilots are able to have more flexibility in their roles allowing an increase in sorties. These results presented many key insights into the overall sortie generation process. As expected, when abort rates are increased, fewer sorties are flown. Additionally, when the number of instructors and four ship leaders are altered, the squadron must adjust to these personnel changes. An overall comparison between all models is presented in Appendix A.

Having this level of quantitative analysis through simulation gives fighter squadrons major insights on how to properly conduct sortie operations both in peacetime and wartime situations. This study puts numbers with logical patterns in results. The impact and significance of this analysis is further explored in Chapter 5.

V. Conclusions and Recommendations

5.1. Chapter Overview

This chapter concludes major points discussed in this research. In the first chapter, the main problem is defined with critical investigative questions. Then, studies concerning the sortie generation process, scheduling and simulation are discussed in the second chapter. Next, a description of produced models is explained and model improvements. Finally, the previous chapter defines results from the performed analysis. After forming the problem, determining the methodology, and analyzing the results, conclusion and recommendations are made. This section now summarizes the impact and significance of these findings. In addition, suggestions and recommendations for future research are included.

5.2. Conclusions of Research

The main purpose of this study was to create reasonable simulation models representing the sortie generation process for a fighter squadron. The models are run through Simio and could provide value as a tool for Air Force planners and operators. Important investigative questions are answered by altering and adjusting various model parameters and running comparisons. For example, the effects of abort rates have been considered by adding them to a baseline model. It's noted that sortie numbers drop significantly as abort rate rise. Furthermore, various "What-If" scenarios are run in these analyses. Final findings on the effects of certain features are summarized in Table 26 below.

Table 26. Model Feature Modifications and Effects

	Abort Rates	InstNum	FourShipNum	SortieNum	AcftUtil	InstPilot	FourshipLdr	TwoshipLdr	Wingman
Change	↑	↔	↔	↓	↓	↓	↓	↓	↓
	↓	↔	↔	↑	↑	↑	↑	↑	↑
	↔	↓	↔	↓	↓	↑	↑	↔	↓
	↔	↔	↓	↓	↓	↑	↑	↔	↓
	↔	↓	↓	↓	↓	↑	↑	↔	↓
	↔	↓	↓	↓	↓	↑	↑	↔	↓

The features highlighted in green are modified in the various models and scenarios. The effects examined from the output of the simulation are highlighted in blue. Also, we observed that removal of mission planning function provided the ability to generate more sorties. The significance and impact of these findings are now explained.

5.3. Significance and Recommendations

A proper method for efficient sortie generation is critical for a high performing fighter squadron. The research conducted in this study explores many insights that can assist key decision makers towards this goal. This simulation gives planners a basis to make calculations on required missions, aircraft, and personnel according to their pilot ratings. These findings give personnel the confidence to make improved decisions with quantitative support.

This tool is not only useful at the tactical level, but can be used in other fields as well. Some of the diverse areas where this research can be applied are listed:

- Providing improved estimates of aircraft and pilot requirements when creating new squadrons,
- Serving as a baseline for personnel and aircraft estimates before deployments,

- Informing policy-makers on modifying specific functions in the sortie generation process to improve sortie numbers/utilizations,
- Giving supporting numerical information during modernization efforts where abort rates are guaranteed to be affected,
- Observing the effect on the sortie numbers during times of conflict where there are dynamic changes in personnel and aircraft,
- Assisting in the analysis of the effects that pilot ratings and crew rest have on sortie numbers and the overall squadron status.

5.4. Recommendations for Future Research

The model can be enhanced by increasing the scope of this simulation. A simplified baseline sortie generation process was modeled. The number of missions, pilots, aircraft and blocks are limited. By increasing these numbers with minor logic changes in the model, more representative system performance could be captured. Scheduling is created using a DSS or randomly. In future studies, the schedules can be created automatically.

In this study, the sortie generation model was generated and ran in Simio for a fighter squadron. It can be transformed for transportation squadrons. Furthermore, this simulation model can be used for the simulators to see the effect of these centers in sortie generation during training phases. Future research can include generating models based on deploying to unique geographical locations that are much different than your current climate such as desert. The crew rest may change during the conflicts and this change can be plugged into a different model and see the results compared to the baseline model. This study modeled the SOF and RSU for the ground duties. Future studies may focus on the BO and SIM as well.

Appendix. In Depth Analysis of Models

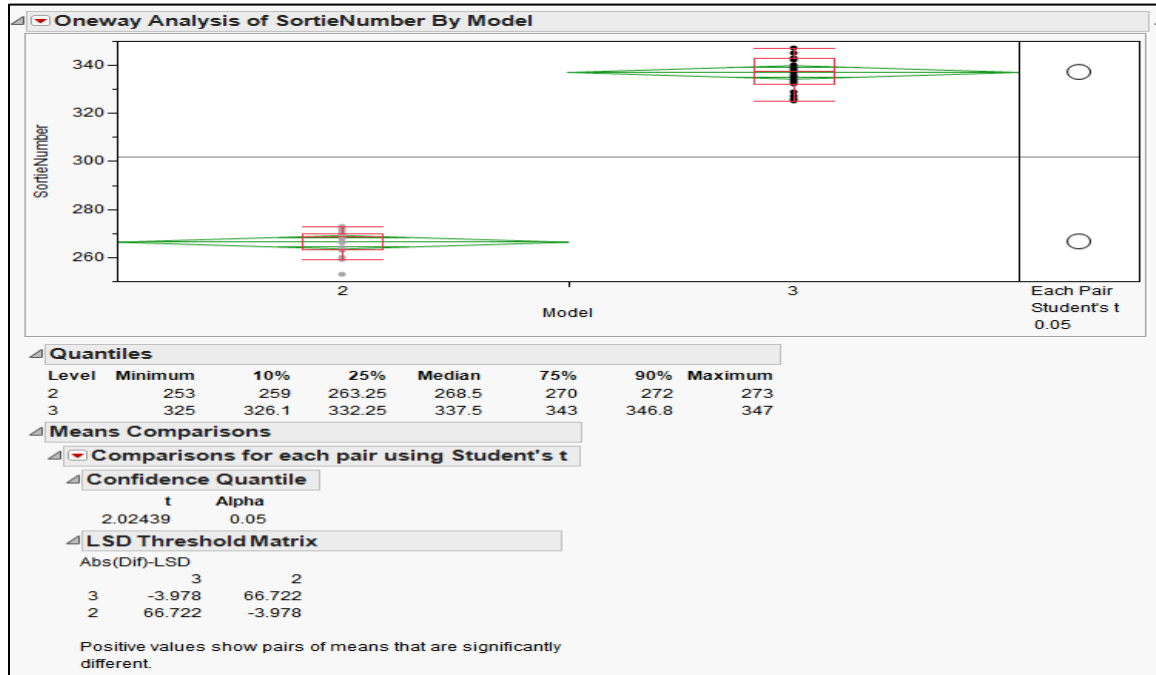


Figure 17. Model 1 and Model 2 Comparison Analyses of Sortie Number

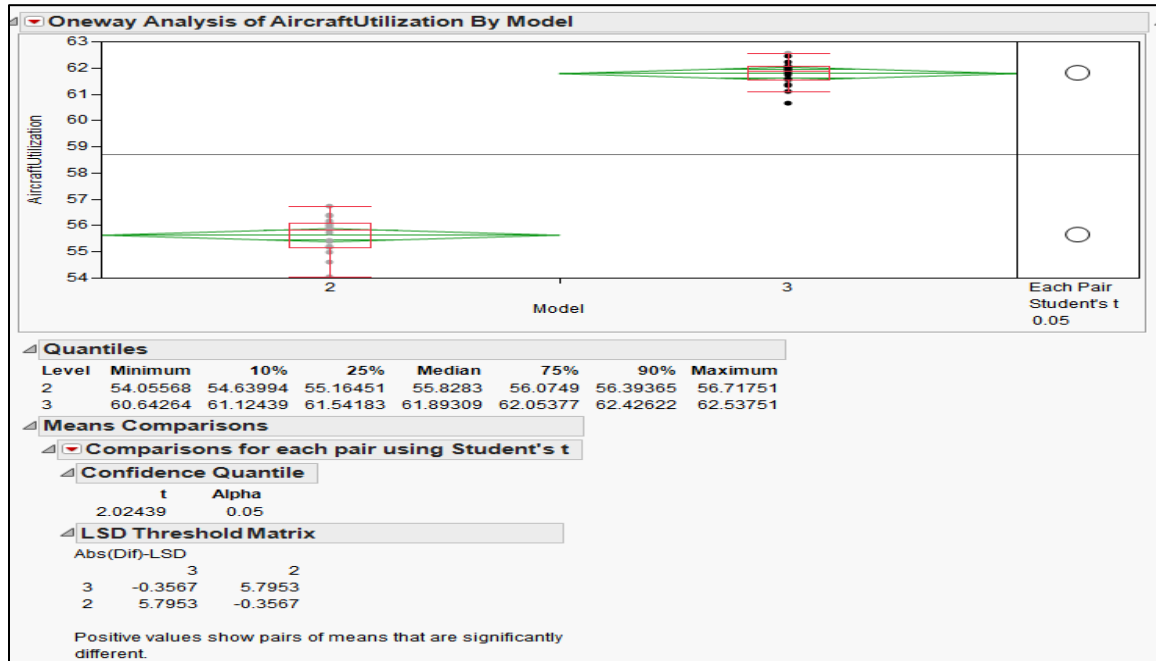


Figure 18. Model 1 and Model 2 Comparison Analyses of Aircraft Utilization

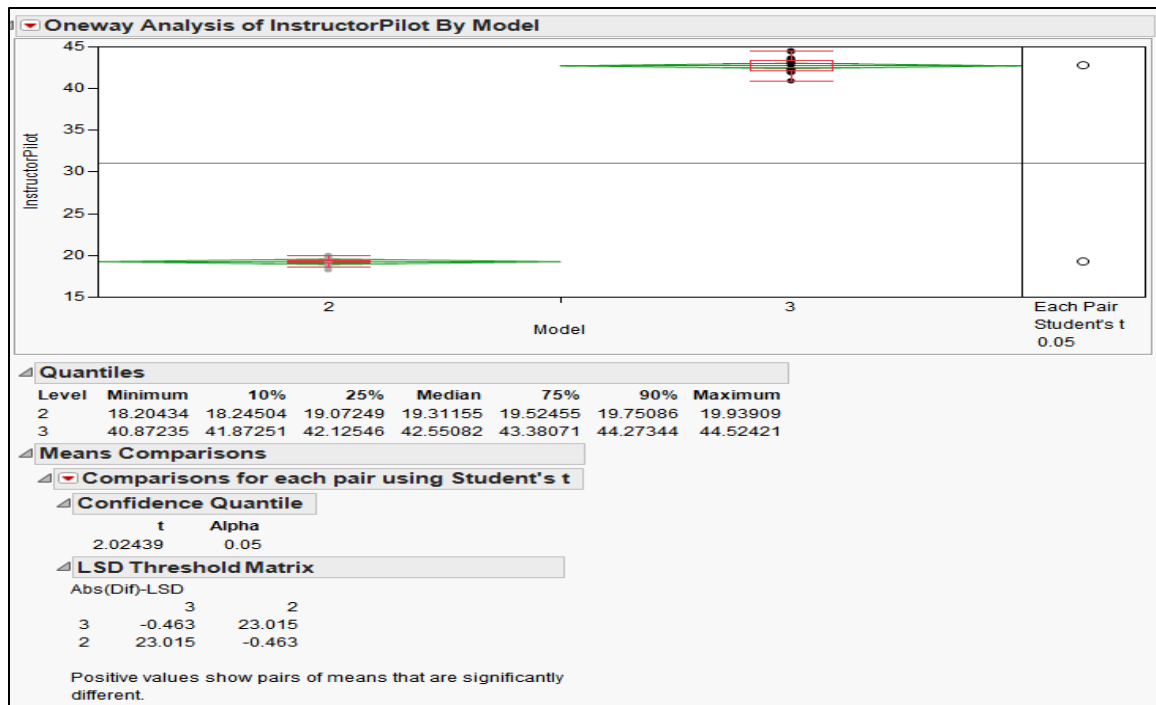


Figure 19. Model 1 and Model 2 Comparison Analyses of Instructor Pilot

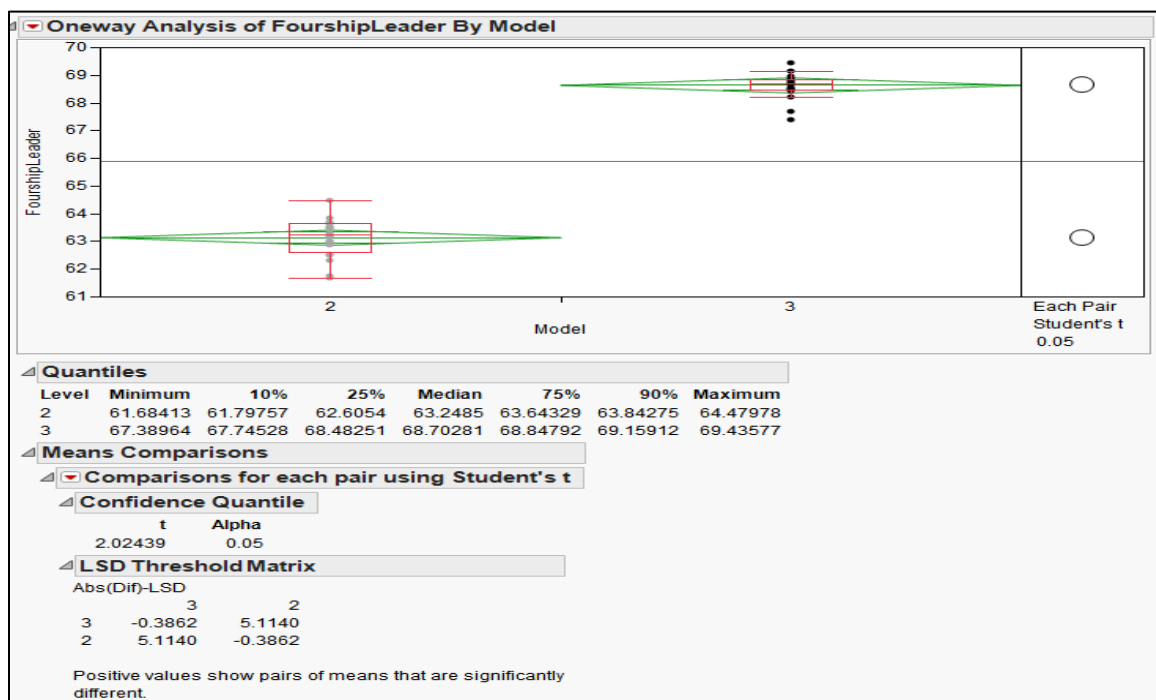


Figure 20. Model 1 and Model 2 Comparison Analyses of Four Ship Leader

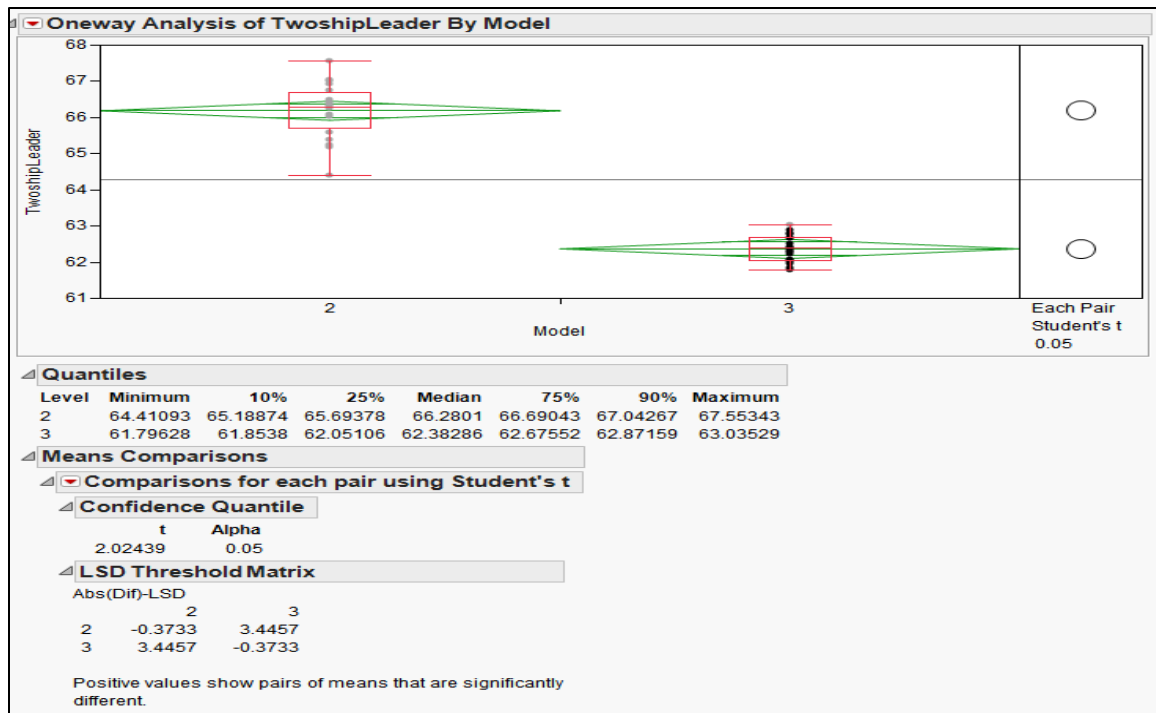


Figure 21. Model 1 and Model 2 Comparison Analyses of Two Ship Leader

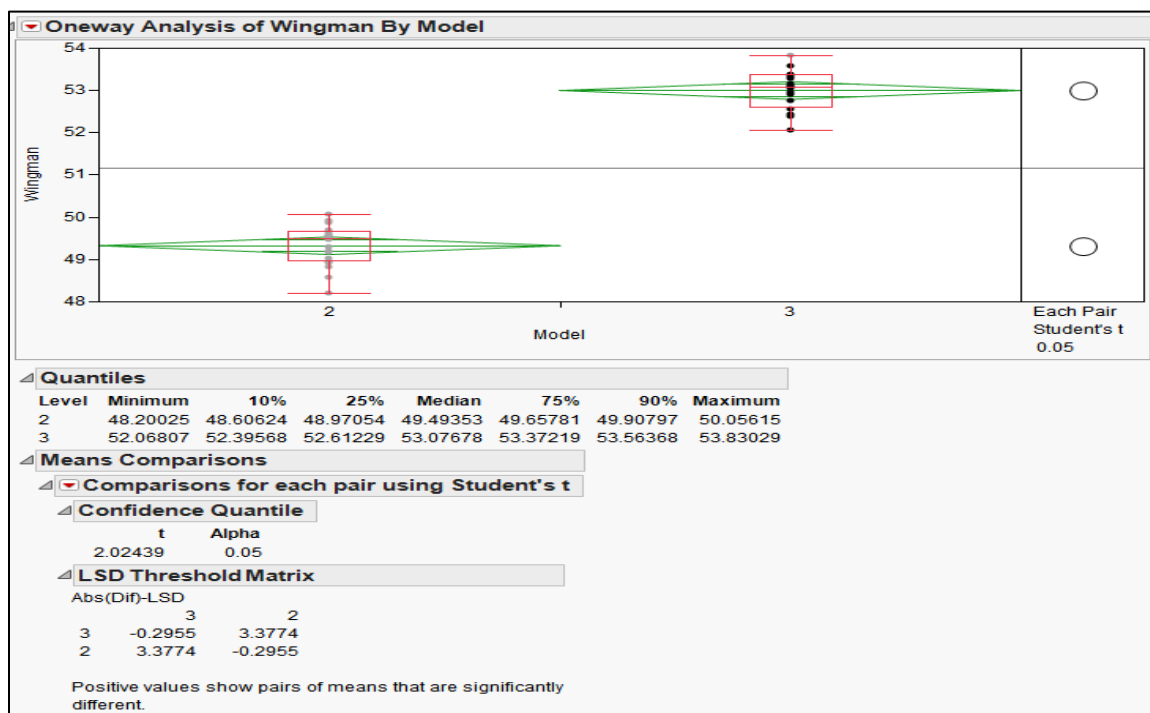


Figure 22. Model 1 and Model 2 Comparison Analyses of Wingman

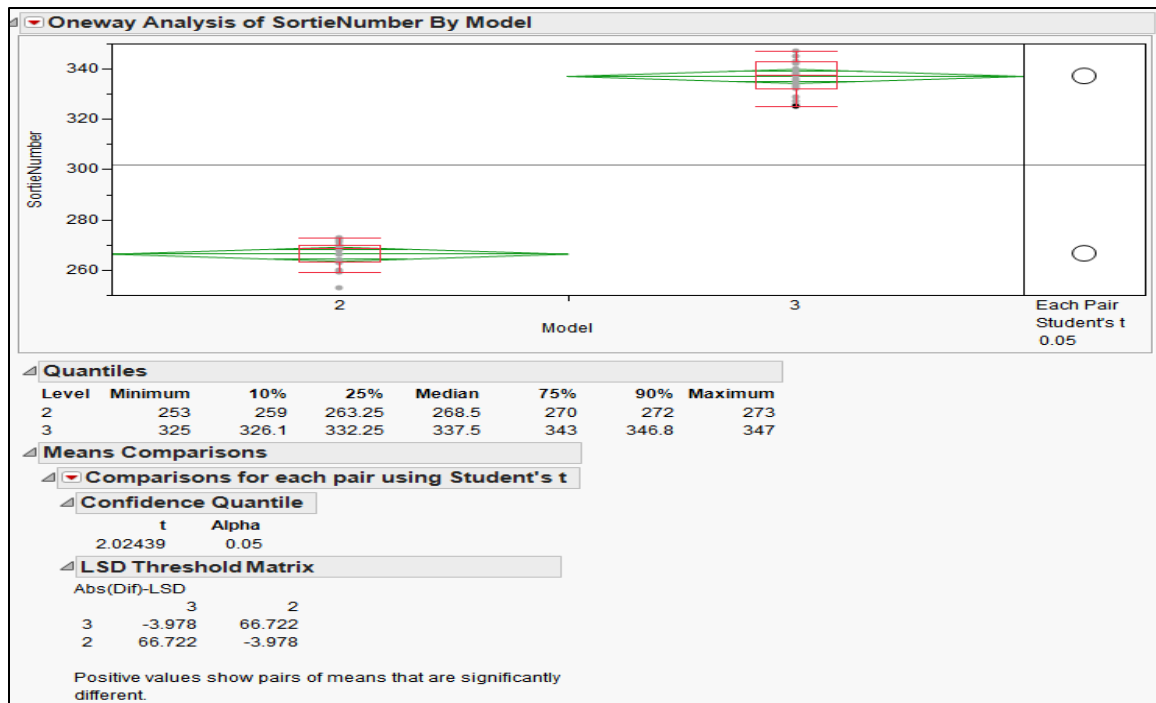


Figure 23. Model 2 and Model 3 Comparison Analyses of Sortie Number

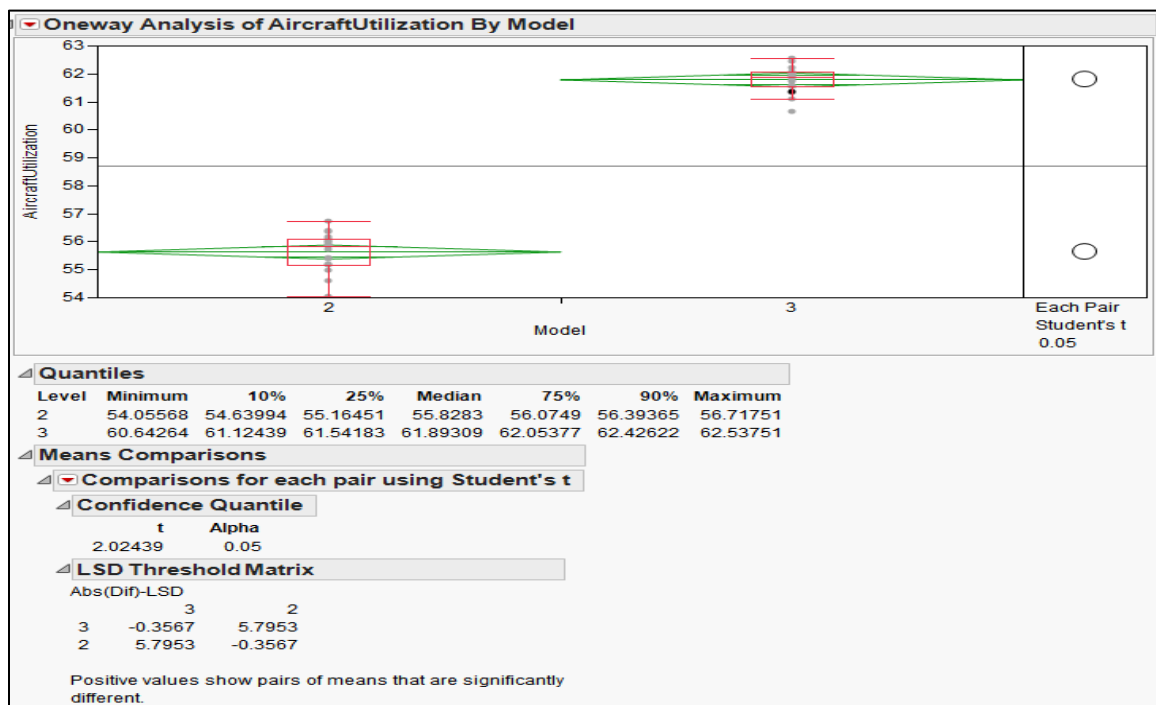


Figure 24. Model 2 and Model 3 Comparison Analyses of Aircraft Utilization

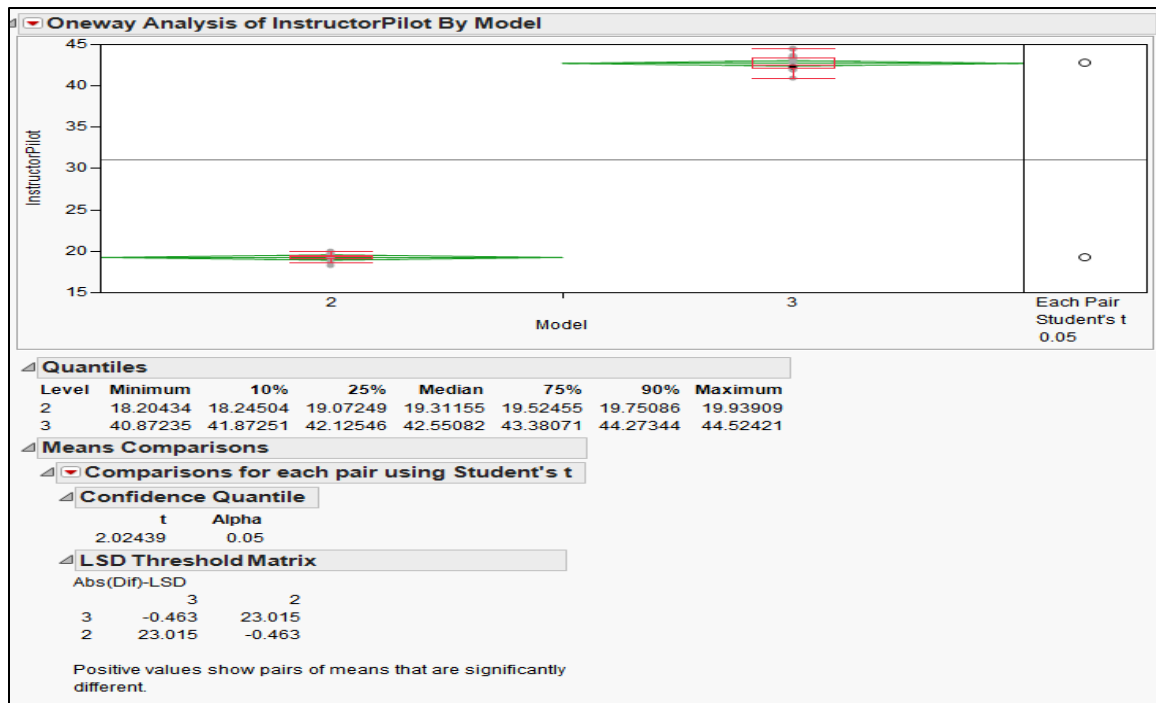


Figure 25. Model 2 and Model 3 Comparison Analyses of Instructor Pilot

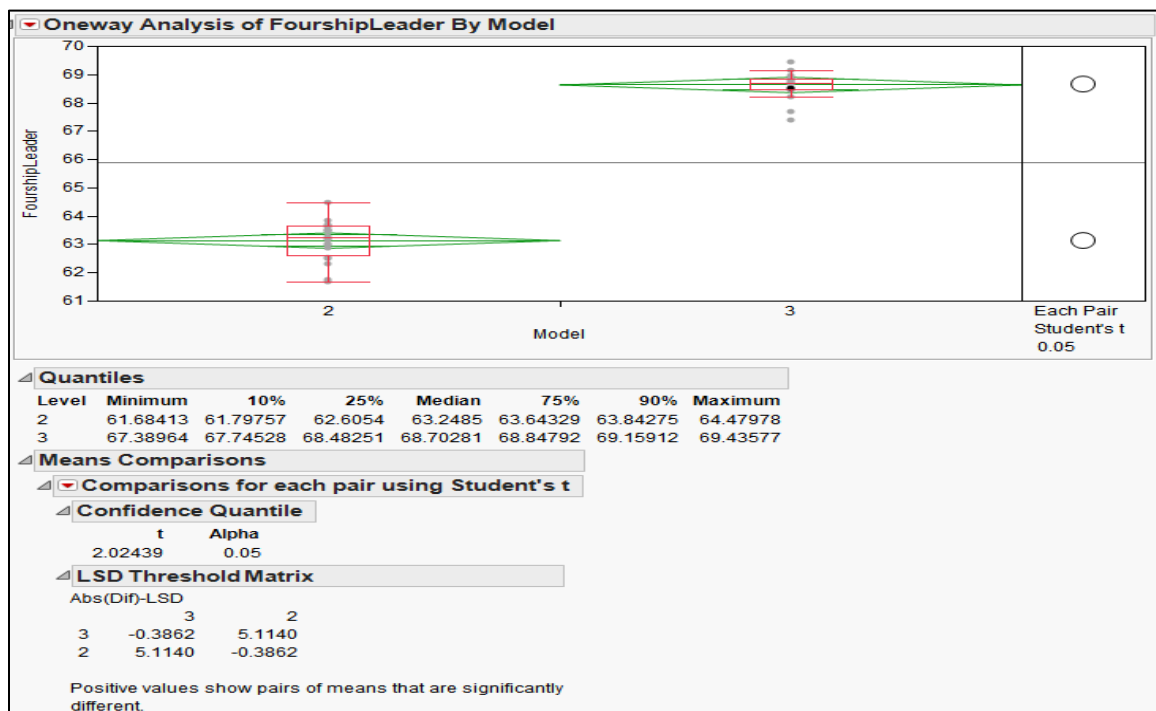


Figure 26. Model 2 and Model 3 Comparison Analyses of Four Ship Leader

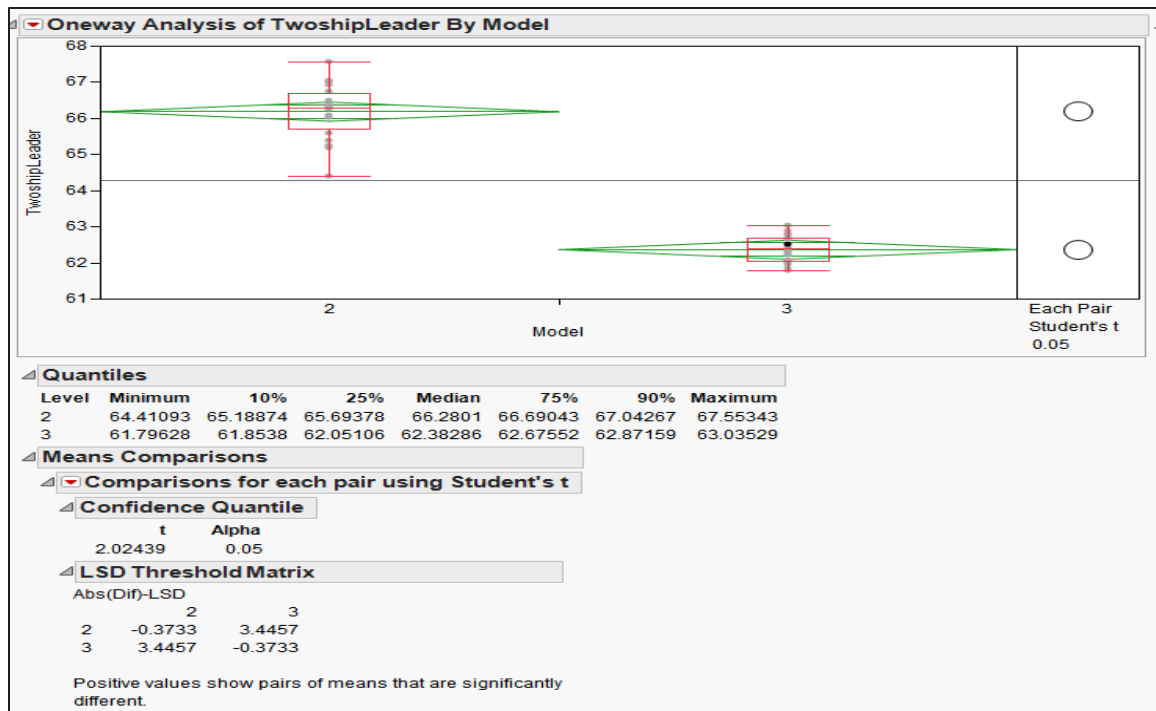


Figure 27. Model 2 and Model 3 Comparison Analyses of Two Ship Leader

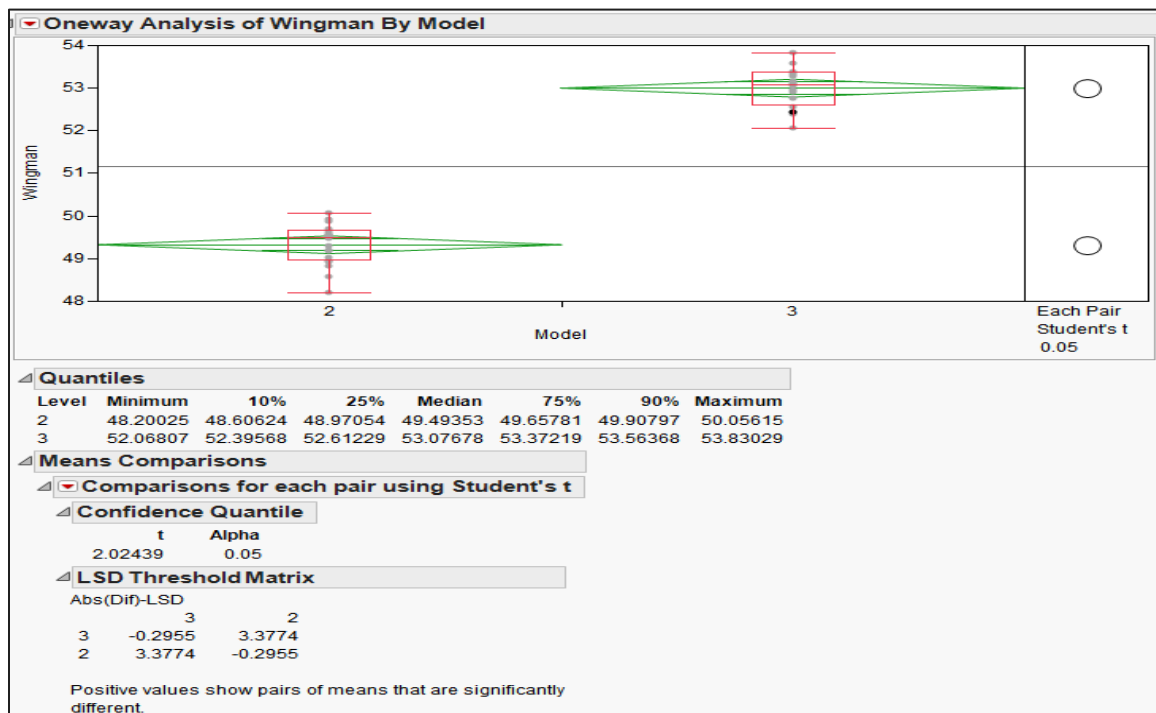


Figure 28. Model 2 and Model 3 Comparison Analyses of Wingman

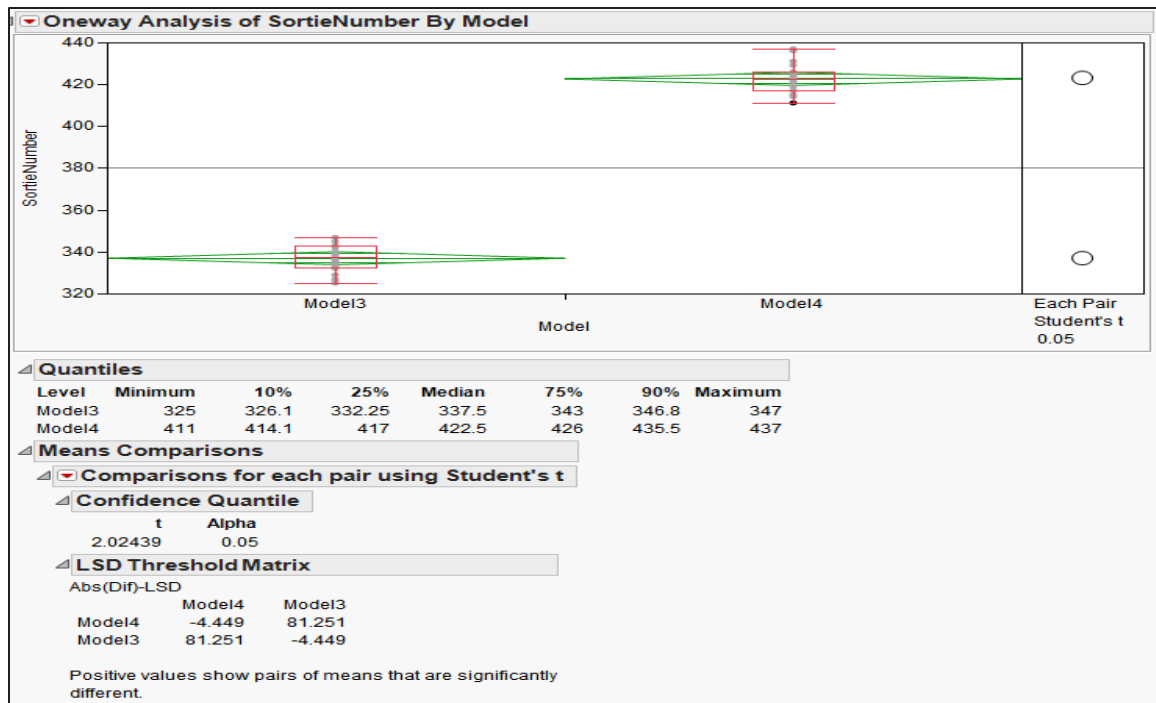


Figure 29. Model 3 and Model 4 Comparison Analyses of Sortie Number

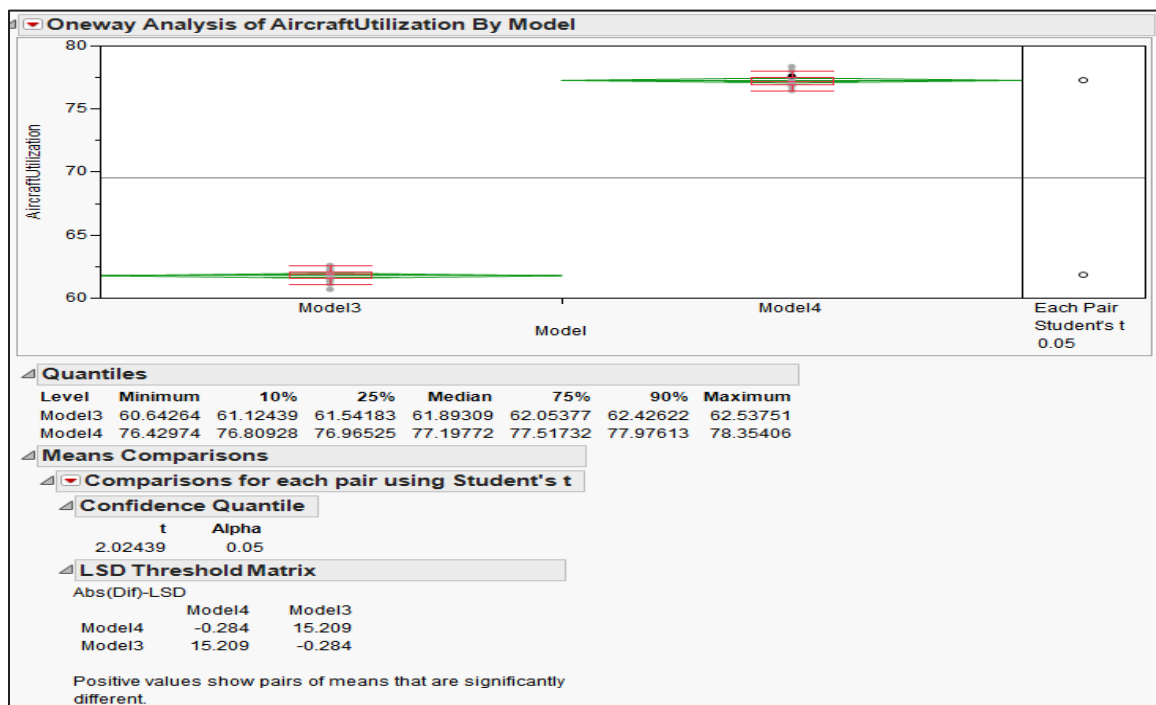


Figure 30. Model 3 and Model 4 Comparison Analyses of Aircraft Utilization

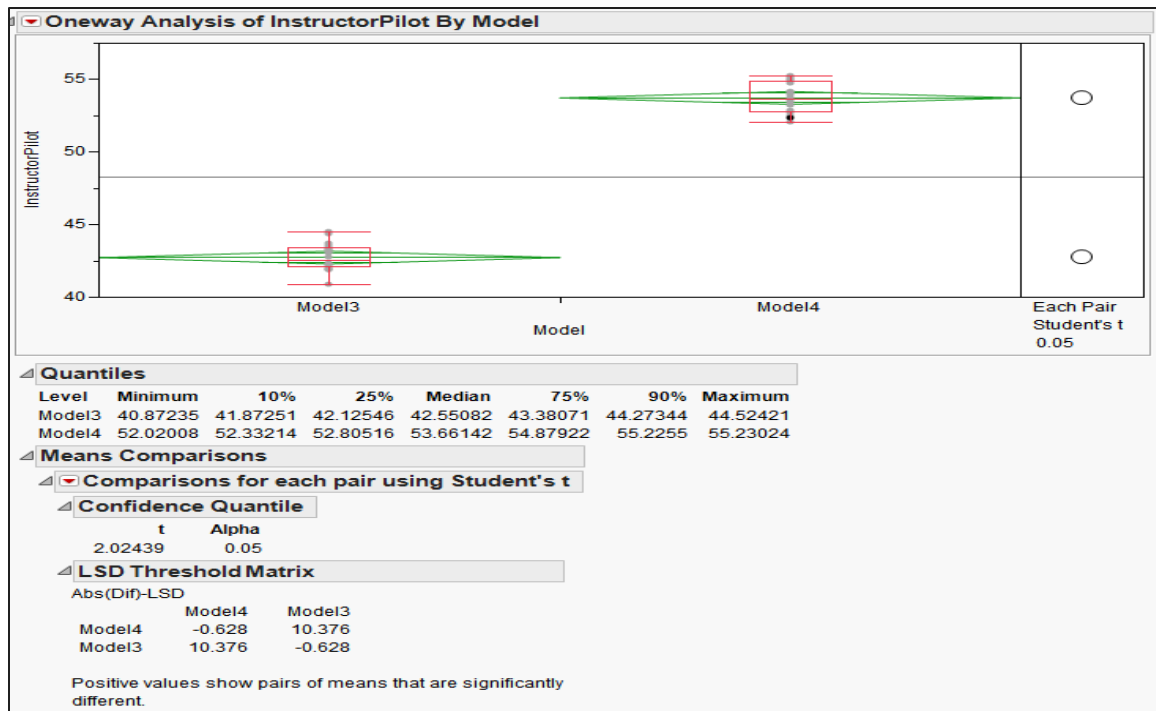


Figure 31. Model 3 and Model 4 Comparison Analyses of Instructor Pilot

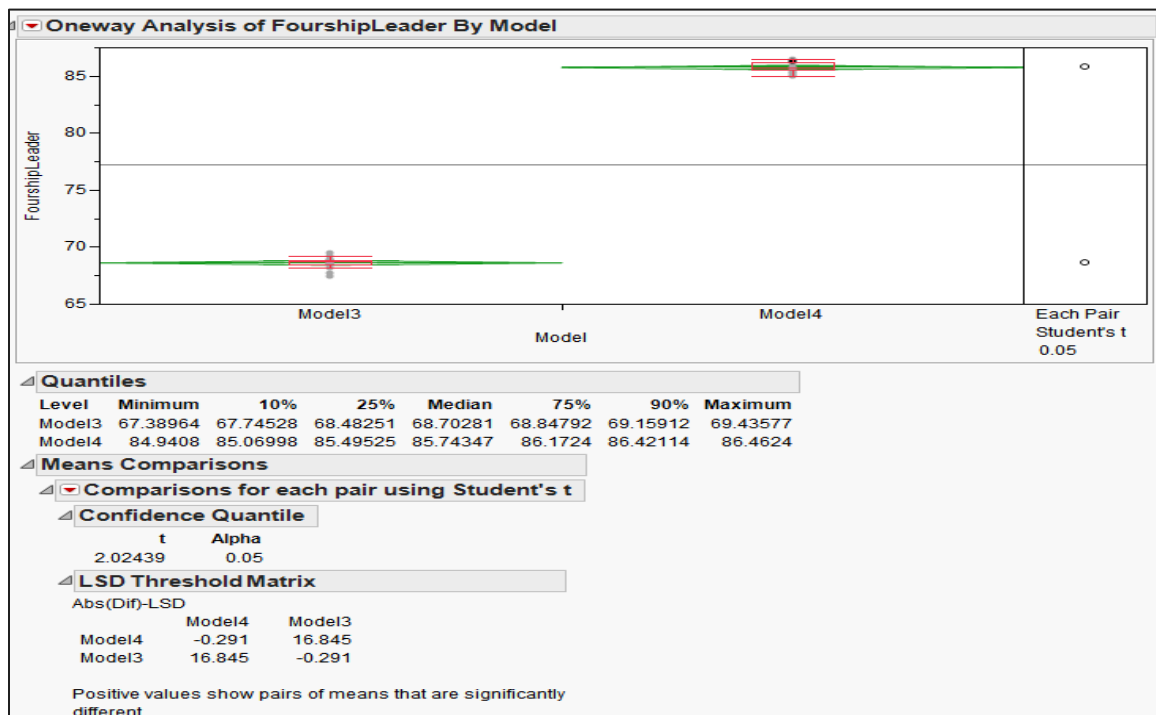


Figure 32. Model 3 and Model 4 Comparison Analyses of Four Ship Leader

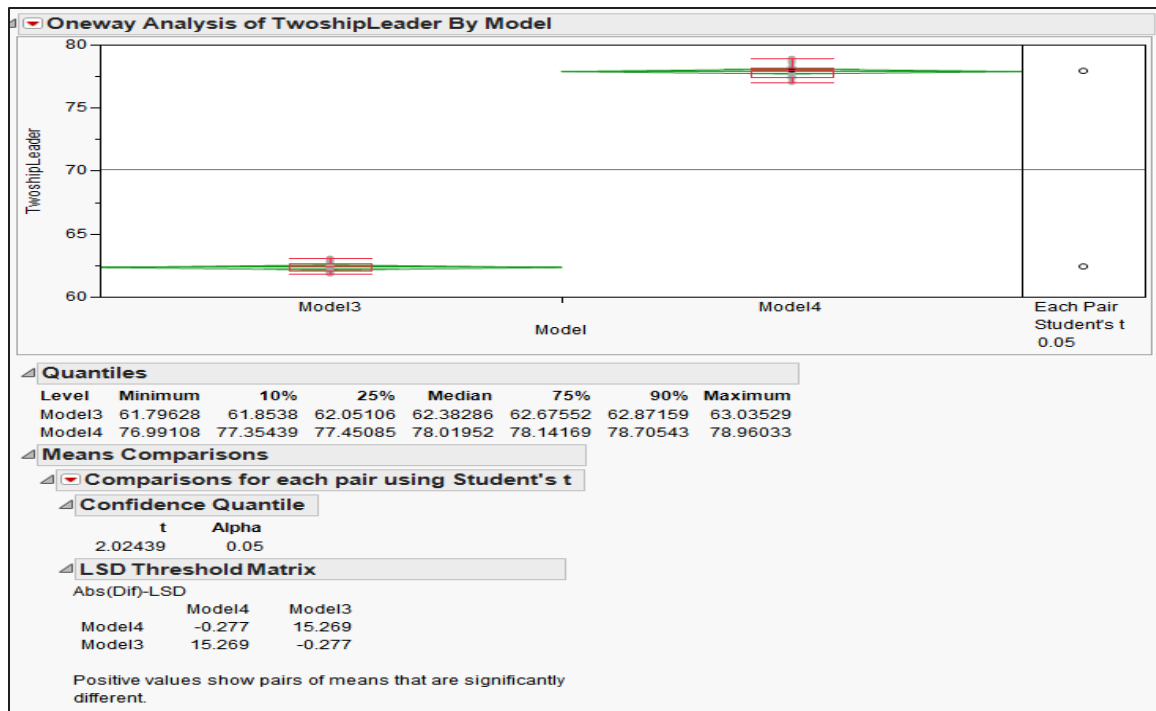


Figure 33. Model 3 and Model 4 Comparison Analyses of Two Ship Leader

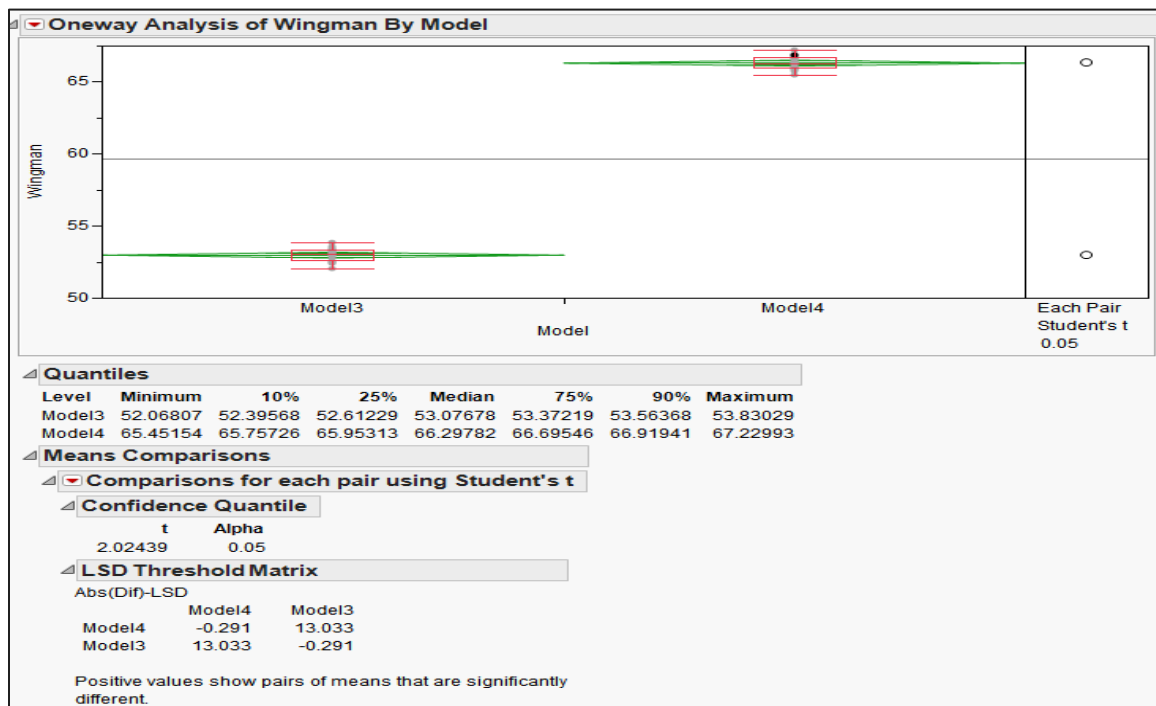


Figure 34. Model 3 and Model 4 Comparison Analyses of Wingman

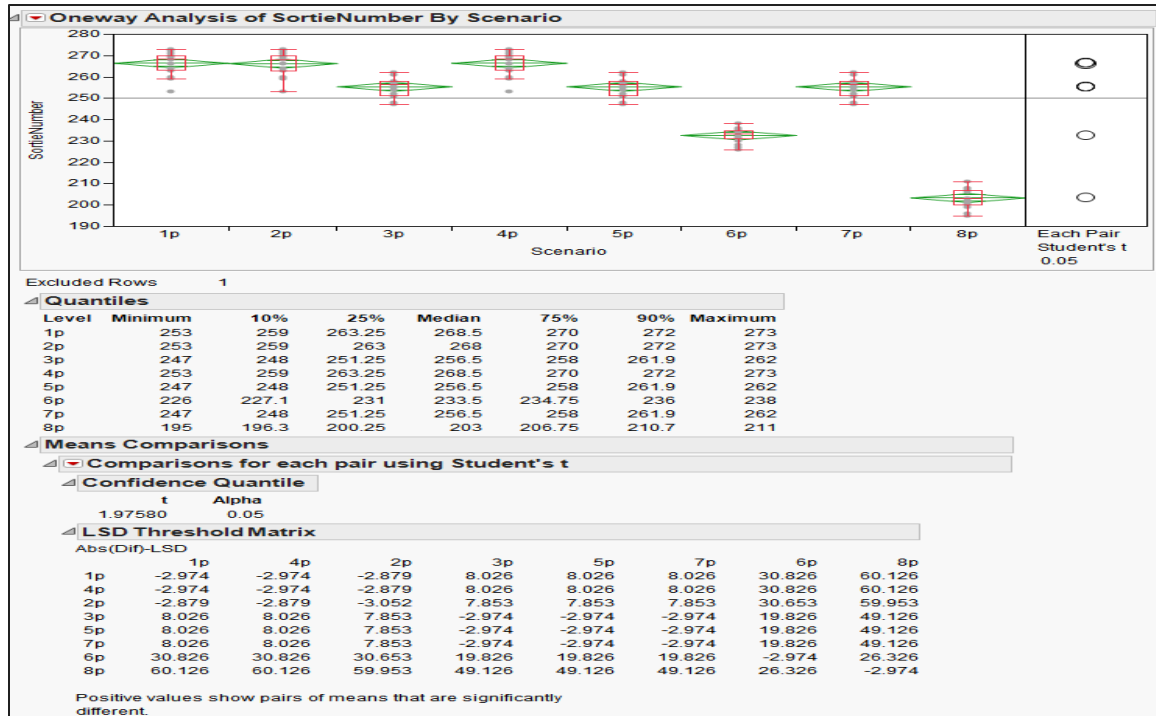


Figure 35. Model 5a Scenarios Comparison Analyses of Sortie Number

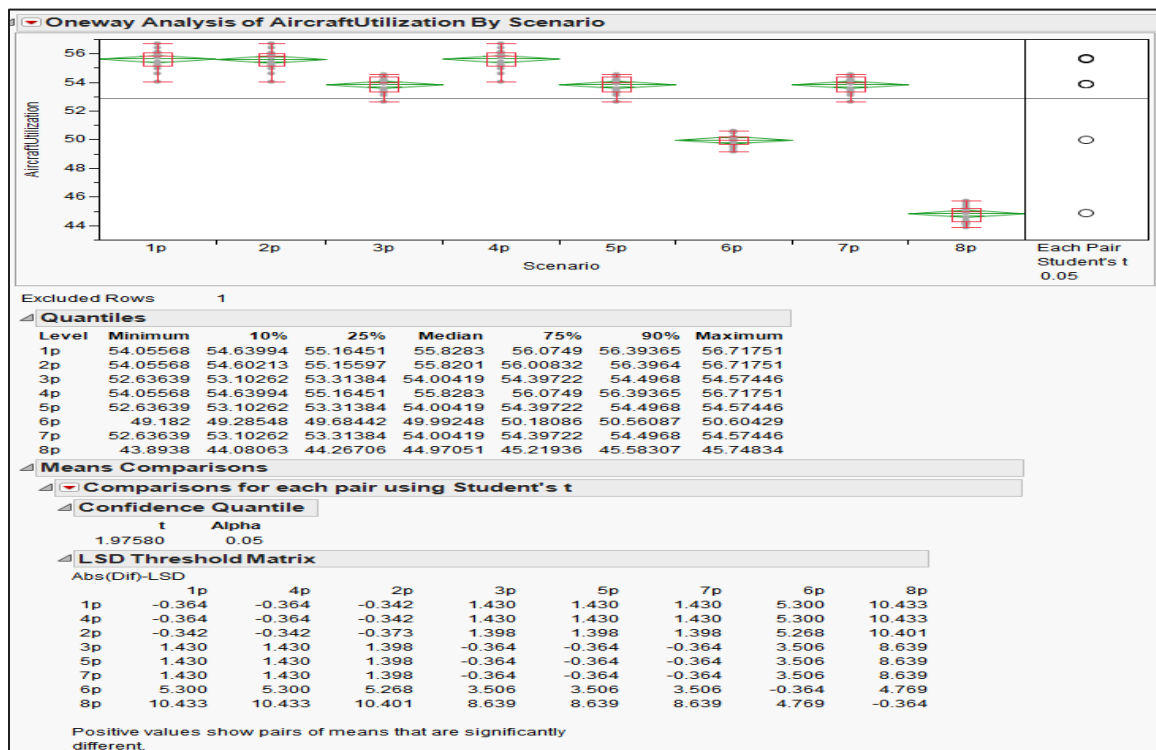


Figure 36. Model 5a Scenarios Comparison Analyses of Aircraft Utilization

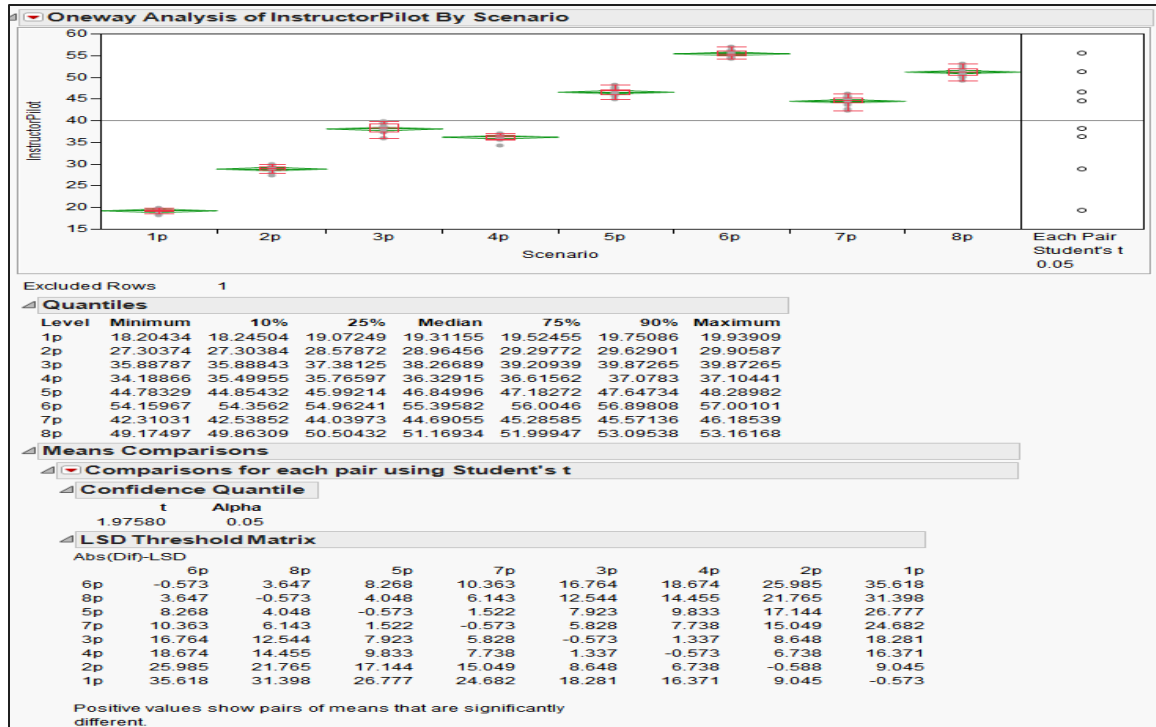


Figure 37. Model 5a Scenarios Comparison Analyses of Instructor Pilot

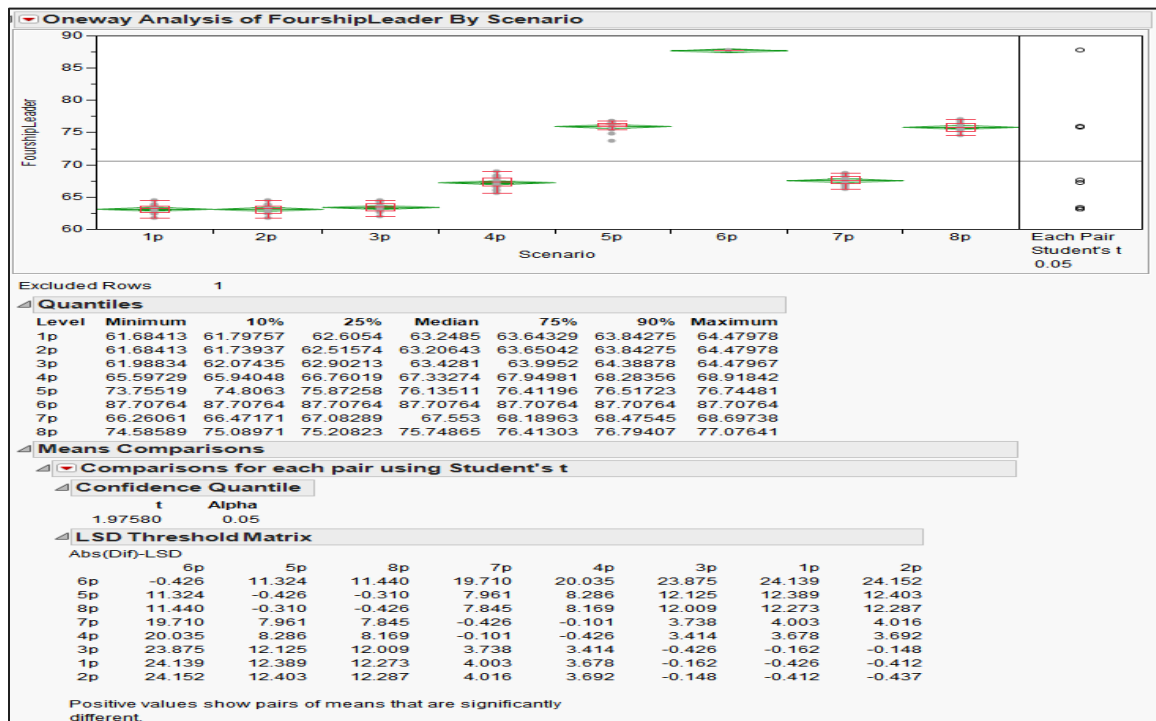


Figure 38. Model 5a Scenarios Comparison Analyses of Four Ship Leader

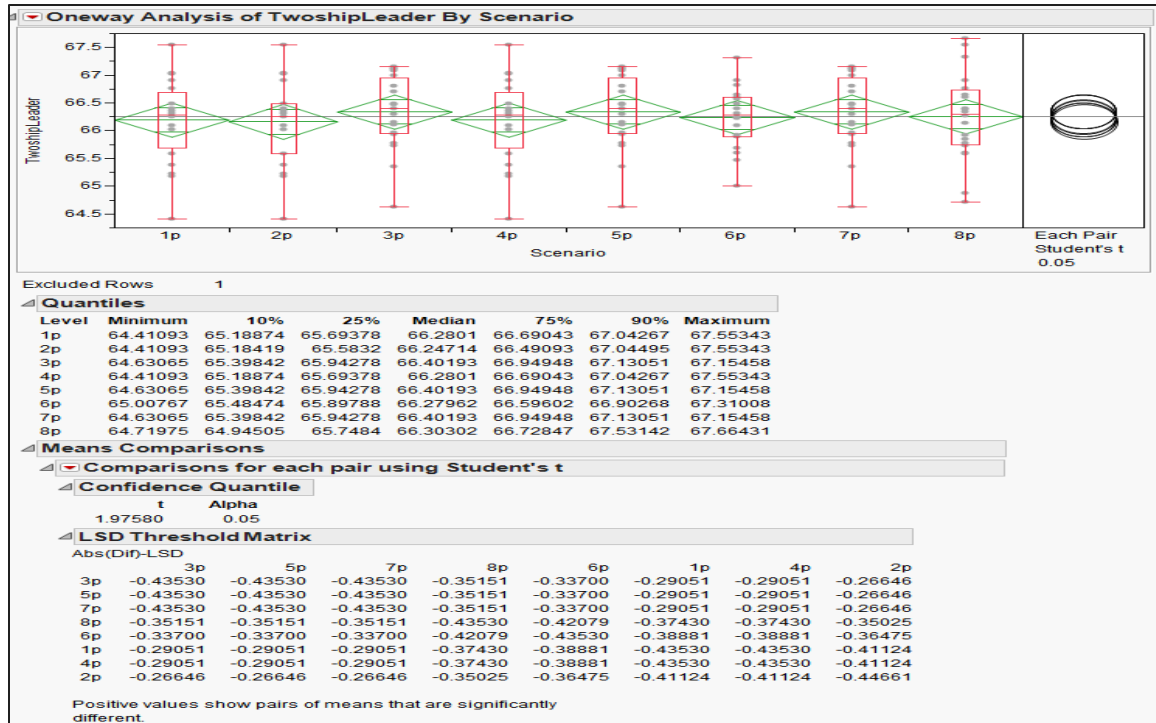


Figure 39. Model 5a Scenarios Comparison Analyses of Two Ship Leader

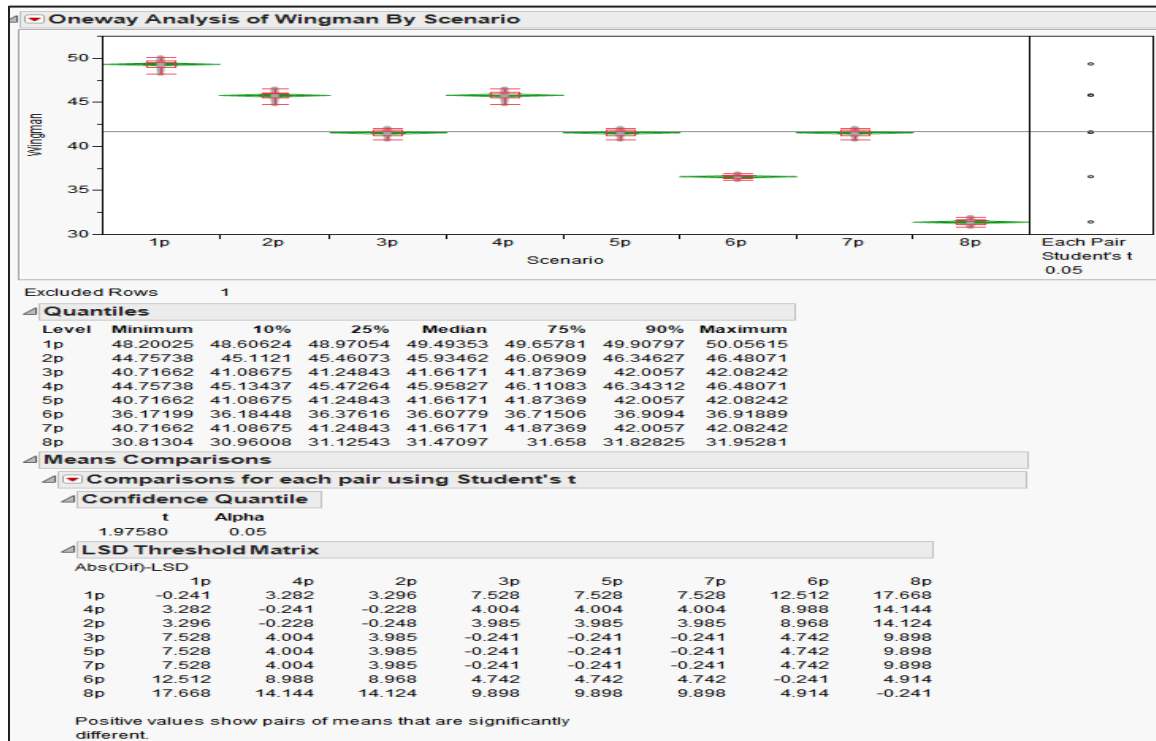


Figure 40. Model 5a Scenarios Comparison Analyses of Wingman

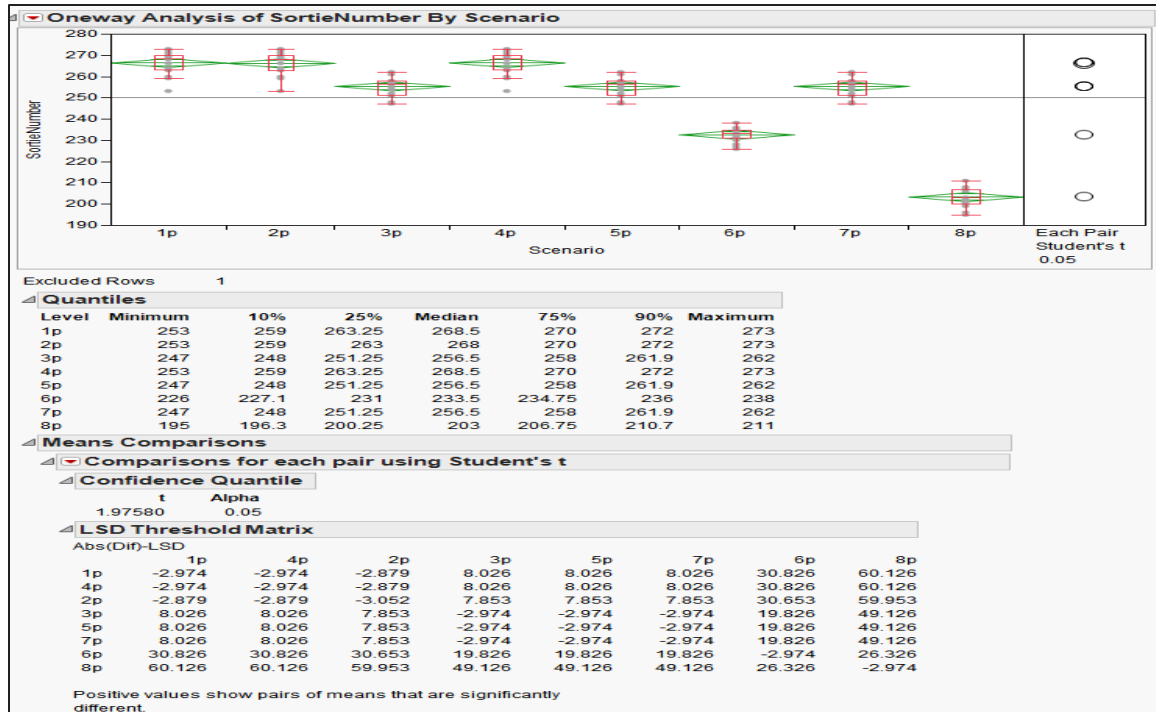


Figure 41. Model 5p Scenarios Comparison Analyses of Sortie Number

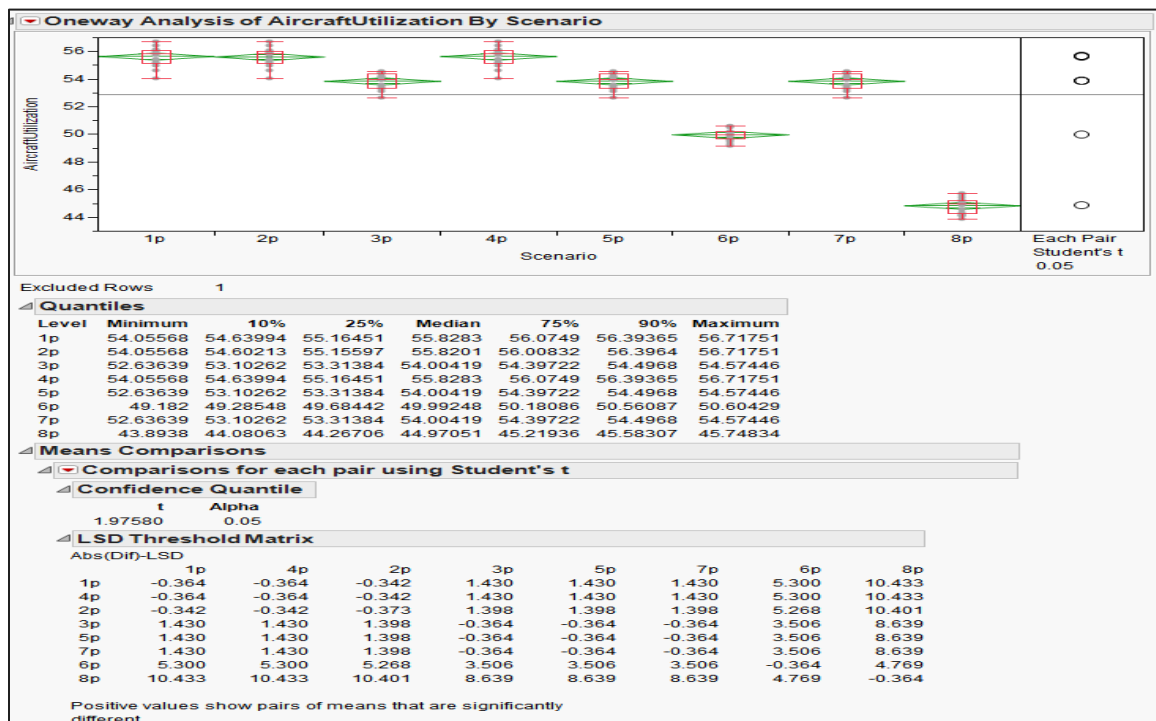


Figure 42. Model 5p Scenarios Comparison Analyses of Aircraft Utilization

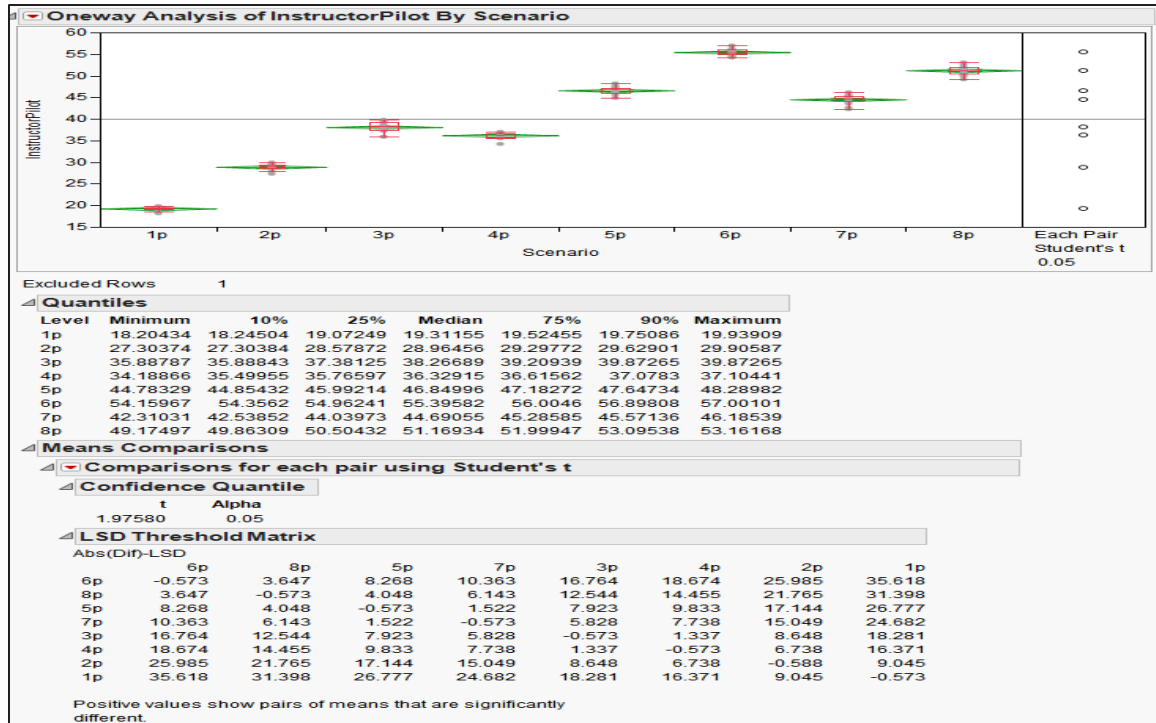


Figure 43. Model 5p Scenarios Comparison Analyses of Instructor Pilot

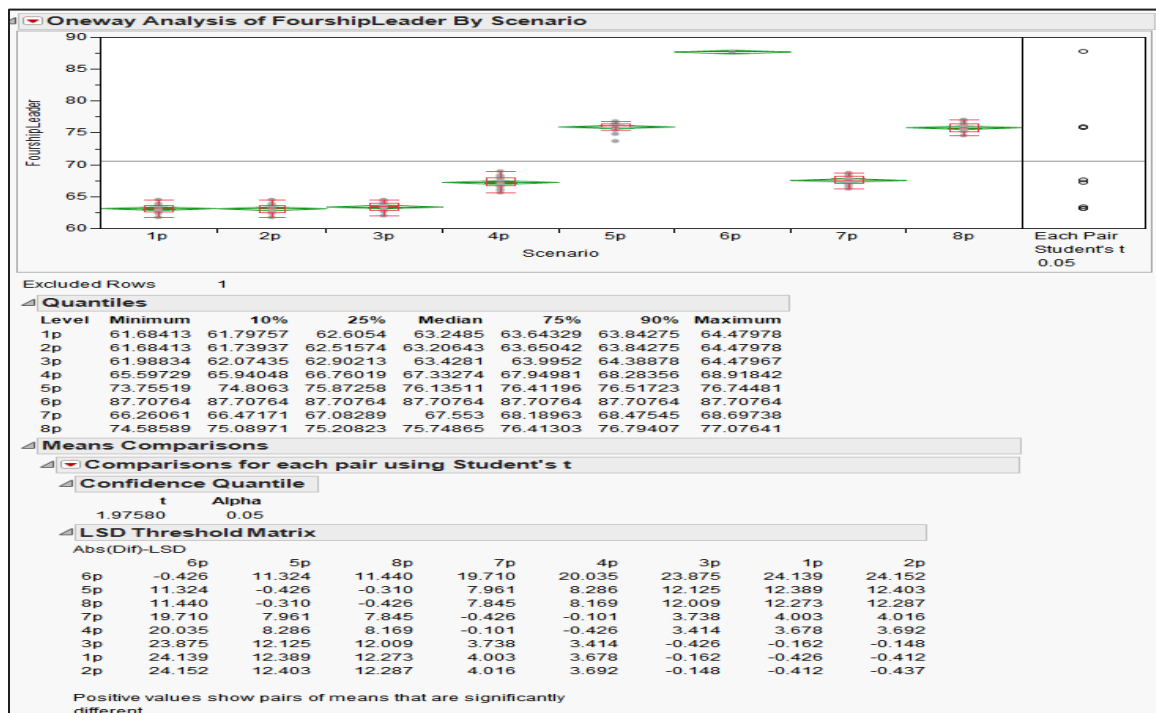


Figure 44. Model 5p Scenarios Comparison Analyses of Four Ship Leader

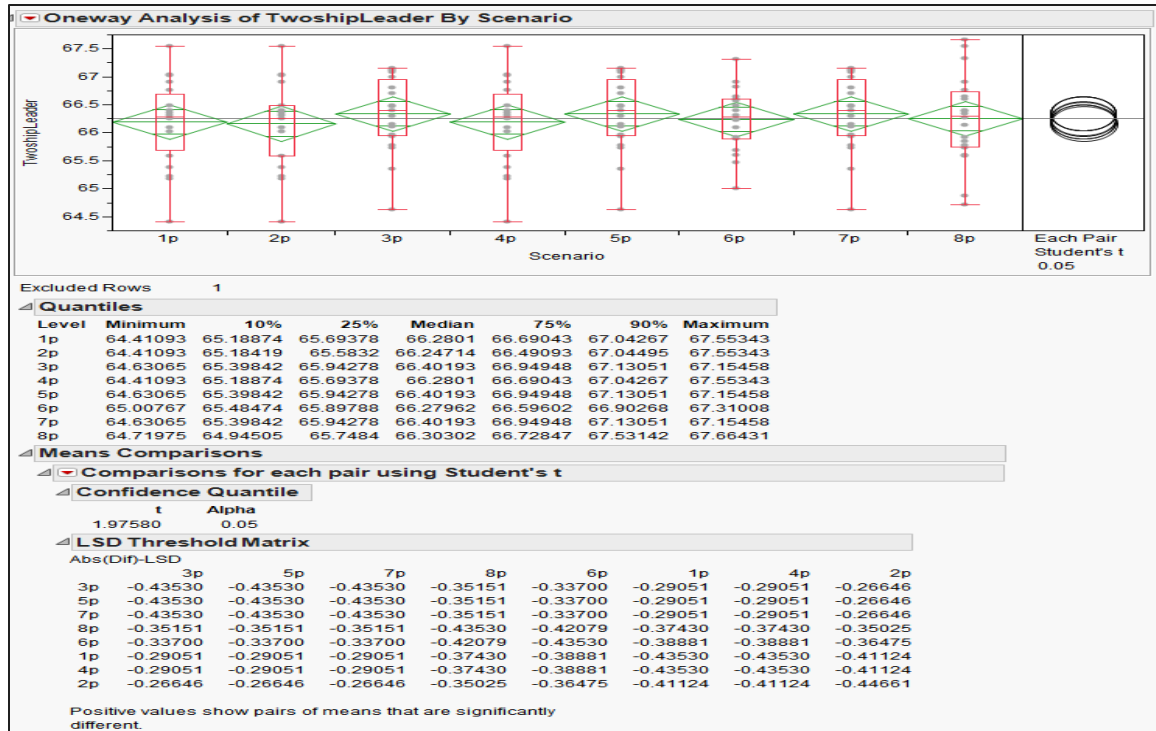


Figure 45. Model 5p Scenarios Comparison Analyses of Two Ship Leader

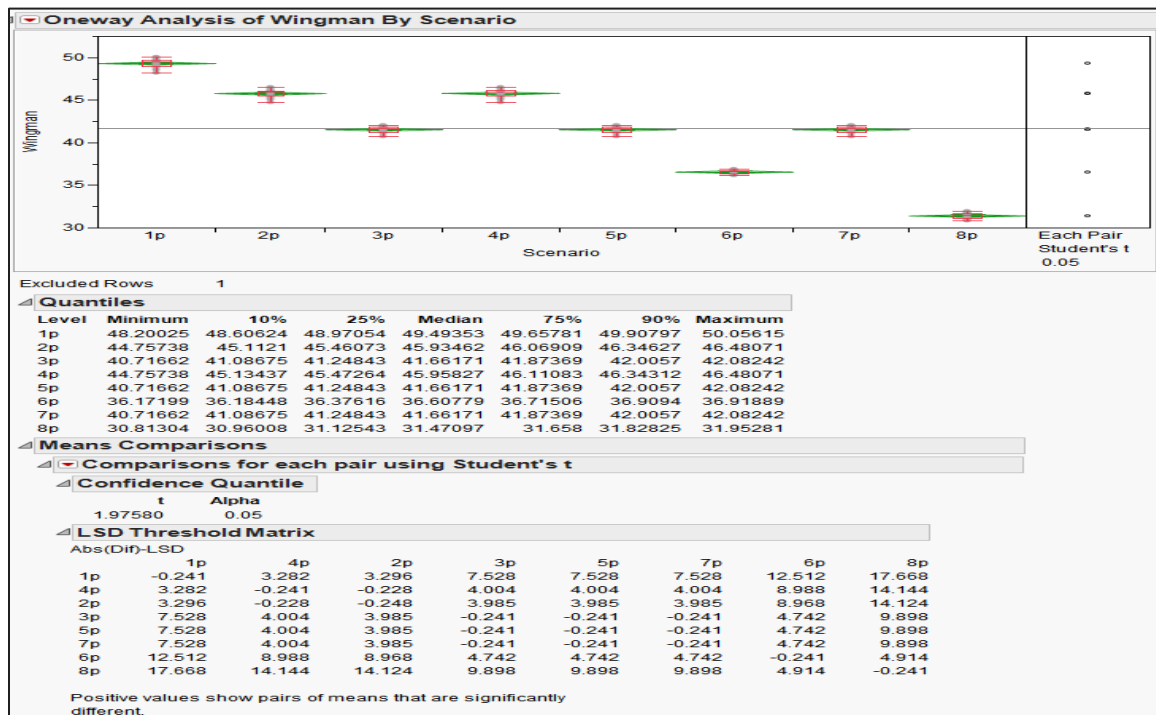


Figure 46. Model 5p Scenarios Comparison Analyses of Wingman

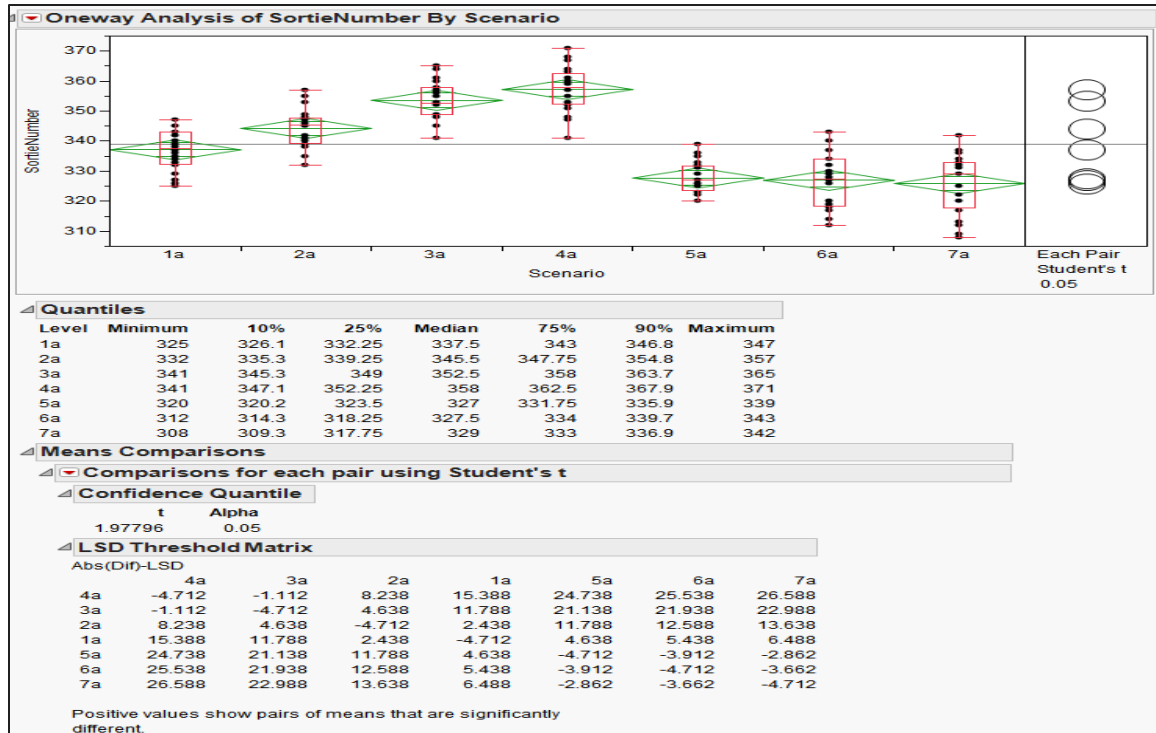


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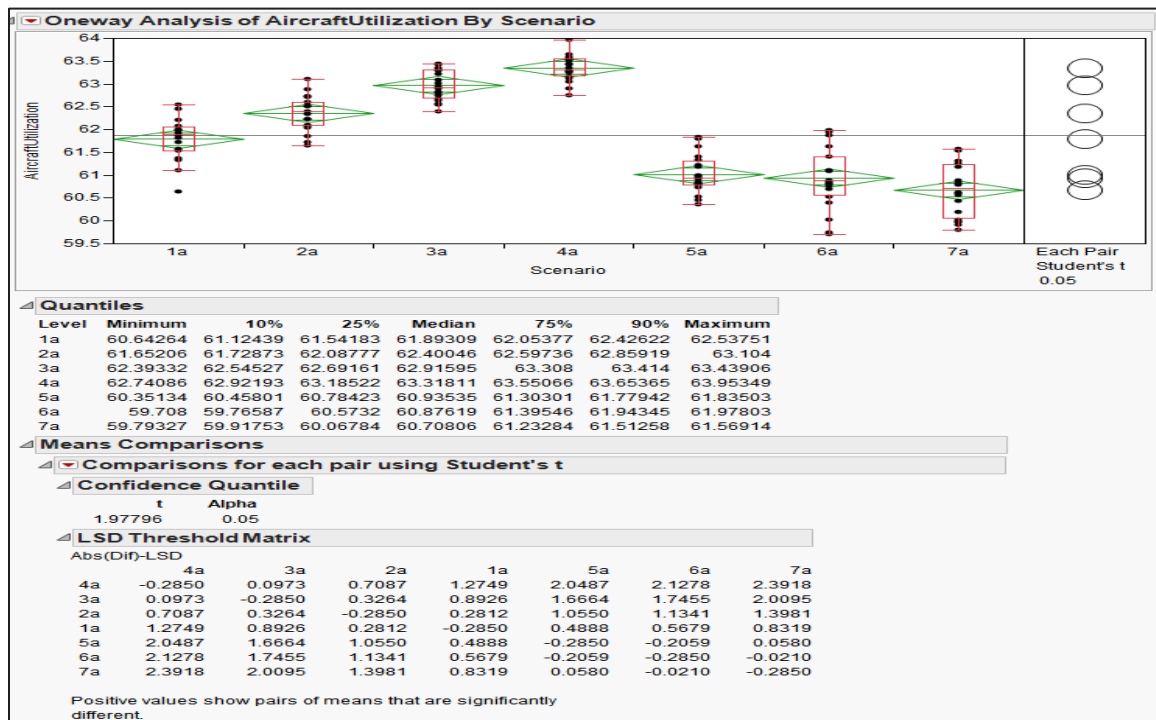


Figure 48. Model 6a Scenarios Comparison Analyses of Aircraft Utilization

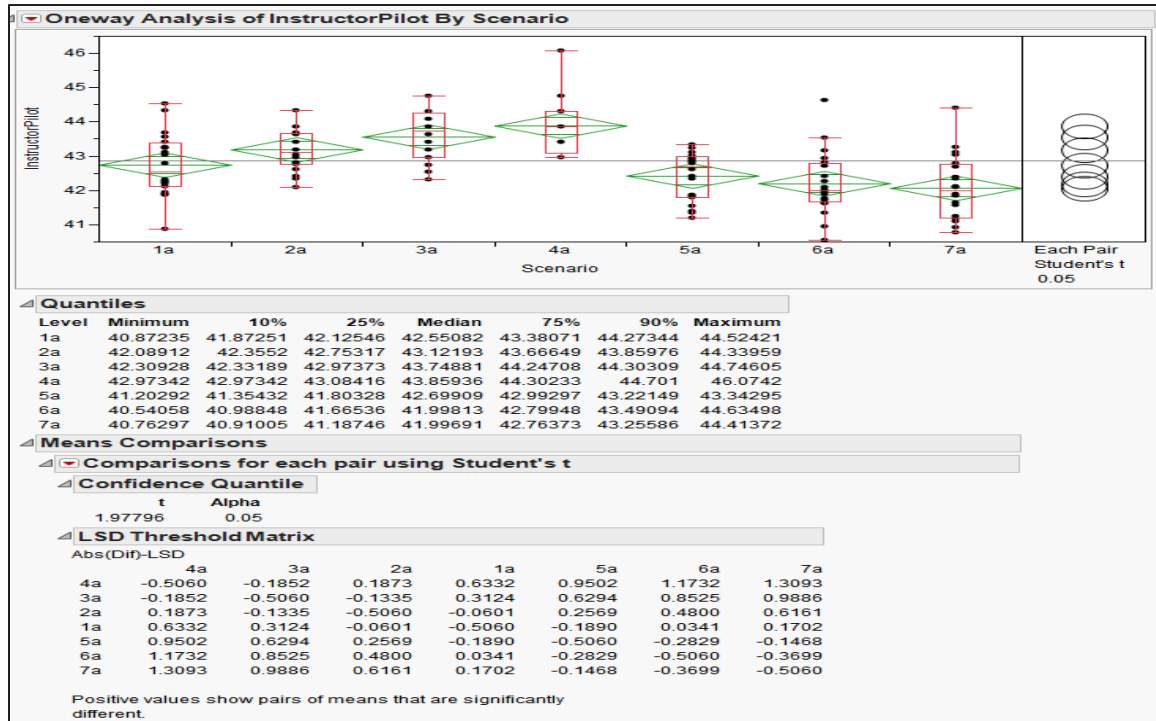


Figure 49. Model 6a Scenarios Comparison Analyses of Instructor Pilot

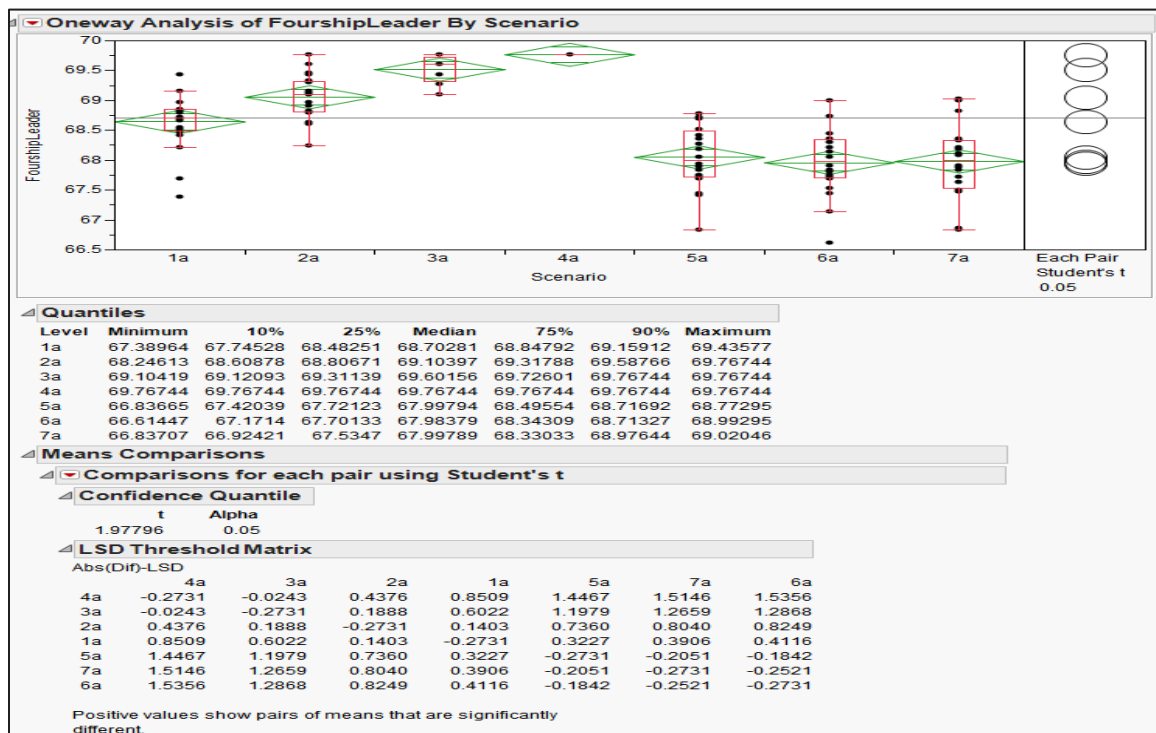


Figure 50. Model 6a Scenarios Comparison Analyses of Four Ship Leader

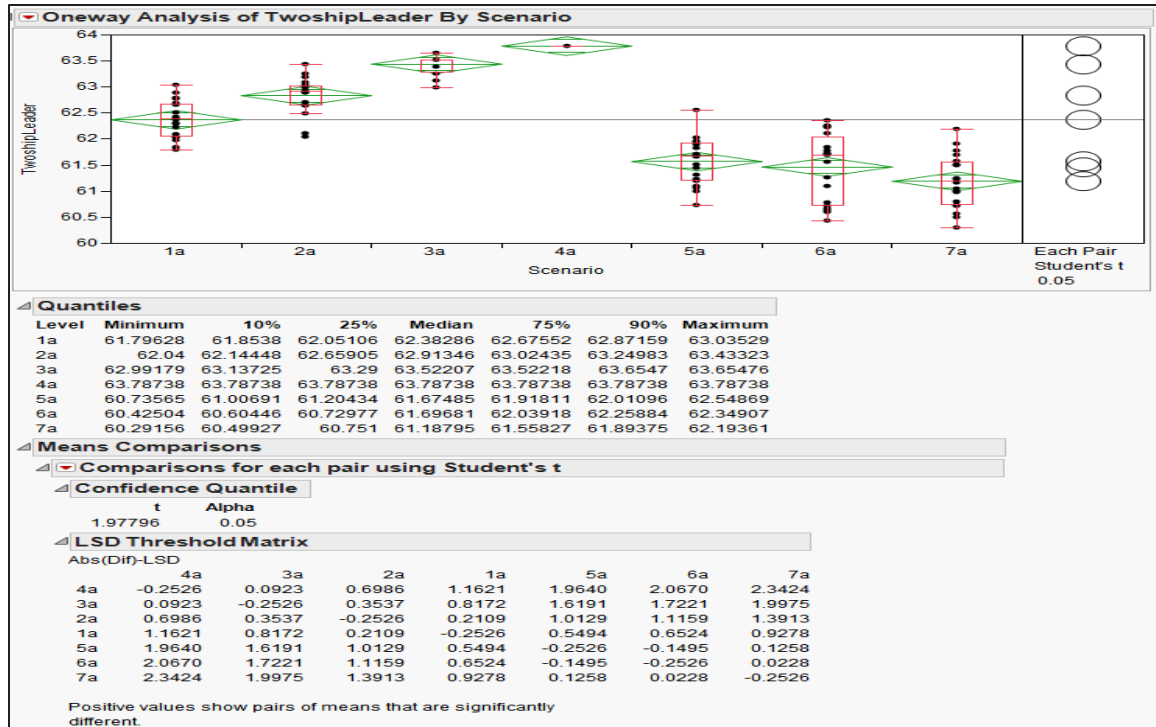


Figure 51. Model 6a Scenarios Comparison Analyses of Two Ship Leader

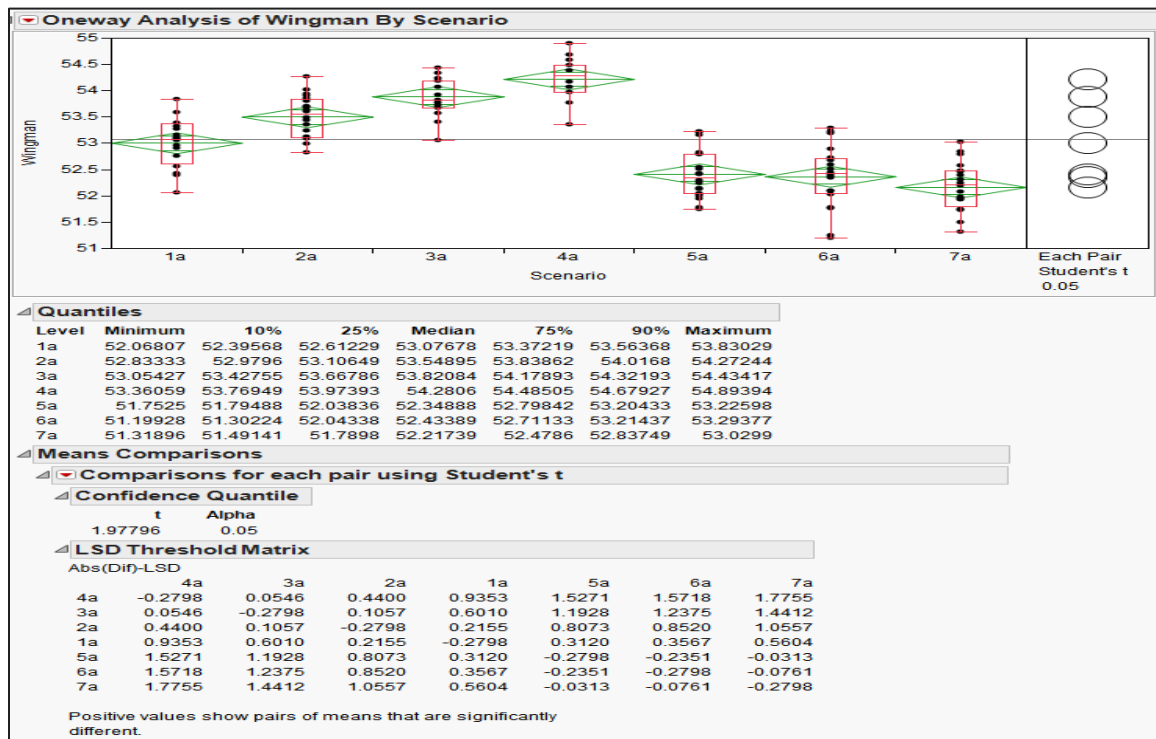


Figure 52. Model 6a Scenarios Comparison Analyses of Wingman

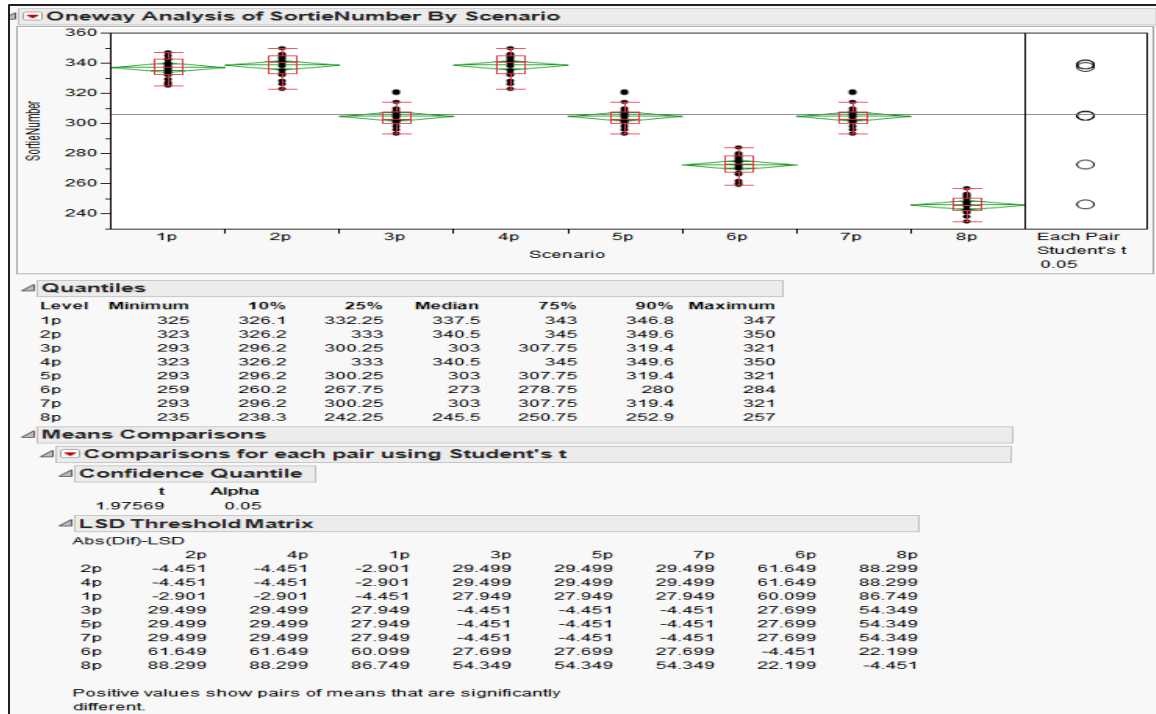


Figure 53. Model 6p Scenarios Comparison Analyses of Sortie Number

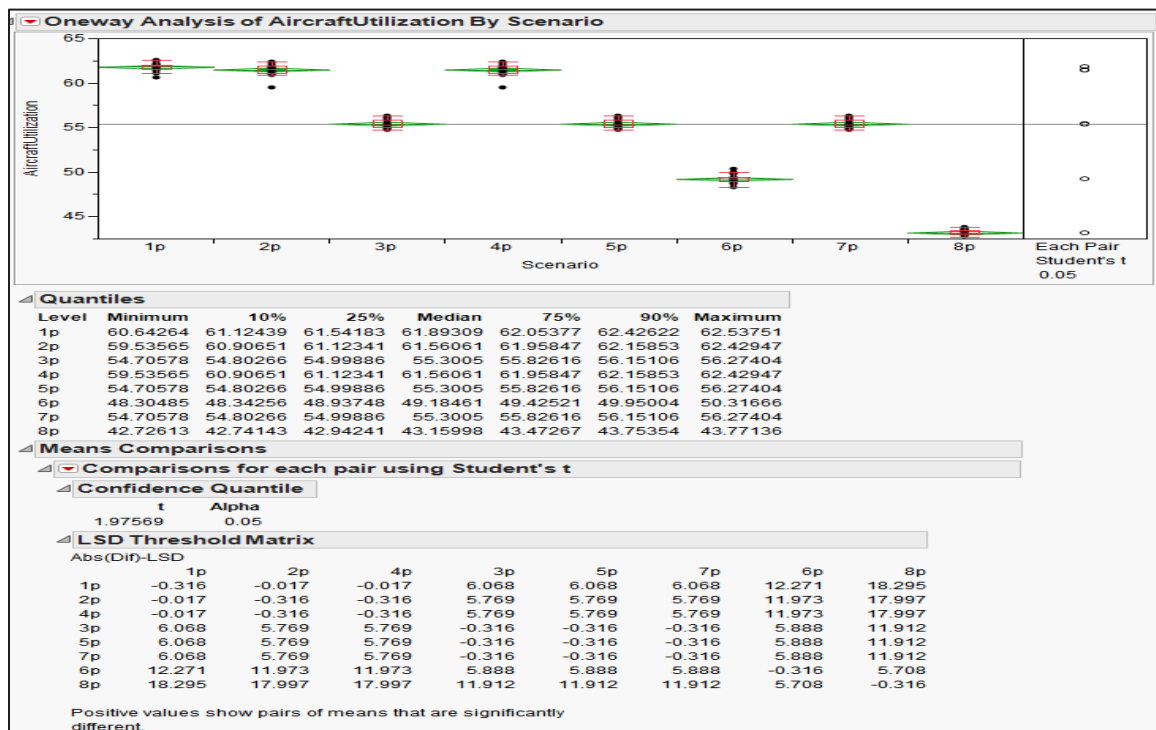


Figure 54. Model 6p Scenarios Comparison Analyses of Aircraft Utilization

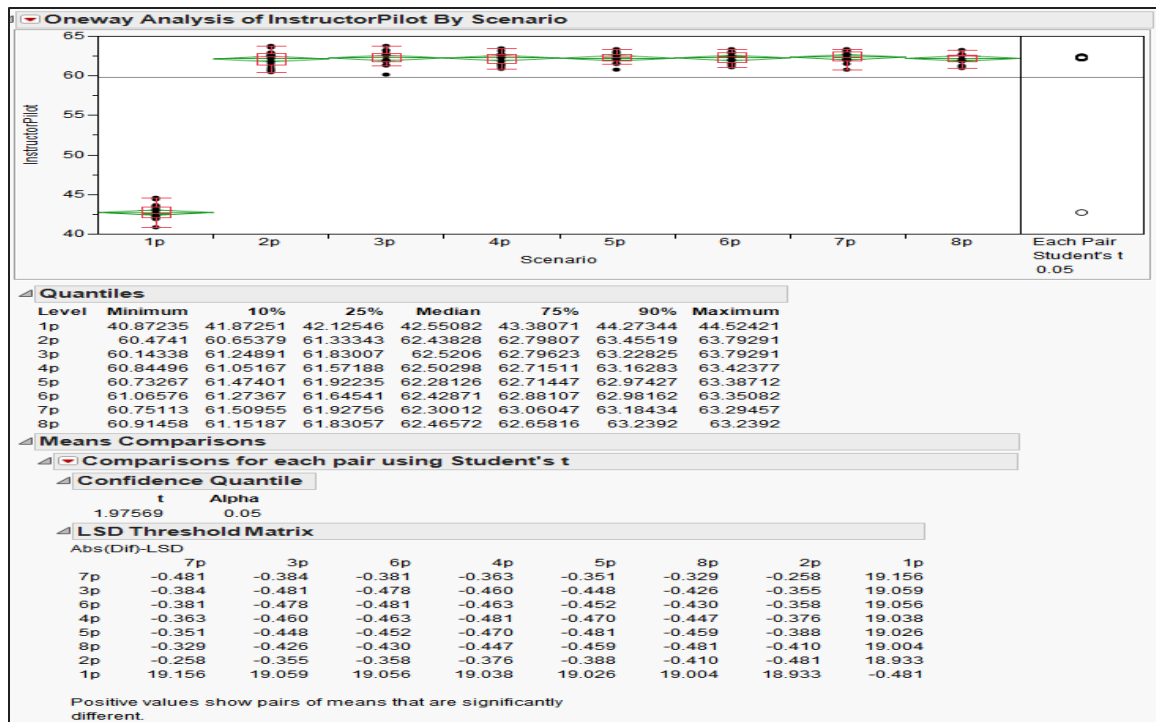


Figure 55. Model 6p Scenarios Comparison Analyses of Instructor Pilot

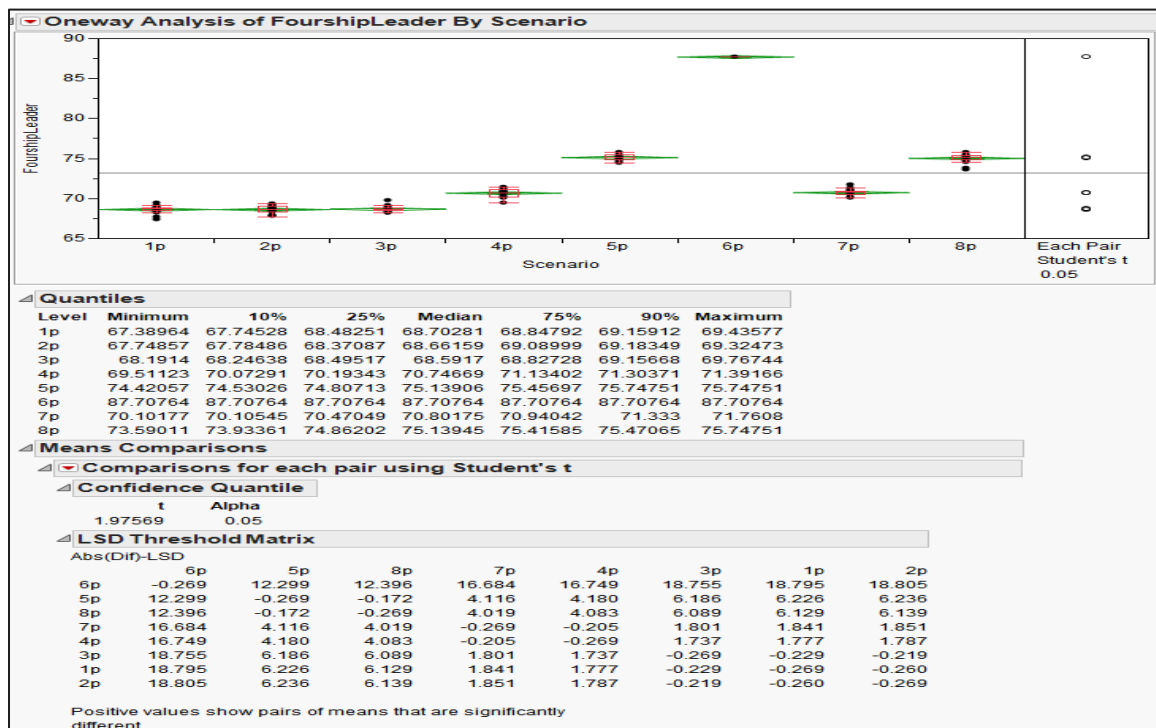


Figure 56. Model 6p Scenarios Comparison Analyses of Four Ship Leader

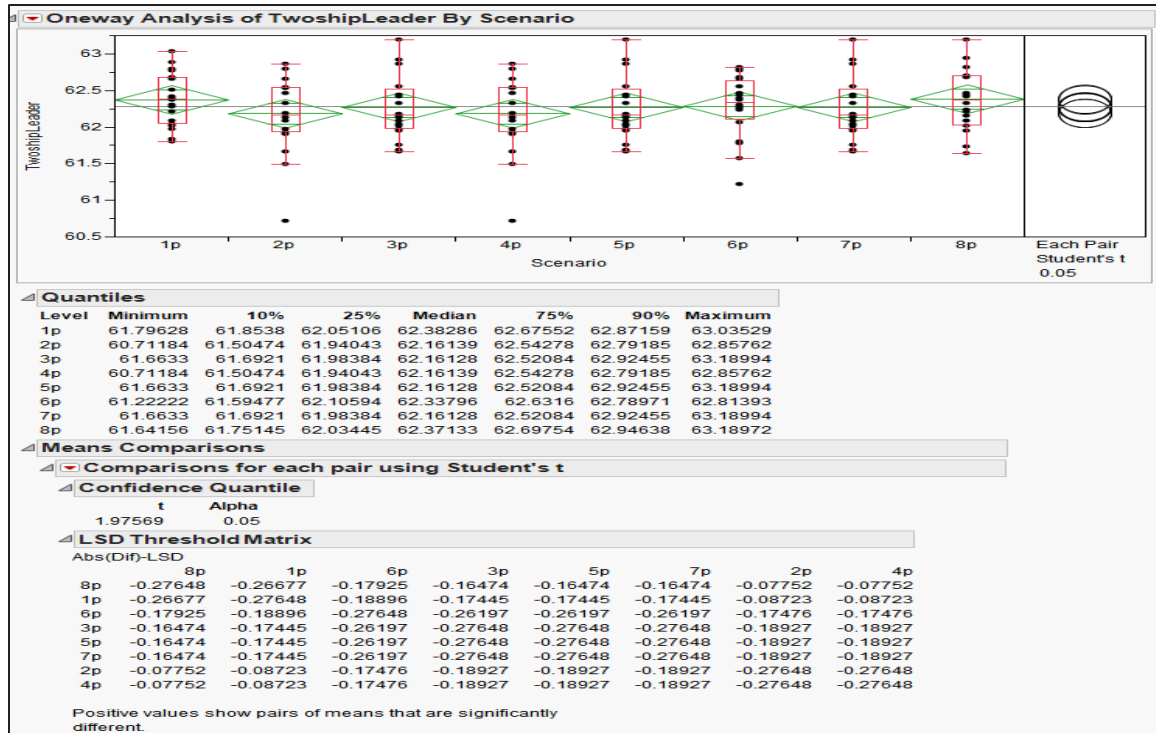


Figure 57. Model 6p Scenarios Comparison Analyses of Two Ship Leader

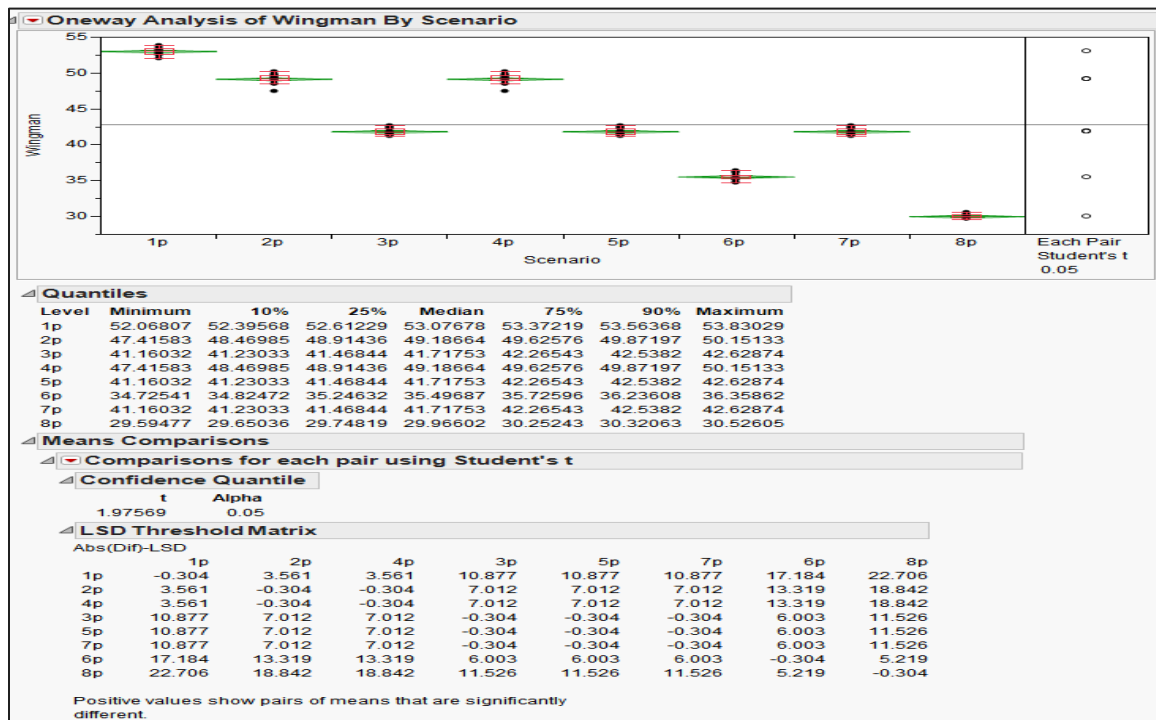


Figure 58. Model 6p Scenarios Comparison Analyses of Wingman

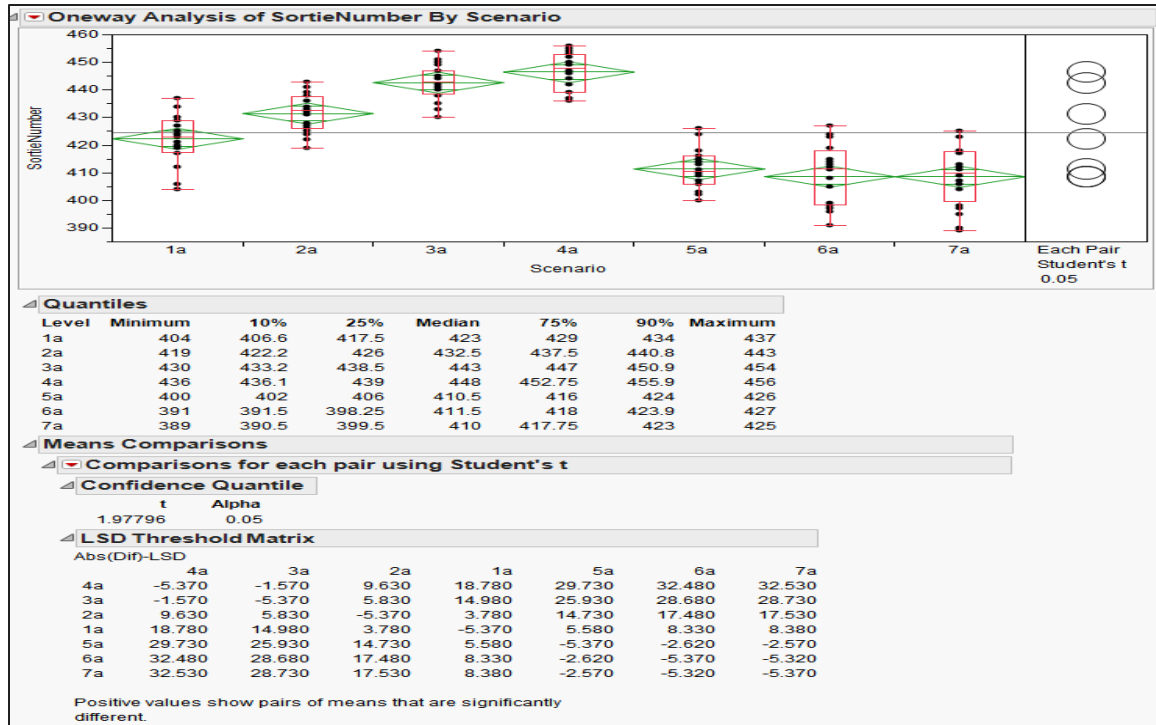


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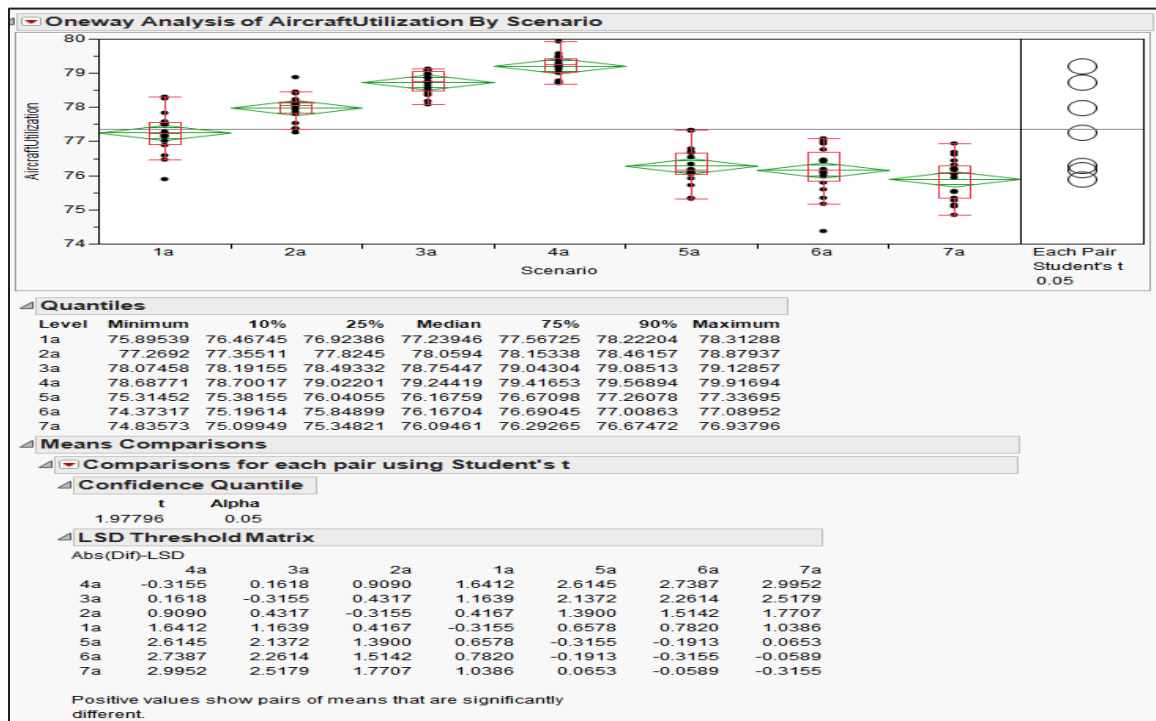


Figure 60. Model 7a Scenarios Comparison Analyses of Aircraft Utilization

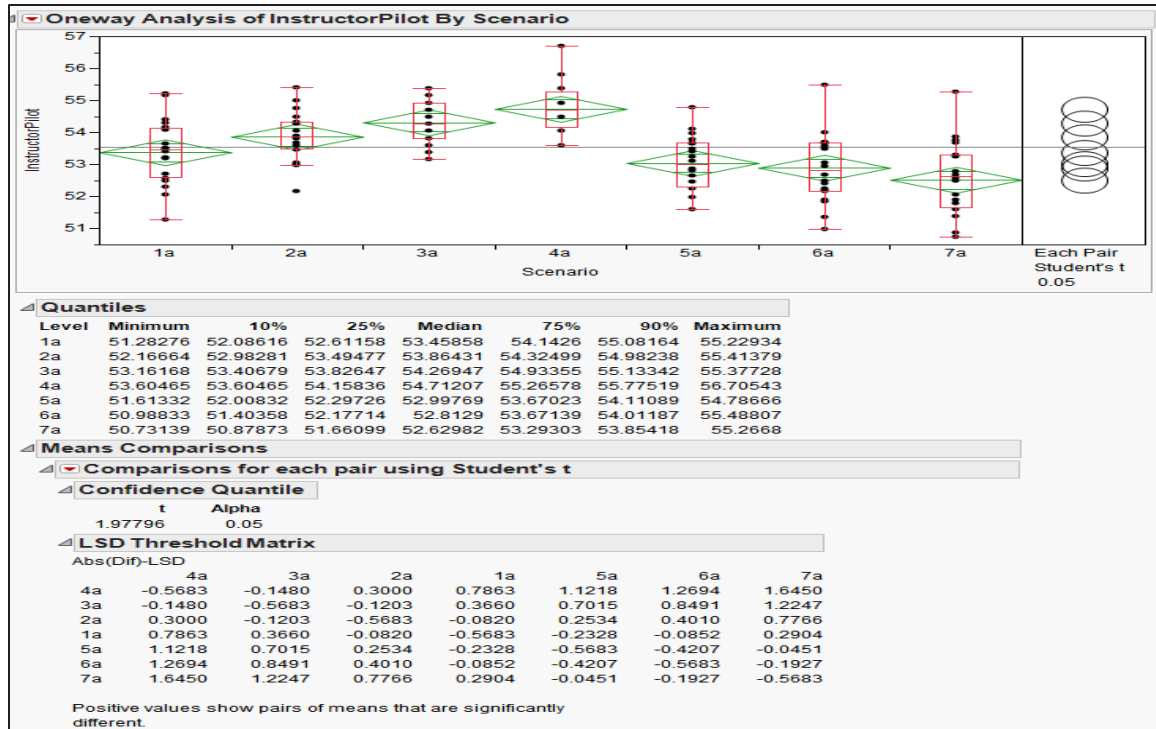


Figure 61. Model 7a Scenarios Comparison Analyses of Instructor Pilot

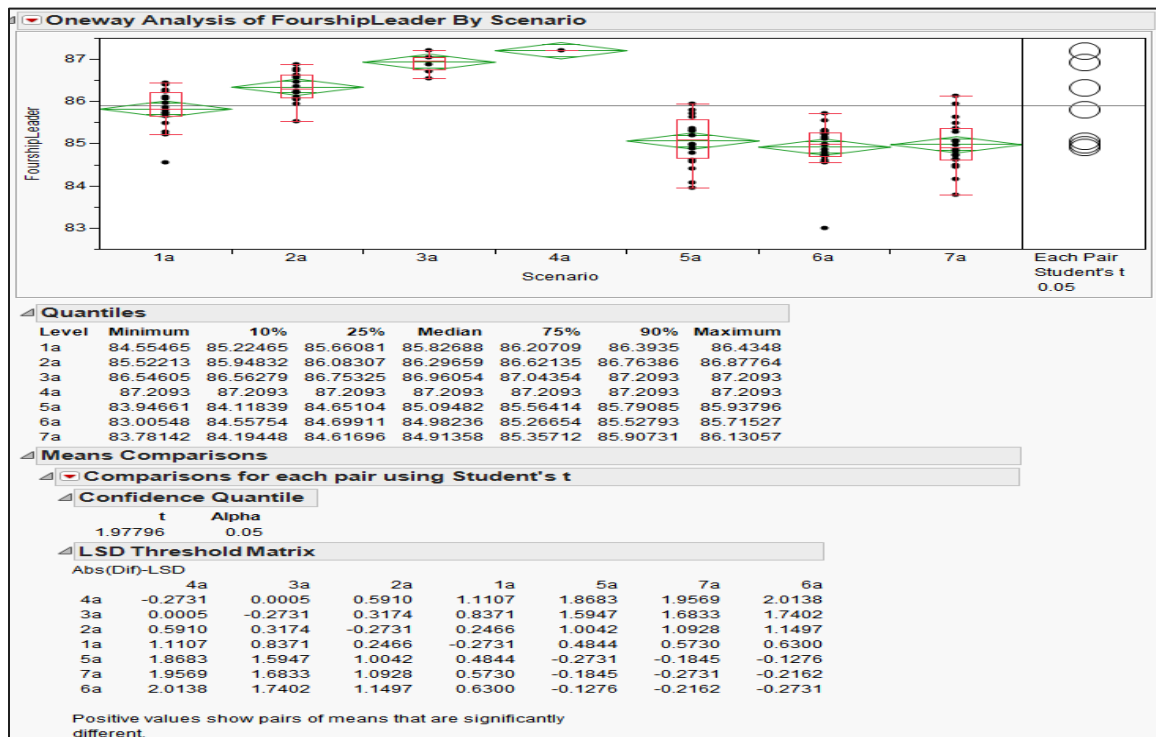


Figure 62. Model 7a Scenarios Comparison Analyses of Four Ship Leader

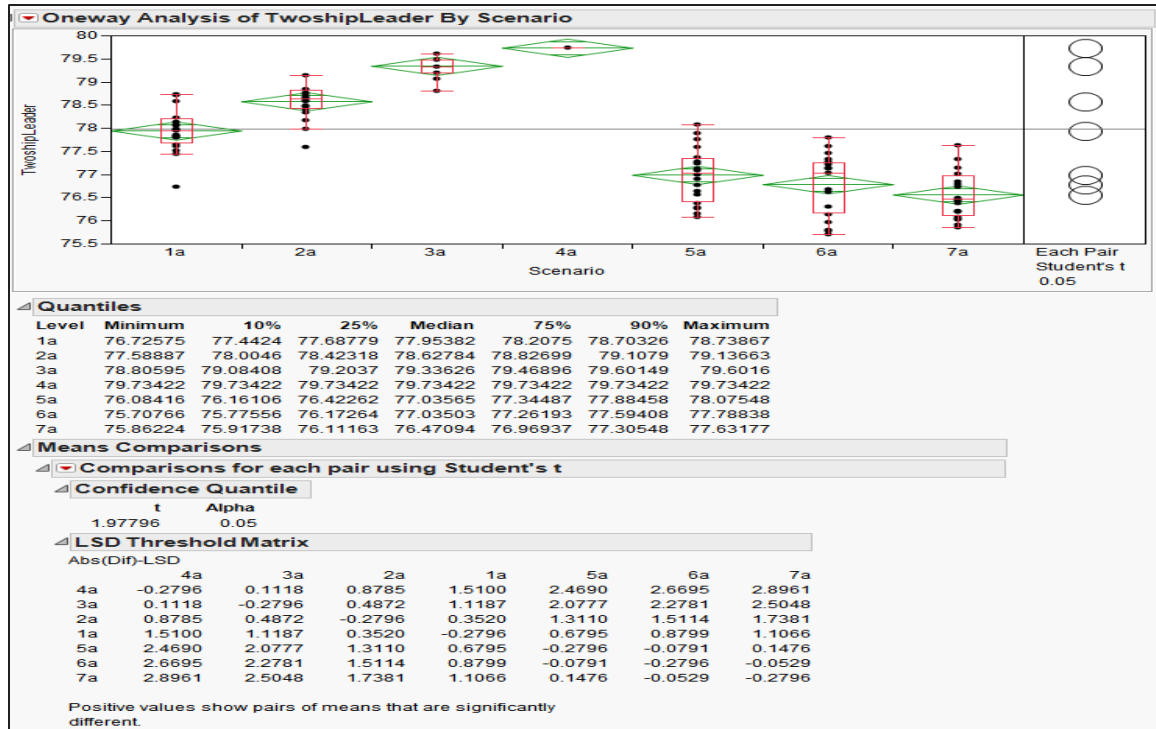


Figure 63. Model 7a Scenarios Comparison Analyses of Two Ship Leader

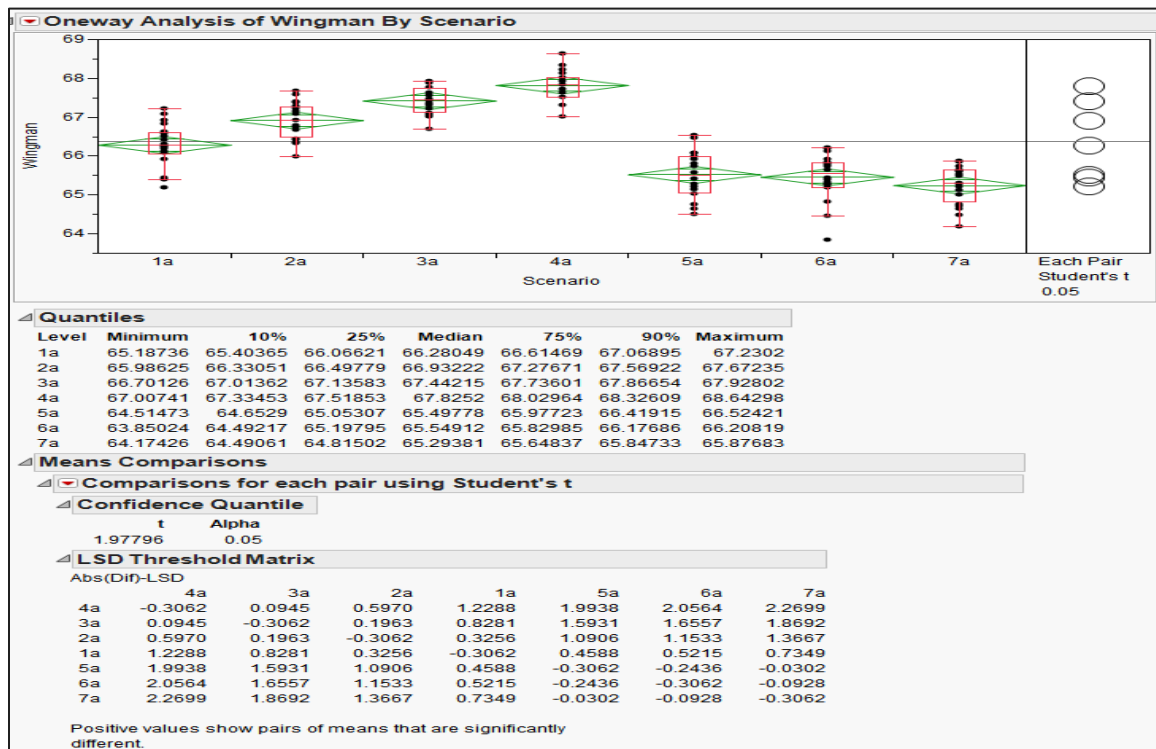


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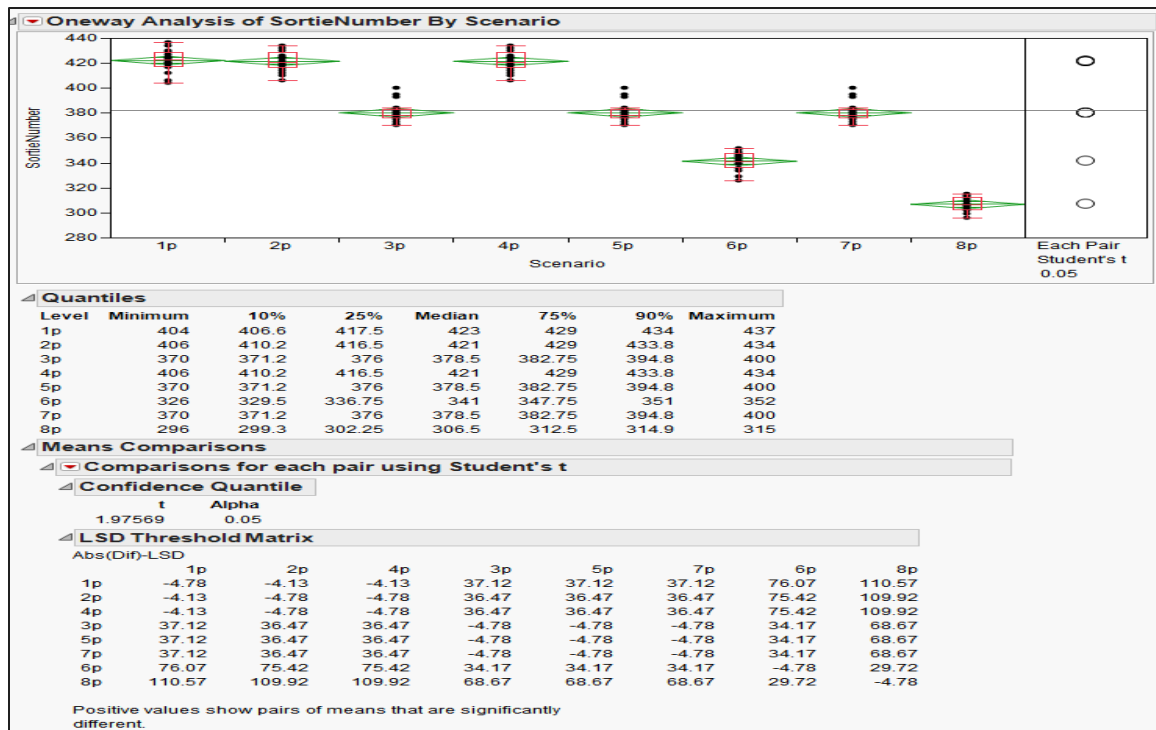


Figure 65. Model 7p Scenarios Comparison Analyses of Sortie Number

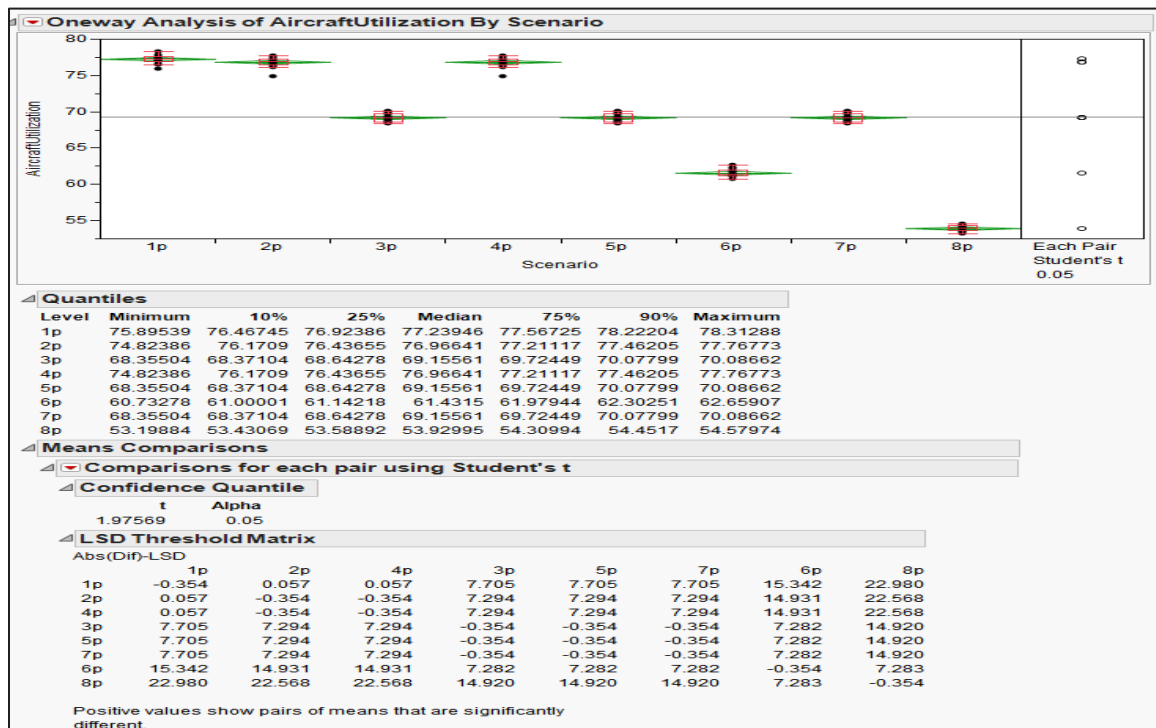


Figure 66. Model 7p Scenarios Comparison Analyses of Aircraft Utilization

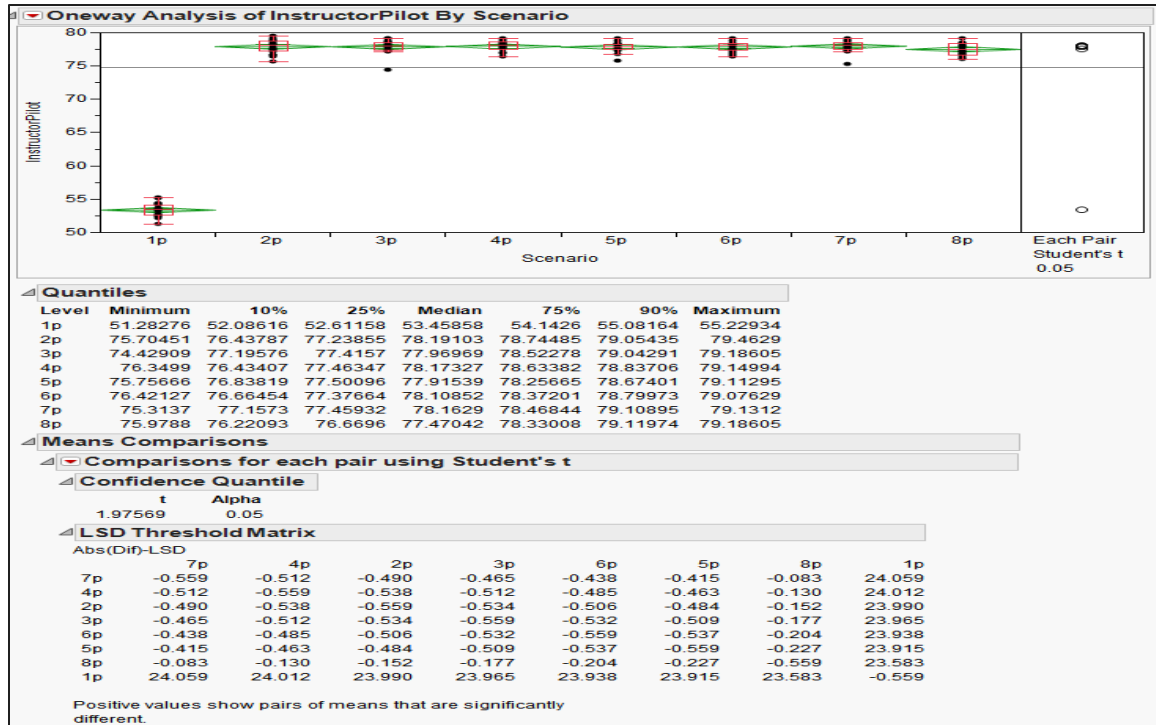


Figure 67. Model 7p Scenarios Comparison Analyses of Instructor Pilot

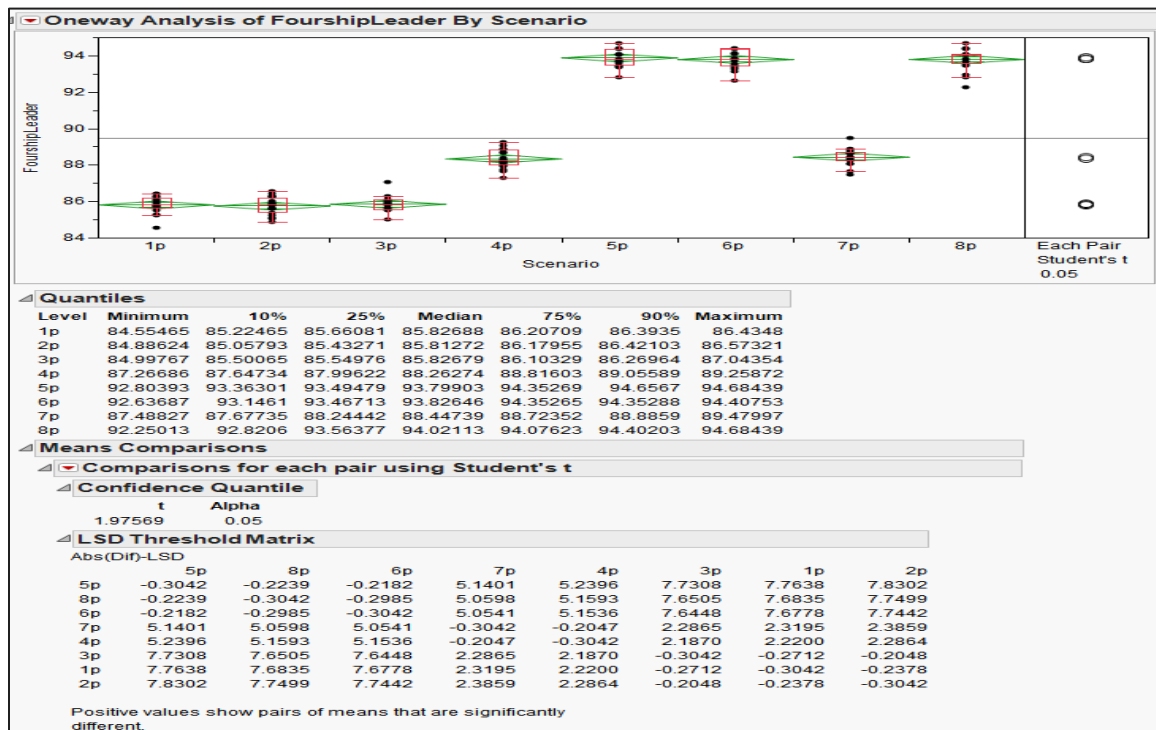


Figure 68. Model 7p Scenarios Comparison Analyses of Four Ship Leader

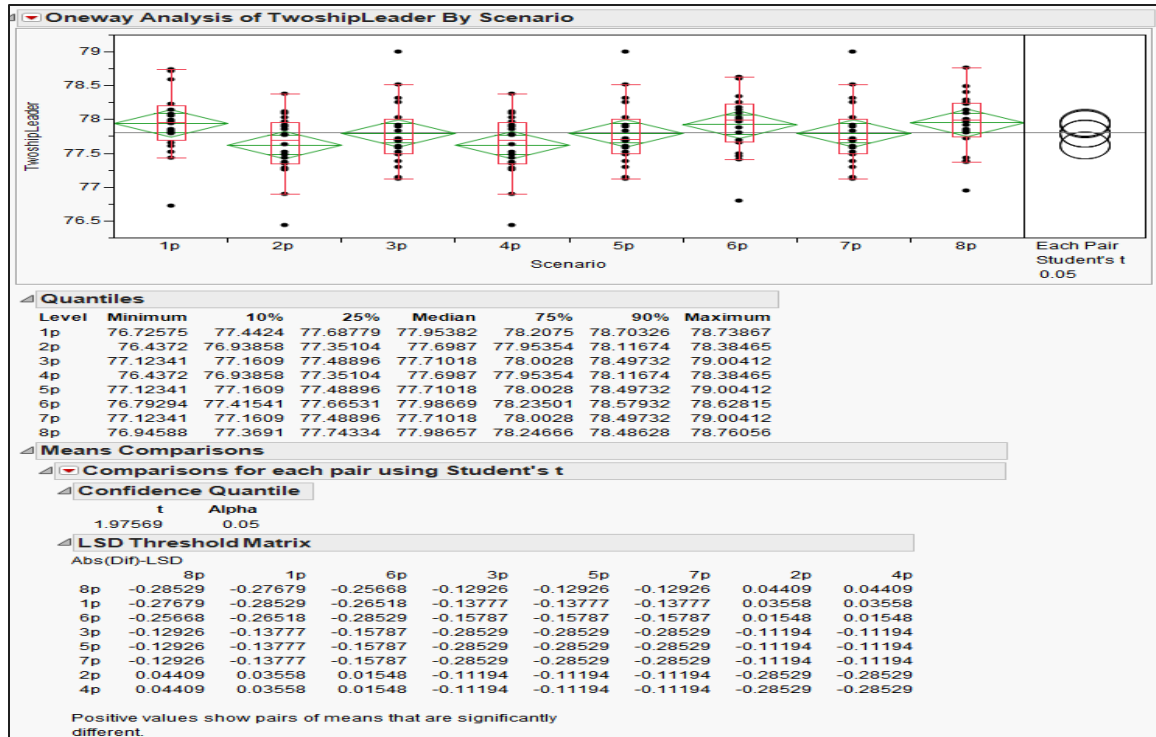


Figure 69. Model 7p Scenarios Comparison Analyses of Two Ship Leader

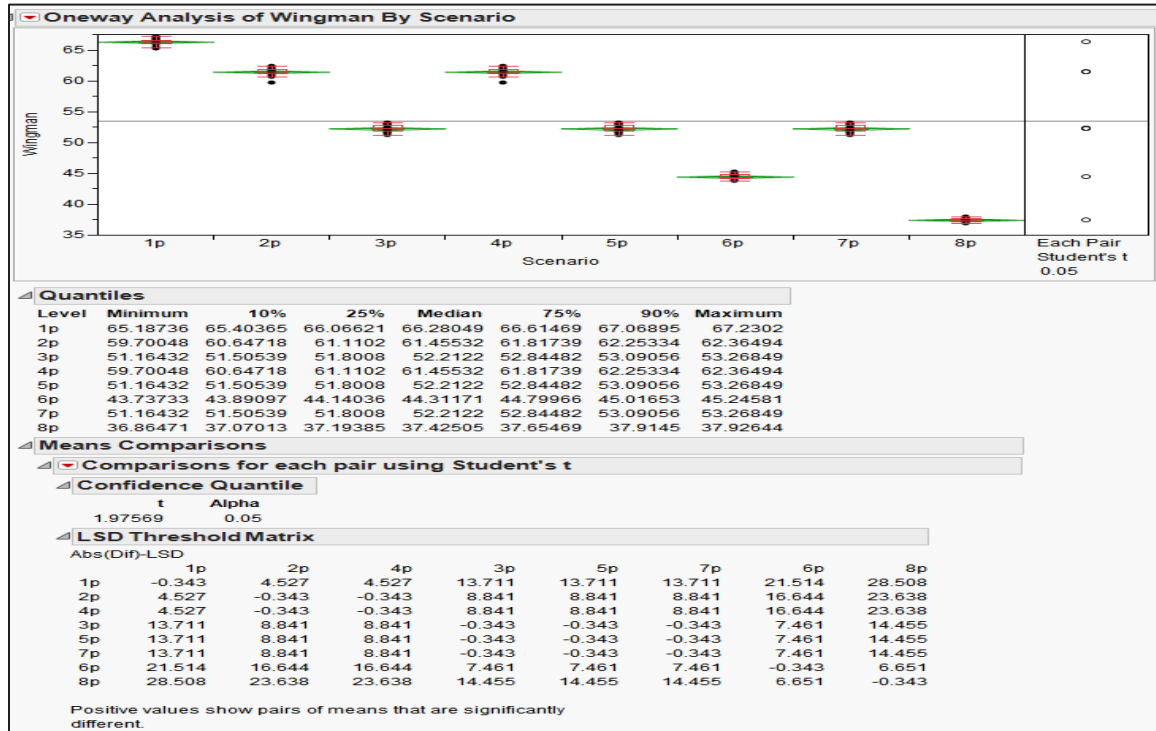


Figure 70. Model 7p Scenarios Comparison Analyses of Wingman

Table 27. An overall comparison between all models

Model	Scenario	Replication	SortieNumber	AircraftUtilization	InstructorPilot	FourshipLeader	TwoshipLeader	Wingman
1	1	20	288.00	51.14	16.62	57.92	57.59	43.80
2	1	20	266.45	55.64	19.26	63.14	66.19	49.33
3	1	20	337.15	61.79	42.74	68.64	62.37	53.00
4	1	20	422.85	77.28	53.75	85.78	77.92	66.33
5a	1	20	266.50	55.60	19.30	63.10	66.20	49.30
5a	2	20	275.20	56.60	19.40	64.00	67.40	50.10
5a	3	20	283.10	57.50	19.80	64.70	68.40	50.80
5a	4	20	288.00	58.10	19.90	65.10	69.10	51.20
5a	5	20	257.70	54.70	18.90	62.70	65.00	48.70
5a	6	20	250.70	54.20	18.70	62.40	64.40	48.30
5a	7	20	246.60	53.60	18.50	61.70	63.70	47.80
5p	1	20	266.50	55.60	19.30	63.10	66.20	49.30
5p	2	20	266.30	55.60	28.90	63.10	66.20	45.80
5p	3	20	255.50	53.80	38.10	63.40	66.30	41.60
5p	4	20	266.50	55.60	36.20	67.20	66.20	45.80
5p	5	20	255.50	53.80	46.60	76.00	66.30	41.60
5p	6	20	232.70	50.00	55.50	87.70	66.20	36.60
5p	7	20	255.50	53.80	44.50	67.60	66.30	41.60
5p	8	20	203.40	44.80	51.20	75.80	66.30	31.40
6a	1	20	337.2	61.8	42.7	68.6	62.4	53.0
6a	2	20	344.3	62.4	43.2	69.1	62.8	53.5
6a	3	20	353.7	63.0	43.6	69.5	63.4	53.9
6a	4	20	357.3	63.4	43.9	69.8	63.8	54.2
6a	5	20	327.8	61.0	42.4	68.0	61.6	52.4
6a	6	20	327.0	60.9	42.2	68.0	61.5	52.4
6a	7	20	326.0	60.7	42.1	68.0	61.2	52.2
6p	1	20	337.15	61.79	42.74	68.64	62.37	53.00
6p	2	20	327.38	59.47	62.23	69.34	62.21	46.70
6p	3	20	304.75	55.41	62.28	68.68	62.27	41.82
6p	4	20	338.70	61.49	62.26	70.69	62.18	49.14
6p	5	20	304.75	55.41	62.25	75.14	62.27	41.82
6p	6	20	272.60	49.21	62.28	87.71	62.29	35.52
6p	7	20	304.75	55.41	62.38	70.75	62.27	41.82
6p	8	20	245.95	43.18	62.23	75.04	62.38	29.99
7a	1	20	422.35	77.25	53.38	85.83	77.94	66.29
7a	2	20	431.50	77.99	53.87	86.35	78.58	66.92
7a	3	20	442.70	78.73	54.31	86.94	79.34	67.42
7a	4	20	446.50	79.21	54.73	87.21	79.73	67.82
7a	5	20	411.40	76.28	53.04	85.07	76.99	65.52
7a	6	20	408.65	76.16	52.90	84.92	76.79	65.46
7a	7	20	408.60	75.90	52.52	84.98	76.56	65.24
7p	1	20	421.85	77.27	53.69	85.81	77.96	66.23
7p	2	20	422.08	76.89	78.06	85.73	77.67	61.42
7p	3	20	379.00	69.19	78.09	85.81	77.74	52.22
7p	4	20	422.08	76.89	77.97	88.39	77.67	61.42
7p	5	20	379.00	69.19	77.88	93.85	77.74	52.22
7p	6	20	341.50	61.57	77.78	109.63	78.03	44.44
7p	7	20	379.00	69.19	78.13	88.36	77.74	52.22
7p	8	20	306.92	53.89	77.73	93.67	77.94	37.42

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Vita

Major Abdurrahman Sevimli was born in Bitlis. He graduated from Air Force Academy in İstanbul, in 2003 and he earned the degree of Bachelor of Science in Aviation Engineering. In the same year, he began his flight training in the 2nd Main Jet Base in İzmir. In 2006, after graduating from F-16 Basic Training Program, he was assigned to the 162nd Squadron, Bandırma as a wingman. In 2010, he was selected to Air War College and graduated in 2012. Next, he was assigned to 192th Squadron as a two ship leader. In 2014, he applied and selected for Operations Research Master Program in Graduation School of Engineering and Management, Air Force Institute of Technology in 2014.

REPORT DOCUMENTATION PAGE				Form Approved OMB No. 074-0188	
<p>The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of the collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.</p> <p>PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.</p>					
1. REPORT DATE (DD-MM-YYYY) 24-03-2016		2. REPORT TYPE Master's Thesis		3. DATES COVERED (From – To) Aug 14 – Mar16	
4. TITLE AND SUBTITLE Sortie Generation Simulation of a Fighter Squadron				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Sevimli, Abdurrahman Major, TURAF				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(S) Air Force Institute of Technology Graduate School of Engineering and Management (AFIT/EN) 2950 Hobson Way, Building 640 WPAFB OH 45433-8865				8. PERFORMING ORGANIZATION REPORT NUMBER AFIT-ENS-MS-16-M-127	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) TURKISH AIR FORCE, 06100 BAKANLIKLAR/ANKARA ,TURKEY				10. SPONSOR/MONITOR'S ACRONYM(S) TURAF	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Distribution Statement A: Approved for Public Release; Distribution Unlimited.					
13. SUPPLEMENTARY NOTES This material is declared a work of the U.S. Government and is not subject to copyright protection in the United States.					
14. ABSTRACT The Turkish Air Force utilizes several fighter squadrons to enhance its military capabilities. One of the most critical challenges for these squadrons is generating sorties to meet the currency and demand during both peacetime and wartime. This sortie generation process directly affects the success of both training and operations. In this study, this process is assessed using a discrete event simulation. Air Force decision makers require a simulation tool to conduct “what-if” analysis on how potential changes in the environment affect an F-16 fighter squadron’s sortie generation process. Creating a usable simulation provides decision makers with a flexible tool to analyze and evaluate the possible scenarios. The model assists in determining new concepts to provide benefits over current systems. These benefits may include increased operational availability and better system performance.					
15. SUBJECT TERMS Sortie generation, fighter squadron, flight schedule, Simio.					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT UU	18. NUMBER OF PAGES 102	19a. NAME OF RESPONSIBLE PERSON John.O.MILLER, Ph.D. (ENS)
a. REPORT U	b. ABSTRACT U	c. THIS PAGE U			19b. TELEPHONE NUMBER (Include area code) (937) 255-6565, ext 4523; (john.miller@afit.edu)

Standard Form 298 (Rev. 8-98)
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