MODELING AND ANALYZING ARMY AIR ASSAULT OPERATIONS VIA SIMULATION

A THESIS
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FOR THE DEGREE OF
MASTER OF SCIENCE

By
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June, 2001

I certify that I have read this thesis and that in my opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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ABSTRACT

MODELING AND ANALYSIS OF ARMY AIR ASSAULT OPERATIONS VIA SIMULATION

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June, 2001

It is very important to use combat simulations in personel training and as a scientific decision tool in developed countries. The use of simulation and analysis methodologies gives opportunity to the staff officers and the commanders to foresee the results of their plans and to take some precautions accordingly. Different combat scenarios can be tried without deploying the units to the combat area and getting losts, costs and risks. As one of the most complicated and decisive operation in the way to victory "Air assault operations" are high risk, high payoff operations, that, when properly planned and vigorously executed, allow commanders to take the initiative of the combat area. The use of Air Assault Operations Simulation Model (AAOSM) allows planners: (1) to build models of air assault operations early in the decision process and refine those models as their decision process evolve, (2) perform "*Bottleneck analysis*" of the preplanned operation using statistical procedures and take some precautions accordingly. (3) perform "*Risk management*" of the operation before conducting the real one.

AAOSM is created by using ARENA 3.0 simulation program and SIMAN programming languauge.The outputs of the model is analysed using experimental design procedures and the significant factors that are significant to the outputs are analysed. Moreover, the best scenarios are evaluated in different weather and terrain conditions and different refuelling and maintenance configurations.

***Key Words*: Simulation, Air Assault Operations, Experimental Design, Scientific Decision tool**

ÖZET

KARA KUVVETLERİ UÇARBİRLİK HAREKATININ MODELLENMESİ VE SİMÜLASYON YOLUYLA DEĞERLENDİRİLMESİ

Gökhan Virlan

Endüstri Mühendisligi Bölümü Yüksek Lisans

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Haziran, 2001

Gelişmiş ülkelerde harb simülasyonlarının personel eğitiminde ve bilimsel karar destek mekanizması olarak kullanılması günümüzde çok önem kazanmıştır. Karmaşık harekatlarda, simülasyon ve analiz metodlarının kullanılması karargah subaylarına ve komutanlara planlamalarının sonuçlarını önceden görmeye ve sonuçlara göre bazı tedbirler almaya olanak sağlar. Böylece birlikleri harp meydanına çıkarmadan hiç bir zayiata ve masrafa katlanmaksızın ve risk üstlenmeden, değişik muharebe senaryolarının denenmesi sağlanabilir. Uçarbirlik Harekatı da doğru olarak planlandığı ve cesaretle icra edildiği takdirde komutanlara harekat alanının insiyatifini ele geçirmeyi sağlayan yüksek riskli fakat getirisi de ona göre çok önemli olan ve zafere götüren bir harekat şeklidir. Uçarbirlik Harekatı Simülasyon modelini kullanılarak: (1) Komutana, karargah subaylarına ve uygulayıcılara planlama safhasında ve karar verme sürecinde bilimsel karar destek mekanizması olarak yardımcı olunabilir. (2) Planlanan harekat icra edilmeden önce bilgisayar modelinin çıktıları istatiksel metodlarla incelenerek harekatta oluşabilecek darboğazlar önceden görülerek tedbir alınabilmesi sağlanabilir. (3) Değişik senaryolar modele adapte edilerek bir çeşit "Risk Yönetimi " icra edilebilir.

Uçarbirlik Harekatı Simülasyon modeli ARENA 3.0 simülasyon programı kullanılarak ve SIMAN dilinde hazırlanmıştır. Modelin çıktıları deneysel tasarım metodları kullanılarak incelenmekte ve harekatta hangi unsurların daha fazla etkin olduğu belirlenmektedir. Ayrıca değişik hava ve arazi şartlarında, değişik bakım ve ikmal konfigürasyonlarında hangi senaryonun en iyi olduğu incelenmektedir.

***Anahtar sözcükler*: Simülasyon, Uçarbirlik Harekatı, deneysel tasarım, bilimsel karar destek**

To my wife Dilek and my beloved daughter Yaren;

And to the souls of all courageous and bold pilots, technicians and the soldiers who lost their lives and sacrificed their souls in Air Assault Operations for the nation's undividable unity and for the republic .

They are the real knights of the battlefield....

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I would like to express my deep gratitude to Assoc. Prof. Dr. İhsan Sabuncuoğlu for his guidance, attention, understanding, motivating suggestions and patience throughout all this work.

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Gökhan Virlan

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Chapter 1

Introduction

1.1 Air Assault Operations

Army aviation and infantry units can be fully integrated with other members of the combined arms team to form powerful and flexible air assault task forces that can project combat power throughout the entire depth, width, and breadth of the modern battlefield with little regard for terrain barriers. The unique versatility and strength of an air assault task force is achieved by combining the capabilities of modern rotary-wing aircraft - speed, agility, and firepower - with those of the infantry and other combat arms to form tactically tailored air assault task forces that can be employed in low-, mid-, and high-intensity environments.

Air assault operations are those in which assault forces (combat, combat support, and combat service support), using the firepower, mobility, and total integration of helicopter assets, maneuver on the battlefield under the control of the ground or air maneuver commander to engage and destroy enemy forces or to seize and hold key terrain. Air assault operations are not merely movements of soldiers, weapons, and materiel by Army aviation units. They are deliberate, precisely planned, and vigorously executed combat operations designed to allow friendly forces to strike over extended distances and terrain barriers to attack the enemy when and where he is most vulnerable.

An air assault task force provides commanders with truly unique capabilities. They can extend the battlefield, move, and rapidly concentrate combat power like no other available forces. Specifically, an air assault task force can attack enemy positions from any direction, conduct deep attacks and raids beyond the forward line of own troops using helicopters, rapidly place forces at tactically decisive points in the battle area, bypass enemy positions, conduct operations under adverse weather conditions and at night to facilitate deception and surprise.

There are some limitations for the air assault operations. An air assault task force relies on continuous helicopter support throughout any air assault operation. The helicopters may be limited by adverse weather, extreme heat and cold, and other environmental conditions such as blowing snow and sand that limit flight operations or helicopter lifting capability. Hostile aircraft, air defense, and electronic warfare action, availability of suitable landing zones (LZ) and pickup zones (PZ), high fuel and ammunition consumption rates are also limitations for the air assault operations.

An air assault task force uses the helicopter to move to and close with the enemy. Initial assault elements must be light and mobile. They are often separated from weapon systems, equipment, and materiel that provide protection and survivability on the battlefield. Thus, an air assault task force is particularly vulnerable to enemy attack by aircraft and air defense weapon systems.

1.2 Stages of The Air Assault Operation

Successful air assault execution is based on a careful analysis of (Mission, Enemy, Terrain, Troops Available-Time) METT-T and detailed, precise reverse planning. Five basic plans that comprise the reverse planning sequence are developed for each air assault operation. They are:

- The ground tactical plan.
- The landing plan.
- The air movement plan.
- The loading plan.
- The staging plan.

These plans should not be developed independently. The ground tactical plan is normally developed first and is the basis from which the other plans are derived. Figure 1.2.1 describes the basic stages of the air assault operations schematically.

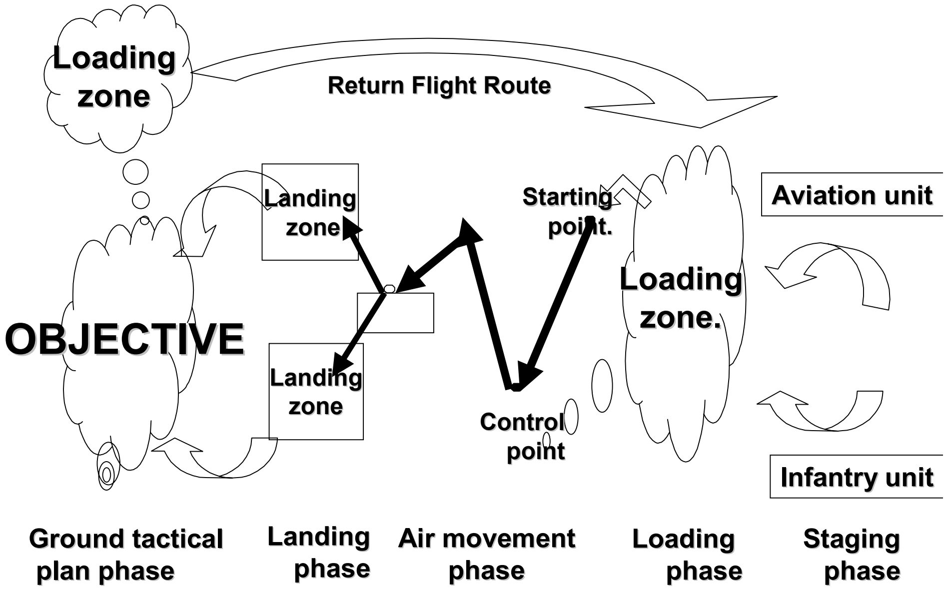


Figure 1.2.1:Stages of the Air Assault Operation

1.2.1 The Ground Tactical Plan

The foundation of a successful air assault operation is the commander's ground tactical plan, around which subsequent planning is based. The ground tactical plan specifies actions in the objective area to ultimately accomplish the mission and address subsequent operations.

1.2.2 The Landing Plan

The landing plan must support the ground tactical plan. This plan sequences elements into the area of operations, ensuring that units arrive at designated locations and times prepared to execute the ground tactical plan. The availability, location, and size of potential LZs are overriding factors. The air Assault task force is most vulnerable during landing. Elements must land with tactical integrity and be prepared to fight in any direction immediately.

1.2.3 The Air Movement Plan

The air movement plan is based on the ground tactical and landing plans. It specifies the schedule and provides instructions for air movement of troops, equipment, and supplies from PZs to LZs. It also provides coordinating instructions regarding air routes, air control points, and aircraft speeds, altitudes, and formations. When operations involve multiple lifts from the same PZ, a lift table is prepared to ensure lifts are properly organized. The staff prepares Air movement table which consists of:

- Aircraft allocations,
- Number and type of each aircraft in each serial,
- Departure point, route to and from the loading area, and loading, lift–off, and landing times.

It is a basic scheduling process that the infantry units and the aviation units come together to accomplish the air movement plan. It is also very important to achieve the ground tactical plan. If it is not punctual, the commander will have some mishaps and difficulties to get the objective.

1.2.4 The Loading Plan

The loading plan is based on the air movement plan. It ensures that troops, equipment, and supplies are loaded on the correct aircraft. Unit integrity is maintained when aircraft loads are planned. However, assault forces and equipment may be cross-loaded so that command and control assets, all types of combat power, and a mix of weapons arrive at the LZ ready to fight. The loading plan should receive command attention to ensure that it goes smoothly. It is imperative for mission success that loading operation must be well planned and properly executed.

1.2.5 The Staging Plan

The staging plan is based on the loading plan and prescribes the arrival time of ground units (troops, equipment, and supplies) at the PZ in the proper order for movement. Loads must be ready before aircraft arrive at the PZ; usually, ground units are expected to be in PZ posture 15 minutes before aircraft arrive. The staging plan also restates the PZ organization, defines flight routes to the PZ, and provides instructions for linkup of all aviation elements.

1.3 Objective of the study

Air assault Operations are very important operations that the modern army commanders want to implement. The Turkish Army has a big and modern fleet of helicopters and capable of performing succesful Air Assault Operations. There are many ongoing projects about purchasing modern helicopters and changing the organizational structure of the Army to perform such kind of operations.

The exact planning, organization and the proper execution are the keywords to the success in Air assault operations. It is a fact that the combat area is not predictable and always has stochastic events. The use of helicopters gives a great initiative and power to the commander. However, it is a risky operation that when fails, may result in the loss of many soldiers and helicopters. By studying this subject, we want to show the capabilities and the bottlenecks of the preplanned operation to the commanders and make use of the simulation model a kind of a decisionmaking tool. We think the model will help the commanders to analyze their plans before conducting the real operation. By doing so, they will foresee the results of their plans and take some precautions accordingly. Next, we will explain the basic stages of the air assault operation.

1.4 Thesis Outline

The rest of the thesis is organized as follows. Chapter 2 presents the related literature with the simulation software and methods; the requirements of military simulation modeling; general applications that are being used in the United States Army. Chapter 3 describes the Air Assault Operations Simulation Model (AAOSM). Chapter 4 interprets design and analysis of experiments by showing the numerical results. Chapter 5 presents the output data analysis that evaluates and interprets the results of the simulation models related with ranking and selection. In this chapter, the results are shown numerically and graphically, and then the interpretations of these results are given. Chapter 6 gives the concluding remarks; ideas and suggestions for future work are also listed. Appendices provide the computer codes, outputs and summary tables used in the thesis.

Chapter 2

Literature Review

During our literature survey we have not come up with any research that is directly related with this study. There are some studies in the U.S. but they are not open to public due to security reasons. Thus, we cannot get any detailed information about these researches. Instead, we present references about methodology and the military simulation related with our study in three groups. We mainly focus on how they deal with the subject, what types of pitfalls they face and what are the significant outcomes of their studies.

2.1. Simulation Software and Methodology

We used the basic principles, which are stated, in Banks (1998) throughout our study. The fundamentals of the modeling methodologies, brief information about the use of simulation and a stepwise logic for all phases of simulation are covered in this study.

ARENA software is selected as appropriate simulation software because of its flexibility and easiness. This software allowed us to animate the model and analyze the outputs effectively. Takus and Profozich (1997) explain the software and its capabilities in their tutorial.

Balci (1989), Law (1991), Banks (1996) and Sargent (1998) discuss how to assess the acceptability and credibility of simulation results, principles and techniques of simulation validation, verification and testing. After describing validation techniques they discuss conceptual model validity, model verification, operational validity, data validity. Shannon (1981) discusses and offers tests for the verification and validation of computer models. Whitner and Balci (1998), describes some guidelines for selecting and using simulation model verification techniques.

Kleijnen (1999) explains the statistical techniques to validate simulation models depending on the type of the data available. He explains three different cases as no data, only output data, both input and output data and gives some examples about them.

Kelton (1997), Centeno and Reyes (1998), Alexopoulos and Seila (1998) and Sanchez (1999) all study on the procedures, techniques about the simulation output analysis. Seila (1992) reviews some advanced aspects of methods for analyzing data produced by simulations.

Kelton (1999) introduces some of the ideas, issues, challenges, solutions and opportunities in deciding how to experiment with a simulation model to learn about its behavior. Hood and Welch (1992) discuss experimental design issues in simulation and give examples from semiconductor manufacturing. Montgomery (1992) thoroughly discusses the design and analysis of experiments in his book. He introduces factorial designs, regression analysis, response surface methods and designs and gives examples about them.

Goldsman and Nelson (1998) present screening, selection, and multiple comparison procedures that are used to compare systems design via computer simulation. They describe methods for three broad classes of problems: screening a large number of system designs, selecting the best system, and comparing all systems to a standard. Bechhofer, Santner and Goldsman (1995) discuss design and analysis of experiments for statistical selection, screening and multiple comparisons. Gray and Goldsman (1988) present a real world application of a ranking and selection procedure for selecting the best of a number of competing systems. Their example involves the selection of an airspace configuration, which minimizes airspace route delays. Swisher and Jacobson (1999) presents a survey of the literature for two widely-used statistical methods for selecting the best design from among of a finite set of k alternatives: ranking and selection and multiple comparison procedures. Boesel (2000) discusses a method that uses initial sample data to choose between statistical procedures for identifying the simulated system with the best (maximum or minimum) expected performance. The method chooses the procedure that minimizes the additional number of simulation replications required to return a pre-specified probability guarantee.

2.2. Military Simulation

In this study, we mainly focus on Air Assault operations. Our survey is limited with the papers and conference proceedings published in the scientific literature considering the confidentiality of this particular subject. The existing studies are classified as shown in Table 1. During this survey, we particularly focus on to how they use the input data, how they validate the model and how they implement the particular scenarios. In order to gain some insight about the future use of the model we also analyzed the impacts of the studies on the decision making process of the Armed forces.

Smith (1998) identifies the essential techniques necessary for modern military training simulations. A brief historical introduction; discussions of system architecture; multiple interactive training simulations; event and time management; distributed simulation; and verification, validation, and accreditation are provided.

Page and Smith (1998) provide an overview of military training simulation in the form of an introductory tutorial. Basic terminology is introduced, and current trends and researches focus in the military training simulation domain are described. Perla (1990) presents the art of war gaming discussing the backbones of the procedures and techniques.

Roland (1998) categorizes the military simulation as engineering models, analyses models and training models in the panel “The future of military simulation”. Today’s major modeling and simulation opportunities and challenges and major problems in the current state of modeling and simulation development and use are discussed in the panel.

Hartley (1997) discusses the difficulties, ways and cost of the military simulation model validation and verification. He compares the other simulation models with the military ones in terms of validation, verification and accreditation.

2.3. Tactical and Combat Simulations

Krueger (1992) discusses the pitfalls in Combat simulations. He confines the discussion to staff training simulations, specifically two simulations within the family of

Table 1. Summary table of related literature

CLASSIFICATION	PUBLICATION	SUBJECT
Simulation Software and Methodology	Takus and Profozich (1997)	ARENA software tutorial
	Balci (1989), Law (1991), Banks (1996), Sargent (1998)	Simulation Validation Verification and Testing
	Shannon (1981)	Tests for Verification and Validation of models
	Klejinen (1999)	Statistical techniques and data availability
	Kelton (1997), Centeno & Reyes (1998), Alexopoulos & Seila (1998), Sanchez (1999)	Procedures, techniques about the simulation output analysis
	Hood & Welch (1992), Montgomery (1992)	Design and Analysis of experiments
	Goldsman & Nelson (1998) Bechhofer et. Al (1995), Swisher & Jacobson (1999), Boesel (2000)	Screening Selection and Multiple Comparison procedures
Military Simulation	Smith (1998)	Essential techniques for military modeling and simulation
	Page and Smith (1998)	Overview of military simulation training
	Roland et. al (1998)	Panel: The future of military simulation
	Perla (1990)	Procedures and techniques of war gaming
	Hartley (1997)	Verification and validation in military simulations
Tactical & Combat Simulations	Henry (1992)	Corps Battle Simulation
	Blais (1994)	Marine Tactical Warfare Simulation
	Garrabrants (1998), Sawyers (1998), Martin (1999)	Tactical development systems of warfare Simulations
	Krueger (1992)	Pitfalls in Combat Simulations
Air Warfare Simulations	Haeme et. al (1988)	Airline performance modeling to support schedule development
	Hurst and Flynn (1999)	ADVOCATE (Air Defense Verification of Options by Computer Analysis of Target Engagement)
	McKay Laube (1988)	Major techniques used in Search and Rescue (SAR) model
	Rubin & Sowers (1988)	Air Operations Modeling in a War gaming Environment
	Litko & Carter (1991)	A model to support decisions on employment of aircrews in Desert Storm Operations
	Briggs et. al (1995)	A model to plan mass tactical airborne Operations

simulation (FAMSIM); the Corps/Battle Simulation (CBS) and the Brigade/Battalion Simulation (BBS).

Henry (1994) describes the techniques use to transform Corps Battle Simulation. The U.S. Army as a standard tool for training commanders and their staff establishes the corps Battle Simulation during the mid 1980’s. The need for the training tools that support emerging missions such as Low Intensity Conflict, multi-factional scenarios, Operations Other Than War, and joint and combined training remodeled the model for new visions.

Blais (1994) provides an overview of the Marine Tactical Warfare Simulation (MTWS) system hardware and software, including basic design philosophy, exercise control concept, and combat modeling approach. This simulation is the next generation training system for the U.S Marine Corps. It is designed to support training of tactical commanders and their staffs in various exercises.

Garrabrants (1998) proposes “an expansion of simulation systems’ role to support all levels of command and control functioning, especially staff planning after receipt of orders and mission rehearsal” in his study. He explains how Marine Tactical Warfare Simulation (MTWS), an advanced simulation system, is used to model all aspects of combat (air, land, sea, and amphibious ship-to-shore activities) and gives detailed information about its usage.

Sawyers (1998) discusses the evolving analytic modeling capabilities of the Marine Corps. He describes the new Mission Area Analysis process to identify operational requirements and deficiencies.

Martin (1999) describes a concept for tactical development system that allows the analyst to study the tactics, to vary the order of steps without having to break open the model each time. This methodology for modeling tactics and procedures uses a component based system written in EXTEND ™ from Imagine that Inc.

2.4. Air Warfare Simulations

Haeme, Huttinger and Shore (1988) provide Airline performance modeling to support schedule development. They study the problem of flight schedules, burden on air traffic control, airport facilities and develop a model for that problem.

Hurst and Flynn (1999) describe the ADVOCATE (Air Defense Verification of Options by Computer Analysis Of Target Engagement) land based air defense simulation program. The key features of the simulation program are given together with a description of how weapon systems and threats have been modeled.

McKay Laube (1988) gives a case study description of the major techniques used in the design of a Search and Rescue (SAR) model, how the methods contribute to the flexibility, and how these software engineering principles relate to a formal methodology that has been proposed specifically for simulation development.

Rubin and Sowers (1988) presents air operations modeling in a war-gaming environment. The Air Operations system compromises the user interface, models, and the data structures for representing the deployment and control of Naval air assets within the war game.

Litko and Carter (1991) describe a model, which was widely used to support decisions on employment of aircrews in Desert Storm Operation. They describe the Desert Storm scenario and define the components of the airlift system and the rules for its operation. Next they describe the model and its inputs and outputs. Then they discuss the application of the model to specific decisions and the validation of model results.

Zahn, Stute and Clark (1995) summarize a joint study by the U.S. air Force that models aerospace support equipment usage during a deployment of fighter aircraft. The model explains the present role of the equipment, and introduces a possible alternative.

Briggs, Mollaghasemi and Sepulveda (1995) develop a hybrid analytical/simulation model to plan for mass tactical airborne operations. This automated tool enables the user to properly load aircraft according to the mission and user specifications, so that the minimum amount of time is required to seize all assigned objectives.

Chapter 3

The Simulation Model

3.1. Formulation of the Problem and Planning the Study

It is a well-known fact that no other force can match Army aviations ability to rapidly project the force and build combat power in the battlefield. On the other hand, training and defense budgets are always constraints to military staff. It is a “must” to be well trained and well prepared for the combat while staying within the budget considerations. We think the use of the simulation and statistical procedures analyzing the operations will help these aspects.

The air assault operations simulation model is developed to:

- Allow planners to build models of air assault operations early in the decision process and refine those models as their decision process evolve.
- Permit accurate and efficient modeling of the capabilities, limitations and vulnerabilities of the air assault operations especially from the Army Aviations point of view.
- Perform “*Bottleneck analysis”* of the preplanned operation using statistical procedures.
- Perform “ *Risk management”* for the operations before conducting the real exercises.

By using this model; the commander and the staff officers can accurately and efficiently examine the behavior of the system, establish the nature of the relationships among one or more significant factors and the systems’ responses, analyze the results gotten from the software and perform “bottleneck analysis” for a given scenario. They can have the ability to select the best alternative by using the certain statistical procedures according to their performance measures and decision variables. This research is intended to have a positive effect on decision process of the staff that plans such kind of operations and affective risk management for the decision maker. By using this simulation model we try to answer the following questions:

- Does the system operate properly? (Do the troops arrive at the landing points on their schedule?) .
- If not, what are the critical factors to be examined, changed, added or omitted?
- Is there a need to change the constructions of the facilities of the system?
- Are the routes safe enough against effectiveness of enemy air defense weapons according to planned scenario?

In order to answer above questions, the model is capable of evaluating a wide variety of performance measures. These are:

- Time in system for the helicopters
- Time in queue in the refueling area
- Number of helicopters waiting in refueling area
- Number of helicopters that failed during the operation
- Number of helicopters that needed maintenance during the operation
- Time in queue in the maintenance area
- Number of helicopters waiting in maintenance area
- Number of helicopters that are hit by the enemy air defense weapons
- Utilization of helicopters
- Utilization of refueling tankers
- Utilization of maintenance facilities
- Punctuality on the preplanned schedule
- Utilization of flight route
- Utilization of return flight route

Since our system considers the war conditions, we had the difficulty of obtaining the data that fits into the real conditions. In the simulation model we need the following data:

- Velocity of the helicopters
- Loading capacity of a helicopter
- Loading time of a helicopter
- Critical fuel level for a helicopter
- Critical weather conditions for an operation
- Critical ” mission abort “ or ” mission failed” level for the number of helicopters hit by the enemy air defense weapons

- Hitting percentages for particular enemy air defense weapons
- Number of units to be air assaulted
- Number of control points in the flight routes
- Unloading time of a helicopter
- Refueling capacity of a tanker
- Refueling time of a tanker
- Maintenance capacities for particular breakdowns
- Maintenance times for particular breakdowns
- Pilot tiredness factors

The data used in the model is analyzed in the input data analysis section. The warfare related data are mostly taken from the publications of the army, which are the statistics gathered from the past experiences.

This study helps to see how the system operates, how the behavior of the system changes under certain conditions, and what are the bottleneck areas in the system. The end user of this study is the Turkish Army Aviation System. By using the model the user can make decisions and evaluations on the system by way of sensitivity analysis. The model can be easily adapted to model other scenarios with more details using the flexibility of adding and subtracting some of these modules of ARENA software to develop the model. The model enables the user to see the system behavior physically with the help of animation features. The limitations of the model mostly come from the size of the system. Due to the difficulty of gathering the quality data, time limitation the AAOSM only deals with the Loading, Air movement and the Landing phases of the operation and assumes that Staging phase is conducted properly beforehand.

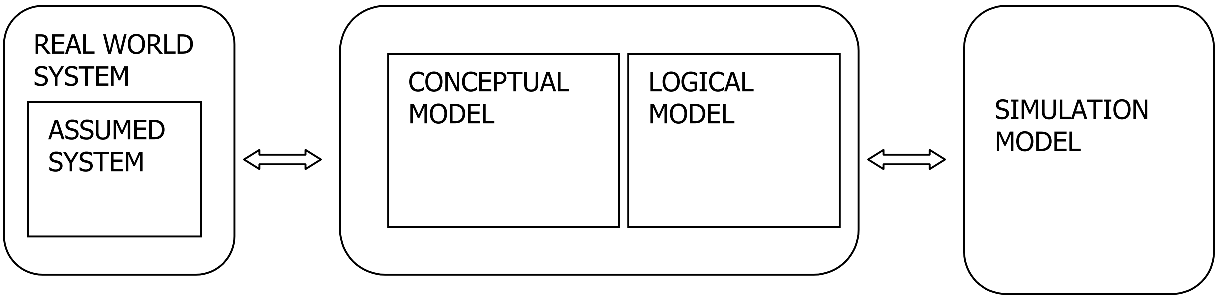
The simulation procedure has stochastic in its nature just like the battlefield. It may help us to model the operations with *almost* all its features. There are several unpredictable and stochastic factors in the air assault operations. These are:

- Enemy disposition and capabilities
- Enemy ground and air capabilities
- Hit rate of the guns for both enemy and the friendly troops
- Punctuality of the troops
- Intelligence
- Maintenance considerations of the helicopters

- Reloading and refueling considerations of the helicopters
- Terrain
- Weather conditions

3.2. Model Development

To be able to simulate the essence of the system, the conceptual model is first formed after the interviews with the experts of the real system and the users, then the logic model and the computer model are constructed. As a schematic view of model development is:



3.2.1. Conceptual Model

The AAOM is capable of implementing different scenarios under different:

- Weather and terrain conditions
- Enemy air defense conditions

You can see a screen shot of the AAOM below:

Figure 3.2.1: Screen shot of the Air Assault Operation Model

The assumptions of our model are:

- There is no escort mission by the friendly attack helicopters
- The operation under consideration is offense.
- There is no hindrance by the enemy attack helicopters and jetfighters during the operation.
- The infantry units only consist of soldiers; there are no additional operational packages.
- There are no restrictions at the pick up and the landing zones.
- There is no SAR (Search and Rescue) mission during the operation.
- The Infantry units are always ready at the time of loading in the Pick up zone.

- There are no enemy electronic countermeasures to hinder the flight of the helicopters.
- There are no friendly, artillery, naval artillery and air force support for the operation.
- The pilots don't make any pilotage mistakes throughout the operation
- All the helicopters taking part in the operation are S-70 Sikorsky type utility helicopters.

AAOSM is capable of collecting many different statistics but we concentrated on the main statistics according to the scenarios we tested. These are:

- Time in the system: the time of the soldiers from the pick up zone until they land at the landing zone.
- Time in the maintenance queue
- Time in the tanker queue
- Number of the soldiers that are able to arrive to landing zone
- Number of helicopters shot during the operation

It is a terminating system according to the criteria's below:

- If all the soldiers arrive to the landing zone
- If a total of 20 helicopters are shot by enemy
- If a total of 20 helicopters are withdrawn from the operation due to pilot fatigue
- If a total of 20 helicopters are out of operation due to 4th type of breakdown (that needs overall maintenance in the rear area)

These criteria's can be changed according to the commander's risk decisions. The input probability distributions and the variables change according to which scenario is under consideration.

Enemy air defense conditions:

We have 5 different checkpoints in the flight route and 5 different checkpoints in the return flight route. The user can input different air defense weapons on these check points according to the intelligence reports. We used typical intensity air weapons (infantry weapons, turrets and small rockets) and inputted them to 4th, 5th, LZ, 6th and 7th control points with certain probabilities. The AAOSM first checks if there may be an enemy weapon on the control point or not then with certain probability it engages a weapon to the helicopter, which is checking the control point. Again with certain probability the engaged weapon hits the helicopter or misses it (PH –probability of hit). If the weapon hits the helicopter, with another probability (PK-probability of kill) it makes the helicopter down or not. If the helicopter is downed, we assume that all the soldiers are killed. If not the helicopter continues its flight. The probability distributions are taken from the database of the JANUS (http://www-leav.army.mil/nsc/famsim/janus/index.htm) software.

Weather and terrain conditions:

AAOSM consists of five different weather and terrain conditions, which are

- Hot weather and High Terrain
- Hot weather and Sea level
- Cold weather and High Terrain
- Cold weather and Sea level
- Night flight with Night Vision Goggles (NVG)

These conditions affect the probabilities of breakdowns occurrence for helicopters, the repair times of these breakdowns. Furthermore user can apply the particular scenario in Night Vision Goggles conditions that effects of enemy air defense weapons. For example, in Hot and High condition the breakdown and the maintenance times are worse than the Cold and Sea level condition but they are better than Night Vision Goggles conditions.

Maintenance Facilities:

We have different number of maintenance stations in the AAOSM. In these stations the helicopter technicians try to repair the helicopters that need to be repaired. The model consists of 4 different types of breakdowns for the helicopters. They occur stochastically within the model and repaired according to their repair time.

Refueling tankers:

The helicopters can fly at most 2 hour and 15 minutes. Then they have to refuel in order to continue the operation. For this reason, the tankers are located in the rear operation area. Tankers are capable of refueling at most 21 helicopters with full depot and then it takes a certain time for a tanker to go and refuel its depot. Furthermore, they are affected by certain breakdowns with some probability distribution.

Pilot tiredness:

A pilot can fly at most 8 hours according to Army regulations and flight manuals. After this period he must rest for a certain period of the time in order to fly again. In AAOSM, if a pilot exceeds 8 hours of flight limit, he and his helicopter is automatically withdrawn from the operation. This feature is included in the model to show the decision makers if any bottleneck occurs in the number of pilots or not. Furthermore, due to physical stress and hardness in the environmental conditions a pilot can fly at most 4 hours in the Night Vision Goggles (NVG) flight conditions.

Events:

The events that occur during the model are the followings:

- Arrival of infantry unit to pick up zone
- Arrival of helicopters to pick up zone
- Loading of units to the helicopters
- Departure of the helicopters from the pick up zone
- Hitting or missing of a helicopter by an enemy air defense weapon
- Arrival of the helicopters to the landing zone (LZ)
- Deployement of the units from the helicopters
- Returning of helicopters to the Pick up zone
- Going for the refuelling
- Breakdown of a helicopter
- Maintanence of a helicopter
- Exceeding pilot tiredness factors
- Mission failure due to heavy air defense
- Mission accomplishment

Entities:

- Infantry Units

Activities:

- The move of helicopters
- Refuelling
- Breakdowns
- Hittings
- Maintenance
- Mission failure due to heavy air defense

Attributes:

- Helicopter flight hours for pilot tiredness considerations
- Helicopter fuel level
- The beginning time of flight

Exogeneous Variables (Input Variables):

- Number of helicopters
- Number of Infantry units
- Number of tankers at the refueling points
- Capacity of tankers (number of helicopters to be served at one time)
- Number of maintenance units
- Capacity of maintenance units
- Loading capacity of helicopters
- Velocity of helicopters
- The distances between Pick up zone and the Landing zone
- Hitting percentages of the enemy air defense weapons
- Weather and terrain conditions

Endegenous Variables (Output Variables):

State variables:

- Number of helicopters waiting in the refuelling queues
- Number of helicopters waiting in the maintanence queues
- State of the tanker units (busy or idle)
- State of the maintanence units (busy or idle)

Starting and Stopping time:

Start at a scheduled time

Stop when;

- All the infantry units are brought to the LZ
- Mission is failed due to heavy air defense (20 helicopters are shot by enemy air defense)
- Mission is failed due to pilot fatique (20 helicopters are withdrawn from the operation due to pilot fatique)
- Mission is failed due to breakdowns (20 helicopters need overall maintenance at the rear area)

Note that the commander according to his risk decisions can change the stopping criterias.

3.2.2 Flowchart of the system

We present flowchart of the model in Figure 3.2.2.1. The staging phase of the air assault operation is assumed to be implemented beforehand. The model performs several checks at the beginning. These checks are important for the change of the parameters and decision of the stopping criteria. According to the attributes and the variables the entities get at those checkpoints, they are sent to the other parts of the model.

In the Figure 3.2.2.2 effects of the weather and terrain conditions are presented. The model decides the breakdown ratio for helicopters, maintenance times for the particular breakdowns, and the information about the refueling tankers. The following figures are the flowcharts of the helicopter fuel consumption, breakdowns, pilot fatique and enemy air defense conditions. At last, the model checks for the accomplishment of the mission. If the mission is not over yet, the helicopters return to the LZ via return flight route for the next sortie.

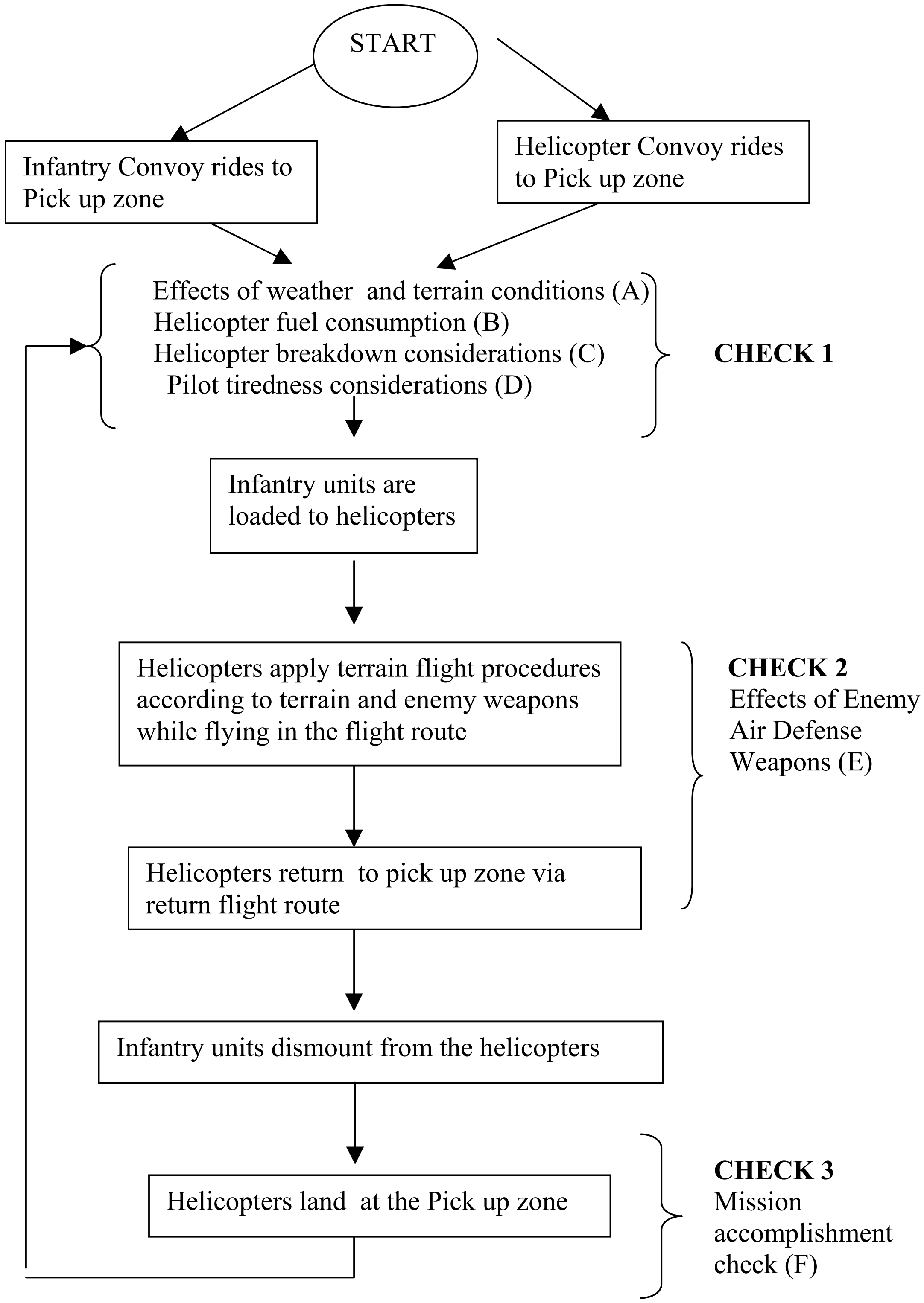


Figure 3.2.2.1:The flowchart of the Logical Model

CHECK 1

(A) Effects of weather and terrain conditions

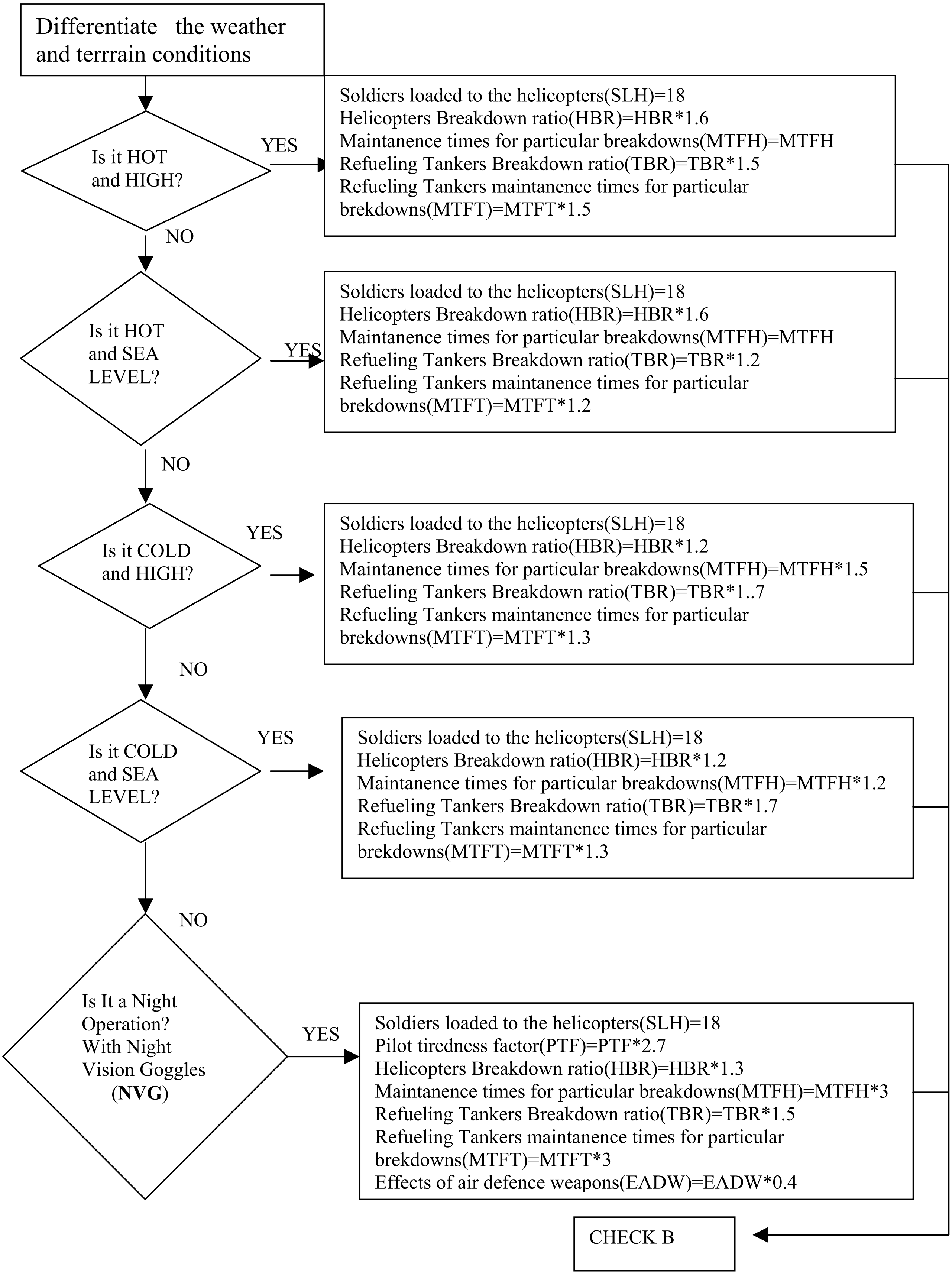


Figure 3.2.2.2:The flowchart of effects of Weather & Terrain Conditions

(B) Helicopter fuel consumption

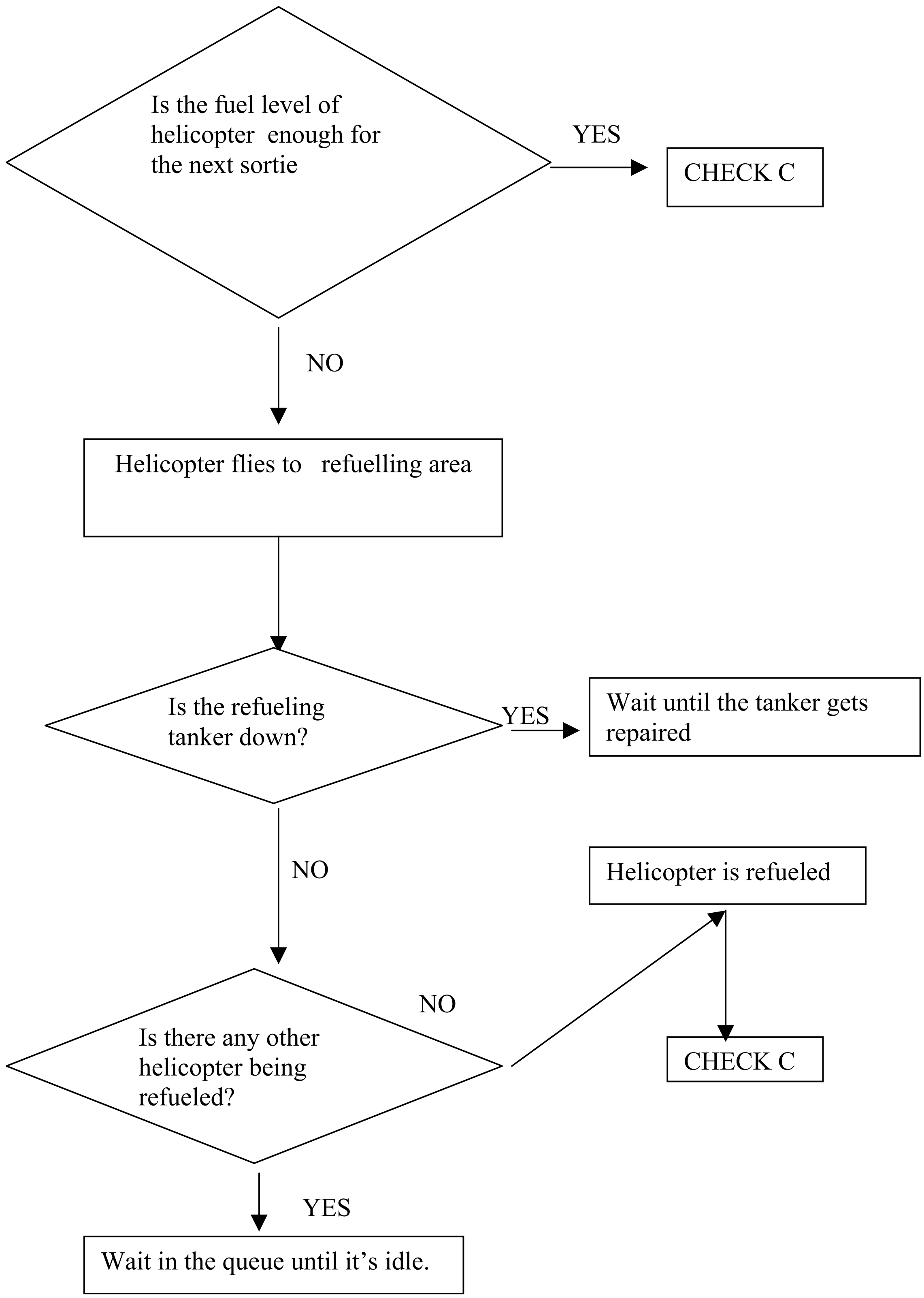


Figure 3.2.2.3:The flowchart of Helicopter fuel Consumption

(C) Helicopter breakdown considerations

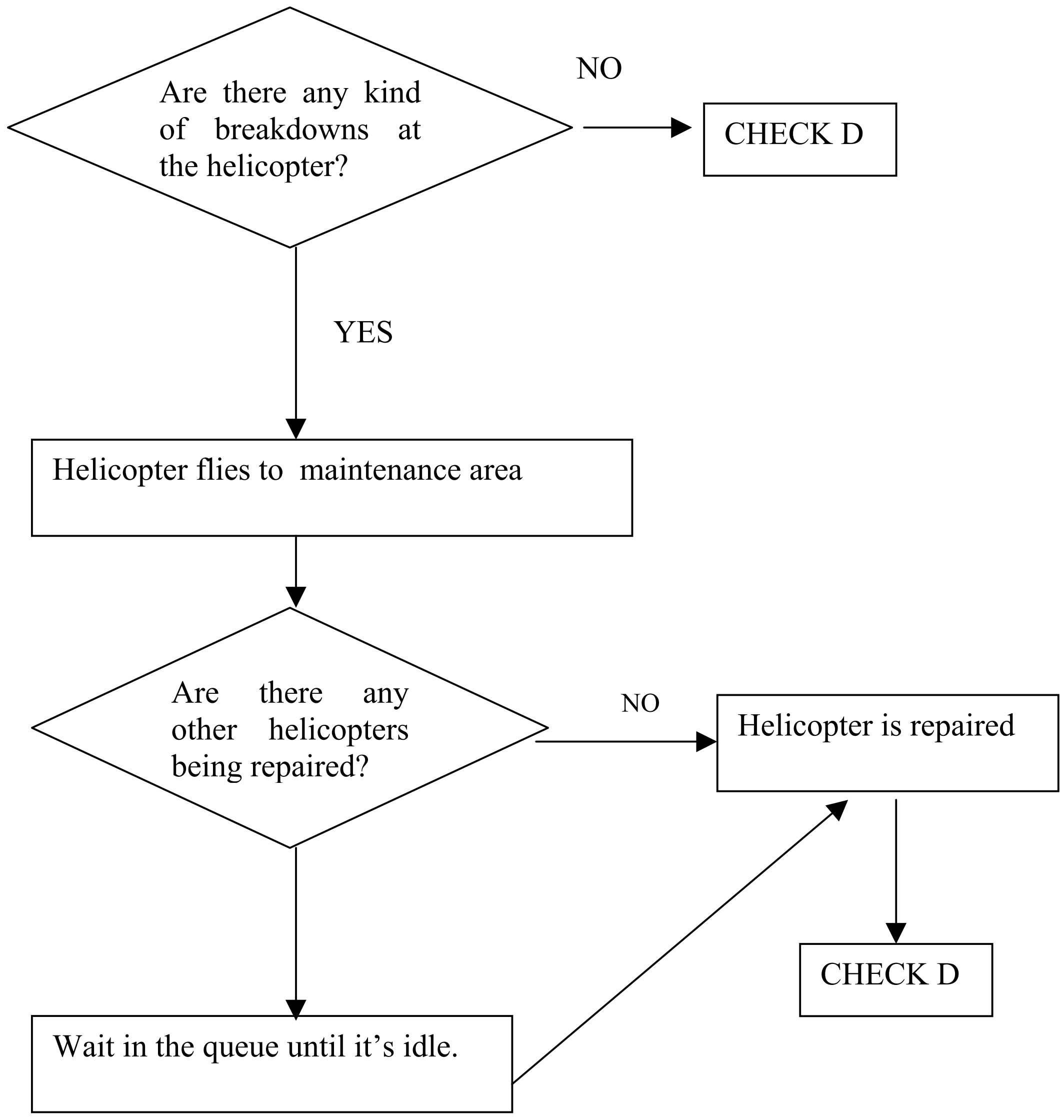


Figure 3.2.2.4:The flowchart of Helicopter breakdown considerations

(D) Pilot tiredness considerations

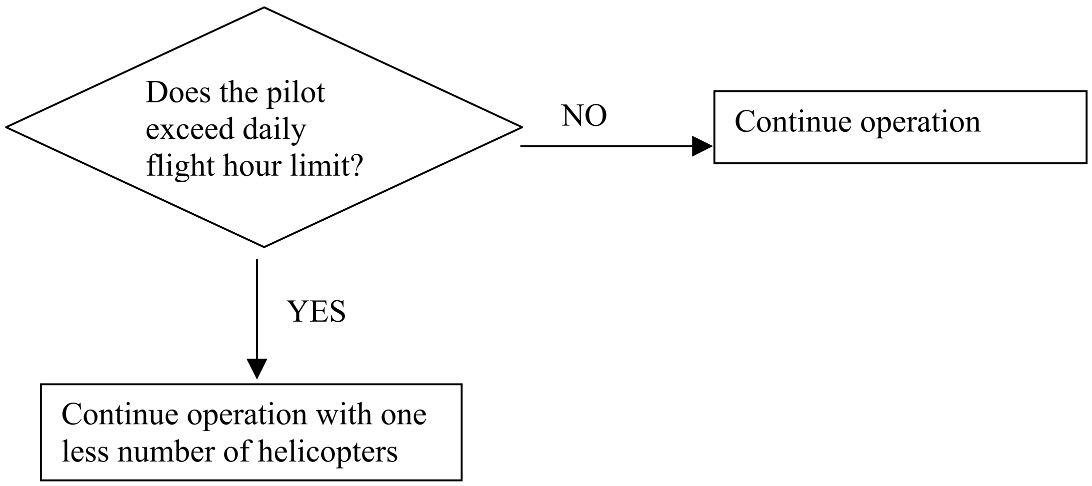


Figure 3.2.2.5:The flowchart of pilot tiredness considerations

<u>CHECK 2</u>

(E) Effects of enemy air defence weapons

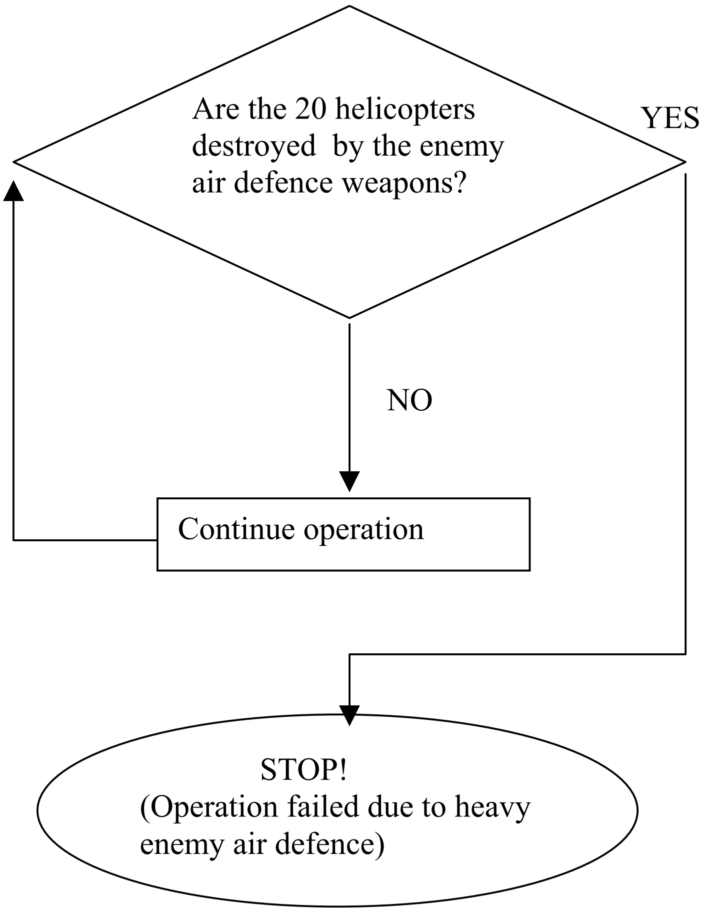


Figure 3.2.2.6:The flowchart of effects of enemy air defense weapons

CHECK 3

(G) Mission accomplishment check

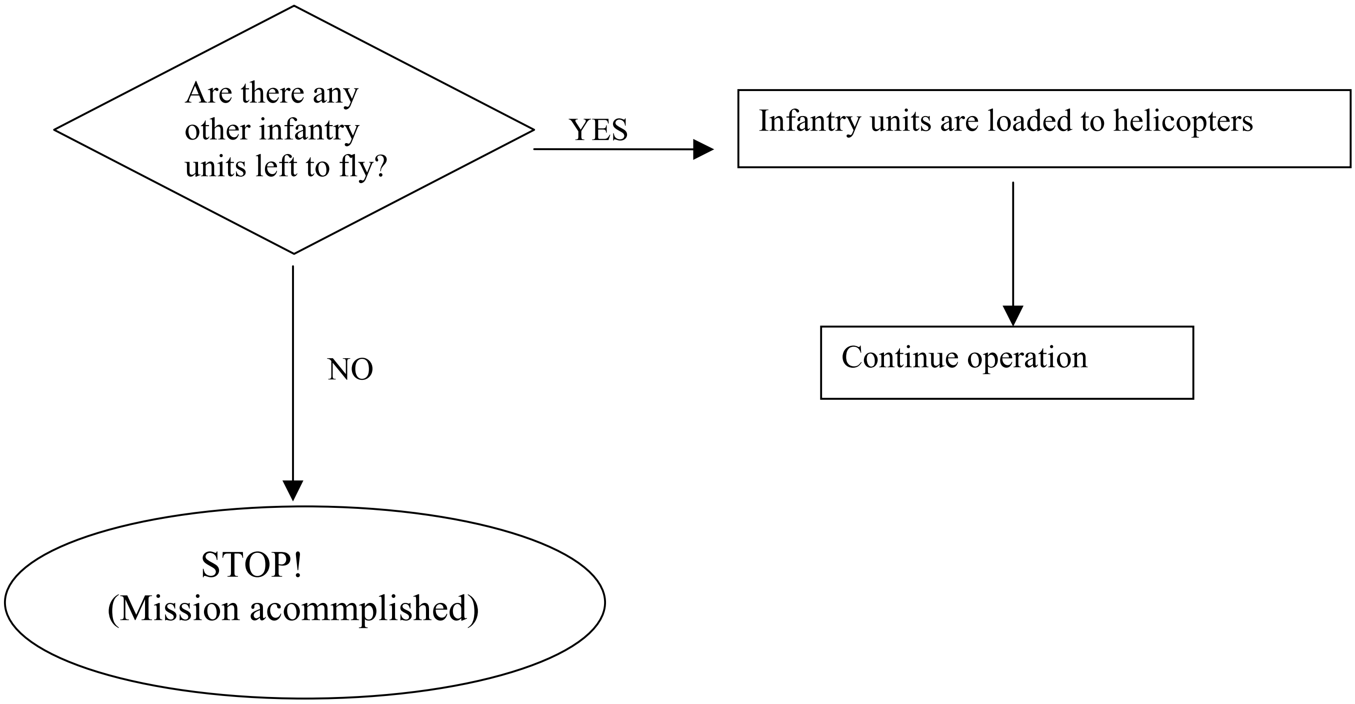


Figure 3.2.2.7: The flowchart of mission accomplishment

3.2.3. Simulation Model (Computer Code)

We use ARENA software (http://www.arenasimulation.com) since it is a flexible and powerful tool that allows us to create graphical and animated models easily and offers reasonably good simulation input and output process.

The computer codes occupy 4083 KB, 530 SIMAN lines, and one run takes approximately 30 seconds according to the stopping criteria we explained above. We present some parts of the computer code due to confidentiality of the subject studied. For the computer codes of model and experimental frame of the model, one can refer to Appendix A.

3.3. Input Data Analysis

We consider the war conditions and have no opportunity to experience and collect data in real life. As Smith (1998) recommends we use triangular and uniform distributions in the absence of data. The parameters of the distributions are determined by interviewing with the personnel who are experienced pilots, technicians and maintenance chief pilots. Some of the data are taken from the army field manuals that are written according to the war experiences. Since the data taken from that manuals are not raw data and certain numbers we used them for the minimum, average and maximum values of the triangular distribution. In the future applications, as we gather new data, the input data analysis techniques discussed in Law and Kelton (1991) can be used to fit correct distribution functions to the data set. The input data is presented in Appendix I.

3.4. Model Verification and Validation

Considering the principles Balci (1989) stated we performed the Verification and Validation (V&V) techniques for all steps of our study from the beginning.

3.4.1. Verification

"Computerized model verification ensures that the computer programming and implementation of the conceptual model are correct." We apply the techniques that Banks (1998) recommended. Specifically,

- We use ARENA debugger function with the logic flow together to see whether the events occur properly or not. It helps us to monitor the simulation as it progresses.
- We test our model for the different and extreme conditions to observe whether the model behaves reasonable.
- Since ARENA has the capability of collecting most of the statistics automatically we have the chance to observe the outputs easily. Besides, we use different output statistics that are verifying the other statistics (total time in system and partial time in some activities, queues and utilization etc.)

- Since we use animation in our models, we see the movements of the entities toward the system that ensures the model verification.
- We check our computer model by other analysts.

3.4.2. Validation

3.4.2.1. Face Validity

A model with face validity is the model that, on the surface, seems reasonable to people who are knowledgeable about the system under study. It includes conversations with system experts, observations of the system, experience and intuition. (Law and Kelton, 2000)

From the beginning of the study we include the users in the process of model development. Thus, we assure that the model behaves as expected in the real conditions. Since we have no opportunity to observe the real conditions we consulted with the instructor pilots of the Army Aviation School. The model, assumptions and the results are presented to them in a formal meeting. Moreover, two maintenance pilots from the 901 Army Aviation Depot are included to validate the maintenance parts of the model. In tactical considerations and the planning phase of the operation a staff officer who is both pilot and the planner of such kind of operations take a part. At last the commander of the Army Aviation School and his staff are included in face validity. They find the results reasonable and quite satisfactory.

3.4.2.2. Statistical Validation

We could not do the statistical validation because of a lack of data from actual war conditions.

Chapter 4

Design and Analysis of the Experiments

4.1. 2^5 Factorial Designs and Analysis of Experiments on the AAOSM

One of the principal goals of experimental design is to estimate how changes in input factors affect the results, or *response*s, of the experiment. While these methods were developed with physical experiments in mind (like agricultural or industrial applications), they can easily be used in computer- simulation experiments as described in Law and Kelton (2000). In fact, using them in simulation presents several opportunities for improvement those are difficult or impossible to use in physical experiments. As a basic example of such techniques, suppose that we can identify just two values, or *level*s, of each of input factors. There is no general prescription on how to set these levels, but we should set them to be opposite in nature but not so extreme that they are unrealistic. If you have *k* input factors, there are thus 2 *k* different combinations of the input factors, each defining a different configuration of the model; this is called a *2 k factorial desig*n.

Factorial designs are widely used in experiments involving several factors where it is necessary to study the joint effect of the factors on a response. By a factorial design we mean that in each complete trial or replication of experiment all possible combinations of the levels of the factors are investigated.

The most important of these special cases is that of k factors, each at only two levels. These levels may be qualitative, such as two values of temparature, pressure or queue discipline, or they may be quantitative such as two machines, the high and low values of a factor, or perhaps the precense or absence of a factor. A complete replicate of such a design requires 2^k observations and is called 2^k factorial design. In factorial design we assume that :

- the factors are fixed
- the designs are completely randomized
- the usual normality assumptions are satisfied

In our study we will try to study the effects of the main factors in Air Assault Operation Model (AAOSM) according to our performance measures, and will attempt to find out the answer for the following question :

"What effects do the factors have on the performance measures?"

In our analysis we have 5 different factors with two different values which are:

Table 4.1:Factors effecting AAOSM

FACTOR NUMBER	FACTOR DESCRIPTION	-1	+1
1	Number of tankers	2	4
2	Size of the maintenance facilities	3	5
3	Queue discipline for maintenance	FIFO	LVF
4	Weather and terrain conditions	Cold and seal level	Hot and High
5	Enemy air defense conditions	Typical	Severe

Note that the factors (1) and (2) are quantitative in nature but the factors (3), (4), (5) are qualitative factors. For example, for the factor (5) we increase the probability of the hit data of the enemy air defense weapons by 20 % and called it "severe air defense". Our performance measures are as follows:

- Time in the system
- Time in the tanker queue
- Time in the maintenance queue
- Number of soldiers arrived to Landing Zone (LZ)
- Number of helicopters that are shot during the operation

In order to achieve the assumptions above we replicated 32 design point 20 times using ARENA 3.0 software with different seeds.

4.2. Departures from Assumptions in Analyses of Variance

The assumption of homogeneity of variance may cause serious problems in ANOVA tests. The treatments may have different variances if they produce erratic effects, or if the data follows a nonnormal skewed distribution, because the variance in a skewed distribution is usually related to the mean. There are a number of statistical procedures that may be used to test for inequality of variance. Here we present Bartlett's test (Montgomery 1992). Suppose that there are treatments, and we wish to test the hypothesis

H_0: $\sigma_1^2 = \sigma_2^2 = ... = \sigma_a^2$

H_1: above not true for at least one σ_i^2

The test procedure uses a statistic whose sampling distribution is approximated by the chi-square distribution with a-1 degrees of freedom when the random samples are from independent normal populations. Therefore, we should reject H_0 if

$$\chi_0^2 \rangle \chi_{\alpha,a-1}^2 .$$

We applied the Bartlett's test to see if our assumption of common variance is true or not. The results indicate that we cannot reject the null hypothesis that the sample variances are equal (Table 4.2). The scatter plots of the variances of the particular performance measures are also given in Appendix B.

Table 4.2:The results of Bartletts test according to performance measures

	PERFORMANCE MEASURES				
	TIME IN THE SYSTEM	TIME IN THE TANKER QUEUE	TIME IN THE MAINTENANCE QUEUE	SOLDIERS ARRIVED TO LZ	NUMBER OF HELICOPTERS SHOT
χ_0^2	-2843,92	-538,300	-4032,684	-4771,104	-472,380
$\chi_{\alpha,a-1}^2$	14	14	14	14	14
	DO NOT REJECT	DO NOT REJECT	DO NOT REJECT	DO NOT REJECT	DO NOT REJECT

After checking the validity of the ANOVA asumptions, we calculate the contrasts and the main and the interaction effects of the factors of the five different performance measures and performed ANOVA to find out which factor and the interactions are significant on that performance measure. In a design with 5 factors we have 5 main effects, 10 two-factor interactions and 10 tree-factor interactions. That for a 2^5 design the complete model would contain 31 effects. To estimate an effect or to compute the sum of squares for an effect, we must first determine the contrast associated with that effect. Once the contrast for the effects have been computed, we may easily estimate the effects and compute the sum of squares.

4.3. Evaluation of the Performance Measures

We begin evaluation of the performance measures by analyzing the ANOVA results. We validate the findings of the ANOVA by plotting effect estimates on the normal probability plot and by analyzing the scatter plot of the effects according to the factors. We give the methodology of our analysis in detail for only the first performance measure. The plots and details of other performance measures are given in Appendices C, D, and E. We now explain the results for each performance measure in the following sections.

4.3.1. Time in the System Statistics

Time in the system is the interval between the time a soldier arrives to the PZ and the time he lands on the LZ. In Table 4.3.1.1, we present the ANOVA results. The results indicate that factor 4 (weather and terrain conditions) is the only significant factor.

Table 4.3.1.1: Analysis of variance of time in the system statistics

ANALYSIS OF VARIANCE OF TIME IN THE SYTEM STATISTICS

Source of variation	EFFECTS	SSx	df	MSx	Fo	
1	-7,364622021	8678,0252	1	8678,0252	0,873152	INSIGNIFICANT
2	-7,892746102	9967,27056	1	9967,27056	1,002871	INSIGNIFICANT
3	-2,607828747	1088,12332	1	1088,12332	0,109483	INSIGNIFICANT
4	56,85353722	517171,951	1	517171,951	52,03597	**SIGNIFICANT**
5	5,557283488	4941,34396	1	4941,34396	0,49718	INSIGNIFICANT
1-2	-2,262828494	819,262847	1	819,262847	0,082431	INSIGNIFICANT
1-3	-7,347533648	8637,80011	1	8637,80011	0,869104	INSIGNIFICANT
1-4	9,422815397	14206,312	1	14206,312	1,429388	INSIGNIFICANT
1-5	4,627933786	3426,84338	1	3426,84338	0,344797	INSIGNIFICANT
2-3	2,472450774	978,082053	1	978,082053	0,098411	INSIGNIFICANT
2-4	-2,867931108	1316,00461	1	1316,00461	0,132412	INSIGNIFICANT
2-5	1,31300244	275,836065	1	275,836065	0,027754	INSIGNIFICANT
3-4	-5,000752711	4001,20443	1	4001,20443	0,402587	INSIGNIFICANT
3-5	-3,101996505	1539,58117	1	1539,58117	0,154907	INSIGNIFICANT
4-5	-14,386357	33114,7628	1	33114,7628	3,331888	INSIGNIFICANT
1-2-3	5,880991277	5533,76934	1	5533,76934	0,556788	INSIGNIFICANT
1-2-4	-3,120516636	1558,01985	1	1558,01985	0,156762	INSIGNIFICANT
1-2-5	-1,495134011	357,668114	1	357,668114	0,035987	INSIGNIFICANT
1-3-4	-4,054520206	2630,26146	1	2630,26146	0,264647	INSIGNIFICANT
1-3-5	0,931613082	138,864469	1	138,864469	0,013972	INSIGNIFICANT
1-4-5	2,032184888	660,764067	1	660,764067	0,066484	INSIGNIFICANT
2-3-4	3,418537356	1869,82362	1	1869,82362	0,188135	INSIGNIFICANT
2-3-5	4,791857488	3673,90371	1	3673,90371	0,369655	INSIGNIFICANT
2-4-5	1,370637207	300,583417	1	300,583417	0,030244	INSIGNIFICANT
3-4-5	-3,532072678	1996,08598	1	1996,08598	0,200839	INSIGNIFICANT
1-2-3-4	2,86191508	1310,48927	1	1310,48927	0,131857	INSIGNIFICANT
1-2-3-5	2,253999891	812,882481	1	812,882481	0,081789	INSIGNIFICANT
1-2-4-5	0,414393747	27,4755484	1	27,4755484	0,002764	INSIGNIFICANT
1-3-4-5	1,586763105	402,850744	1	402,850744	0,040533	INSIGNIFICANT
2-3-4-5	3,593274702	2065,85969	1	2065,85969	0,207859	INSIGNIFICANT
1-2-3-4-5	1,74912656	489,510996	1	489,510996	0,049253	INSIGNIFICANT
Error		6042753,49	608	9938,73929		
Total		6676744,7	639			

In order to validate this finding, we analyze the normal probability effects of the time in the system statistics. These results are given in Table 4.3.1.2 and Figure 4.3.1.1. Note that all of the effects that lie along the line are negligible, whereas the point number 1 corresponding to the factor 4 is significantly far from the line.

Table 4.3.1.2: Analysis of normal P-P plot effects of time in the system statistics

ANALYSIS NORMAL P-P EFFECTS OF TIME IN THE SYTEM STATISTICS

ORDER (j)	EFFECT	ESTIMATE	(j-.5)/32
31	**4**	56,8535372	0,953125
30	**1-4**	9,4228154	0,921875
29	**1-2-3**	5,88099128	0,890625
28	**5**	5,55728349	0,859375
27	**2-3-5**	4,79185749	0,828125
26	**1-5**	4,62793379	0,796875
25	**2-3-4-5**	3,5932747	0,765625
24	**2-3-4**	3,41853736	0,734375
23	**1-2-3-4**	2,86191508	0,703125
22	**2-3**	2,47245077	0,671875
21	**1-2-3-5**	2,25399989	0,640625
20	**1-4-5**	2,03218489	0,609375
19	**1-2-3-4-5**	1,74912656	0,578125
18	**1-3-4-5**	1,5867631	0,546875
17	**2-4-5**	1,37063721	0,515625
16	**2-5**	1,31300244	0,484375
15	**1-3-5**	0,93161308	0,453125
14	**1-2-4-5**	0,41439375	0,421875
13	**1-2-5**	-1,49513401	0,390625
12	**1-2**	-2,26282849	0,359375
11	**3**	-2,60782875	0,328125
10	**2-4**	-2,86793111	0,296875
9	**3-5**	-3,1019965	0,265625
8	**1-2-4**	-3,12051664	0,234375
7	**3-4-5**	-3,53207268	0,203125
6	**1-3-4**	-4,05452021	0,171875
5	**3-4**	-5,00075271	0,140625
4	**1-3**	-7,34753365	0,109375
3	**1**	-7,36462202	0,078125
2	**2**	-7,8927461	0,046875
1	**4-5**	-14,386357	0,015625

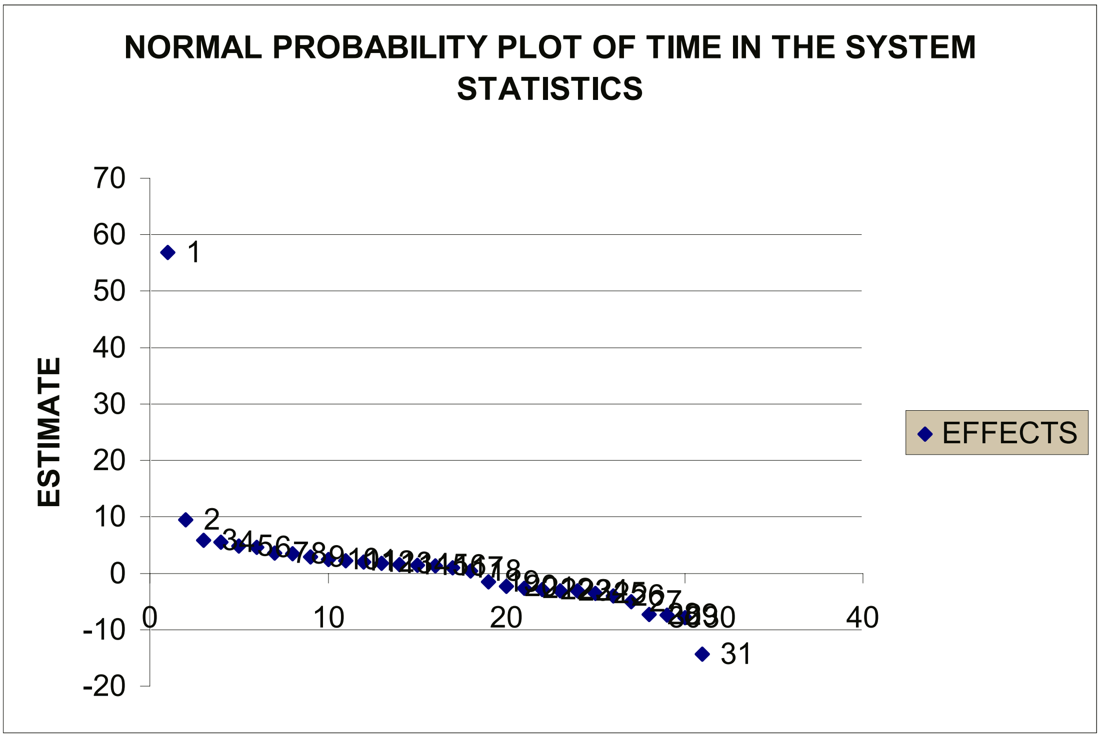


Figure 4.3.1.1:Normal probability plot of time in the system statistics

We also analyze the scatter plot of the effects according to the factors (Figure 4.3.1.2). Again all of the factors other than the factor 4 are along the centerline.

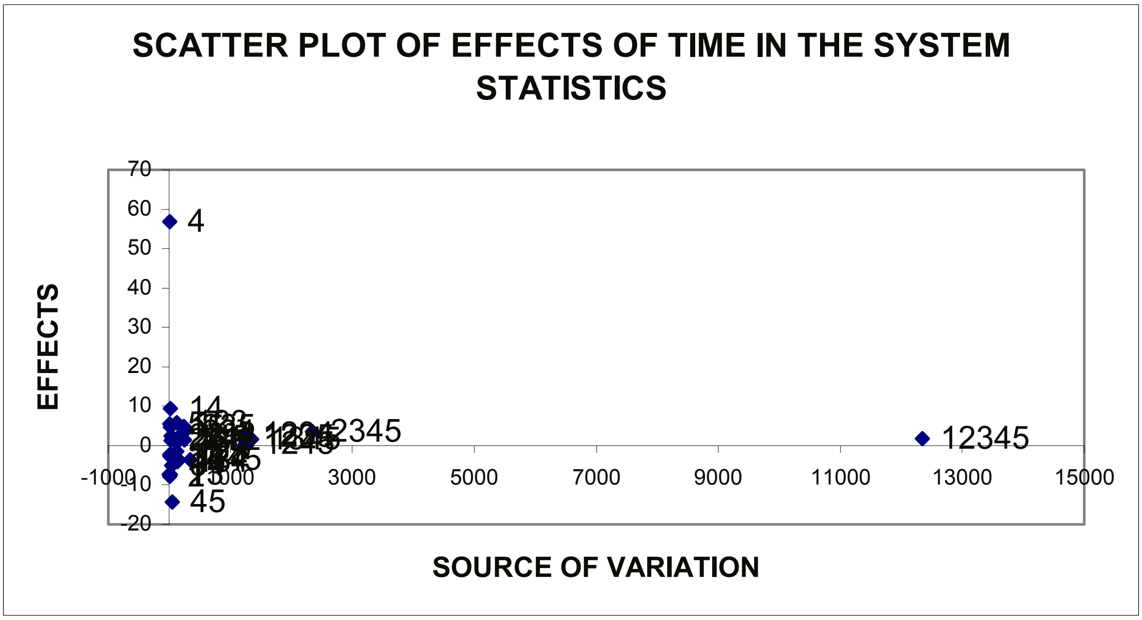
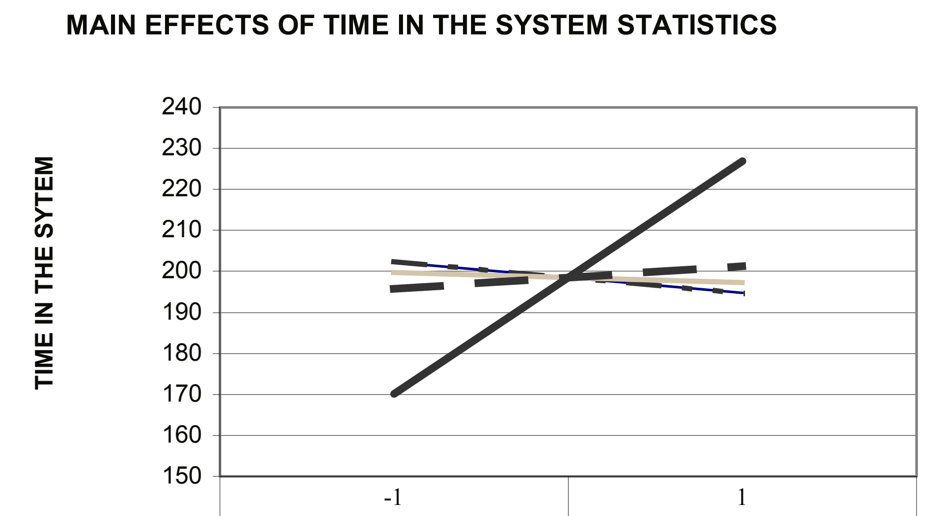


Figure 4.3.1.2: Scatter plots of effects of time in the system statistics

The effect diagram in Figure 4.3.1.3 summarizes the results. It clearly shows that factor 4 is the only significant factor. This means that the weather and terrain conditions (being cold-or-hot and sea level-or- high level) affects the time in the system performance measure.



	-1	1
NUMBER OF TANKERS	202,1797013	194,8150793
NUMBER OF MAINT	202,4437633	194,5510172
QUEUE DIS.	199,8013047	197,1934759
WEATHER AND TERRAIN	170,0706217	226,9241589
AIR DEFENCE	195,7187485	201,276032

LEVELS

Figure 4.3.1.3:Main effects of time in the system statistics

Note that if we change the scenario from Hot-and-High to Cold-and-Sea level weather and terrain conditions, time in the system increases by 34 %. That means, the changes in the parameters of the helicopter breakdown ratio, maintenance times for particular breakdowns, tanker breakdown ratio and refueling tankers maintenance times, yields that 34 % increase in time in the system. These tell us that the weather and terrain conditions are very important for the success of the operation. As explained before, the success of the ground operation phase is related to the success of the air movement phase and punctuality of the troops. If the soldiers cannot arrive to LZ on time, they cannot support the other soldiers arrived to LZ before them. This may affect the success of the overall operation. Moreover, the soldiers waiting in the PZ can be susceptible to the enemy long distance and air assaults. The commander and the staff officers must be prepared for the results of this factor and try to increase or decrease the percentages that effect the time in the system by training and by using proper utilities and tools.

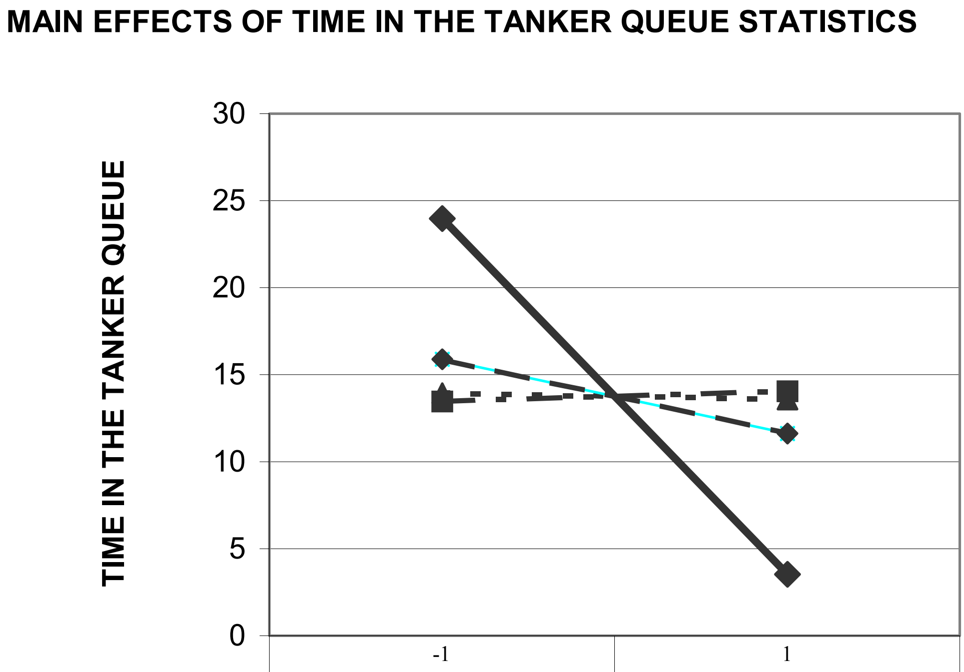
4.3.2. Time in the Tanker Queue Statistics

According to the ANOVA tests (Table 4.3.2.1 in Appendix C), the factors 1, 4, 5, and the interaction between factor 1 and 4 (1-4), and the interaction between 1 and 5 (1-5) are found significant. These are: number of tankers, weather and terrain conditions and enemy air defense conditions. Number of tankers-weather and terrain conditions and number of tankers-enemy conditions interactions are also found significant. The effect estimates on the normal probability plot (Figure 4.3.2.1 in Appendix E), and the scatter plot (Table 4.3.2.2 in Appendix D) verifies this observation.

As seen in Figure 4.3.2 if number of tankers increases from 2 to 4, time in the tanker queue decreases significantly by about 580 %. This shows us the importance of the combat service support during the operation. The number of the refueling tankers are also important for the utilization of the helicopters. This must be analyzed with the pilot tiredness considerations and maintenance considerations. As explained before, a pilot cannot exceed 8 hours of daily flight limit according to Army regulations.

Another significant factor is weather and terrain conditions. The percentages that we presented above in different weather and terrain conditions yields 27 % decrease in time in the tanker queue. Enemy air defense weapons are also significant factor on this performance measure. If we increase probability of hit value by 20 % from typical conditions to severe conditions this will yield 28 % decrease in time in the tanker queue because we will not have any more helicopters to refuel due to losses.

Also interaction of number of tankers – weather and terrain conditions and number of tankers–enemy air defense conditions yields 16,3 % and 25 % increase in the performance measure, respectively.

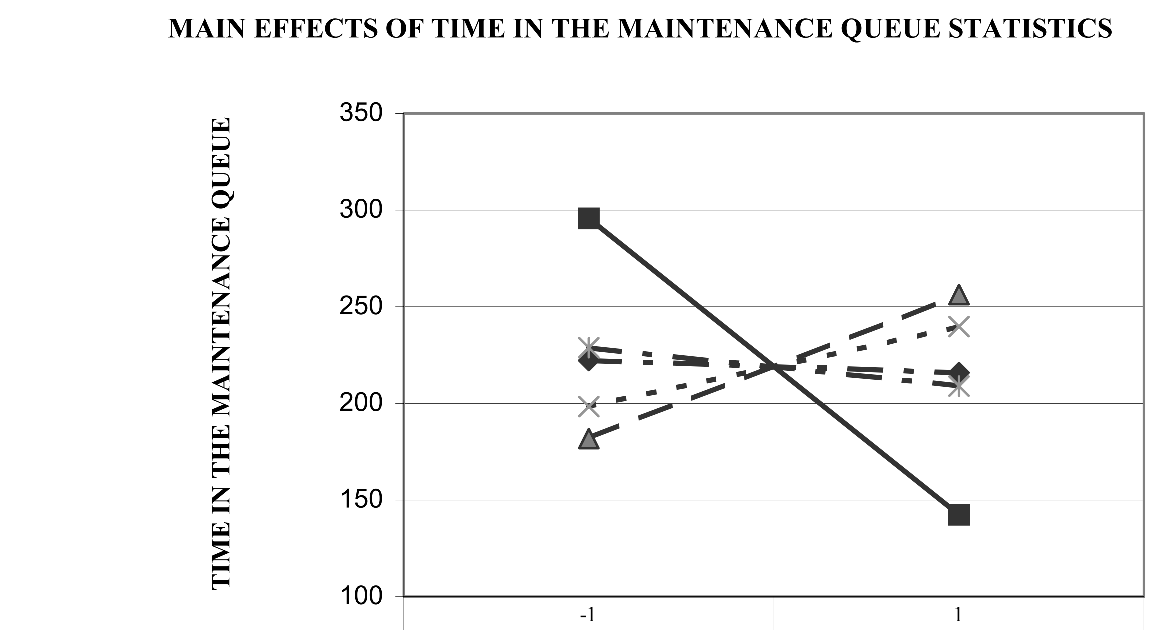


	-1	1
NUMBER OF TANKERS	23,97850195	3,520227293
SIZE OF MAINTENANCE	13,45870603	14,04002321
QUEUE DISCIPLINE	13,93908153	13,55964771
WEATHER AND TERRAIN CONDITIONS	15,8942769	11,60445234
ENEMY AIR DEFENCE	15,8942769	11,60445234

Figure 4.3.2:Main effects of time in the tanker queue statistics

4.3.3. Time in the Maintenance Queue Statistics

According to the ANOVA tests (Table 4.3.3.1 in Appendix C) factors 2 and 3 are found significant. These are: size of maintenance facilities and the queue discipline in the maintenance queues. The normal probability plot (Figure 4.3.3.1 in Appendix E) and the scatter plot (Table 4.3.3.2 in Appendix D) also display the same observation. As seen in Figure 4.3.3, the time in the maintenance queue significantly decreases when we change the size of the maintenance facilities from three to five.



	-1	1
NUMBER OF TANKERS	222,1336536	215,7899089
SIZE OF MAINTENANCE	295,6945942	142,2289683
QUEUE DISCIPLINE	181,6654904	256,2580722
WEATHER AND TERRAIN CONDITIONS	198,1977005	239,725862
ENEMY AIR DEFENCE	228,9170732	209,0064894

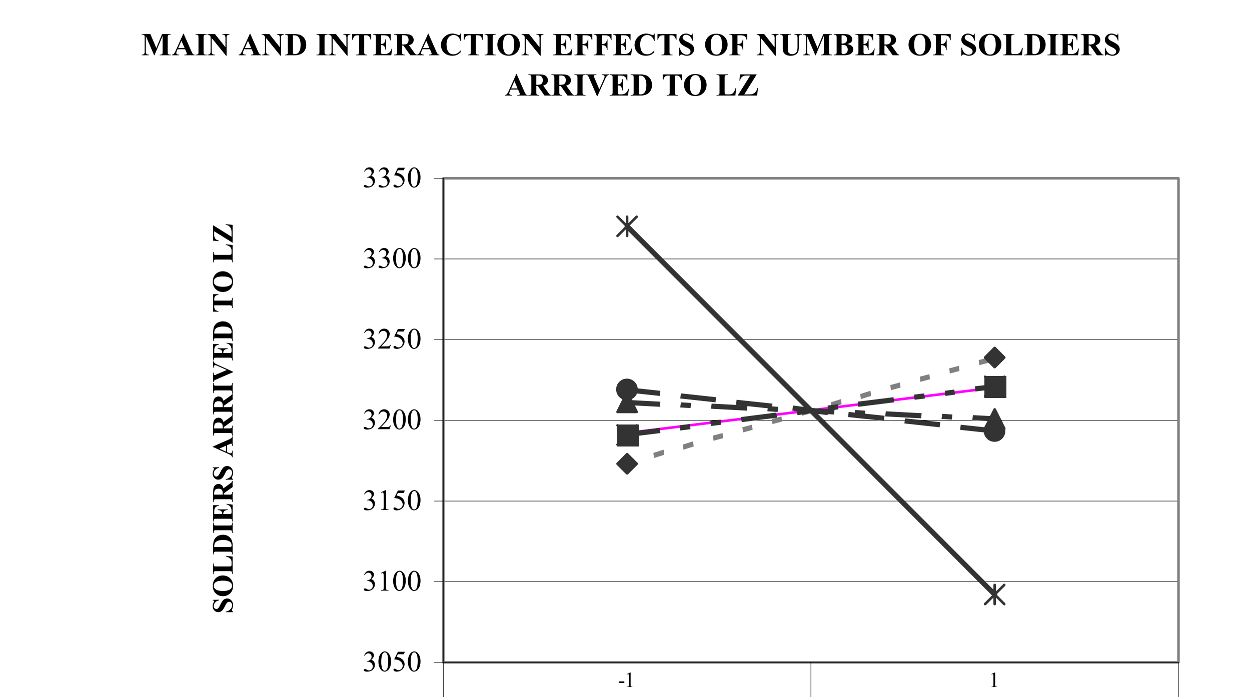
Figure 4.3.3: Main effects of time in the maintenance queue statistics

If we increase size of the maintenance facilities from 3 technicians to 5 technicians we get 52 % decrease in the time in the maintenance queue. The commander and the staff officers must be concentrated on the manpower planning according to that data. This change also affects the utilization of helicopters and time in the system of course again with regard to the consideration that we mentioned above.

Changing the queue discipline that we apply in the maintenance area yield 29 % increase in the performance measure. That means we must organize our maintenance facilities so that the helicopter which needs maintenance must be immediately repaired without analyzing the size and the type if the breakdown if we want to improve on that performance measure.

4.3.4. Number of Soldiers Arrived to LZ Statistics

According to the ANOVA tests (Table 4.3.4.1 in Appendix C) the only significant factor is 5 and interaction of factors 4 and 5 (4-5). These are enemy air defense weapons and the interaction of weather and enemy defense conditions. The normal probability plot (Figure 4.3.4.1 in Appendix E) and the scatter plot (Table 4.3.4.2 in Appendix D) also display the same results. The main and interaction effect diagram of the number of soldiers arrived to LZ can be seen in the Figure 4.3.4



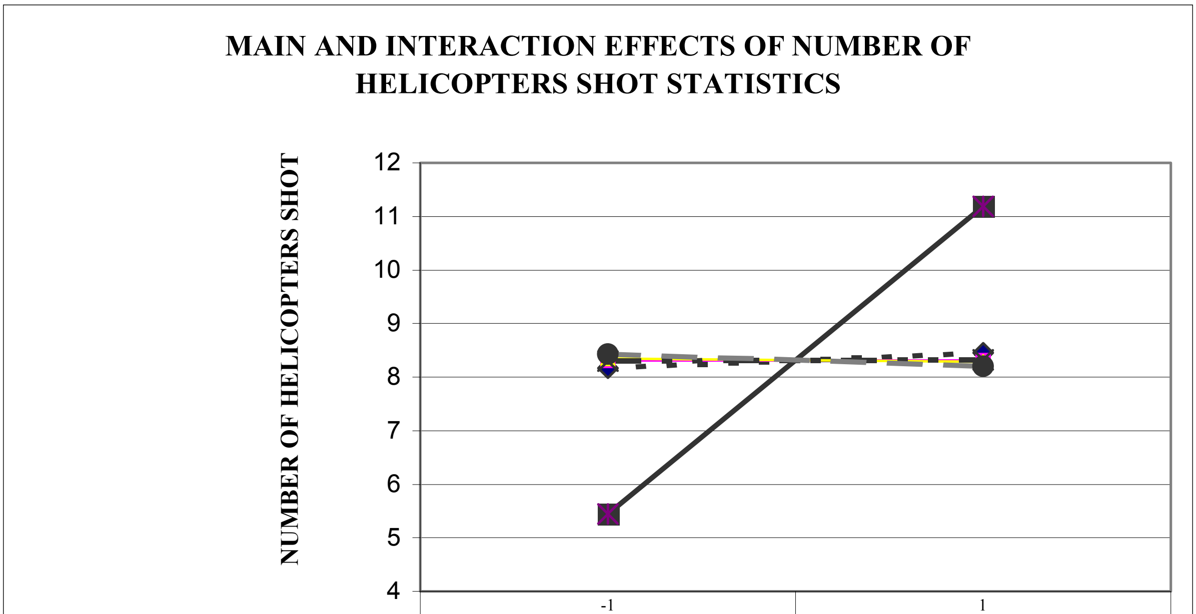
	-1	1
NUMBER OF TANKERS	3173,0625	3238,93125
SIZE OF MAINTENANCE	3191,90625	3220,0875
QUEUE DISCIPLINE	3211,2	3200,79375
WEATHER AND TERRAIN CONDITIONS	3191,0625	3220,93125
ENEMY AIR DEFENCE	3320,1	3091,89375
WEATHER AND TERRAIN & AIR DEFENCE	3218,85	3193,14375

Figure 4.3.4: Main and Interaction effects of number of soldiers arrived to LZ statistics

If probability of hit data increases by 20 % in enemy air defense weapons, this yields 7 % less number of soldiers that we can land on LZ. This percentage may affect our unity of troops and the ground tactical plan stage of the operation may fail to success. The commanders and staff officers must take all the precautions not to danger the unity of the troops. The enemy air defense weapons must be suppressed by using all the weapons that are available at that time.

4.3.5. Number of Helicopters Shot During The Operation Statistics

The factor number 5 and interaction of factors 4 and 5 (4-5) are found significant according to the ANOVA tests (Table 4.3.5.1 in Appendix C). The same results again can be seen in the normal probability plot (Figure 4.3.5.1 in Appendix E) and the scatter plot (Table 4.3.5.2 in Appendix D). Figure 4.3.5 displays the interactions and the effects of the factors.



	-1	1
NUMBER OF TANKERS	8,16875	8,459375
SIZE OF MAINTENANCE	8,3125	8,315625
QUEUE DISCIPLINE	8,340625	8,2875
WEATHER & TERRAIN COND.	8,303125	8,325
ENEMY AIR DEFENCE	5,44375	11,184375
WEATHER & TERRAIN & ENEMY	8,428125	8,2

Figure 4.3.5:Main and Interaction effects of number of helicopters shot during the operation statistics

This performance measure is directly related to the one above. The same factors are significant again. The change from typical to severe in enemy air defense weapons yields 51 % increase in the number of helicopters shot. This is a very significant and important number for an air assault operation. The counteractions must be taken immediately to lower that value. In order to give more insight to the commander and the staff officers, we provide avarage, maximum and the minimum numbers of the helicopters shot during the operation; based on the 20 replications of the AAOSM in the table 4.3.5. If we think of the value of the S-70 type of helicopters-that is approximately $15 million –we can understand the importance of the air superiority and suppressing of air defense weapons more clearly.

Table 4.3.5: Avarege, maksimum, and mimimum numbers of helicopters shot

	Numbers of helicopters shot during the operation		
Enemy air defense capabilities	**Avarage**	**Maksimum**	**Minimum**
Typical	6	7	5
Severe	12	13	10

All these results are summarized in Table 4.3.6. Specifically, the magnitude and the direction of the factor effects on each performance are given in this table. Note that the effects are measured when we change the factor from its low level to high level.

Table 4.3.6:Results of the Factors effecting the Performance Measures

Performance measures	Significant Factors	Improvement
Time in the System	Weather and terrain Conditions	+33.48 %
Time in the Tanker Queue	Number of tankers	-580 %
	Weather and terrain Conditions	-27 %
	Enemy Air Defense Conditions	-28%
	Number of tankers –weather and Terrain Conditions	+16.3 %
	Number of tankers –Enemy Air Defense Conditions	+25 %
Time in the Maintenance Queue	Size of Maintenance Facilities	-52 %
	Queue discipline	+ 29 %
Number of Soldiers arrived to LZ	Enemy Air Defense Weapons	- 7 %
	Weather and Terrain Conditions-Enemy Air Defense Conditions	- 0.8 %
Number of Helicopters Shot during the Operation	Enemy Air Defense Weapons	+ 51 %
	Weather and Terrain Conditions-Enemy Air Defense Conditions	- 2.6 %

4.4. Diagnostic Checking

Here in this section, we check the validity of ANOVA assumptions. Examination of the residuals should be an automatic part of the analysis of variance. If the model is adequate, the residuals should be structureless; that is, they should contain no obvious patterns. Violations of the basic assumptions and model adequacy can be easily investigated by the examinations of the residuals. We define the residual for observation j in treatment i as:

$$e_{ij} = y_{.ij} - \hat{y}_{ij}$$

In general, moderate departures from normality are of little concern in the fixed effects analysis of variance. Since the F test is only slightly affected, we say that the analysis of variance is robust to the normality assumption. We computed the residuals via regression model. Table 4.4 shows the models that we used.

Table 4.4: Regression models of the performance measures

PERFORMANCE MEASURE	**FITTED EQUATION**
TIME IN THE SYSTEM	Y^=198,497+(56,853/2)*x_4
TIME IN THE TANKER QUEUE	Y^=13,7494+(-20,458275/2)*x_1+(-4,2898/2)*x_4+ (-5,0141/2)*x_5+(2,45/2)*x_1*x_4+(3,993/2)*x_1*x_5
TIME IN THE MAINTENANCE QUEUE	Y^=218,962+(-153,465/2)*x_2+(74,5925/2)*x_3
NO OF SOLDIERS ARRIVED TO LZ	Y^=3206+(-228,206/2)*x_5+(-242,325/2)*x_4*x_5
NUMBER OF HELICOPTERS SHOT	Y^=8,31+(5,74/2)*x_5+(-0,871/2)*x_4*x_5

The first terms are the average responses and the coded variables take on the values (+1) and (–1) (Montgomery 1992).

In Appendix F we present the residual analysis using the models and the scatter plots of the residuals. The scatter plots indicate structureless pattern.

Another way to check the normality assumption is plotting a histogram of the residuals. If the normality assumption on the errors is satisfied, then this plot should look like a sample from a normal distribution centered at zero. Unfortunately, with small samples, considerable fluctuation often occurs, so the appearance of a moderate departure from normality does not necessarily imply a serious violation of the assumptions.

Another useful procedure is to construct a normal probability plot of the residuals. We implied the both procedures, used the software BESTFIT (http://www.palisade.com) and checked the data of the residuals of the performance measures according to the Chi Square test. You can see the results of the Chi Square test in Table 4.5. The histograms and the probability plots are also analyzed. The test results, histograms and the probability plots indicate that our assumptions are valid. We present the histogram and the probability plot of the time in the system statistics in Appendix G as an example.

Table 4.5: Chi Square tests for residuals of the performance measures

Performance Measures	**Calculated test value**	**Chi Square test Value**	**Confidence level**	**Result**
Time in the System	20.0023	21.6659	0.01	Passed
Time in the tanker queue	16.6050	16.9189	0.05	Passed
Time in the maintenance queue	6.8818	8.3428	0.5	Passed
Number of soldiers arrived to LZ	13.2187	14.6836	0.15	Passed
Number of helicopters shot	3.1417	5.8988	0.15	Passed

Chapter 5

Implementations of Ranking and Selection Procedures to AAOSM

5.1. Introduction

The most common goal of discrete-event simulation models is to choose the best system design from among a set of competing alternatives. *Simulation optimization* provides a structured approach to determine optimal input parameters (i.e., the best system design), where optimality is measured by a function of (steady state or transient) output performance measures associated with a simulation model.

Ranking and Selection (R&S) procedures are statistical methods specifically developed to select the best system or a subset that contains the best system design from a set of *k* competing alternatives (Goldsman and Nelson (1998)). In general, these methods ensure the probability of a correct selection at or above some user-specified level. Multiple Comparison Procedures (MCPs) specify the use of certain pairwise comparisons to make inferences in the form of confidence intervals about relationships among all designs. In short, R&S provides the experimenter with the best system design while MCPs provide information about the relationships among the designs (e.g., how much better the best design is in comparison to the alternatives).

5.2 Objective of the Study

The commander and the staff officers may want to differentiate the combinations of the utilities of the force while conducting air assault operations in a combat field. They want to use the optimum configuration of the forces for particular criteria and try to preserve the force for the other parts of the combat area. R&S and MCPs provide excellent tools for that purpose. By using MCPs they can differentiate different alternatives, and by using R&S procedures they can screen out the alternatives and find the best alternative for their particular purpose. Staff officers can support their ideas for proposal of decision to the commander by using these scientific tools.

In AAOSM we concentrate on the main performance measures according to the scenarios we implemented. These are:

- Time in the system
- Time in the tanker queue
- Time in the maintenance queue
- Number of soldiers arrived to LZ

Note that the “the number of the helicopters shot during the operation” performance measure is discarded this time because, the effects of that performance measure are found the same as “the number of the soldiers arrived to LZ” performance measure in the previous chapter.

We used 4 different models and 16 different scenarios. The models are:

- 5 maintenance facilities, 2 refuel tankers
- 5 maintenance facilities, 4 refuel tankers
- 3 maintenance facilities, 2 refuel tankers
- 3 maintenance facilities, 4 refuel tankers

We pick the numbers 3 and 5 in the maintenance facilities, and 2 and 4 in number of tankers because that numbers are the least and the most number of facilities and number of tankers of which an army aviation regiment can afford to support for an air assault operation.

All the scenarios above are run under typical enemy air defense conditions, two different weather and terrain conditions (Hot and High, Cold and Sea level) and two different queue disciplines for maintenance facilities (FIFO, LVF). Thus, we had totally 16 different scenarios and run them 100 times. We assume that under all experimental conditions we have totally 28 helicopters (air assault helicopter battalion) and 1 commando brigade and the flight route is approximately 40 minutes. The scenarios can be seen at the Table 5.2.1

Table 5.2.1:Scenarios of the Air Assault Operation Model

Scenario Number	Weather and Terrain Conditions	Number of Maintenance Facilities	Number of tankers	Queue discipline in maintenance facilities
1	Hot & High	5	4	FIFO
2	Hot & High	5	4	LVF
3	Hot & High	5	2	FIFO
4	Hot & High	5	2	LVF
5	Hot & High	3	4	FIFO
6	Hot & High	3	4	LVF
7	Hot & High	3	2	FIFO
8	Hot & High	3	2	LVF
9	Cold &Sea Level	5	4	FIFO
10	Cold &Sea Level	5	4	LVF
11	Cold &Sea Level	5	2	FIFO
12	Cold &Sea Level	5	2	LVF
13	Cold &Sea Level	3	4	FIFO
14	Cold &Sea Level	3	4	LVF
15	Cold &Sea Level	3	2	FIFO
16	Cold &Sea Level	3	2	LVF

First we will try to compare the scenarios by implementing MCPs and try to differentiate them according to the performance measures we selected. Then we will use R&S procedures to select:

- The best system
- A subset size 4 containing the best of 16 systems
- 4 best of 16 systems

Selecting the best system helps the commander and the staff officers to know which one of the scenarios is the best according to their criteria. By analyzing this, they can have an ability to know their best configuration before conducting the real operation. Selecting a subset size 4 containing the best screens the alternatives and gives time to commander not to analyze the inferior ones. Selecting 4 best of 16 systems is also important for the decision maker since, in a battle field the best system can not be conducted all the time due to lack of personnel and equipment.

5.3 Comparison of the Scenarios with MCPs

As we mention above MCPs are very useful tools to compare the different alternatives and to differentiate them according to the particular criteria. By using MCPs the commander can be able to know which configuration of the force is inferior to the other ones with respect to some important performance measure, which is very vital at that time and the place of the battlefield.

In performance among k systems, MCPs provide information about the relative performance of the systems.They are typically not designed to find the best, they are only concerned with comparing alternatives. There are many multiple comparison procedures in the literature. With any particular procedure, the observed difference between any two means is compared to the appropriate critical value for that procedure. If the observed difference exceeds the critical value, the two means are declared significantly different; otherwise, the difference is considered non-significant. We present Tukey test (Montgomery 1992) and the Welch approach in our study. You can see the values of the Tukey test for performance measures according to the weather and terrain conditions in the Table 5.3.1.1 The numbers in the boxes represent the eliminated scenario numbers.For example, at cold-and-sea-level weather and terrain conditions, and in time in the system performance measure Tukey test does not differentiate any of the alternatives.At the same conditions, in the time in the maintenance queue performance measure, scenario number 16 is found to be inferior with respect to other scenarios.

Table 5.3.1.1: The results of the Tukey test

Weather & Terrain Conditions	**Time in the system**	**Time in the Maintenance queue**	**Time in the Tanker queue**	**Number of soldiers arrived to LZ**
Cold & Sea Level	-	16	11,12,15,16	-
Hot & High	-	5,7,8	4,8	8

We now try Welch approach to get a better insight about the competing alternatives. In this method, instead of making all pair wise comparison, we chose the two alternatives, which have the smallest average, and variance and made pair wise comparisons according to them. We present the values of the Welch approach for performance measures according to the weather and terrain conditions in the Table 5.3.1.2. The numbers in the boxes represent the eliminated scenario numbers.

Welch approach diffirentiates more alternatives than the Tukey test. For example, scenario numbers 12, 13, 14, 15, 16 are found inferior at cold-and-sea-level weather and terrain conditions, in time in the maintenance queue performance measure. That means scenarios 9, 10, 11 are better in comparison with the former ones. In Appendix H, you can also see the detailed all pair wise comparisons and confidence intervals.

Table 5.3.1.2: The results of the Welch approach

Weather & Terrain Conditions	**Time in the system**	**Time in the Maintenance queue**	**Time in the Tanker queue**	**Number of soldiers arrived to LZ**
Cold & Sea Level	11	12,13,14,15,16	11,12,15,16	-
Hot & High	3,5,7,8	4,5,6,7,8	3,4,7,8	3,5

We apply the two methods and eliminate some of the scenarios according to some performance measures. But we are not sure which one of them is the best. Now we will use the R&S methods to evaluate the scenarios.

5.4 Selecting the best system

The goal is selecting the best system from a set of alternative systems for different weather and terrain conditions and define the best system as the smallest expected average time-in-system, time in the maintenance queue, time in the tanker queue and as the biggest expected average number of soldiers arrived to landing zone.

The procedure that we apply involves "two-stage" sampling from each of the k systems. In the first stage, we make fixed number replications (n_o=20) of each system; then use the resulting variance estimates to determine how many more replications from each system are necessary in second stage sampling in order to reach a decision. We use Dudewicz-Dalal (1975) procedure. We want to be 90 % (P^*=0.90) sure that we have made the correct selection provided that $\mu_{[2]}$ - $\mu_{[1]}$ >=d. We make n_o=20 initial independent replications of each system and apply Dudewicz-Dalal procedure. We determine the desired probability of correct selection and the indifference amount between $\mu_{[2]}$ and $\mu_{[1]}$ as h(0,9,8,20) =3.051.(Law and Kelton 1991). The d values for different alternatives are:

- Time in the system **d=15** minutes
- Time in the maintenance queue **d=60** minutes
- Time in the tanker queue **d=5** minutes
- Number of the soldiers landed **d=180** soldiers (2 teams)

These values represent the commanders risk decisions for that particular weather and terrain conditions. If the differences among the scenarios are less than these values the method does not differentiate the scenarios and they are treated as the same. For example, the method can differ the scenarios if the difference between the numbers of the soldiers landed to LZ is more than 180 soldiers between two scenarios. That means losses up to 180 soldiers are not important for a commander. But if it exceeds that number, the commander does not want that alternative since that number of losses may affect the success of the ground tactical operation. If a commander wants to be strict on the differences, the results may change. We chose these values such that they can alter the ongoing of the operation. Table 5.4.1.1 present the results. The details of the results are given in Appendix H.

Table 5.4.1.1: The best systems for particular performance measures

Weather & Terrain Conditions	**Time in the system**	**Time in the Maintenance queue**	**Time in the Tanker queue**	**Number of soldiers arrived to LZ**
Cold & Sea Level	10	10	13	10
Hot & High	4	3	1	2

Note that the best system differs according to the performance measure and weather and terrain conditions in consideration. In Cold and Sea level the scenario number 10 seems to be the best system in most of the performance measures. That is 4 tankers 5-maintenance facilities and the LVF queue discipline at the maintenance queue. The method offers us different scenarios for different performance measures. This is important for the commander to select the best scenario while analyzing the ongoing of the operation. For example, if the enemy long distance, air assault weapons and jet fighters are superior than the friends weapons he may want to minimize the time in the system of the soldiers and select the scenario number 4. And if the operation seems to fail due to the long maintenance times of the helicopters in the maintenance queue he selects the scenario number 3. This approach gives a valuable insight to the commander and his staff.

5.5 Selecting a subset of size m containing the best of k systems

The commander and the staff officers may want to screen the alternatives of the systems and make a decision quicker without analyzing the inferior ones. Thus, this kind of study helps the decision makers for time management of the headquarters' activities

Selecting a subset of size m of the k systems so that, with probability at least P*, the selected subset will contain the best system. This could be useful goal in the initial stages of a simulation study, where there may be large number of alternative systems and we would like to perform an initial screening to eliminate those that appear to be clearly inferior. Thus, we could avoid expending a large amount of computer time getting precise estimates of the behavior of these inferior systems. The same procedure is applied except h_1 becomes h_2. The details of the results are given in Appendix H. Table 5.5.1.1 summarizes findings for different weather and terrain conditions.

Table 5.5.1.1: The subset of 4 containing the best of 16 systems for particular performance measures

Weather & Terrain Conditions	**Time in the system**	**Time in the Maintenance queue**	**Time in the Tanker queue**	**Number of soldiers arrived to LZ**
Cold & Sea Level	9,10,14,16	10,12,13,16	9,10,13,14	10,12,13,16
Hot & High	2,4,5,8	1,2,3,5	1,2,5,6	1,2,7,8

This time we present 4 scenarios to the commander to decide on. We do not tell which one of them is the best one but we can say that this four contains the best one. For example, at hot-and-high weather and terrain conditions, and in time in the system performance measure, scenario numbers 2, 4, 5, 8 contain the best scenario among them. Note that, in the previous section the scenario number 4 is found to be the best at that particular performance measure. That means, he should construct the rear maintenance area with 5 maintenance facilities, apply LVF queue discipline in maintenance facilities, and 2 refueling tankers will be enough for minimizing time in the system of the soldiers. This kind of approach is important in the battlefield particularly when there is no time for further analysis. He can safely concentrate on these alternatives without even thinking of the other ones. This will save him and his staff great time that is the most precise thing in the battlefield.

5.6 Selecting the m best of k systems

This particular selection might be useful for commanders and the staff officers if they want to identify several good options, since the best system might prove unacceptable for loss of equipment or time. The goal is selecting a subset of specified size m (1<=m<=k-1) so that with probability at least P* the expected responses of the selected subset are equal to the m best of k systems. It is important to note that m selected systems are not ranked or ordered in any way among themselves, but only that the unordered set of the m best systems. The solution procedure is developed by Koenig and Law (1985). The findings are presented in the Table 5.6.1.1 for different weather and terrain conditions. The details can be found in Appendix H.

Table 5.6.1.1: The 4 best of 16 systems for particular performance measures

Weather & Terrain Conditions	Time in the system	Time in the Maintenance queue	Time in the Tanker queue	Number of soldiers arrived to LZ
Cold & Sea Level	9,10,15,16	9,10,12,16	9,10,13,14	9,10,12,16
Hot & High	2,4,5,8	1,3,4,8	1,2,5,6	1,2,3,8

These results show that he has 4 different alternatives. If the conditions and the equipment are not suitable for one scenario he can select the one that he can afford with what he has in his hand. This situation is the most expectable situation in a battlefield. Most of the time you cannot accomplish what you plan due to the lack of the equipment and the changes in the circumstances.

Chapter 6

Conclusion

6.1 General

In this study, we developed a simulation model capable of analyzing the behavior of the Air Assault Operations in a typical battlefield. We only considered the air movement phase of the system and did not consider the tactical ground operation phase due to complexity. We tried to see the process in Army Aviations view of sight. The model has many capabilities. Easy use of the software gives opportunity to implement the other scenarios easily to the end user. The objectives of this study are:

- To understand the behaviors of the system,
- To detect the bottlenecks or problem areas in a particular scenario,
- To analyze the factors that effect to the performance measures,
- To perform risk management before conducting the real operation,
- To allow planners to build models of air assault operations early in the decision process and refine those models as their decision process evolve.

In this study, we evaluate the system, with a particular scenario, analyze the outputs by using the performance measures: time in system, time in the tanker queue, time in maintenance queue, number of soldiers arrived to landing zone, number of helicopters that are shot by the enemy air defense weapons during the operation. First we try to find out the answer of the question “What effects do the factors have on the performance measures we selected?” Then we compare different scenarios according to the performance measures we select, screen them and select the best one with regard to the particular weather and terrain conditions. This gives an idea to the commander and the staff officers that which configuration would be best according to their risk decisions.

6.1.1 Factors effecting the Performance measures

We analyze the factors affecting the performance measures by design and analysis of the experiments. Chapter 4 presents the significant factors and what may be affect of these factors to the operation. In Table 6.1 we give a summary table from our analysis.

Table 6.1:Factors effecting the performance measures

Performance Measures	**Significant factors**
Time in the system	• Weather and terrain conditions
Time in the tanker queue	• Number of tankers • Weather and terrain conditions • Enemy air defense conditions • Number of tankers –Weather and terrain conditions • Number of tankers – Enemy air defense conditions
Time in the maintenance queue	• Size of maintenance facilities • Queue discipline
Number of soldiers arrived to LZ	• Weather and terrain conditions • Weather and terrain conditions-Enemy air defense conditions
Number of helicopters shot	• Weather and terrain conditions • Weather and terrain conditions-Enemy air defense conditions

Weather and terrain conditions and enemy air defense capabilities are significant factors for all performance measures. Air assault operations are very vulnerable to both of the factors. The ground tactical phase of the operation is strictly related with the changing conditions in both factors. The planners must be aware of the fact that, these two factors can alter the ongoing of the operation and may cause failure. The commanders and the staff officers must take all the precautions to suppress the enemy air defense capabilities. The equipment in the helicopters and the training of the pilots must be perfect to fly in all weather conditions. Also the training of the technicians must be developed to deal with the changing weather conditions. The breakdown ratio of the helicopters and the refueling tankers must be reduced by using proper equipment and high level of training.

Queue discipline in the maintenance queue is also a significant factor at the time in the maintenance queue performance measure. The maintenance facilities must be configured to apply different queue disciplines. The classical FIFO approach can be changed time to time to get better results for different performance measures.

6.1.2 The best configuration according to weather and terrain conditions

We try to give an idea to the end user that, which configuration of effects gives us the best results according to the performance measures we selected. We obtained the following results:

Table 6.1.2.1:The best configurations according to Cold and Sea level

Time in the system	LVF, 4 tankers, 5 maintenance facilities
Time in the tanker queue	FIFO, 4 tankers, 3 maintenance facilities
Time in the maintenance queue	LVF, 4 tankers, 5 maintenance facilities
Number of soldiers arrived to LZ	LVF, 4 tankers, 5 maintenance facilities

Table 6.1.2.2:The best configurations according to Hot and High

Time in the system	LVF, 2 tankers, 3 maintenance facilities
Time in the tanker queue	FIFO, 4 tankers, 5 maintenance facilities
Time in the maintenance queue	FIFO, 2 tankers, 5 maintenance facilities
Number of soldiers arrived to LZ	LVF, 4 tankers, 5 maintenance facilities

By looking at the results the user can have an idea to decide which configuration to use in particular weather and terrain conditions and perform savings in both manpower and equipment and use them at the other portions of the battlefield. Note that for different performance measures in different weather and terrain conditions the best system differs. As we stated before, the commander must analyze the changing conditions in the operation and decide on the best scenario according to the performance measure that he thinks as the most critical one for the success of the operation. For example, if we want to land more number of soldiers to maneuver on the battlefield to engage and destroy enemy forces rather than to hold key terrain; 4 refueling tankers and 5 maintenance facilities must be employed at the rear area and LVF queue discipline must be applied at the maintenance facilities.

In chapter 5, we also select a subset of size 4 containing the best of 16 systems and 4 best of 16 systems to get a better insight for the commander. These kinds of selections are also valuable since they save time by screening the alternatives and give other opportunities to the planners when best system becomes impossible to implement due to lack of time or lack of equipment.

6.2 Concluding Remarks and Future Research Directions

From the results of our analysis we make the following conclusions:

1. Enemy air defense capabilities are very important for the success of the Air Assault operation.
2. Size of the maintenance facilities and number of tankers are important factors for each performance measure.
3. Commanders and troops must be well prepared to overcome the adverse affects of weather and terrain properties.
4. The different queue disciplines may be better for the different weather and terrain conditions.

5. If the number of troops increase the time in the system will increase. This may yield to lose of the main purpose of the Air assault operation that is "surprise". The planners must be aware of this fact.
6. Pilot tiredness is an important factor. If pilot exceeds his 8-hour of daily flight limit he must rest to fly again according to army regulations. That must be taken care of by the planners.
7. The probability of the breakdowns and time to repair this breakdowns must be lessened by proper equipment and training in order to achieve the success of the operation.

Air Assault Operation is a very important issue in military. It represents the modern part of the 21st centuries battlefield. We did not include the staging and ground tactical operation phase of the air assault operations due to time and data limitations. This can be undertaken in the future studies.

The other types of utility helicopters such as UH-1, AS 532, MI-17 and attack helicopters AH-1P and AH-1W can be included in the model by their special features. Also CSAR (Combat Search and Rescue) operation can be included in the model. This of course reveal more detailed planning in the air movement phase.

Other support fire systems such as, artillery, naval artillery and jetfighters can be included in the system. Moreover, other capabilities of the helicopters such as electronic warfare and external load operations can be introduced into the model and can be analyzed. Attacks of enemy NBC systems and decontamination can be studied.

The coordination in Pick up zones and Landing zones are assumed perfect in our study. The lack of coordination can affect the success of the operation. Some features of the PZ and LZ may be added to the model to see their affects.

The most important of all; this model can be used to analyze our top-secret air assault plans by some minor modifications and real data. Some developments on the plans can be made and some configurations of the plans can be changed accordingly to obtain the best results.

Appendix A

Computer code of the AAOSM

The model frame:

```
9$          STATION,      CP1;
242$         ASSIGN:       SHOT=0;
243$         BRANCH,       1:
                    If,SHOT>0,D1,Yes:
                    Else,GO2,Yes;
D1          ASSIGN:       WEAPONTYPE=DISC(0.8,1,1,2):NEXT(CHECK21);
CHECK21      BRANCH,       5:
                    If,WEAPONTYPE==1,SHOT1,Yes:
                    If,WEAPONTYPE==2,SHOT2,Yes:
                    If,WEAPONTYPE==3,SHOT3,Yes:
                    If,WEAPONTYPE==4,SHOT4,Yes:
                    If,WEAPONTYPE==5,SHOT5,Yes;
SHOT1        ASSIGN:       PH=EADW*DISC(0.99,0,1,1);
19$          BRANCH,       1:
                    If,PH>0,83$,Yes:
                    Else,GO2,Yes;
83$          ASSIGN:       PK=DISC(0.8,0,1,1);
84$          BRANCH,       1:
                    If,PK>0,XX1,Yes:
                    Else,GO2,Yes;
XX1          DUPLICATE:    1,MM1;
296$         COUNT:        # HELISHOT BY W1,1:NEXT(XX6);
XX6          MOVE:         HELI(INDEX),TRASH,3000;
297$         COUNT:        TOTAL HELISHOT,1;
299$         COUNT:        DER,1;
408$         COUNT:        CONTROLC2,1;
302$         HALT:         HELI(INDEX);
301$         FREE:         HELI(INDEX);
300$         ASSIGN:       PICTURE=BRKHLK;
TRS          STATION,      TRASH;
298$         DISPOSE;
MM1          STATION,      BOMBA1;
303$         STORE:        STOR1;
306$         ASSIGN:       PICTURE=BOMB;
304$         DELAY:        3;
305$         UNSTORE:      STOR1;
307$         DISPOSE;
GO2          TRANSPORT:    HELI(INDEX),CP2,2700;
SHOT2        ASSIGN:       PH=EADW*DISC(0.7,0,1,1);
20$          BRANCH,       1:
                    If,PH>0,114$,Yes:
                    Else,GO2,Yes;
114$         ASSIGN:       PK=DISC(0.8,0,1,1);
115$         BRANCH,       1:
                    If,PK>0,XX2,Yes:
                    Else,GO2,Yes;
XX2          DUPLICATE:    1,MM1;
4$           COUNT:        # HELISHOT BY W2,1:NEXT(XX6);
SHOT3        ASSIGN:       PH=EADW*DISC(0.55,0,1,1);
21$          BRANCH,       1:
                    If,PH>0,146$,Yes:
                    Else,GO2,Yes;
146$         ASSIGN:       PK=DISC(0.7,0,1,1);
```

```
147$        BRANCH,       1:
                    If,PK>0,XX3,Yes:
                    Else,GO2,Yes;
XX3         DUPLICATE:    1,MM1;
5$          COUNT:        # HELISHOT BY W3,1:NEXT(XX6);

SHOT4       ASSIGN:       PH=EADW*DISC(0.9,0,1,1);
22$         BRANCH,       1:
                    If,PH>0,178$,Yes:
                    Else,GO2,Yes;
178$        ASSIGN:       PK=DISC(0.8,0,1,1);
179$        BRANCH,       1:
                    If,PK>0,XX4,Yes:
                    Else,GO2,Yes;
XX4         DUPLICATE:    1,MM1;
6$          COUNT:        # HELISHOT BY W4,1:NEXT(XX6);
SHOT5       ASSIGN:       PH=EADW*DISC(0.5,0,1,1);
23$         BRANCH,       1:
                    If,PH>0,210$,Yes:
                    Else,GO2,Yes;
210$        ASSIGN:       PK=DISC(0.1,0,1,1);
211$        BRANCH,       1:
                    If,PK>0,XX5,Yes:
                    Else,GO2,Yes;
XX5         DUPLICATE:    1,MM1;
7$          COUNT:        # HELISHOT BY W5,1:NEXT(XX6);
10$         STATION,      CP2;
244$        ASSIGN:       SHOT=0;
245$        BRANCH,       1:
                    If,SHOT>0,D2,Yes:
                    Else,GO3,Yes;
D2          ASSIGN:       WEAPONTYPE=DISC(0.5,1,0.6,2,1,3):NEXT(CHECK22);

CHECK22     BRANCH,       5:
                    If,WEAPONTYPE==1,SHOT6,Yes:
                    If,WEAPONTYPE==2,SHOT7,Yes:
                    If,WEAPONTYPE==3,SHOT8,Yes:
                    If,WEAPONTYPE==4,SHOT9,Yes:
                    If,WEAPONTYPE==5,SHOT10,Yes;
SHOT6       ASSIGN:       PH=EADW*DISC(0.99,0,1,1);
24$         BRANCH,       1:
                    If,PH>0,85$,Yes:
                    Else,GO3,Yes;
85$         ASSIGN:       PK=DISC(0.8,0,1,1);
86$         BRANCH,       1:
                    If,PK>0,383$,Yes:
                    Else,GO3,Yes;
383$        DUPLICATE:    1,MM2;
362$        COUNT:        # HELISHOT BY W1,1:NEXT(XX6);


MM2         STATION,      BOMBA2;
308$        STORE:        STOR2;
311$        ASSIGN:       PICTURE=BOMB;
309$        DELAY:        4;
310$        UNSTORE:      STOR2;
312$        DISPOSE;

GO3         TRANSPORT:    HELI(INDEX),CP3,3000;

SHOT7       ASSIGN:       PH=EADW*DISC(0.7,0,1,1);
116$        BRANCH,       1:
                    If,PH>0,117$,Yes:
                    Else,GO3,Yes;
……………………………………………………………………………………
```

Experimental Frame:

```
BEGIN,
PROJECT,      AIR ASSAULT OPERATION,GOKHAN VIRLAN,20/10/2000,Yes;

ATTRIBUTES:   TIME1:
          BRKDWN:
          TIME5:
          PICTURE:
          TIME9:
          ARRTIME:
          __ActionLabel:
          MAINTTIME:
          INDEX,1;

STORAGES:     STOR7:
          STOR8:
          STORLZ:
          STOR9:
          STOR10:
          STOR1:
          STOR2:
          STOR3:
          STOR4:
          STOR5:
          STOR6;

VARIABLES:    SS,0:
          SC:
          GOKHAN(1..28,1..2),:
          HBR:
          I:
          FL:
          K:
          PH:
          MTFH:
          REFUEL:
          WEAPONTYPE:
          SHOT:
          PK:
          PLT TRDNESS:
          REFUEL TIME:
          FLIGHT TIME,0:
          EADW:
          PTF:
          TWF,;

QUEUES:       HELIQ,FirstInFirstOut:
          TECHQ,LowValueFirst(BRKDWN):
          MAINTQ,FirstInFirstOut:
          TANKERQ,FirstInFirstOut;

PICTURES:     1,SOLDIER:
          BOMB:
          TECH:
          TANKER:
          BRKHLK;
FAILURES:     1,T1F1,Time(TRIANGULAR(4320,10080,21600),TRIANGULAR(15,120,180),):
          2,T2F1,Time(TRIANGULAR(4320,10080,21600),TRIANGULAR(15,120,180),):
          3,T3F1,Time(TRIANGULAR(4320,10080,21600),TRIANGULAR(15,120,180),):

………………………………………………………………………………..
```

Appendix B

The Scatter Plots of the Variances of Performance Measures

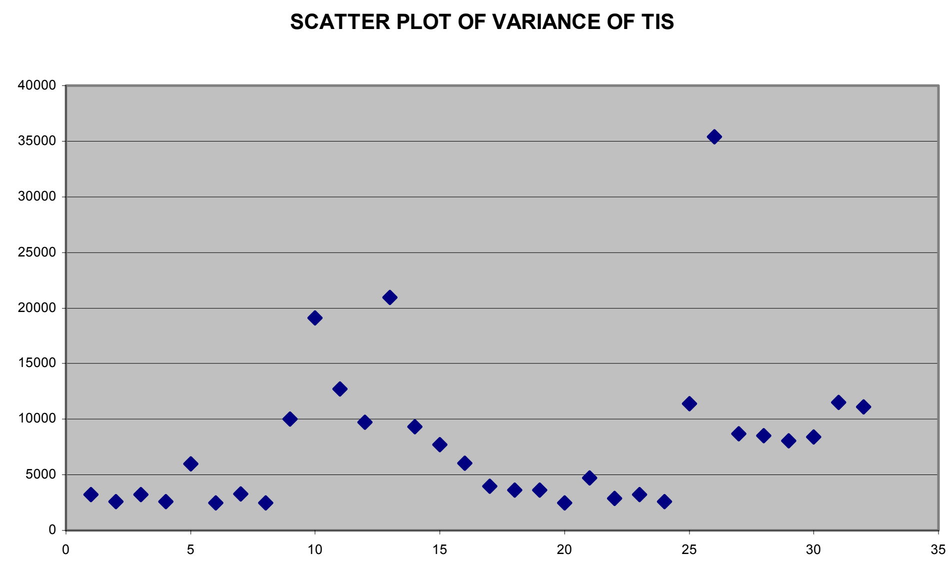


Figure 4.2.1:Scatter plot of variances of time in the system

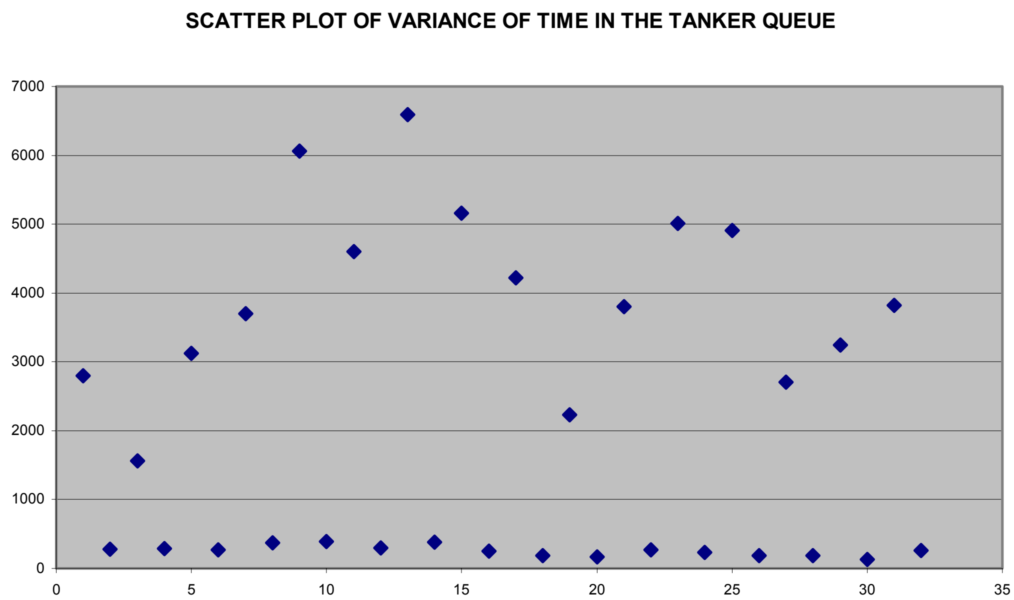


Figure 4.2.2:Scatter plot of variances of time in the tanker queue

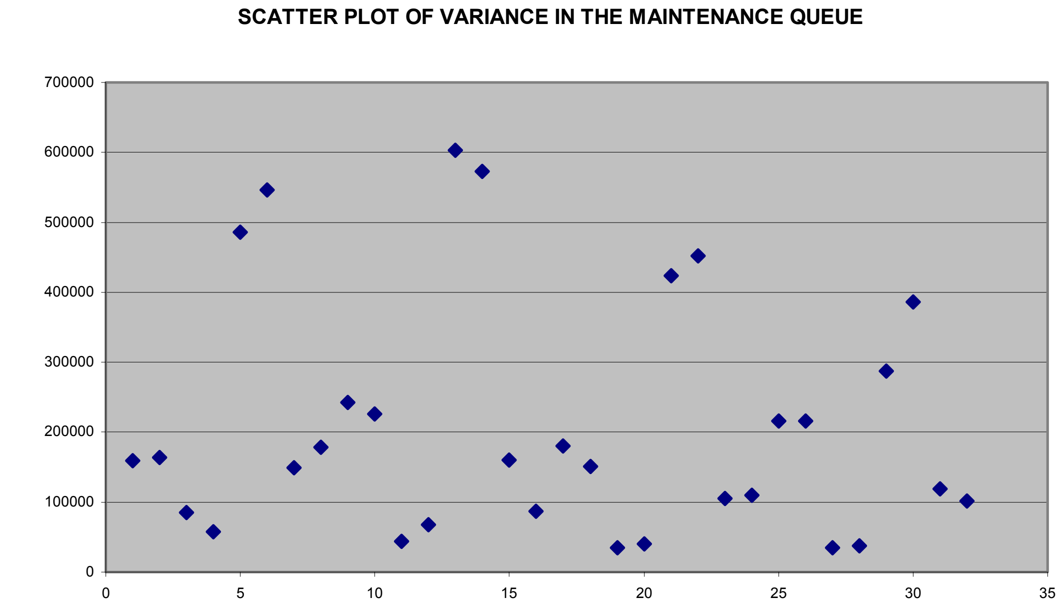


Figure 4.2.3:Scatter plot of variances of time in the maintenance queue

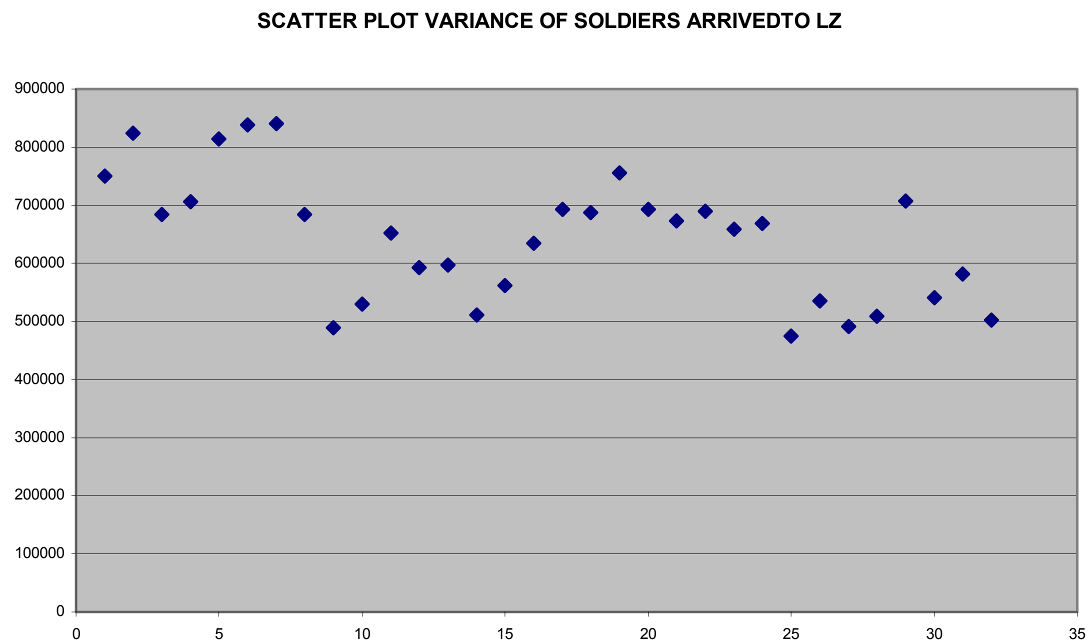


Figure 4.2.4:Scatter plot of variances of number of soldiers arrived to LZ

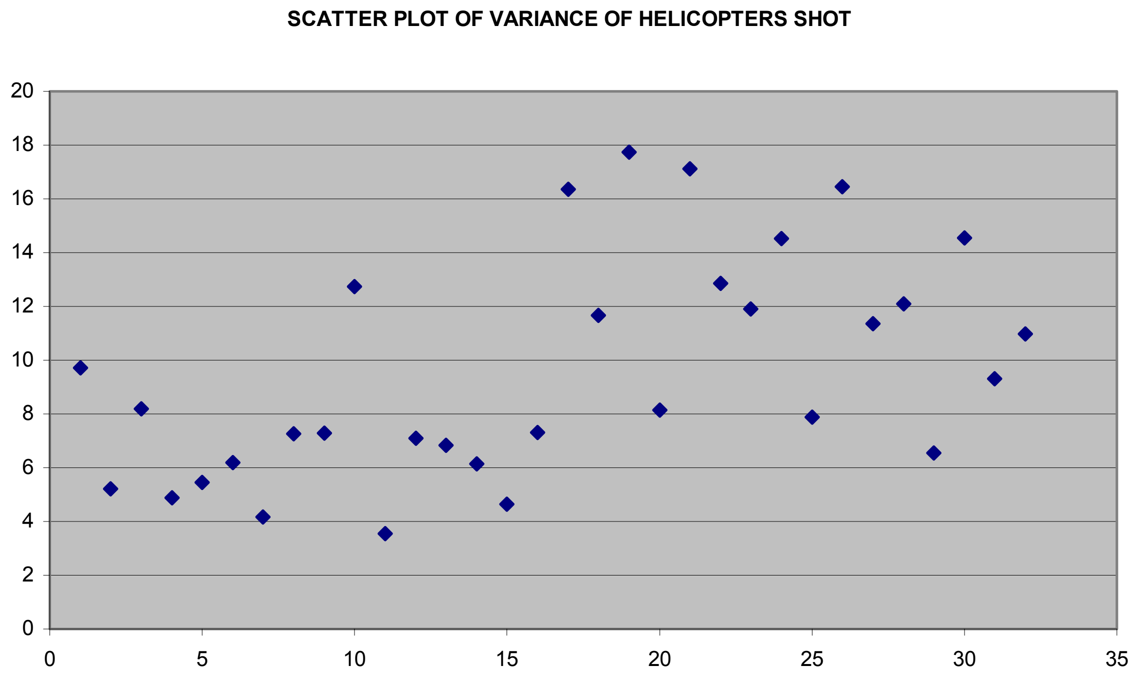


Figure 4.2.5:Scatter plot of variances of number of helicopters shot

Appendix C

ANOVA Tables of the Performance Measures

Table 4.3.2.1: Analysis of variance of time in the tanker queue statistics

ANALYSIS OF VARIANCE OF TIME IN THE TANKER QUEUE STATISTICS

Source of variation	EFFECTS	SSx	df	MSx	Fo	
1	-20,45827466	66966,5603	1	66966,5603	791,7126	**SIGNIFICANT**
2	0,581317182	54,0687466	1	54,0687466	0,639228	INSIGNIFICANT
3	-0,379433817	23,0352034	1	23,0352034	0,272334	INSIGNIFICANT
4	-4,289824557	2944,41516	1	2944,41516	34,81037	**SIGNIFICANT**
5	-5,014134875	4022,64777	1	4022,64777	47,55778	**SIGNIFICANT**
1-2	-0,320496504	16,4348815	1	16,4348815	0,194301	INSIGNIFICANT
1-3	0,48240667	37,2345913	1	37,2345913	0,440206	INSIGNIFICANT
1-4	2,450630489	960,894367	1	960,894367	11,36018	**SIGNIFICANT**
1-5	3,993759921	2552,01893	1	2552,01893	30,17126	**SIGNIFICANT**
2-3	0,592389161	56,1479869	1	56,1479869	0,66381	INSIGNIFICANT
2-4	-0,556409696	49,5346799	1	49,5346799	0,585624	INSIGNIFICANT
2-5	-0,36653985	21,4962339	1	21,4962339	0,254139	INSIGNIFICANT
3-4	0,647935015	67,1711655	1	67,1711655	0,794132	INSIGNIFICANT
3-5	-0,37185902	22,1246609	1	22,1246609	0,261569	INSIGNIFICANT
4-5	0,689266632	76,0141585	1	76,0141585	0,898678	INSIGNIFICANT
1-2-3	-0,533401598	45,5227624	1	45,5227624	0,538193	INSIGNIFICANT
1-2-4	0,346233084	19,1803758	1	19,1803758	0,22676	INSIGNIFICANT
1-2-5	0,344868576	19,0294936	1	19,0294936	0,224976	INSIGNIFICANT
1-3-4	-0,644253424	66,4099959	1	66,4099959	0,785133	INSIGNIFICANT
1-3-5	0,402734837	25,9512559	1	25,9512559	0,306809	INSIGNIFICANT
1-4-5	0,387943445	24,0800187	1	24,0800187	0,284686	INSIGNIFICANT
2-3-4	0,441256097	31,1531108	1	31,1531108	0,368308	INSIGNIFICANT
2-3-5	0,412245675	27,1914394	1	27,1914394	0,321471	INSIGNIFICANT
2-4-5	0,396334218	25,13293	1	25,13293	0,297134	INSIGNIFICANT
3-4-5	0,802768352	103,109924	1	103,109924	1,219018	INSIGNIFICANT
1-2-3-4	-0,441436876	31,1786425	1	31,1786425	0,36861	INSIGNIFICANT
1-2-3-5	-0,455775214	33,2369673	1	33,2369673	0,392944	INSIGNIFICANT
1-2-4-5	-0,273297751	11,9506657	1	11,9506657	0,141287	INSIGNIFICANT
1-3-4-5	-0,808936581	104,700543	1	104,700543	1,237823	INSIGNIFICANT
2-3-4-5	0,328405335	17,2560103	1	17,2560103	0,204009	INSIGNIFICANT
1-2-3-4-5	-0,064130904	0,65804365	1	0,65804365	0,00778	INSIGNIFICANT
Error		51427,3355	608	84,5844335		
Total		129882,877	639			

Table 4.3.3.1: Analysis of variance of time in the maintenance queue statistics

ANALYSIS OF VARIANCE OF TIME IN THE MAINTENANCE QUEUE STATISTICS

Source of variation	EFFECTS	SSx	df	MSx	Fo	
1	-6,343744678	6438,89545	1	6438,89545	0,030228	INSIGNIFICANT
2	-153,4656259	3768271,73	1	3768271,73	17,69052	**SIGNIFICANT**
3	74,59258178	890248,521	1	890248,521	4,179358	**SIGNIFICANT**
4	41,52816145	275934,111	1	275934,111	1,295399	INSIGNIFICANT
5	-19,91058382	63429,0157	1	63429,0157	0,297774	INSIGNIFICANT
1-2	0,23802686	9,06508576	1	9,06508576	4,26E-05	INSIGNIFICANT
1-3	-9,906847853	15703,3015	1	15703,3015	0,073721	INSIGNIFICANT
1-4	8,115911583	10538,8833	1	10538,8833	0,049476	INSIGNIFICANT
1-5	4,124491038	2721,82821	1	2721,82821	0,012778	INSIGNIFICANT
2-3	-17,18900412	47273,898	1	47273,898	0,221932	INSIGNIFICANT
2-4	-13,43327985	28872,4812	1	28872,4812	0,135545	INSIGNIFICANT
2-5	0,792583138	100,510085	1	100,510085	0,000472	INSIGNIFICANT
3-4	-12,64144425	25568,978	1	25568,978	0,120036	INSIGNIFICANT
3-5	-11,12820985	19813,9287	1	19813,9287	0,093018	INSIGNIFICANT
4-5	-2,068158359	684,36464	1	684,36464	0,003213	INSIGNIFICANT
1-2-3	2,593126357	1075,88869	1	1075,88869	0,005051	INSIGNIFICANT
1-2-4	-7,843169637	9842,44959	1	9842,44959	0,046206	INSIGNIFICANT
1-2-5	-1,592098273	405,564306	1	405,564306	0,001904	INSIGNIFICANT
1-3-4	-11,5773224	21445,503	1	21445,503	0,100678	INSIGNIFICANT
1-3-5	3,90382134	2438,37137	1	2438,37137	0,011447	INSIGNIFICANT
1-4-5	4,300121453	2958,56712	1	2958,56712	0,013889	INSIGNIFICANT
2-3-4	14,9071771	35555,8286	1	35555,8286	0,16692	INSIGNIFICANT
2-3-5	9,638094556	14862,8587	1	14862,8587	0,069775	INSIGNIFICANT
2-4-5	20,6056505	67934,8532	1	67934,8532	0,318927	INSIGNIFICANT
3-4-5	-5,868099943	5509,53551	1	5509,53551	0,025865	INSIGNIFICANT
1-2-3-4	-4,232742766	2866,57781	1	2866,57781	0,013457	INSIGNIFICANT
1-2-3-5	5,604854236	5026,30256	1	5026,30256	0,023596	INSIGNIFICANT
1-2-4-5	-7,189974207	8271,31666	1	8271,31666	0,03883	INSIGNIFICANT
1-3-4-5	6,668989063	7116,06642	1	7116,06642	0,033407	INSIGNIFICANT
2-3-4-5	4,999383968	3999,01441	1	3999,01441	0,018774	INSIGNIFICANT
1-2-3-4-5	10,02459514	16078,8012	1	16078,8012	0,075483	INSIGNIFICANT
Error		129510592	608	213010,842		
Total		134871589	639			

Table 4.3.4.1: Analysis of variance of soldiers arrived to LZ statistics

ANALYSIS OF VARIANCE OF SOLDIERS ARRIVED TO LZ STATISTICS

Source of variation	EFFECTS	SSx	df	MSx	Fo	
1	65,86875	694190,756	1	694190,756	0,593623	INSIGNIFICANT
2	28,18125	127069,256	1	127069,256	0,108661	INSIGNIFICANT
3	-10,40625	17326,4063	1	17326,4063	0,014816	INSIGNIFICANT
4	29,86875	142742,756	1	142742,756	0,122064	INSIGNIFICANT
5	-228,20625	8332494,81	1	8332494,81	7,12536	**SIGNIFICANT**
1-2	3,54375	2009,30625	1	2009,30625	0,001718	INSIGNIFICANT
1-3	5,11875	4192,25625	1	4192,25625	0,003585	INSIGNIFICANT
1-4	-17,60625	49596,8063	1	49596,8063	0,042412	INSIGNIFICANT
1-5	8,04375	10352,3062	1	10352,3062	0,008853	INSIGNIFICANT
2-3	4,55625	3321,50625	1	3321,50625	0,00284	INSIGNIFICANT
2-4	-23,56875	88877,7563	1	88877,7563	0,076002	INSIGNIFICANT
2-5	5,45625	4763,30625	1	4763,30625	0,004073	INSIGNIFICANT
3-4	43,36875	300935,756	1	300935,756	0,257339	INSIGNIFICANT
3-5	-22,78125	83037,6563	1	83037,6563	0,071008	INSIGNIFICANT
4-5	-242,325	9395424,9	1	9395424,9	8,034303	**SIGNIFICANT**
1-2-3	-16,81875	45259,2563	1	45259,2563	0,038703	INSIGNIFICANT
1-2-4	6,35625	6464,30625	1	6464,30625	0,005528	INSIGNIFICANT
1-2-5	-2,19375	770,00625	1	770,00625	0,000658	INSIGNIFICANT
1-3-4	-8,60625	11850,8062	1	11850,8062	0,010134	INSIGNIFICANT
1-3-5	-6,13125	6014,75625	1	6014,75625	0,005143	INSIGNIFICANT
1-4-5	-21,65625	75038,9063	1	75038,9063	0,064168	INSIGNIFICANT
2-3-4	17,15625	47093,9062	1	47093,9062	0,040271	INSIGNIFICANT
2-3-5	6,80625	7412,00625	1	7412,00625	0,006338	INSIGNIFICANT
2-4-5	2,53125	1025,15625	1	1025,15625	0,000877	INSIGNIFICANT
3-4-5	37,96875	230660,156	1	230660,156	0,197244	INSIGNIFICANT
1-2-3-4	-6,91875	7659,05625	1	7659,05625	0,006549	INSIGNIFICANT
1-2-3-5	0,95625	146,30625	1	146,30625	0,000125	INSIGNIFICANT
1-2-4-5	3,88125	2410,25625	1	2410,25625	0,002061	INSIGNIFICANT
1-3-4-5	-26,83125	115186,556	1	115186,556	0,098499	INSIGNIFICANT
2-3-4-5	9,28125	13782,6562	1	13782,6562	0,011786	INSIGNIFICANT
1-2-3-4-5	24,58125	96678,0562	1	96678,0562	0,082672	INSIGNIFICANT
Error		711003625	608	1169413,86	1169414	
Total		730927413	639			

Table 4.3.5.1: Analysis of variance of number of helicopters shot statistics

ANALYSIS OF VARIANCE OF NUMBER OF HELICOPTERS SHOT STATISTICS

Source of variation	EFFECTS	SSx	df	MSx	Fo	
1	0,290625	13,5140625	1	13,5140625	1,003032	INSIGNIFICANT
2	0,003125	0,0015625	1	0,0015625	0,000116	INSIGNIFICANT
3	-0,053125	0,4515625	1	0,4515625	0,033516	INSIGNIFICANT
4	0,021875	0,0765625	1	0,0765625	0,005683	INSIGNIFICANT
5	5,740625	5272,76406	1	5272,76406	391,3517	**SIGNIFICANT**
1-2	-0,171875	4,7265625	1	4,7265625	0,350812	INSIGNIFICANT
1-3	-0,178125	5,0765625	1	5,0765625	0,376789	INSIGNIFICANT
1-4	0,171875	4,7265625	1	4,7265625	0,350812	INSIGNIFICANT
1-5	0,190625	5,8140625	1	5,8140625	0,431528	INSIGNIFICANT
2-3	-0,028125	0,1265625	1	0,1265625	0,009394	INSIGNIFICANT
2-4	-0,065625	0,6890625	1	0,6890625	0,051143	INSIGNIFICANT
2-5	0,303125	14,7015625	1	14,7015625	1,09117	INSIGNIFICANT
3-4	-0,534375	45,6890625	1	45,6890625	3,391104	INSIGNIFICANT
3-5	0,084375	1,1390625	1	1,1390625	0,084543	INSIGNIFICANT
4-5	-0,871875	121,626563	1	121,626563	9,027288	**SIGNIFICANT**
1-2-3	0,209375	7,0140625	1	7,0140625	0,520593	INSIGNIFICANT
1-2-4	0,096875	1,5015625	1	1,5015625	0,111448	INSIGNIFICANT
1-2-5	-0,109375	1,9140625	1	1,9140625	0,142064	INSIGNIFICANT
1-3-4	0,003125	0,0015625	1	0,0015625	0,000116	INSIGNIFICANT
1-3-5	-0,053125	0,4515625	1	0,4515625	0,033516	INSIGNIFICANT
1-4-5	-0,315625	15,9390625	1	15,9390625	1,183019	INSIGNIFICANT
2-3-4	-0,096875	1,5015625	1	1,5015625	0,111448	INSIGNIFICANT
2-3-5	0,096875	1,5015625	1	1,5015625	0,111448	INSIGNIFICANT
2-4-5	0,096875	1,5015625	1	1,5015625	0,111448	INSIGNIFICANT
3-4-5	-0,509375	41,5140625	1	41,5140625	3,08123	INSIGNIFICANT
1-2-3-4	-0,021875	0,0765625	1	0,0765625	0,005683	INSIGNIFICANT
1-2-3-5	-0,178125	5,0765625	1	5,0765625	0,376789	INSIGNIFICANT
1-2-4-5	0,121875	2,3765625	1	2,3765625	0,176392	INSIGNIFICANT
1-3-4-5	0,240625	9,2640625	1	9,2640625	0,687591	INSIGNIFICANT
2-3-4-5	-0,309375	15,3140625	1	15,3140625	1,13663	INSIGNIFICANT
1-2-3-4-5	-0,121875	2,3765625	1	2,3765625	0,176392	INSIGNIFICANT
Error		8191,7125	608	13,4732113		
Total		13790,1609	639			

Appendix D

Scatter Plots of Effects of Performance Measures

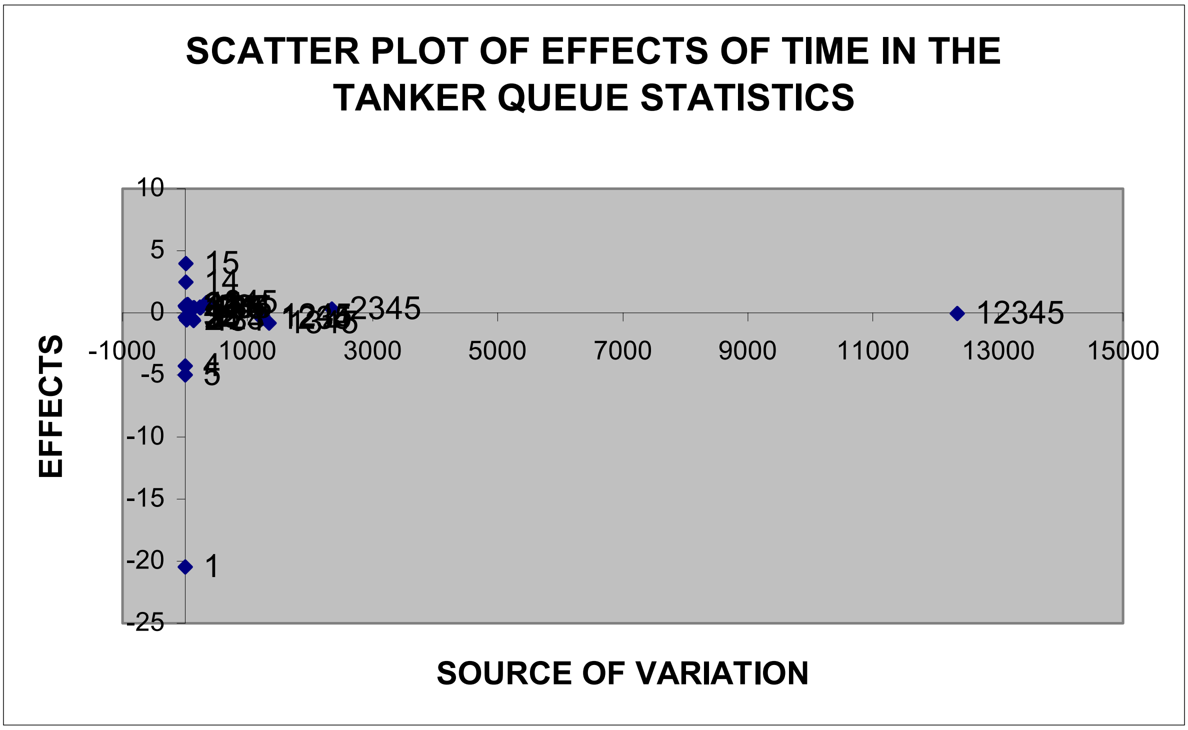


Figure 4.3.2.2: Scatter plots of effects of time in the tanker queue statistics

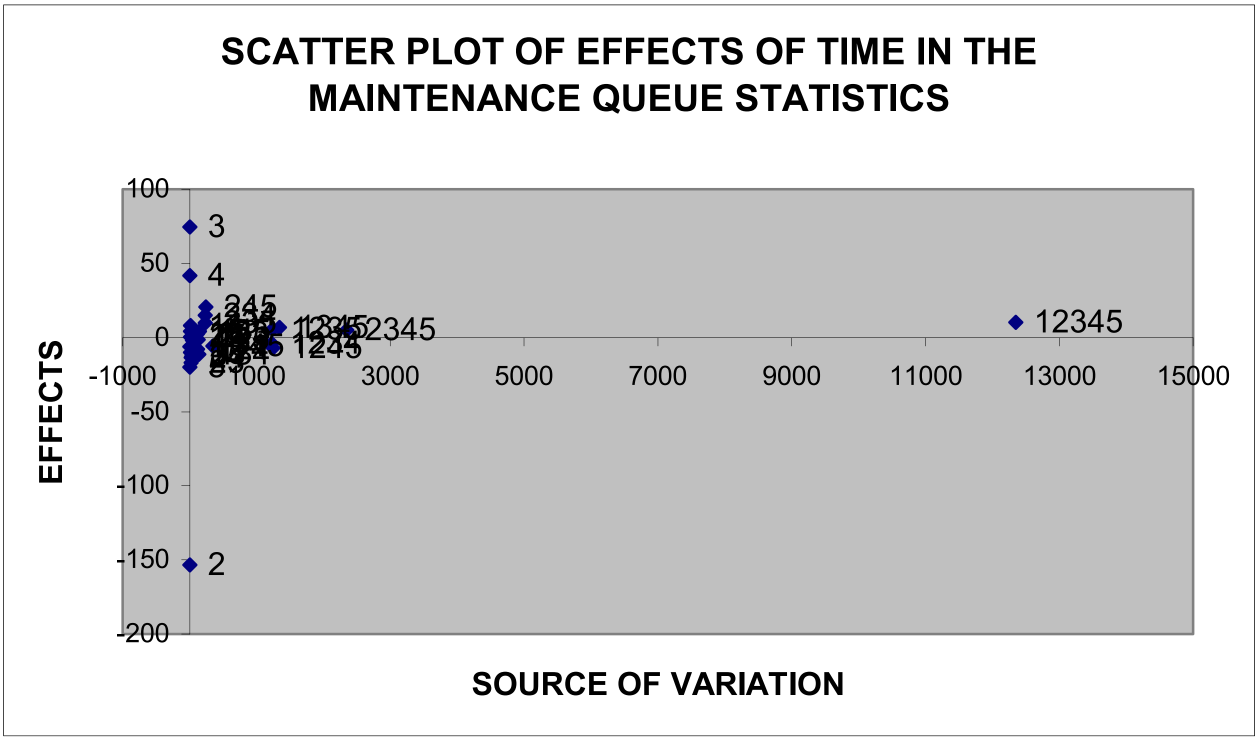


Figure 4.3.3.2: Scatter plots of effects of time in the maintenance queue statistics

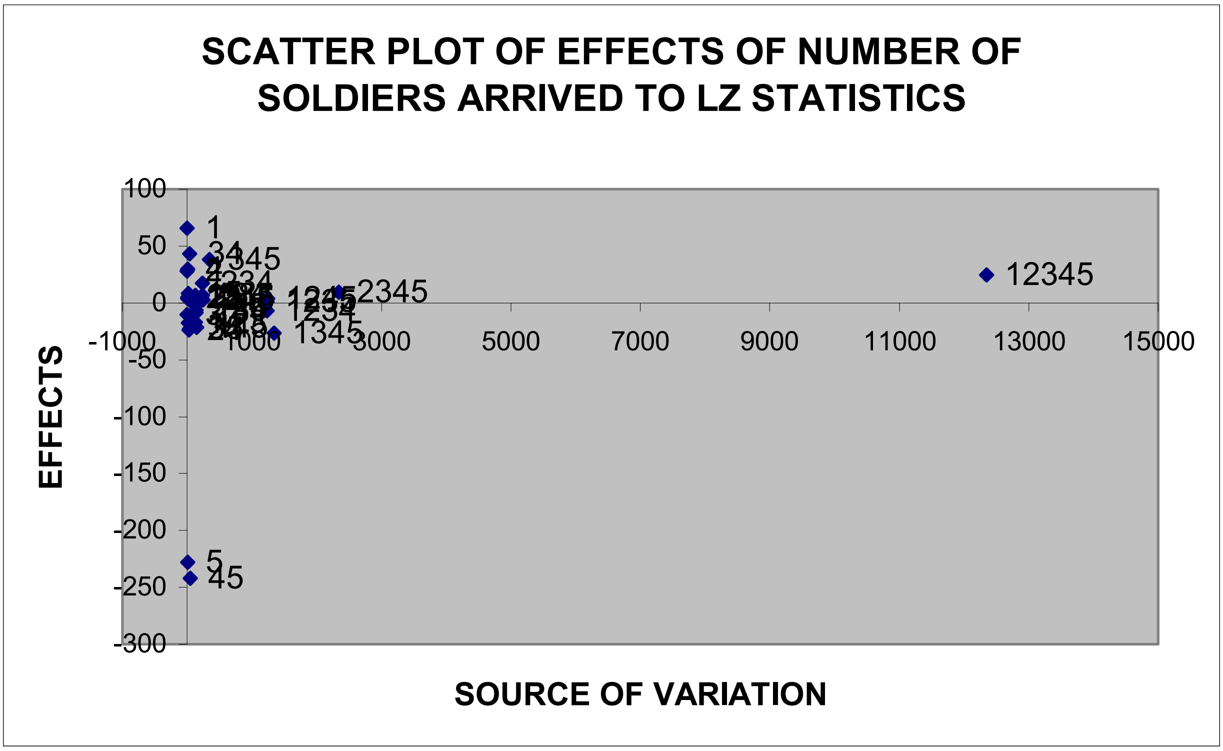


Figure 4.3.4.2: Scatter plots of effects number of soldiers arrived to LZ statistics

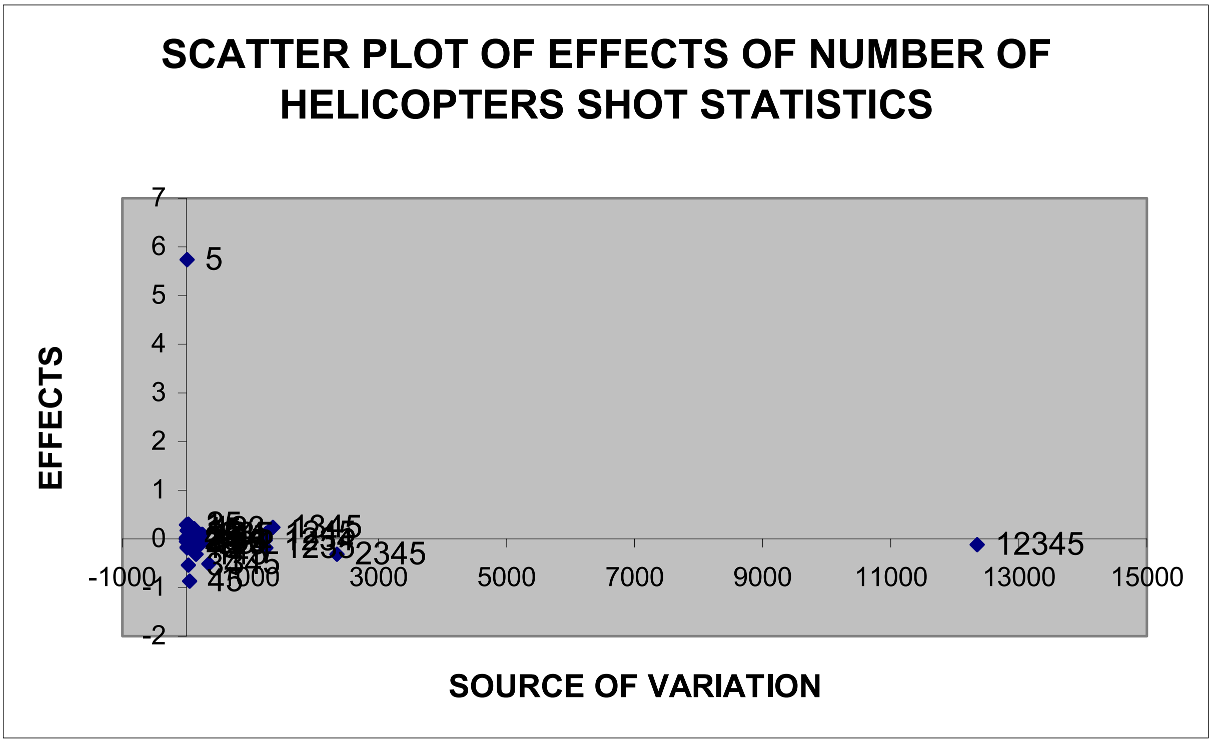


Figure 4.3.5.2: Scatter plots of effects of time in the system statistics

Appendix E

Analysis of Normal Probability Plots and Effects of the Performance Measures

Table 4.3.2.3: Analysis of normal P-P plot effects of time in the tanker queue statistics

ANALYSIS NORMAL P-P OF EFFECTS OF TIME IN THE TANKER QUEUE STATISTICS

ORDER (j)	EFFECT	ESTIMATE	(j-.5)/32
31	**1-5**	3,99375992	0,953125
30	**1-4**	2,45063049	0,921875
29	**3-4-5**	0,80276835	0,890625
28	**4-5**	0,68926663	0,859375
27	**3-4**	0,64793502	0,828125
26	**2-3**	0,59238916	0,796875
25	**2**	0,58131718	0,765625
24	**1-3**	0,48240667	0,734375
23	**2-3-4**	0,4412561	0,703125
22	**2-3-5**	0,41224567	0,671875
21	**1-3-5**	0,40273484	0,640625
20	**2-4-5**	0,39633422	0,609375
19	**1-4-5**	0,38794345	0,578125
18	**1-2-4**	0,34623308	0,546875
17	**1-2-5**	0,34486858	0,515625
16	**2-3-4-5**	0,32840534	0,484375
15	**1-2-3-4-5**	-0,0641309	0,453125
14	**1-2-4-5**	-0,27329775	0,421875
13	**1-2**	-0,3204965	0,390625
12	**2-5**	-0,36653985	0,359375
11	**3-5**	-0,37185902	0,328125
10	**3**	-0,37943382	0,296875
9	**1-2-3-4**	-0,44143688	0,265625
8	**1-2-3-5**	-0,45577521	0,234375
7	**1-2-3**	-0,5334016	0,203125
6	**2-4**	-0,5564097	0,171875
5	**1-3-4**	-0,64425342	0,140625
4	**1-3-4-5**	-0,80893658	0,109375
3	**4**	-4,28982456	0,078125
2	**5**	-5,01413487	0,046875
1	**1**	-20,4582747	0,015625

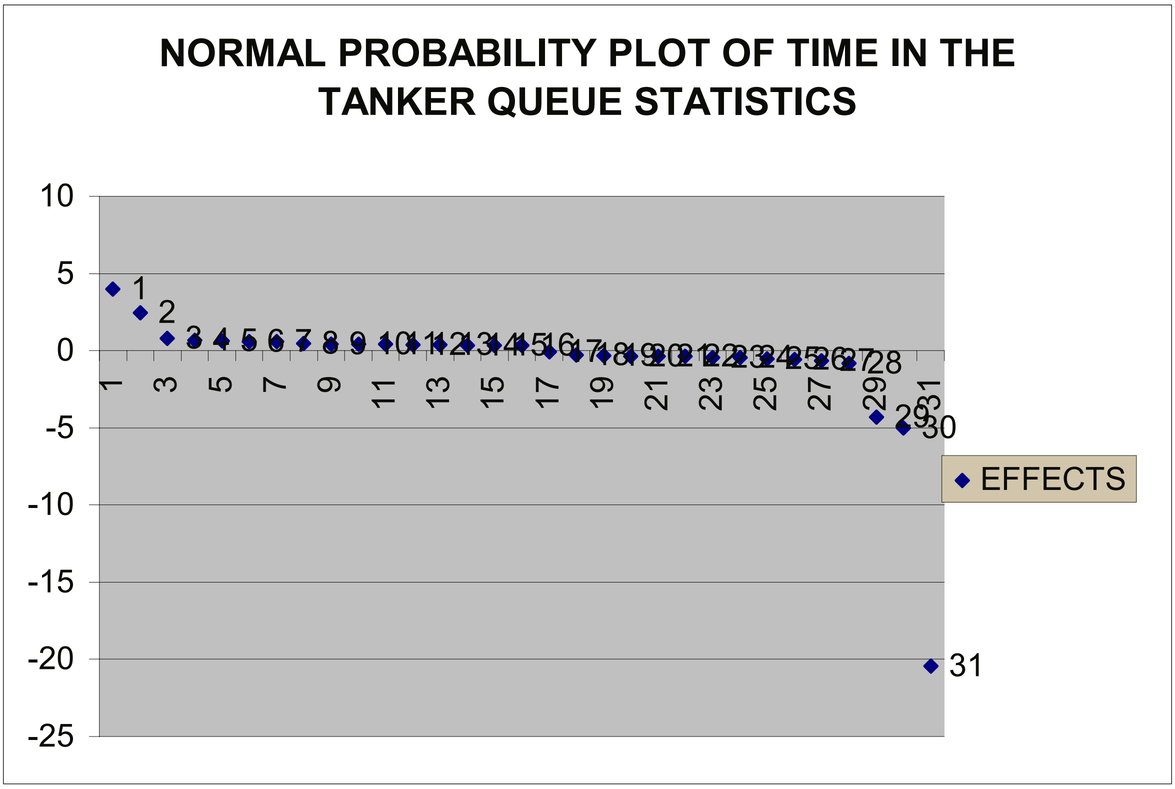


Figure 4.3.2.1:Normal probability plot of time in the tanker queue statistics

Table 4.3.3.3: Analysis of normal P-P plot effects of time in the maintenance queue statistics

ANALYSIS NORMAL P-P OF EFFECTS OF TIME IN THE MAINTENANCE QUEUE STATISTICS

ORDER (j)	EFFECT	ESTIMATE	(j-.5)/32
31	**3**	74,5925818	0,953125
30	**4**	41,5281615	0,921875
29	**2-4-5**	20,6056505	0,890625
28	**2-3-4**	14,9071771	0,859375
27	**1-2-3-4-5**	10,0245951	0,828125
26	**2-3-5**	9,63809456	0,796875
25	**1-4**	8,11591158	0,765625
24	**1-3-4-5**	6,66898906	0,734375
23	**1-2-3-5**	5,60485424	0,703125
22	**2-3-4-5**	4,99938397	0,671875
21	**1-4-5**	4,30012145	0,640625
20	**1-5**	4,12449104	0,609375
19	**1-3-5**	3,90382134	0,578125
18	**1-2-3**	2,59312636	0,546875
17	**2-5**	0,79258314	0,515625
16	**1-2**	0,23802686	0,484375
15	**1-2-5**	-1,59209827	0,453125
14	**4-5**	-2,06815836	0,421875
13	**1-2-3-4**	-4,23274277	0,390625
12	**3-4-5**	-5,86809994	0,359375
11	**1**	-6,34374468	0,328125
10	**1-2-4-5**	-7,18997421	0,296875
9	**1-2-4**	-7,84316964	0,265625
8	**1-3**	-9,90684785	0,234375
7	**3-5**	-11,1282099	0,203125
6	**1-3-4**	-11,5773224	0,171875
5	**3-4**	-12,6414442	0,140625
4	**2-4**	-13,4332798	0,109375
3	**2-3**	-17,1890041	0,078125
2	**5**	-19,9105838	0,046875
1	**2**	-153,465626	0,015625

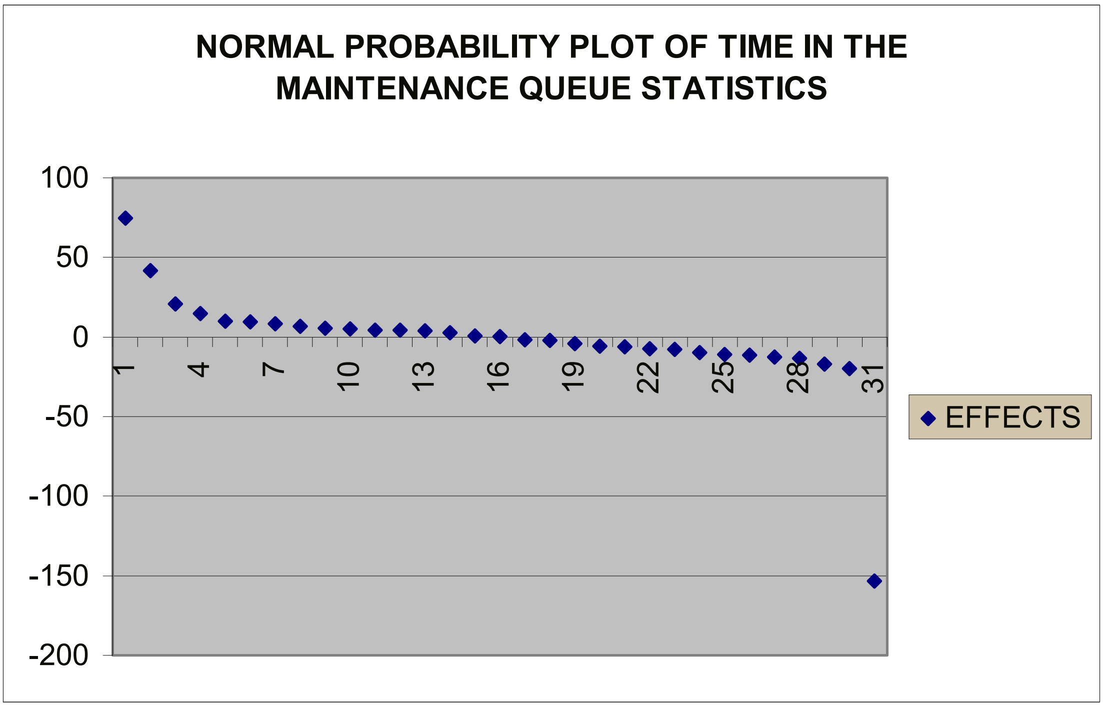


Figure 4.3.3.1:Normal probability plot of time in the maintenance queue statistics

Table 4.3.4.3: Analysis of normal P-P plot effects of number of soldiers arrived to LZ statistics

ANALYSIS NORMAL P-P OF EFFECTS OF SOLDIERS ARRIVED TO LZ STATISTICS

ORDER (j)	EFFECT	ESTIMATE	(j-.5)/32
31	**1**	65,86875	0,953125
30	**3-4**	43,36875	0,921875
29	**3-4-5**	37,96875	0,890625
28	**4**	29,86875	0,859375
27	**2**	28,18125	0,828125
26	**1-2-3-4-5**	24,58125	0,796875
25	**2-3-4**	17,15625	0,765625
24	**2-3-4-5**	9,28125	0,734375
23	**1-5**	8,04375	0,703125
22	**2-3-5**	6,80625	0,671875
21	**1-2-4**	6,35625	0,640625
20	**2-5**	5,45625	0,609375
19	**1-3**	5,11875	0,578125
18	**2-3**	4,55625	0,546875
17	**1-2-4-5**	3,88125	0,515625
16	**1-2**	3,54375	0,484375
15	**2-4-5**	2,53125	0,453125
14	**1-2-3-5**	0,95625	0,421875
13	**1-2-5**	-2,19375	0,390625
12	**1-3-5**	-6,13125	0,359375
11	**1-2-3-4**	-6,91875	0,328125
10	**1-3-4**	-8,60625	0,296875
9	**3**	-10,40625	0,265625
8	**1-2-3**	-16,81875	0,234375
7	**1-4**	-17,60625	0,203125
6	**1-4-5**	-21,65625	0,171875
5	**3-5**	-22,78125	0,140625
4	**2-4**	-23,56875	0,109375
3	**1-3-4-5**	-26,83125	0,078125
2	**5**	-228,20625	0,046875
1	**4-5**	-242,325	0,015625

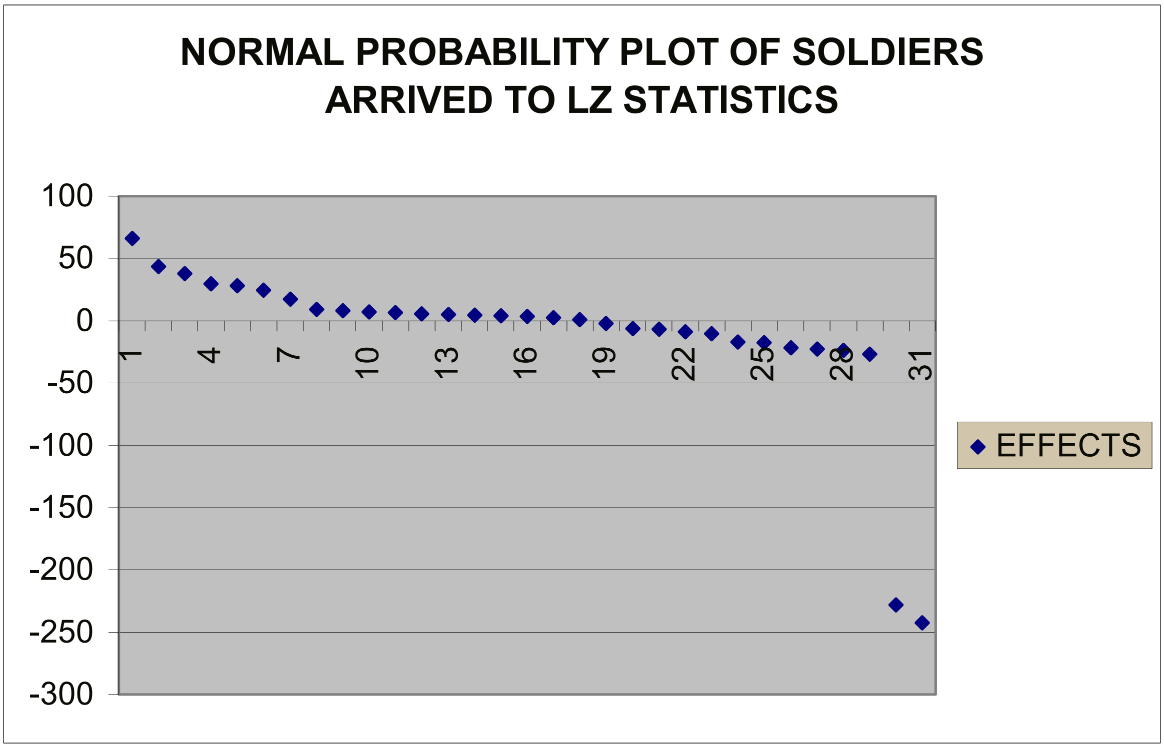


Figure 4.3.4.1:Normal probability plot of number of soldiers arrived to LZ statistics

Table 4.3.5.3: Analysis of normal P-P plot effects of number of helicopters shot statistics

ANALYSIS NORMAL P-P OF EFFECTS OF NUMBER OF HELICOPTERS SHOT STATISTICS

ORDER (j)	EFFECT	ESTIMATE	(j-.5)/32
31	**5**	5,740625	0,953125
30	**2-5**	0,303125	0,921875
29	**1**	0,290625	0,890625
28	**1-3-4-5**	0,240625	0,859375
27	**1-2-3**	0,209375	0,828125
26	**1-5**	0,190625	0,796875
25	**1-4**	0,171875	0,765625
24	**1-2-4-5**	0,121875	0,734375
23	**2-4-5**	0,096875	0,703125
22	**1-2-4**	0,096875	0,671875
21	**2-3-5**	0,096875	0,640625
20	**3-5**	0,084375	0,609375
19	**4**	0,021875	0,578125
18	**1-3-4**	0,003125	0,546875
17	**2**	0,003125	0,515625
16	**1-2-3-4**	-0,021875	0,484375
15	**2-3**	-0,028125	0,453125
14	**1-3-5**	-0,053125	0,421875
13	**3**	-0,053125	0,390625
12	**2-4**	-0,065625	0,359375
11	**2-3-4**	-0,096875	0,328125
10	**1-2-5**	-0,109375	0,296875
9	**1-2-3-4-5**	-0,121875	0,265625
8	**1-2**	-0,171875	0,234375
7	**1-2-3-5**	-0,178125	0,203125
6	**1-3**	-0,178125	0,171875
5	**2-3-4-5**	-0,309375	0,140625
4	**1-4-5**	-0,315625	0,109375
3	**3-4-5**	-0,509375	0,078125
2	**3-4**	-0,534375	0,046875
1	**4-5**	-0,871875	0,015625

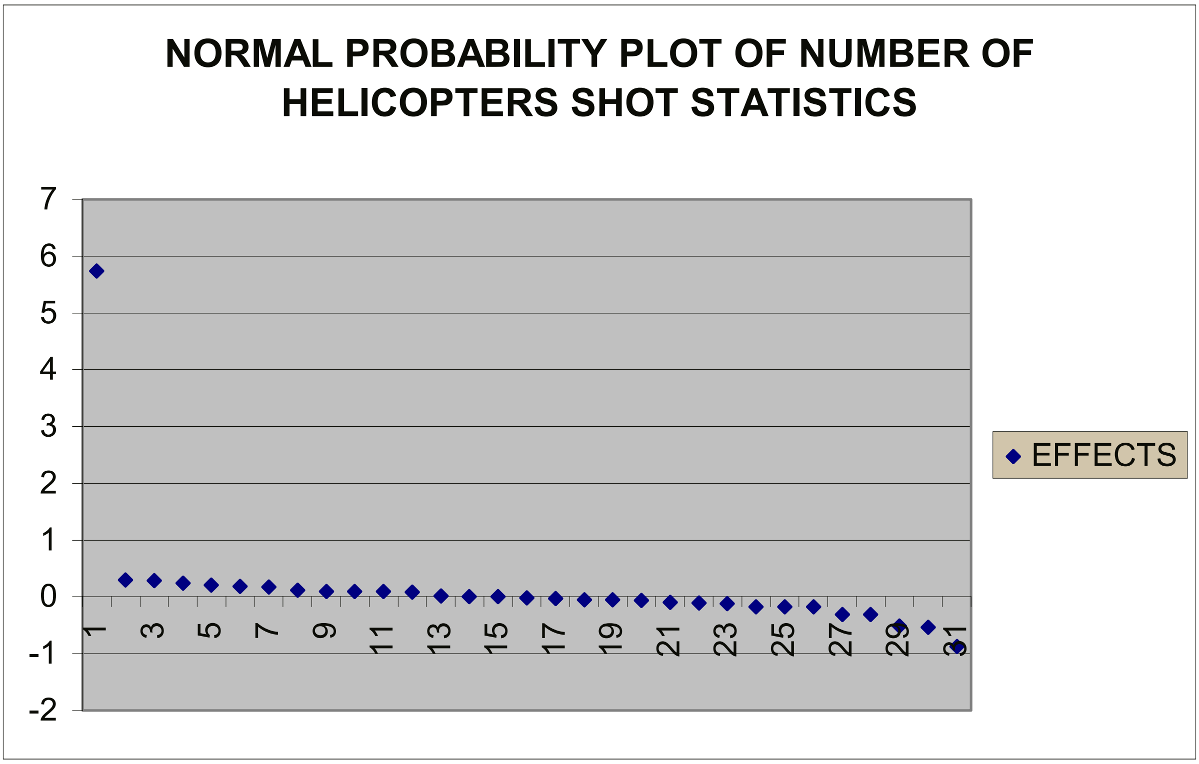


Figure 4.3.5.1:Normal probability plot of number of helicopters shot statistics

Appendix F

Residual Analysis and Scatter Plots of Performance Measures

Table 4.4.1:Residual analysis for time in the system statistics

RESIDUAL ANALYSIS FOR TIME IN THE SYSTEM STATISTICS

DESIGN POINTS	y	y^	e=y-y^
1	175,811149	170,07	5,74114862
2	157,915392	170,07	-12,15460837
3	171,838204	170,07	1,76820367
4	156,243315	170,07	-13,82668514
5	185,070732	170,07	15,00073206
6	156,870843	170,07	-13,1991575
7	171,780043	170,07	1,710042645
8	155,937833	170,07	-14,13216727
9	222,234667	226,924	-4,689333185
10	239,698135	226,924	12,77413527
11	219,429458	226,924	-7,49454227
12	220,602999	226,924	-6,32100124
13	242,414509	226,924	15,49050855
14	222,557557	226,924	-4,36644289
15	225,141452	226,924	-1,78254847
16	207,953692	226,924	-18,97030771
17	178,246356	170,07	8,176356175
18	171,681199	170,07	1,611199205
19	176,589778	170,07	6,519778295
20	162,667885	170,07	-7,402114845
21	188,288973	170,07	18,2189731
22	166,77959	170,07	-3,290409855
23	180,089489	170,07	10,01948857
24	165,319168	170,07	-4,75083244
25	229,18482	226,924	2,26082013
26	265,099507	226,924	38,17550699
27	225,144359	226,924	-1,77964061
28	224,433652	226,924	-2,490348035
29	222,29576	226,924	-4,628240355
30	214,951026	226,924	-11,97297445
31	221,315474	226,924	-5,60852607
32	228,329477	226,924	1,405476785

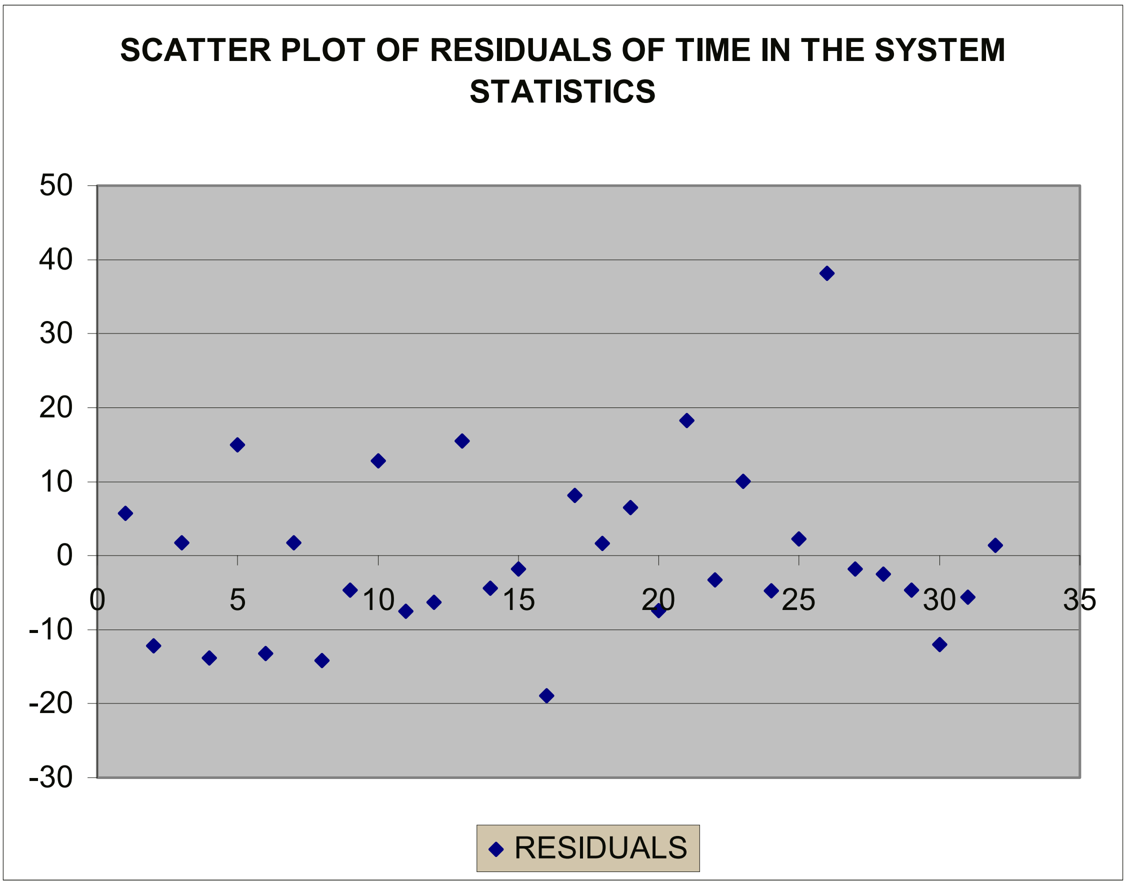


Figure 4.4.1: Scatter plot of residuals for time in the system statistics

Table 4.4.2:Residual analysis for time in the tanker queue statistics

RESIDUAL ANALYSIS FOR TIME IN THE TANKERQ STATISTICS

DESIGN POINTS	y	y^	e=y-y^
1	29,6451564	31,8519875	-2,206831099
2	4,999655487	4,9507125	0,048942987
3	33,26267401	31,8519875	1,41068651
4	5,04875432	4,9507125	0,09804182
5	30,10981313	31,8519875	-1,742174373
6	4,69493039	4,9507125	-0,25578211
7	33,26255701	31,8519875	1,410569511
8	5,477973849	4,9507125	0,527261349
9	25,85190281	25,1121875	0,739715307
10	3,008736052	3,1109125	-0,102176448
11	25,34455745	25,1121875	0,232369949
12	2,92031915	3,1109125	-0,19059335
13	24,69721308	25,1121875	-0,414974422
14	3,252621015	3,1109125	0,141708515
15	25,68572093	25,1121875	0,573533429
16	2,840327897	3,1109125	-0,270584603
17	25,44533892	22,8448875	2,600451417
18	3,568506841	3,9296125	-0,361105659
19	25,34980643	22,8448875	2,504918935
20	3,943798135	3,9296125	0,014185635
21	20,18642876	22,8448875	-2,658458737
22	3,953477778	3,9296125	0,023865278
23	21,52806115	22,8448875	-1,316826347
24	3,831497815	3,9296125	-0,098114685
25	16,74397704	16,1050875	0,638889544
26	2,293666622	2,0898125	0,203854122
27	13,63196452	16,1050875	-2,473122982
28	1,966490323	2,0898125	-0,123322177
29	14,74239521	16,1050875	-1,362692287
30	2,14547698	2,0898125	0,05566448
31	18,16846441	16,1050875	2,063376905
32	2,377404033	2,0898125	0,287591533

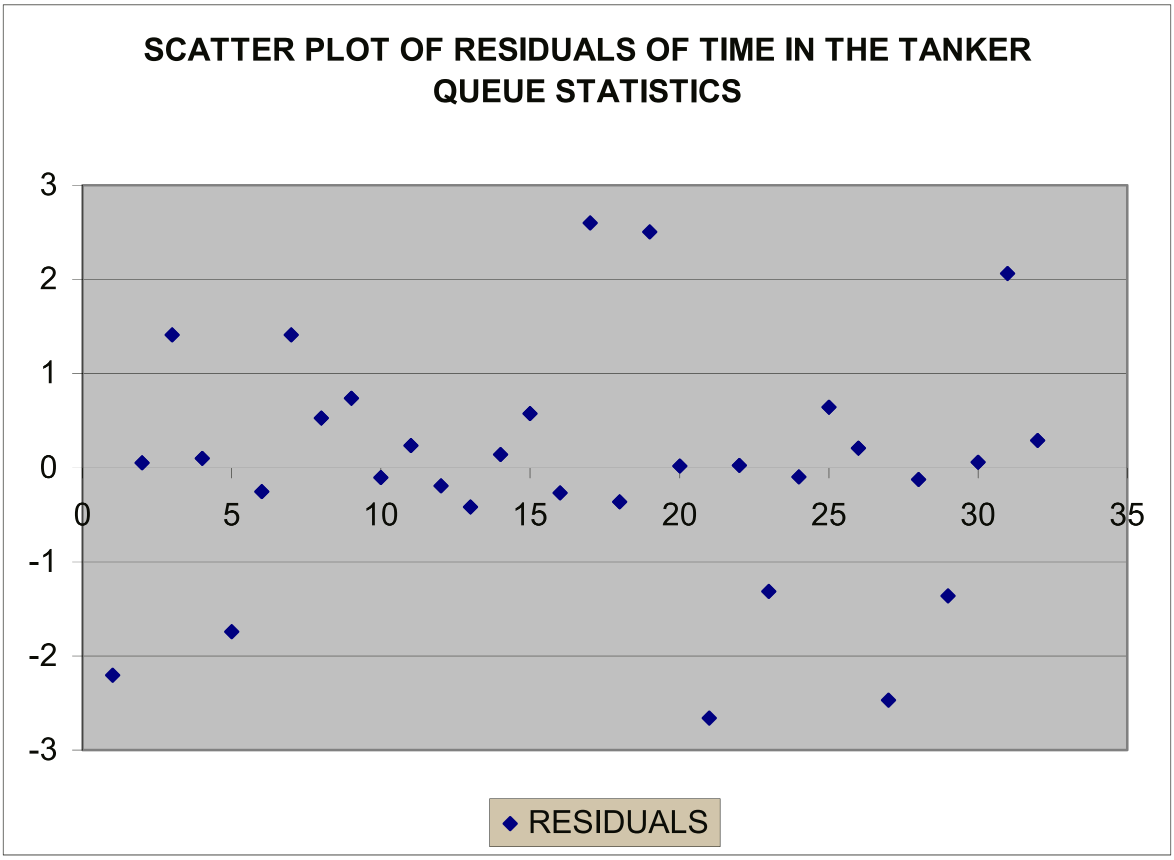


Figure 4.4.2: Scatter plot of residuals for time in the tanker queue statistics

Table 4.4.3:Residual analysis for time in the maintenance queue statistics

RESIDUAL ANALYSIS FOR TIME IN THE MAINTEANCEQ STATISTICS

DESIGN POINTS	y	y^	e=y-y^
1	204,971597	258,39825	-53,42665299
2	195,3567016	258,39825	-63,04154845
3	130,5919828	104,93325	25,65873282
4	102,7675421	104,93325	-2,16570794
5	341,0105925	332,99075	8,019842515
6	317,7757615	332,99075	-15,21498847
7	170,6699747	179,52575	-8,855775335
8	174,2080385	179,52575	-5,31771151
9	295,7298044	258,39825	37,33155439
10	303,0308272	258,39825	44,63257715
11	106,2484583	104,93325	1,315208284
12	149,7565057	104,93325	44,82325566
13	406,3844721	332,99075	73,39372213
14	384,1096652	332,99075	51,11891516
15	217,6026465	179,52575	38,07689651
16	162,458601	179,52575	-17,06714899
17	229,1689178	258,39825	-29,22933216
18	204,6978633	258,39825	-53,70038668
19	85,85051407	104,93325	-19,08273593
20	83,2403816	104,93325	-21,6928684
21	342,101126	332,99075	9,110375985
22	310,6284287	332,99075	-22,36232134
23	139,0555245	179,52575	-40,47022548
24	139,0682621	179,52575	-40,45748787
25	256,8235141	258,39825	-1,574735945
26	308,6511847	258,39825	50,25293471
27	129,6867219	104,93325	24,7534719
28	120,0753297	104,93325	15,14207973
29	314,3238831	332,99075	-18,6668669
30	316,3491681	332,99075	-16,64158188
31	183,918728	179,52575	4,39297802
32	180,4642821	179,52575	0,938532095

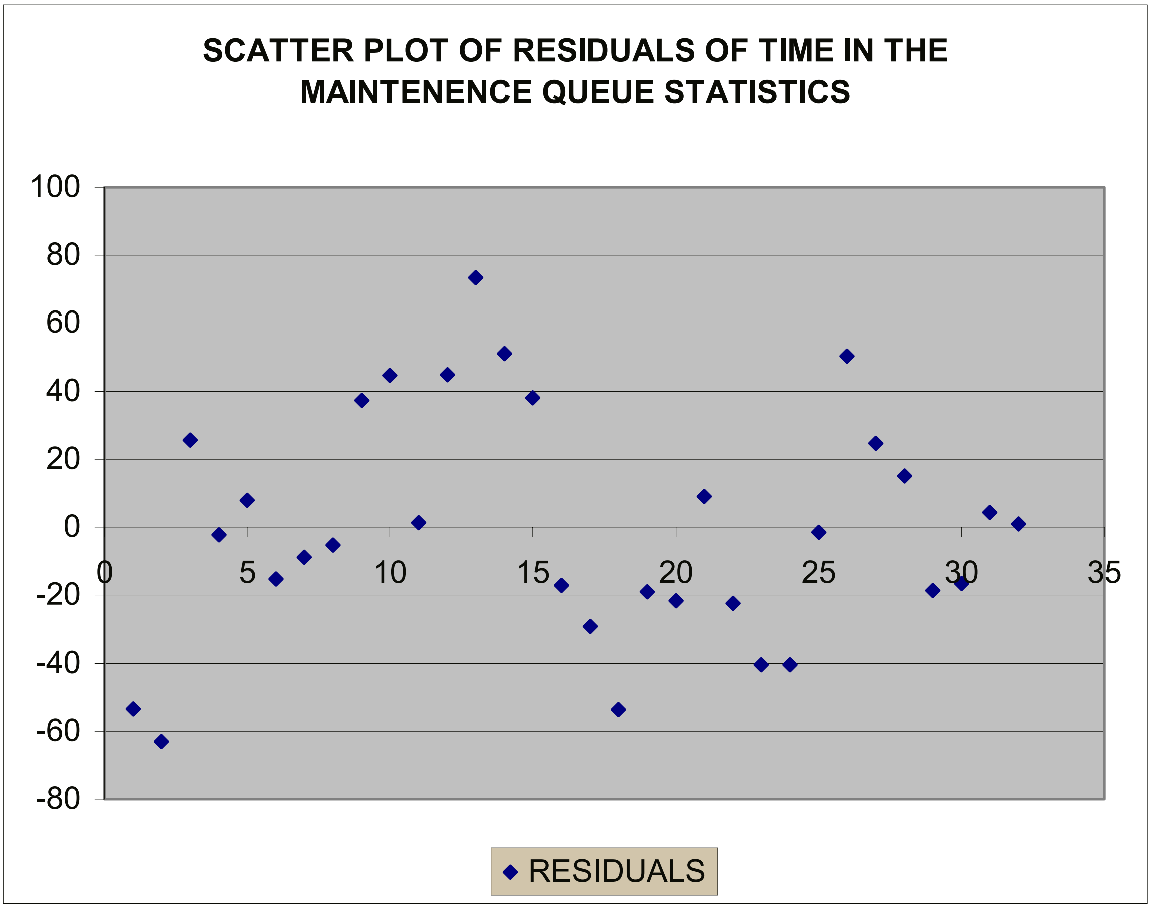


Figure 4.4.3: Scatter plot of residuals for time in the maintenance queue statistics

Table 4.4.4:Residual analysis for time number of soldiers arrived to LZ statistics

RESIDUAL ANALYSIS FOR NUMBER OF SOLDIERS STATISTICS

DESIGN POINTS	y	y^	e=y-y^
1	3224,7	3198,9405	25,7595
2	3294	3198,9405	95,0595
3	3292,2	3198,9405	93,2595
4	3344,4	3198,9405	145,4595
5	3262,5	3198,9405	63,5595
6	3290,4	3198,9405	91,4595
7	3282,3	3198,9405	83,3595
8	3348	3198,9405	149,0595
9	3357	3441,2655	-84,2655
10	3330	3441,2655	-111,2655
11	3288,6	3441,2655	-152,6655
12	3380,4	3441,2655	-60,8655
13	3290,4	3441,2655	-150,8655
14	3420,9	3441,2655	-20,3655
15	3331,8	3441,2655	-109,4655
16	3384	3441,2655	-57,2655
17	3086,1	3213,0595	-126,9595
18	3138,3	3213,0595	-74,7595
19	3129,3	3213,0595	-83,7595
20	3234,6	3213,0595	21,5405
21	2918,7	3213,0595	-294,3595
22	3106,8	3213,0595	-106,2595
23	2998,8	3213,0595	-214,2595
24	3105,9	3213,0595	-107,1595
25	3052,8	2970,7345	82,0655
26	3112,2	2970,7345	141,4655
27	3015,9	2970,7345	45,1655
28	3098,7	2970,7345	127,9655
29	3101,4	2970,7345	130,6655
30	3084,3	2970,7345	113,5655
31	3136,5	2970,7345	165,7655
32	3150	2970,7345	179,2655

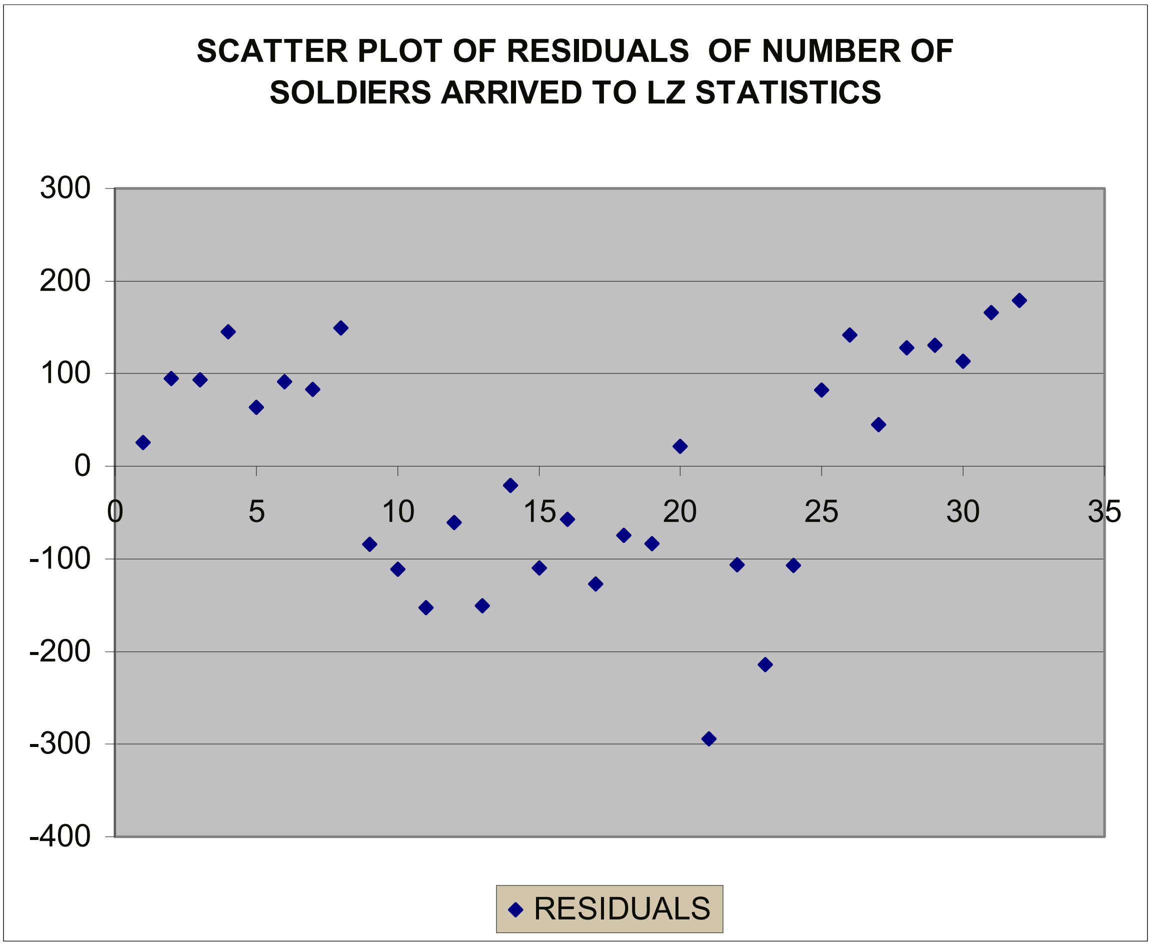


Figure 4.4.4 : Scatter plot of residuals for number of soldiers arrived to LZ statistics

Table 4.4.5:Residual analysis for number of helicopters shot statistics

RESIDUAL ANALYSIS FOR NUMBER OF HELICOPTERS SHOT STATISTICS			
DESIGN POINTS	**y**	**y^**	**e=y-y^**
1	5,35	5,0045	0,3455
2	5,2	5,0045	0,1955
3	5,9	5,0045	0,8955
4	5,05	5,0045	0,0455
5	5,75	5,0045	0,7455
6	5,25	5,0045	0,2455
7	5,05	5,0045	0,0455
8	5	5,0045	-0,0045
9	5,15	5,8755	-0,7255
10	6,7	5,8755	0,8245
11	5,2	5,8755	-0,6755
12	5,55	5,8755	-0,3255
13	5,75	5,8755	-0,1255
14	5,6	5,8755	-0,2755
15	5	5,8755	-0,8755
16	5,6	5,8755	-0,2755
17	9,95	11,6155	-1,6655
18	11,75	11,6155	0,1345
19	10,45	11,6155	-1,1655
20	10,85	11,6155	-0,7655
21	11,2	11,6155	-0,4155
22	11,7	11,6155	0,0845
23	12,3	11,6155	0,6845
24	12,1	11,6155	0,4845
25	11,1	10,7445	0,3555
26	11,4	10,7445	0,6555
27	11,75	10,7445	1,0055
28	12,1	10,7445	1,3555
29	10,3	10,7445	-0,4445
30	10,85	10,7445	0,1055
31	10,5	10,7445	-0,2445
32	10,65	10,7445	-0,0945

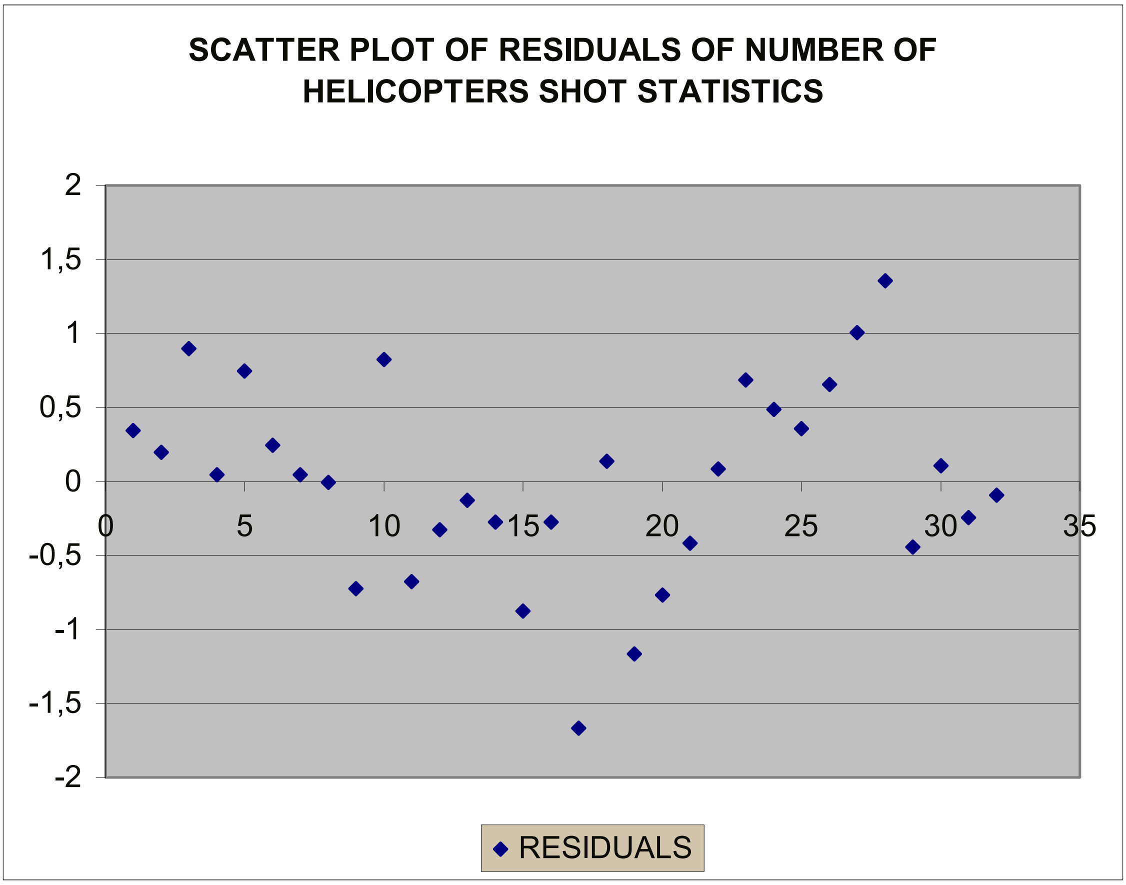


Figure 4.4.5: Scatter plot of residuals for number of helicopters shot statistics

Appendix G

Histograms and P-P Comparison Graphs of Residuals

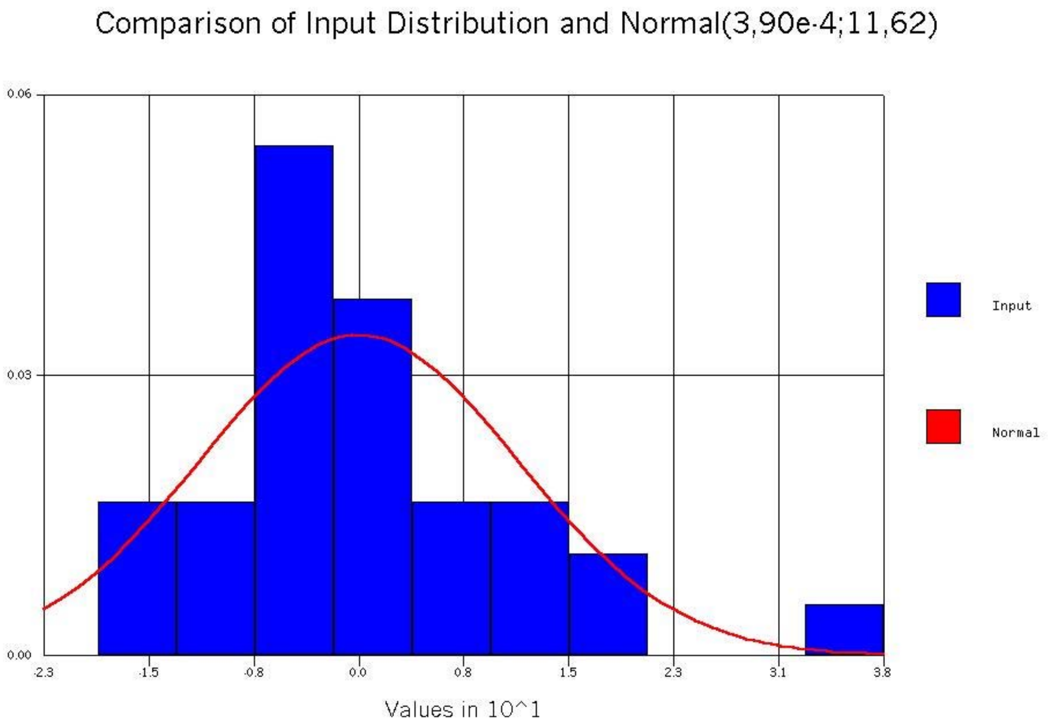


Figure 4.4.6:Histogram of residuals of time in the system statistics

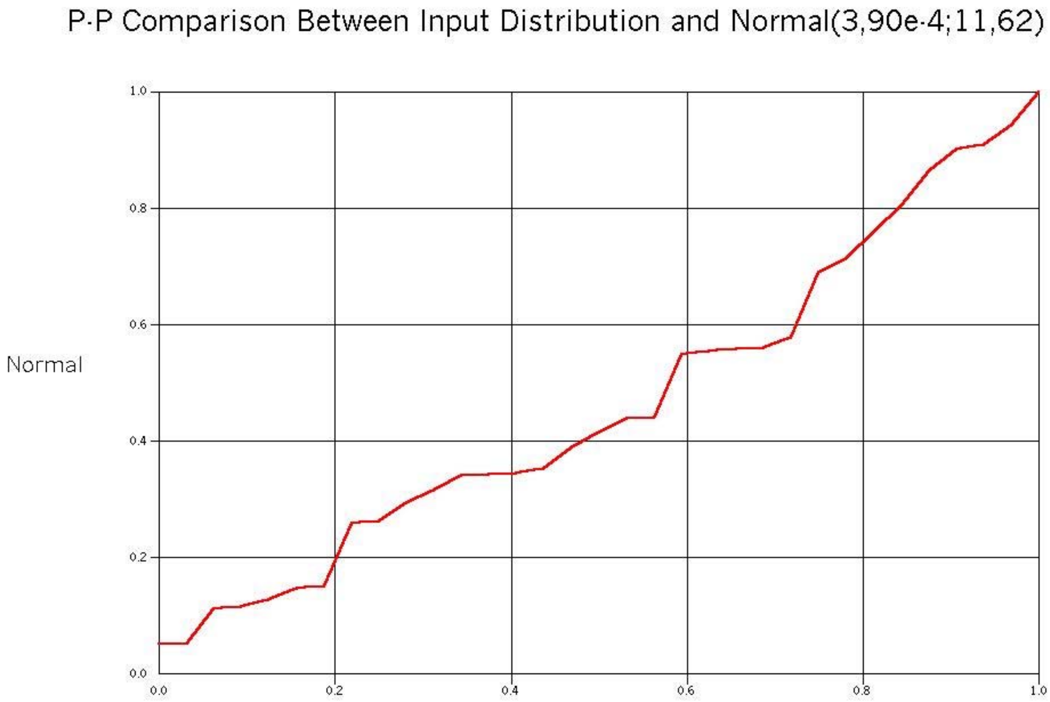


Figure 4.4.7: Probability plot of residuals of time in the system statistics

Appendix H

MCPs and R&S Tables for Different Weather and Terrain Conditions and Performance Measures

Cold and Sea Level Weather and Terrain Conditions

Time in the System (Test value= 200)

Table 5.3.1:Tukey test results for Time in the system performance measure in Cold and Sea level

ALTERNATIVE	Xi(100)	Si^2(100)	Si^2	HALF LENGTH	ELIMINATED	SELECTED
FIFO,4TAN, 5MAINT	178,807	3570,357	4060,1	27,335		X
FIFO,4TAN, 3MAINT	185,779	11442,611				X
FIFO,2TAN, 5MAINT	186,948	1641,843				X
FIFO,2TAN, 3MAINT	187,592	4229,702				X
LVF,4TAN, 5MAINT	172,363	2942,574				X
LVF,4TAN, 3MAINT	176,450	2715,529				X
LVF,2TAN, 5MAINT	182,440	3332,305				X
LVF,2TAN, 3MAINT	336	69418,813				X

Time in the maintenance queue (Test value=187)

Table 5.3.2:Tukey test results for time in the maintenance queue performance measure in Cold and Sea level

ALTERNATIVE	Xi(100)	Si^2(100)	Si^2	HALF LENGTH	ELIMINATED	SELECTED
FIFO,4TAN ,5MAINT	65,807	27991,545	114476,271	145,149		X
FIFO,4TAN, 3MAINT	127,715	91127,51				X
FIFO,2TAN ,5MAINT	42,126	18022,812				X
FIFO,2TAN ,3MAINT	163,986	108473,27				X
LVF,4TAN, 5MAINT	75,112	57802,462				X
LVF,4TAN, 3MAINT	166,568	231554,23				X
LVF,2TAN, 5MAINT	111,722	92639,603				X
LVF,2TAN, 3MAINT	202,854	288198,73			X	

Time in the tanker queue (Test value=7,18)

Table 5.3.3:Tukey test results for time in the tanker queue performance measure in Cold and Sea level

ALTERNATIVE	Xi (100)	Si^2(100)	Si^2	HALF LENGTH	ELIMINATED	SELECTED
FIFO,4TAN ,5MAINT	4,32609	7,1572	44,269	2,854		X
FIFO,4TAN, 3MAINT	4,3607	7,253				X
FIFO,2TAN, 5MAINT	33,131	78,112			X	
FIFO,2TAN, 3MAINT	31,424	98			X	
LVF,4TAN, 5MAINT	4,551	7,070				X
LVF,4TAN, 3MAINT	4,425	6,549				X
LVF,2TAN, 5MAINT	33,689	66,257			X	
LVF,2TAN, 3MAINT	33,057	83,755			X	

The number of soldiers landed (Test value=3170)

Observe that we eliminated the alternatives, which have smaller average values than the test value, since our goal is to maximize the number of soldiers landed.

Table 5.3.4:Tukey test results for number of soldiers landed performance measure in Cold and Sea level

ALTERNATIVE	Xi(100)	Si^2(100)	Si^2	HALF LENGTH	ELIMINATED	SELECTED
FIFO,4TAN, 5MAINT	3488	372266,4	330213,24	246,52135		X
FIFO,4TAN, 3MAINT	3560,363	244745,5				X
FIFO,2TAN, 5MAINT	3520,727	209045,5				X
FIFO,2TAN, 3MAINT	3419,636	432268,7				X
LVF,4TAN, 5MAINT	3542	299148,2				X
LVF,4TAN, 3MAINT	3554,545	255261,3				X
LVF,2TAN, 5MAINT	3433,818	472476,8				X
LVF,2TAN, 3MAINT	3460,363	356493,1				X

Hot and High Weather and Terrain Conditions

Time in the System (Test value=261)

Table 5.3.5:Tukey test results for Time in the system performance measure in Hot and High

ALTERNATIVE	Xi(100)	$Si^2(100)$	Si^2	HALF LENGTH	ELIMINATED	SELECTED
FIFO,4TAN, 5MAINT	235,158	16606,53	15540,02	53,478976		X
FIFO,4TAN, 3MAINT	230,771	14935,58				X
FIFO,2TAN, 5MAINT	244,414	10920,48				X
FIFO,2TAN, 3MAINT	255,996	16879,24				X
LVF,4TAN,5MAINT	207,855	7567,977				X
LVF,4TAN,3MAINT	260,636	26704,23				X
LVF,2TAN,5MAINT	216,603	11343,23				X
LVF,2TAN,3MAINT	243,382	19362,87				X

Time in the maintenance queue (Test value=331)

Table 5.3.6:Tukey test results for time in the maintenance queue performance measure in Hot and High

ALTERNATIVE	Xi(100)	$Si^2(100)$	Si^2	HALF LENGTH	ELIMINATED	SELECTED
FIFO,4TAN, 5MAINT	172,184	48743,63	223004,7	202,588		X
FIFO,4TAN, 3MAINT	370,771	185969,4			X	
FIFO,2TAN, 5MAINT	128,134	32693,20				X
FIFO,2TAN, 3MAINT	368,424	173730,9			X	
LVF,4TAN, 5MAINT	205,552	161648,8				X
LVF,4TAN,3MAINT	418,186	428233,9				X
LVF,2TAN,5MAINT	304,7	233592,7				X
LVF,2TAN,3MAINT	442,367	519425			X	

Time in the tanker queue (Test value=6,63)

Table 5.3.7:Tukey test results for Time in the tanker queue performance measure in Hot and High

ALTERNATIVES	Xi(100)	Si^2(100)	Si^2	HALF LENGTH	ELIMINATED	SELECTED
FIFO,4TAN,5MAINT	2,5060	4,755	92,353	4,122		X
FIFO,4TAN,3MAINT	2,632	6,968				X
FIFO,2TAN,5MAINT	23,973	186,126				X
FIFO,2TAN,3MAINT	20,2453	171,15				X
LVF,4TAN,5MAINT	2,606	5,404				X
LVF,4TAN,3MAINT	2,550	5,181				X
LVF,2TAN,5MAINT	24,206	180,362			X	
LVF,2TAN,3MAINT	24,618	178,872			X	

The number of soldiers landed (Test value=2770)

Observe that we eliminate the alternatives, which have smaller average values than the test value, since our goal is to maximize the number of soldiers landed.

Table 5.3.8:Tukey test results for number of soldiers landed performance measure in Hot and High

ALTERNATIVES	Xi(100)	Si^2(100)	Si^2	HALF LENGTH	ELIMINATED	SELECTED
FIFO,4TAN, 5MAINT	3331,285	699748,1	684744,918	354,994		X
FIFO,4TAN, 3MAINT	3244,591	886833,5				X
FIFO,2TAN, 5MAINT	3431,020	383119,2				X
FIFO,2TAN, 3MAINT	3253,591	673880,3				X
LVF,4TAN,5MAINT	3332,571	731231,2				X
LVF,4TAN,3MAINT	3376,285	581596,7				X
LVF,2TAN,5MAINT	3120,612	858716,1				X
LVF,2TAN,3MAINT	3253,959	662834,0				X
LVF,2TAN, 3MAINT	12,886	155,0405			X	

Cold and Sea Level Weather and Terrain Conditions

Time in the System

Table 5.3.9:Welch approach results for Time in the system performance measure in Cold and Sea level

ALTERNATIVES	Xi(100)	$Si^2(100)$	ELIMINATED	SELECTED
FIFO,4TAN,5MAINT	178,807	3570,357		X
FIFO,4TAN,3MAINT	185,779	11442,611		X
FIFO,2TAN,5MAINT	186,948	1641,843	X	
FIFO,2TAN,3MAINT	187,592	4229,702		X
LVF,4TAN,5MAINT	172,363	2942,57		X
LVF,4TAN,3MAINT	176,450	2715,529		X
LVF,2TAN,5MAINT	182,44	3332,305		X
LVF,2TAN,3MAINT	181,779	2605,879		X

Time in the maintenance queue

Table 5.3.10:Welch approach results for time in the maintenance queue performance measure in Cold and Sea level

ALTERNATIVES	Xi(100)	$Si^2(100)$	ELIMINATED	SELECTED
FIFO,4TAN,5MAINT	65,807	27991,545		X
FIFO,4TAN,3MAINT	127,715	91127,51	X	
FIFO,2TAN,5MAINT	42,126	18022,812		X
FIFO,2TAN,3MAINT	163,986	108473,27	X	
LVF,4TAN,5MAINT	75,112	57802,462		X
LVF,4TAN,3MAINT	166,568	231554,23	X	
LVF,2TAN,5MAINT	111,7221359	92639,603	X	
LVF,2TAN,3MAINT	202,854	288198,73	X	

Time in the tanker queue

Table 5.3.11:Welch approach results for Time in the tanker queue performance measure in Cold and Sea level

ALTERNATIVES	Xi(100)	Si^2(100)	ELIMINATED	SELECTED
FIFO,4TAN,5MAINT	4,326	7,157		X
FIFO,4TAN,3MAINT	4,3607904	7,253		X
FIFO,2TAN,5MAINT	33,131934	78,112	X	
FIFO,2TAN,3MAINT	31,424	98	X	
LVF,4TAN,5MAINT	4,551	7,07		X
LVF,4TAN,3MAINT	4,4257771	6,549		X
LVF,2TAN,5MAINT	33,689	66,257	X	
LVF,2TAN,3MAINT	33,057	83,755	X	

The number of soldiers landed

Table 5.3.12:Welch approach results for number of soldiers landed performance measure in Cold and Sea level

ALTERNATIVES	Xi(100)	Si^2(100)	ELIMINATED	SELECTED
FIFO,4TAN,5MAINT	3488	372266,449		X
FIFO,4TAN,3MAINT	3560,363	244745,499		X
FIFO,2TAN,5MAINT	3520,727	209045,588		X
FIFO,2TAN,3MAINT	3419,636	432268,764		X
LVF,4TAN,5MAINT	3542	299148,244		X
LVF,4TAN,3MAINT	3554,545	255261,372		X
LVF,2TAN,5MAINT	3433,818	472476,82		X
LVF,2TAN,3MAINT	3460,363	356493,172		X

Hot and High Weather and Terrain Conditions

Time in the System

Table 5.3.13:Welch approach results for Time in the system performance measure in Hot and High

ALTERNATIVES	Xi(100)	Si^2(100)	ELIMINATED	SELECTED
FIFO,4TAN,5MAINT	235,158	16606,532		X
FIFO,4TAN,3MAINT	230,771	14935,587		X
FIFO,2TAN,5MAINT	244,414	10920,48	X	
FIFO,2TAN,3MAINT	255,996	16879,241	X	
LVF,4TAN,5MAINT	207,855	7567,977		X
LVF,4TAN,3MAINT	260,636	26704,236	X	
LVF,2TAN,5MAINT	216,603	11343,23		X
LVF,2TAN,3MAINT	243,382	19362,874	X	

Time in the maintenance queue

Table 5.3.14:Welch approach results for Time in the maintenance queue performance measure in Hot and High

ALTERNATIVES	Xi(100)	$Si^2(100)$	ELIMINATED	SELECTED
FIFO,4TAN,5MAINT	172,184	48743,63		X
FIFO,4TAN,3MAINT	370,771	185969,46	X	
FIFO,2TAN,5MAINT	128,134	32693,205		X
FIFO,2TAN,3MAINT	368,424	173730,94	X	
LVF,4TAN,5MAINT	205,552	161648,85		X
LVF,4TAN,3MAINT	418,18	428233,98	X	
LVF,2TAN,5MAINT	304,73	233592,75	X	
LVF,2TAN,3MAINT	442,367	519425,05	X	

Time in the tanker queue

Table 5.3.15:Welch approach results for Time in the system performance measure in Hot and High

ALTERNATIVES	Xi(100)	$Si^2(100)$	ELIMINATED	SELECTED
FIFO,4TAN,5MAINT	2,506	4,755		X
FIFO,4TAN,3MAINT	2,632	6,968		X
FIFO,2TAN,5MAINT	23,973	186,126	X	
FIFO,2TAN,3MAINT	20,245	171,156	X	
LVF,4TAN,5MAINT	2,606	5,404		X
LVF,4TAN,3MAINT	2,55	5,181		X
LVF,2TAN,5MAINT	24,206	180,36	X	
LVF,2TAN,3MAINT	24,618	178,872	X	

The number of soldiers landed

Table 5.3.16:Welch approach results for number of soldiers landed performance measure in Hot and High

ALTERNATIVES	Xi(100)	$Si^2(100)$	ELIMINATED	SELECTED
FIFO,4TAN,5MAINT	3331,285	699748,14		X
FIFO,4TAN,3MAINT	3244,591	886833,5		X
FIFO,2TAN,5MAINT	3431,02	383119,2	X	
FIFO,2TAN,3MAINT	3253,591	673880,33		X
LVF,4TAN,5MAINT	3332,571	731231,26		X
LVF,4TAN,3MAINT	3376,285	581596,7	X	
LVF,2TAN,5MAINT	3120,612	858716,16		X
LVF,2TAN,3MAINT	3253,959	662834,06		X

SELECTING THE BEST OF SYSTEM

COLD AND SEA LEVEL

Table 5.4.1:Results of D-D procedure for time in the system for Cold and Sea level

Alter.	$Xi^{(1)}(20)$	$Si^2(20)$	Ni	Ni-no	$Xi^{(2)}(Ni-20)$	Wi1	Wi2	Xi(Ni)	Ranking
FIFO,4TAN, 5MAINT	1.83E+02	1498.822	63	43	1.74E+02	0.376318	0.623681	177.4504	***2.***
FIFO,4TAN, 3MAINT	1.91E+02	2617.641	109	89	1.84E+02	0.214695	0.785304	185.8605	***4.***
FIFO,2TAN, 5MAINT	1.96E+02	2864.582	119	99					***6***
FIFO,2TAN, 3MAINT	1.86E+02	443.7634	21	1	1.60E+02	1.033148	0.033148	186.6924	***5***
LVF,4TAN,5 MAINT	1.77E+02	2124.216	88	68	1.72E+02	0.242619	0.757380	173.3075	***1***
LVF,4TAN,3 MAINT	1.83E+02	3622.479	150	130					***7***
LVF,2TAN,5 MAINT	2.14E+02	6330.104	262	242					***8***
LVF,2TAN,3 MAINT	1.82E+02	468.0099	21	1	1.69E+02	1.014315	0.014315	182.0694	***3***

Table 5.4.2:Results of D-D procedure for time in the maintenance queue for Cold and Sea level

Alter.	$Xi^{(1)}(20)$	$Si^2(20)$	Ni	Ni-no	$Xi^{(2)}(Ni-20)$	Wi1	Wi2	Xi(Ni)	Ranking
FIFO,4TAN, 5MAINT	1.80E+01	822.8608	21	1	0.00E+00	1.586622	-0.58662	28.62154	2.
FIFO,4TAN, 3MAINT	1.54E+02	109157.0	283	263					7
FIFO,2TAN, 5MAINT	5.92E+01	17759.19	46	26	3.30E+01	0.45543	0.54457	44.91559	5
FIFO,2TAN, 3MAINT	5.03E+01	3905.995	21	1	0.00E+00	1.173617	0.17362	59.0525	6
LVF,4TAN,5 MAINT	1.06E+01	1514.466	21	1	0.00E+00	1.397186	-0.39719	14.87193	1
LVF,4TAN,3 MAINT	1.71E+02	237458.4	615	595					8
LVF,2TAN,5 MAINT	4.24E+01	6891.155	21	1	0.00E+00	1.042365	-0.04237	44.20972	4
LVF,2TAN,3 MAINT	3.18E+01	2297.342	21	1	0.00E+00	1.291459	0.29146	41.13046	3

Table 5.4.3:Results of D-D procedure for time in the tanker queue for Cold and Sea level

Alter.	$Xi^{(1)}(20)$	$Si^2(20)$	Ni	Ni-no	$Xi^{(2)}(Ni\text{-}20)$	Wi1	Wi2	Xi(Ni)	Ranking
FIFO,4TAN, 5MAINT	4.35E+00	7.627666	1	1	4.36E+00	1.490879	-0.490879	4.347508	2
FIFO,4TAN, 3MAINT	3.34E+00	6.892316	21	1	2.23E+00	1.523132	-0.523132	3.921547	1
FIFO,2TAN, 5MAINT	3.11E+01	111.431	42	22	3.47E+01	0.531520	0.468479	32.76609	5
FIFO,2TAN, 3MAINT	3.32E+01	65.84889	5	5	3.15E+01	0.856058	0.143942	32.98294	6
LVF,4TAN,5 MAINT	4.44E+00	5.216861	1	1	2.56E+00	1.619421	-0.619421	5.606937	4
LVF,4TAN,3 MAINT	3.62E+00	5.230562	21	1	1.0891168	1.618458	-0.618458	5.179229	3
LVF,2TAN,5 MAINT	3.42E+01	107.4889	41	21	3.34E+01	0.565906	0.434093	33.82649	7
LVF,2TAN,3 MAINT	3.49E+01	57.57101	1	2	3.66E+01	0.955712	0.044287	34.97556	8

Table 5.4.4:Results of D-D procedure for number of soldiers landed for Cold and Sea level

Alter.	$Xi^{(1)}(20)$	$Si^2(20)$	Ni	Ni-no	$Xi^{(2)}(Ni\text{-}20)$	Wi1	Wi2	Xi(Ni)	Ranking
FIFO,4TAN, 5MAINT	3.67E+03	1851.06	21	1	3.74E+03	2.27354	1.2735	3565.98	4.
FIFO,4TAN, 3MAINT	3.55E+03	253337	73	53	3.56E+03	0.29824	0.70176	3558.84	5.
FIFO,2TAN, 5MAINT	3.47E+03	306363	89	69	3.55E+03	0.26879	0.73121	3527.32	8.
FIFO,2TAN, 3MAINT	3.57E+03	18352	21	1	3.69E+03	1.32018	0.3202	3530.79	7.
LVF,4TAN,5 MAINT	3.67E+03	8045.43	21	1	3.65E+03	1.55792	0.5579	3679.24	1.
LVF,4TAN,3 MAINT	3.55E+03	253705	73	53	3.54E+03	0.2913	0.7087	3545.89	6
LVF,2TAN,5 MAINT	3.61E+03	36543.8	21	1	3.69E+03	1.16536	0.1654	3595.61	3.
LVF,2TAN,3 MAINT	3.63E+03	11386.9	21	1	3.71E+03	1.44813	0.4481	3597.22	2.

HOT AND HIGH

Table 5.4.5:Results of D-D procedure for time in the system for Hot and High

Alter.	$Xi^{(1)}(20)$	$Si^2(20)$	Ni	Ni-no	$Xi^{(2)}(Ni-20)$	Wi1	Wi2	Xi(Ni)	Ranking
FIFO,4TAN, 5MAINT	2.46E+02	17969.05	744	724					5.
FIFO,4TAN, 3MAINT	2.36E+02	13310.83	551	531					3.
FIFO,2TAN, 5MAINT	2.49E+02	11802.89	489	469					6
FIFO,2TAN, 3MAINT	2.72E+02	24056.89	996	976					7.
LVF,4TAN,5 MAINT	2.15E+02	2571.067	107	87					2.
LVF,4TAN,3 MAINT	2.81E+02	36144.98	1496	1476					8
LVF,2TAN,5 MAINT	2.14E+02	8551.664	354	334					1
LVF,2TAN,3 MAINT	2.40E+02	10876.85	450	430					4.

Table 5.4.6:Results of D-D procedure for time in the maintenance queue for Hot and High

Alter.	$Xi^{(1)}(20)$	$Si^2(20)$	Ni	Ni-no	$Xi^{(2)}(Ni-20)$	Wi1	Wi2	Xi(Ni)	Ranking
FIFO,4TAN, 5MAINT	1.41E+02	48995.19	127	107					2.
FIFO,4TAN, 3MAINT	3.11E+02	126399.5	327	307					4
FIFO,2TAN, 5MAINT	1.34E+02	42557.67	111	91					1.
FIFO,2TAN, 3MAINT	3.70E+02	182629.9	473	453					7.
LVF,4TAN,5 MAINT	3.64E+01	3945.449	21	1					6.
LVF,4TAN,3 MAINT	7.82E+02	893746.2	2311	2291					8
LVF,2TAN,5 MAINT	2.82E+02	251966.5	652	632					3.
LVF,2TAN,3 MAINT	3.14E+02	381389.5	987	967					5.

Table 5.4.7:Results of D-D procedure for time in the tanker queue for Hot and High

Alter.	$Xi^{(1)}(20)$	$Si^2(20)$	Ni	Ni-no	$Xi^{(2)}(Ni-20)$	Wi1	Wi2	Xi(Ni)	Ranking
FIFO,4TAN, 5MAINT	2.27E+00	4.466680	21	1	4.91E+00	1.678527	-0.678527	0.478612	1
FIFO,4TAN, 3MAINT	3.19E+00	7.398123	21	1	4.12E-01	1.500454	-0.500454	4.580111	3
FIFO,2TAN, 5MAINT	2.28E+01	246.6421	92	72	2.42E+01	0.234836	0.765163	23.88217	6
FIFO,2TAN, 3MAINT	2.04E+01	213.0961	80	60	1.90E+01	0.289340	0.71066	19.41492	5
LVF,4TAN,5 MAINT	2.25E+00	1.362294	21	1	3.36E-01	2.305974	-1.305974	4.739394	4
LVF,4TAN,3 MAINT	2.35E+00	8.603004	21	1	2.08E+00	1.454340	-0.45434	2.475747	2
LVF,2TAN,5 MAINT	2.48E+01	135.5283	51	31	2.44E+01	0.442513	0.557487	24.60616	8
LVF,2TAN,3 MAINT	2.76E+01	178.8698	67	47	2.29E+01	0.333921	0.666079	24.47657	7

Table 5.4.8:Results of D-D procedure for number of soldiers landed for Hot and High

Alter.	$Xi^{(1)}(20)$	$Si^2(20)$	Ni	Ni-no	$Xi^{(2)}(Ni-20)$	Wi1	Wi2	Xi(Ni)	Ranking
FIFO,4TAN, 5MAINT	3.44E+03	293479	85	65	3.27E+03	0.27346	0.72654	3319.8	3.
FIFO,4TAN, 3MAINT	3.35E+03	668207	192	172					5.
FIFO,2TAN, 5MAINT	3.39E+03	289796	84	64	3.40E+03	0.27827	0.72173	3396.1	2.
FIFO,2TAN, 3MAINT	3.25E+03	695086	200	180					6
LVF,4TAN,5 MAINT	3.56E+03	64881.9	21	1	3.71E+03	1.02814	-0.0281	3552.54	1.
LVF,4TAN,3 MAINT	3.12E+03	1022594	294	274					8.
LVF,2TAN,5 MAINT	3.18E+03	653580	188	168					7.
LVF,2TAN,3 MAINT	3.47E+03	252328	73	53	3.14E+03	0.31122	0.68878	3243.9	4.

2.SELECTING A SUBSET OF SIZE 4 CONTAINING THE BEST OF 16 SYSTEMS

COLD AND SEA LEVEL

Table 5.5.1:Results of D-D procedure for time in the system for cold and Sea level

Alter.	$Xi^{(1)}(20)$	$Si^2(20)$	Ni	Ni-no	$Xi^{(2)}(Ni-20)$	Wi1	Wi2	Xi(Ni)	Selected
FIFO,4TAN ,5MAINT	1,83E+02	1498,82	21	1	1,55E+02	1,09944	0,09944	185,400	*
FIFO,4TAN ,3MAINT	1,91E+02	2617,64	25	5	1,92E+02	0,83280	0,16719	191,008	
FIFO,2TAN ,5MAINT	1,96E+02	2864,58	28	8	1,86E+02	0,79296	0,20703	193,891	
FIFO,2TAN ,3MAINT	1,86E+02	443,763	21	1	1,60E+02	1,37767	0,37767	195,718	
LVF,4TAN, 5MAINT	1,77E+02	2124,21	21	1	2,29E+02	0,99606	0,00393	176,788	*
LVF,4TAN, 3MAINT	1,83E+02	3622,47	35	15	1,71E+02	0,63866	0,36133	178,482	*
LVF,2TAN, 5MAINT	2,14E+02	6330,10	61	41	1,78E+02	0,38684	0,61315	191,977	
LVF,2TAN, 3MAINT	1,82E+02	468,009	21		1,69E+02	1,36366	0,36366	186,474	*

Table 5.5.2:Results of D-D procedure for time in the maintenance queue for cold and Sea level

Alter.	$Xi^{(1)}(20)$	$Si^2(20)$	Ni	Ni-no	$Xi^{(2)}(Ni-20)$	Wi1	Wi2	Xi(Ni)	Selected
FIFO,4TAN ,5MAINT	1,80E+01	822,86	21	1	0,00E+00	2,33320	1,33320	42,0894	*
FIFO,4TAN ,3MAINT	1,54E+02	109157,08	65	45	9,50E+01	0,33795	0,66204	115,098	
FIFO,2TAN ,5MAINT	5,92E+01	17759,190	21	1	0,00E+00	1,16473	0,16473	68,9389	
FIFO,2TAN ,3MAINT	5,03E+01	3905,9956	21		0,00E+00	1,55725	0,55725	78,3559	
LVF,4TAN, 5MAINT	1,06E+01	1514,4667	21		0,00E+00	1,95997	0,95997	20,8624	*
LVF,4TAN, 3MAINT	1,71E+02	237458,43	141	121					
LVF,2TAN, 5MAINT	4,24E+01	6891,1554	21	1	0,00E+00	1,38566	0,38566	58,7701	*
LVF,2TAN, 3MAINT	3,18E+01	2297,3424	21	1	0,00E+00	1,76097	0,76097	56,0836	*

Table 5.5.3:Results of D-D procedure for time in the tanker queue for cold and Sea level

Alter.	$Xi^{(1)}(20)$	$Si^2(20)$	Ni	Ni-	$Xi^{(2)}(Ni-20)$	Wi1	Wi2	Xi(Ni)	Selected
FIFO,4TAN ,5MAINT	4,35E+00	7,6276665	21	1	4,36E+00	2,14276867	1,14276868	4,34103018	*
FIFO,4TAN ,3MAINT	3,34E+00	6,8923161	21	1	2,23E+00	2,20659210	1,2065921	4,68051851	*
FIFO,2TAN ,5MAINT	3,11E+01	111,43125	21	1	4,27E+01	1,18636949	0,1863695	28,8910025	
FIFO,2TAN ,3MAINT	3,32E+01	65,848891	21	1	3,44E+01	1,30457976	0,30457976	32,8850644	
LVF,4TAN, 5MAINT	4,44E+00	5,2168613	21	1	2,56E+00	2,39903654	1,39903654	7,07554478	*
LVF,4TAN, 3MAINT	3,62E+00	5,2305619	21	1	1,08911679	2,39709954	1,39709954	7,14698536	*
LVF,2TAN, 5MAINT	3,42E+01	107,48895	21	1	4,22E+01	1,19408741	0,19408742	32,6133669	
LVF,2TAN, 3MAINT	3,49E+01	57,571011	21	1	5,12E+01	1,33760896	0,33760897	29,3905887	

Table 5.5.4:Results of D-D procedure for number of soldiers landed for cold and Sea level

Alter.	$Xi^{(1)}(20)$	$Si^2(20)$	Ni	Ni-no	$Xi^{(2)}(Ni-20)$	Wi1	Wi2	Xi(Ni)	Selected
FIFO,4TAN ,5MAINT	3,67E+03	1851,063	21	1	3,74E+03	3,73883	2,73884	3451,24	
FIFO,4TAN ,3MAINT	3,55E+03	253337,3	21	1	3,58E+03	1,06060	-0,0606	3549,54	*
FIFO,2TAN ,5MAINT	3,47E+03	306363,3	21	1	3,64E+03	0,99521	0,00478	3470,29	
FIFO,2TAN ,3MAINT	3,57E+03	18352,04	21	1	3,69E+03	1,81398	0,81399	3471,23	
LVF,4TAN, 5MAINT	3,67E+03	8045,432	21	1	3,65E+03	2,27581	1,27581	3690,86	*
LVF,4TAN, 3MAINT	3,55E+03	253704,8	21	1	3,69E+03	1,06021	0,06022	3542,09	
LVF,2TAN, 5MAINT	3,61E+03	36543,79	21	1	3,69E+03	1,54418	0,54419	3564,92	*
LVF,2TAN, 3MAINT	3,63E+03	11386,89	21	1	3,71E+03	2,05881	1,05882	3550,50	*

HOT AND HIGH

Table 5.5.5:Results of D-D procedure for time in the system for Hot and High

Alter.	$Xi^{(1)}(20)$	$Si^2(20)$	Ni	Ni-no	$Xi^{(2)}(Ni-20)$	Wi1	Wi2	Xi(Ni)	Selected
FIFO, 4TAN, 5MAINT	2,46E+02	17969,054	171	151					
FIFO, 4TAN, 3MAINT	2,36E+02	13310,839	127	107					*
FIFO ,2TAN, 5MAINT	2,49E+02	11802,895	112	92					
FIFO, 2TAN, 3MAINT	2,72E+02	24056,891	229	209					
LVF, 4TAN, 5MAINT	2,15E+02	2571,067	25	5	2,82E+02	0,8631999	0,1368001	224,09207	*
LVF, 4TAN, 3MAINT	2,81E+02	36144,982	343	323					
LVF, 2TAN 5MAINT	2,14E+02	8551,6641	82	62	2,11E+02	0,2884346	0,7115654	212,05035	*
LVF, 2TAN, 3MAINT	2,40E+02	10876,857	104	84	2,44E+02	0,2273092	0,7726908	242,99498	*

Table 5.5.6:Results of D-D procedure for time in the maintenance queue for Hot and High

Alter.	$Xi^{(1)}(20)$	$Si^2(20)$	Ni	Ni-no	$Xi^{(2)}(Ni-20)$	Wi1	Wi2	Xi(Ni)	Selected
FIFO, 4TAN, 5MAINT	1,41E+02	48995,198	30	10	1,83E+02	0,75189	0,24810	151,203	*
FIFO, 4TAN, 3MAINT	3,11E+02	126399,51	75	55	3,97E+02	0,27863	0,72136	372,776	*
FIFO, 2TAN, 5MAINT	1,34E+02	42557,678	26	6	1,20E+02	0,84266	0,15733	131,641	*
FIFO, 2TAN, 3MAINT	3,70E+02	182629,98	109	89	3,78E+02	0,21492	0,78507	376,029	
LVF, 4TAN, 5MAINT	3,64E+01	3945,4499	21	1	2,04E+02	1,55384	0,55384	56,3803	*
LVF ,4TAN, 3MAINT	7,82E+02	893746,25	530	510					
LVF, 2TAN, 5MAINT	2,82E+02	251966,56	150	130					
LVF, 2TAN, 3MAINT	3,14E+02	381389,50	227	207					

Table 5.5.6:Results of D-D procedure for time in the tanker queue for Hot and High

Alter.	Xi$^{(1)}$(20)	Si^2(20)	Ni	Ni-no	Xi$^{(2)}$(Ni-20)	Wi1	Wi2	Xi(Ni)	Selected
FIFO, 4TAN, 5MAINT	2,27E+00	4,466680812	21	1	4,91E+00	2,51824101	1,51824	1,73582	*
FIFO, 4TAN, 3MAINT	3,19E+00	7,39812365	21	1	4,12E-01	2,16167	1,16167	6,41692	*
FIFO ,2TAN, 5MAINT	2,28E+01	246,6421117	22	2	1,95E+01	0,96987	0,03012	22,707	
FIFO, 2TAN, 3MAINT	2,04E+01	213,0961121	21	1	1,43E+01	1,03600	0,03600	20,661	
LVF, 4TAN, 5MAINT	2,25E+00	1,362294104	21	1	3,36E-01	3,80591	2,80591	7,60342	*
LVF, 4TAN, 3MAINT	2,35E+00	8,603004919	21	1	2,08E+00	2,07096	1,07096	2,64392	*
LVF, 2TAN, 5MAINT	2,48E+01	135,5283601	21	1	2,68E+00	1,14461	0,14461	28,0054	
LVF, 2TAN, 3MAINT	2,76E+01	178,8698298	21	1	2,87E+01	1,08280	0,08280	27,4713	

Table 5.5.8:Results of D-D procedure number of soldiers landed for Hot and High

Alter.	Xi$^{(1)}$(20)	Si^2(20)	Ni	Ni-no	Xi$^{(2)}$(Ni-20)	Wi1	Wi2	Xi(Ni)	Selected
FIFO,4TAN, 5MAINT	3,44E+03	293479,2	21	1	3,73E+03	1,01488	0,01488	3439,19	*
FIFO,4TAN, 3MAINT	3,35E+03	668206,5	45	25	3,15E+03	0,51852	0,48147	3254,53	
FIFO,2TAN, 5MAINT	3,39E+03	289795,8	21	1	3,58E+03	1,01970	0,01971	3385,60	
FIFO,2TAN, 3MAINT	3,25E+03	695085,7	46	26	3,38E+03	0,46815	0,53184	3320,35	*
LVF,4TAN,5 MAINT	3,56E+03	64881,85	21	1	3,71E+03	1,37363	0,37364	3500,30	*
LVF,4TAN,3 MAINT	3,12E+03	1022594	68	48	3,39E+03	0,33822	0,66177	3299,76	
LVF,2TAN,5 MAINT	3,18E+03	653579,6	44	24	3,20E+03	0,52819	0,47180	3191,96	
LVF,2TAN,3 MAINT	3,47E+03	252327,8	21	1	3,65E+03	1,06165	0,06165	3453,34	*

3.SELECTING THE 4 BEST OF 16 SYSTEMS

COLD AND SEA LEVEL

Table 5.6.1:Results of D-D procedure for time in the system for Cold and Sea level

Alter.	$Xi^{(1)}(20)$	$Si^2(20)$	Ni	Ni-no	$Xi^{(2)}(Ni-20)$	Wi1	Wi2	Xi(Ni)	Selected
FIFO,4TAN, 5MAINT	1,83E+02	1498,82197	85	65	1,76E+02	0,24590	0,75409	177,666	*
FIFO,4TAN, 3MAINT	1,91E+02	2617,64190	147	127					
FIFO,2TAN, 5MAINT	1,96E+02	2864,58281	163	143					
FIFO,2TAN, 3MAINT	1,86E+02	443,763463	26	6	1,61E+02	0,84665	0,15334	181,966	*
LVF,4TAN ,5MAINT	1,77E+02	2124,21624	121	101					*
LVF,4TAN, 3MAINT	1,83E+02	3622,4793	206	186					
LVF,2TAN, 5MAINT	2,14E+02	6330,1048	359	339					
LVF,2TAN ,3MAINT	1,82E+02	468,009907	27	7	1,91E+02	0,79939	0,20060	183,759	*

Table 5.6.2:Results of D-D procedure for time in the maintenance queue for Cold and Sea level

Alter.	$Xi^{(1)}(20)$	$Si^2(20)$	Ni	Ni-no	$Xi^{(2)}(Ni-20)$	Wi1	Wi2	Xi(Ni)	Selected
FIFO,4TAN, 5MAINT	1,80E+01	822,860873	21	1	0,00E+00	1,48284	0,48284	26,7494	*
FIFO,4TAN, 3MAINT	1,54E+02	109157,086	387	367					
FIFO,2TAN, 5MAINT	5,92E+01	17759,1908	63	43	3,82E+01	0,33533	0,66466	45,2540	
FIFO,2TAN, 3MAINT	5,03E+01	3905,99567	21	1	0,00E+00	1,10562	0,10562	55,6311	
LVF,4TAN ,5MAINT	1,06E+01	1514,46676	21	1	0,00E+00	1,31594	0,31594	14,0071	*
LVF,4TAN, 3MAINT	1,71E+02	237458,434	842	822					
LVF,2TAN, 5MAINT	4,24E+01	6891,15541	25	5	0,00E+00	0,86218	0,13781	36,567	*
LVF,2TAN ,3MAINT	3,18E+01	2297,3424	21	1	0,00E+00	1,22011	0,22011	38,8582	*

Table 5.6.3:Results of D-D procedure for time in the tanker queue for Cold and Sea level

Alter.	$Xi^{(1)}(20)$	$Si^2(20)$	Ni	Ni-no	$Xi^{(2)}(Ni-20)$	Wi1	Wi2	Xi(Ni)	Selected
FIFO,4TAN, 5MAINT	4,35E+00	7,62766653	21	1	4,36E+00	1,39895729	0,39895	4,34842238	*
FIFO,4TAN, 3MAINT	3,34E+00	6,89231613	21	1	2,23E+00	1,42729835	0,42729835	3,81512493	*
FIFO,2TAN, 5MAINT	3,11E+01	111,431257	57	37	3,49E+01	0,37627398	0,62372601	33,4282938	
FIFO,2TAN, 3MAINT	3,32E+01	65,8488915	34	14	3,16E+01	0,64272203	0,35727796	32,6657831	
LVF,4TAN, 5MAINT	4,44E+00	5,21686131	21	1	2,56E+00	1,51144136	0,51144136	5,40352881	*
LVF,4TAN, 3MAINT	3,62E+00	5,23056195	21	1	1,0891167	1,51060230	0,51060231	4,90665964	*
LVF,2TAN, 5MAINT	3,42E+01	107,488958	55	35	3,35E+01	0,39056823	0,60943177	33,7670181	
LVF,2TAN ,3MAINT	3,49E+01	57,5710117	30	10	3,28E+01	0,73593669	0,26406330	34,3529663	

Table 5.6.4:Results of D-D procedure for number of soldiers landed for Cold and Sea level

Alter.	$Xi^{(1)}(20)$	$Si^2(20)$	Ni	Ni-no	$Xi^{(2)}(Ni-20)$	Wi1	Wi2	Xi(Ni)	Selected
FIFO,4TAN, 5MAINT	3,67E+03	1851,06	21	1	3,74E+03	2,07571	1,07572	3581,47	*
FIFO,4TAN, 3MAINT	3,55E+03	253337	100	80	3,56E+03	0,22161	0,77838	3560,14	
FIFO,2TAN, 5MAINT	3,47E+03	306363	121	101					
FIFO,2TAN, 3MAINT	3,57E+03	18352,0	21	1	3,69E+03	1,24649	0,24649	3539,67	
LVF,4TAN, 5MAINT	3,67E+03	8045,43	21	1	3,65E+03	1,45776	0,45777	3677,61	*
LVF,4TAN, 3MAINT	3,55E+03	253704	100	80	3,56E+03	0,21532	0,78467	3554,47	
LVF,2TAN, 5MAINT	3,61E+03	36543,7	21	1	3,69E+03	1,09682	0,09683	3601,15	*
LVF,2TAN, 3MAINT	3,63E+03	11386,8	21	1	3,71E+03	1,36122	0,36123	3603,86	*

HOT AND HIGH

Table 5.6.5:Results of D-D procedure for time in the system for Hot and High

Alter.	$Xi^{(1)}(20)$	$Si^2(20)$	Ni	Ni-no	$Xi^{(2)}(Ni-20)$	Wi1	Wi2	Xi(Ni)	Selected
FIFO,4TAN, 5MAINT	2,46E+02	17969,0542	1019	999					
FIFO,4TAN, 3MAINT	2,36E+02	13310,839	755	735					*
FIFO,2TAN, 5MAINT	2,49E+02	11802,8954	669	649					
FIFO,2TAN, 3MAINT	2,72E+02	24056,8916	1364	1344					
LVF,4TAN 5MAINT	2,15E+02	2571,06763	146	126					*
LVF,4TAN, 3MAINT	2,81E+02	36144,9829	2049	2029					
LVF,2TAN ,5MAINT	2,14E+02	8551,66415	485	465					*
LVF,2TAN 3MAINT	2,40E+02	10876,8572	617	597					*

Table 5.6.6:Results of D-D procedure for time in the maintenance queue for Hot and High

Alter.	$Xi^{(1)}(20)$	$Si^2(20)$	Ni	Ni-no	$Xi^{(2)}(Ni-20)$	Wi1	Wi2	Xi(Ni)	Selected
FIFO,4TAN, 5MAINT	1,41E+02	48995,1988	174	154					*
FIFO,4TAN, 3MAINT	3,11E+02	126399,512	448	428					
FIFO,2TAN, 5MAINT	1,34E+02	42557,6781	151	131					*
FIFO,2TAN, 3MAINT	3,70E+02	182629,989	647	627					
LVF,4TAN, 5MAINT	3,64E+01	3945,4499	21	1	2,04E+02	1,10335	0,10335	19,0749	
LVF,4TAN, 3MAINT	7,82E+02	893746,258	3167	3147					
LVF,2TAN, 5MAINT	2,82E+02	251966,56	893	873					*
LVF,2TAN ,3MAINT	3,14E+02	381389,509	1351	1331					*

Table 5.6.7:Results of D-D procedure for time in the tanker queue for Hot and High

Alter.	$Xi^{(1)}(20)$	$Si^2(20)$	Ni	Ni-no	$Xi^{(2)}(Ni-20)$	Wi1	Wi2	Xi(Ni)	Selected
FIFO,4TAN, 5MAINT	2,27E+00	4,46668081	21	1	4,91E+00	1,56283813	0,56283	0,78369964	*
FIFO,4TAN, 3MAINT	3,19E+00	7,39812365	21	1	4,12E-01	1,40738131	0,40738	4,32156370	*
FIFO,2TAN, 5MAINT	2,28E+01	246,642111	26	106					
FIFO,2TAN, 3MAINT	2,04E+01	213,096112	109	89					
LVF,4TAN, 5MAINT	2,25E+00	1,36229410	21	1	3,36E-01	2,10356082	1,10356	4,35290110	*
LVF,4TAN, 3MAINT	2,35E+00	8,60300491	21	1	2,08E+00	1,36672267	0,36672	2,45185049	*
LVF,2TAN, 5MAINT	2,48E+01	135,528360	70	50	2,35E+01	0,33637774	0,66362	23,9500762	
LVF,2TAN, 3MAINT	2,76E+01	178,869829	92	72	2,40E+01	0,25508085	0,74491	24,8758328	

Table 5.6.8:Results of D-D procedure for number of soldiers landed for Hot and High

Alter.	$Xi^{(1)}(20)$	$Si^2(20)$	Ni	Ni-no	$Xi^{(2)}(Ni-20)$	Wi1	Wi2	Xi(Ni)	Selected
FIFO,4TAN, 5MAINT	3,44E+03	293479,2	116	96					*
FIFO,4TAN, 3MAINT	3,35E+03	668206,5	263	243					
FIFO,2TAN, 5MAINT	3,39E+03	289795,8	115	95					*
FIFO,2TAN, 3MAINT	3,25E+03	695085,7	274	254					
LVF,4TAN, 5MAINT	3,56E+03	64881,85	26	6	3,67E+03	0,82600	0,17399	3576,39	*
LVF,4TAN, 3MAINT	3,12E+03	1022594	403	383					
LVF,2TAN, 5MAINT	3,18E+03	653579,6	258	238					
LVF,2TAN, 3MAINT	3,47E+03	252327,8	100	80	3,18E+03	0,23330	0,76669	3244,70	*

Appendix I

Input Data

We will try to define the input data that we used in our ARENA software model. First, the soldiers arrive to Pick Up Zone (PZ) one at a 0.5 seconds verifying our assumption that all the soldiers that are air assaulted are ready at the time of order of begin of operation. After that they are combined as groups of 18 representing two squads that the S70 Sikorsky type of helicopters are capable of lifting in all weather and terrain conditions.

- Fuel consumption of helicopters:

It is 135 minutes that are specified in the technical manuals of S70 type of helicopters.

- Flight time of helicopters:

We assumed that the flight route of helicopters is approximately 20 minutes and the return flight of helicopters is again 20 minutes. We specified that the pilots could fly at different flight speeds because of terrain and enemy considerations. These procedures change according to the intelligence reports and the analysis of terrain. If the terrain is available and the enemy air defense is not so severe they fly higher speeds but if the vice versa is true they apply nap of earth procedures that is more close to the ground but slower. The user can specify these speeds and the number of control points according to the scenario that he implements. These are easily changeable in the software. The speeds we use between the control points in our model are:

Pick up Zone-Control Point 1: 2400 meters per minute
Control Point 1-Control Point 2: 2700 meters per minute
Control Point 2-Control Point 3: 3000 meters per minute
Control Point 3-Control Point 4: 2400 meters per minute

Control Point 4-Control Point 5: 2100 meters per minute
Control Point 5-Landing Zone : 2000 meters per minute
Landing Zone -Control Point 6 : 3600 meters per minute
Control Point 6-Control Point 7 : 3600 meters per minute
Control Point 7-Control Point 8 : 3600 meters per minute
Control Point 8-Control Point 9 : 3000 meters per minute
Control Point 9-Control Point 10: 2700 meters per minute
Control Point10-Pick Up Zone : 2700 meters per minute

- Fuelling time of a tanker for one helicopter:

By asking specialists separately we decide the parameters of the triangular distribution as (5,7.5,10) minutes for minimum, average and maximum values correspondingly.

- Mounting and deploying times of soldiers to the helicopters:

By asking specialists and from the field manual of the army we decide the parameters of the uniform distribution as (2,4) minutes for minimum and maximum values correspondingly.

- Helicopter breakdown times for different weather and terrain conditions:

The capabilities of the helicopters vary according to the weather and terrain conditions. In Hot weather and the High terrain conditions the breakdown ratio increases while in the Cold weather and the sea levels it decreases. We asked the chief maintenance pilots and examined the outputs of the main Depot and we decide that the parameters of the discrete distribution as:

-For Hot Weather and High Terrain conditions (HOT and HIGH): (0.88,0,1,1).
-For Hot Weather and Sea level Terrain conditions (HOT and SEA LEVEL): (0.9,0,1,1).
-For Cold Weather and High Terrain conditions (COLD and HIGH): (0.9,0,1,1).
-For Cold Weather and Sea level Terrain conditions (COLD and SEA LEVEL): (0.95,0,1,1).
-For Night Vision Goggles conditions (NVG): (0.8,0,1,1).

- Types of Helicopter break downs:

We specified 4 types of breakdowns by asking the maintenance chief pilots and the specialists. These types occur in the battlefield according to their importance levels. For example type 1 breakdown occurs more frequently than the type 2 breakdown. But the maintenance time for the type 1 breakdown is shorter than the type 2 breakdown. We decide that the parameters of the discrete distribution as (0.6,1,0.85,2,0.95,3,1,4)

- Maintenance times for particular helicopter breakdowns:

By asking the specialists the maintenance times for particular breakdowns are decided as:

-Type 1:Uniform (60,360) minutes

-Type 2:Uniform (120,600) minutes

-Type 3:Uniform (360,960) minutes

-Type 4: No probability distribution is specified for this kind of breakdown. Because the helicopter needs overall maintenance in the depot at the rear area. Thus in the battlefield the maintenance personnel cannot perform such kind of maintenance. The helicopter is taken out of operation in the model if this kind of breakdown occurs.

- Refueling tanker breakdowns:

We asked the chief maintenance pilots and tanker users; we decide that the parameters of the triangular distribution as (4320,10080,21600) minutes for minimum, average and maximum values correspondingly. Also a refueling tanker must refill its depot after refueling 21 S70 type of helicopter. The time to refill is specified as 120 minutes. The user can change that value according to the scenario he implements.

- Maintenance time for a tanker breakdown:

We asked the chief maintenance pilots and tanker users; we decide that the parameters of the triangular distribution as (15,120,180) minutes for minimum, average and maximum values correspondingly.

- Enemy Air Defense Weapon Types:

In the model we specified 5 types of enemy air defense weapons according to their importance and lethality levels. For example type 1 represents small infantry weapons and the firearms but the weapon type 5 represents guided missiles such as stingers and SA-7 and SA –9 type of former Soviet Union missiles. As you can guess the lethality of type 5 weapons are much more than the type 1 weapons. We settled these weapons on the control points according to the intelligence reports in the scenario. First the model checks if there is a weapon in that particular control point with some probability distribution according to the intelligence report. After that the probability of the type of a particular weapon is checked. If there exists an enemy air defense weapon the weapon shoots at the helicopter with the probability of hit (PH) distribution. It may miss the target or hit it with again a particular probability of kill (PK) distribution. These distributions are taken from the JANUS software with some manipulation. You can see the PH and PK distributions of the types of enemy air defense weapons.

- Type 1:

PH: DISCRETE (0.99,0,1,1)

PK: DISCRETE (0.8,0,1,1)

- Type 2:

PH: DISCRETE (0.7,0,1,1)

PK: DISCRETE (0.8,0,1,1)

- Type 3:

PH: DISCRETE (0.55,0,1,1)

PK: DISCRETE (0.7,0,1,1)

- Type 4:

PH: DISCRETE (0.9,0,1,1)

PK: DISCRETE (0.8,0,1,1)

- Type 5:

PH: DISCRETE (0.5,0,1,1)

PK: DISCRETE (0.1,0,1,1)

In Night Vision Goggles (NVG) Conditions the effects of the probability of hit lessens 50 % because e of the good concealment conditions of the night.

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