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A Demand Side Requirements Model to Forecast C-17 Mobility Aircraft Availability

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THESIS

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Abstract

Current aircraft forecasting methods of the Air Mobility Command (AMC) Directorate of Logistics rely on the experience of personnel and lead to “after the fact”, labor-intensive analysis. These deficiencies led AMC to the development of a Mobility Aircraft Availability Forecasting (MAAF) model. The purpose of the MAAF model is threefold: predict aircraft availability in order to provide the Tanker Airlift Control Center (TACC) with a forecast of aircraft that will be available for AMC mission requirements, provide “what if” capabilities that analyze the effects of tasking and policy changes, and to provide foresight into problems associated with aircraft availability (Briggs, 2003b).

This research uses Arena simulation to model C-17 aircraft generation at a major enroute location to determine how significant the factors of crew chief manning and spares levels affect aircraft throughput and turn-times. From the simulation, ANOVA statistical techniques are applied to determine factor significance. In addition, a hierarchical structure of aircraft generation is generated to include the variability of unscheduled maintenance actions. This provides a more precise analysis of expected turn-time duration, which leads to overall throughput of the system. Ultimately, this research provides an key input to the MAAF project that will enable AMC to predict aircraft availability and provide the TACC with a monthly forecast of the number of aircraft that will be available to fulfill AMC mission requirements.

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Joseph R Huscroft, Jr.

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A DEMAND SIDE REQUIREMENTS MODEL TO FORECAST C-17 MOBILITY AIRCRAFT AVAILABILITY

I. Introduction

Background

The Air Mobility Command (AMC) mission is to provide airlift, air refueling, special air missions, and aeromedical evacuation to US forces. AMC supplies forces to theater commands to support wartime taskings. The command operates 13 stateside bases, six units at non-AMC bases (stateside and overseas), and 71 Air Reserve Component units gained by AMC in mobilization (42 Guard and 29 Reserve) (Nelson, 2003:1).

With today's move toward a more lean and mobile military force, AMCs flexibility is key in ensuring troops and equipment get to the contingency in a fast, reliable manner. According to the Quadrennial Defense Review Report of September 30, 2001, the Department of Defense has shifted its approach from fighting two overlapping major theater wars to (1) defending the United States; (2) swiftly defeating aggression in overlapping major conflicts while being able to strike victoriously in one of them; and (3) swiftly conducting small scale contingency operations (Department of Defense, 2001:5). To successfully meet these three new objectives, AMC must be able to accurately forecast the mission readiness and availability of their cargo and tanker aircraft.

The AMC Directorate of Logistics develops concepts and manages all logistics support for all AMC missions in peacetime and contingencies scenarios. The directorate is responsible for ensuring the mobility fleet consisting of 544 aircraft (C-5, C-17, C-141, C-130, KC-10, KC-135, and C-9 aircraft) is capable of accomplishing the mission of AMC. The Directorate currently does not poses the capability to reliably forecast, assess, or evaluate alternatives key to AMC decision-making process. The deficiency makes it difficult for the Maintenance Division to perform quick, accurate and effective analyses of potential limiting factors and policy changes. Current methods utilize “after the fact” analyses and experience of various managers to determine the best courses of action. These procedures are very labor intensive and forecasts are based solely on the experience of the personnel involved (Nelson, 2003:1).

One of the main goals of the AMC/LG is to develop a state-of-the-art, object oriented model and simulation designed to meet the needs of the Logistics Directorate (Nelson, 2003:1). The goal of the model is to be able to predict aircraft availability and handle mobility taskings in an optimal way by identifying the number of optimal aircraft worldwide by using the latest technology developments (Nelson, 2003:1). This research is being accomplished to determine what the key factors in generating a C-17 aircraft are and how they determine the availability of specific numbers of mobility aircraft. A hierarchical model will be developed to show the key processes and factors that drive the generation of a C-17 and what resources are needed at each step. The hierarchy allowed for the development of an Arena Simulation model to determine the significant key factors in C-17 generation. The model will provide the AMC/LG the data to make necessary decisions at enroute locations as to what type and amounts of resources and manpower they want to devote. The more important locations will be provided the necessary resources to ensure that key factors in C-17 generation are not neglected. The significant factors determined by the model will give the leader in charge the ability to focus assets at the key factors directly affecting aircraft generation and increasing the odds of aircraft availability and possibly mission success.

Problem and Purpose Statement

The current forecasting tool utilized by the AMC Logistics Directorate is inadequate and relies on anecdotal evidence and is not input driven. AMC currently utilizes an Aircrew/Aircraft Tasking System (AATS) to determine the number of available C-17 aircraft to the TACC, on a monthly basis (Briggs, 2003:7). This is their best method for predicting future capability to USTRANSCOM and the problem is that it is a process and not a system to determine aircraft availability (Briggs, 2003:7). To establish a more robust and functional system into the aircraft availability determination, an aircraft availability model needs to be developed that takes into numerous factors and scenarios that a C-17 can encounter from takeoff to landing and generation of next mission. A key segment of this model is a hierarchical structure of the key factors involved in the turning of a C-17 for its next mission. The hierarchy will show the path of required events that occur from landing to next takeoff of a C-17 and allow for tailoring maintenance crews and resource levels to ensure adequate aircraft availability. The path will include unscheduled aircraft maintenance actions that are of a probabilistic nature and can determine how long the aircraft is unavailable due to maintenance or supply.

To enable the Directorate and AMC to better forecast aircraft availability and reliability for specific missions, a requirements determination will be performed on C-17 aircraft in order to develop a hierarchical demand requirements model. The requirements determination will establish a hierarchy of factors and events that will allow for more accurate display of the aircraft generation process and timeline and lead to timely forecasting of mission ready aircraft and optimizing mobility availability in worldwide missions, by being able to assess and affect manpower levels and supply stockage levels. Factor events and data will be gathered on all processes and operations through interviews with process experts/owners, analysis of electronic databases, and review of relevant literature and technical data. Historical and secondary data will be collected to determine the key factors affecting mission ready aircraft and will be used to establish the aircraft generation timeline and hierarchy and establish a path of events and resource listing.

Research Question

The research question surrounding this study is "What are the "demand-side" factors directly impacting AMC C-17 aircraft mission readiness and what is the critical factor path to successful sortie generation and execution?" Once the factors, or variables, are identified, they will be used to develop a hierarchical requirements model that can be used to predict aircraft availability and throughput capacity based on the amount of resources (manpower, spare parts, etc.) available so operations and funding decisions can be made at a strategic level.

Investigative Questions

In order to meet the goals of this research, quantitative and qualitative data must be collected from various sources and the following research questions need to be addressed:

1. What is the history regarding the study of aircraft availability within the Air Force?
2. What is the nature of the current process used by AMC to determine aircraft availability?
3. What is the hierarchical structure for the factors affecting generating a mission ready C-17 aircraft?
4. What are the key resource requirements that affect aircraft availability, and what are the associated relationships?
5. How do aircraft availability metrics respond to changes in levels of the key resources required?

Research Methodology

The methodology used in this research consisted of a two-level investigation of the collected data from AMC. First, an examination of the current forecasting tool used by AMC was conducted to determine the existing key factors used to determine mission readiness.

The data included a review of AMC maintenance regulations and instructions, historical break rate data for C-17 aircraft, review of maintenance requirements for sortie generation and necessary support equipment/resources for C-17 generation, time requirements for performing all tasks required for aircraft repair/generation and other data describing the processes involved with aircraft generation.

Once the current factors were determined and categorized through interviews with subject matter experts and maintenance databases, they were compared with the desired factors of interest from the statement of work and a comparison analysis was performed to determine a hierarchical tree of generating a mission ready C-17 aircraft. Finally, analysis of the data behind the key factors allowed a determination of which contribute most significantly to mission ready aircraft availability and successful aircraft generation and sustainment. The factors were linked in a hierarchical tree based on their association to generating mission ready aircraft and given specific task/event time distributions associated with their occurrence. This provided a detailed hierarchy of C-17 aircraft generation. This hierarchy was utilized to build a simulation with Arena Simulation Software that includes various probabilistic events that occur during daily aircraft operations and maintenance, including unscheduled maintenance, resource unavailability, and insufficient spares levels.

Scope and Limitations

This research only deals with C-17 aircraft and is based on resources available at Ramstein AB, Germany, data gathered from HQ/AMC leaders, and various historical data. The specific recommendations of this research will have direct applicability to the AMC Mobility Aircraft Availability Forecast (MAAF) Model. Even though the results are limited to the AMC MAAF Model, similar research could be performed on various AMC aircraft to enhance the throughput model. The C-17 hierarchy developed in this research can have uses outside of the MAAF Model tool. Once the events path and resource constraints are known and validated, operational users can determine how best to utilize their known resource levels and when to request additional resource funds or levels to maintain a specific aircraft availability level, or how much new resources may impact availability or throughput.

Even though the model is limited to the C-17 operations at Ramstein AB, it can be easily translated to any other base or enroute location that recovers, loads, and launches the C-17. It provides the key elements necessary to provide mission ready aircraft. Users and managers can also use the hierarchical model to make changes to their current operating procedures at a specific base or operating location to better streamline or deconflict resource utilization.

Currently, the model displays the events path and resources necessary to generate one C-17 aircraft. It does not take into account other aircraft landing in at the air base and multiple, conflicting maintenance events/requirements occurring at an installation. This is something that occurs daily at Air Force bases and needs to be taken into consideration. Unscheduled maintenance and off-equipment failures happen on more than one aircraft, at more than one time and this fact has a stress and pull on multiple resources in the aircraft maintenance process. A backshop repair unit can only handle so many tasks at one time and they may decide to make one C-17 wait and sit non-mission capable while they repair an aircraft with higher priority. This fact is not taken into direct account in the hierarchical model or simulation. All aircraft are treated on a First-In, First-Out (FIFO) basis. Because the data collected and utilized is based off of real-world occurrences, the times and critical path for generating one C-17 may be transferable to a model or decision tool that encompasses multiple aircraft with multiple maintenance and operational problems.

The model is based on historical data, and the ever-changing operations tempo and manning levels in the Air Force has an effect on the hierarchical flow of the model, time requirements for specific tasks, and possibly the event path of launching and recovering C-17s. Future data may show that specific events are not needed or modifications to technical orders may allow for the consolidation or expansion of specific steps in the model. As the model is utilized, it needs to be routinely re-validated with operational expectations in AMC.

Summary

In the preceding pages, the current situation faced by the AMC Logistics Directorate was described as it relates to forecasting mission ready aircraft and their availability to perform specific mobility missions. The current forecasting tool utilized by AMC was described as being inadequate and inflexible. The research and investigative questions were presented, along with scope and limitations. In Chapter 2, a review of the relevant literature will be presented. This chapter covered the background, the problem, the research question and investigative questions, the methodology, and the scope and limitations of this thesis document. The remaining four chapters of this thesis include the Literature Review, Methodology, Findings and Analysis, and Conclusions.

II. Literature Review

Chapter Overview

The purpose of this chapter is to provide a thorough review of literature relevant to this research effort. This chapter begins with a basic discussion of the C-17 aircraft and its mission in the USAF and the key role it plays in the future of military airlift. The chapter will then move to a brief discussion of the tool currently used by AMC to forecast mission ready aircraft and the factors they utilize in this determination. A general description of existing aircraft availability/generation flow models will ensue. The final portion of this chapter will involve a discussion of the research relevant to this area of study. The data gleaned from the literature review will be used to resolve key issues presented in Chapter 1, which revolve around what is an accurate and precise hierarchical aircraft generation structure for the C-17 aircraft and how does the flow affect aircraft availability.

Air Mobility Command Structure

Numerous studies have been accomplished to identify the key factors affecting aircraft availability, mobility and fighter. Most efforts have concentrated on Air Combat Command (ACC) aircraft. In order to understand which constraints affect aircraft availability for Air Mobility Command (AMC) airlift aircraft, it is important to understand the key difference between how AMC and ACC accomplish their missions. ACC aircraft fly missions that typically take off from a home station, fly a mission, and return to the base of origin. However, aircraft flying missions for AMC may not always return to the same location. AMC primarily uses C-5, C-17, C-130, C-141, KC-10, and

KC-135 aircraft to fly missions that fulfill one of the following general categories (Briggs, 2003a):

- Air refueling
- Passenger cargo airlift
- Combat delivery
- Aeromedical evacuation
- Special operations forces support
- Forward mobility presence
- C2ISR link

These missions often require mobility aircraft to use fixed and deployed en route locations, bed down locations, and other bases located within the United States. Simple as this difference in locations may seem, it increases the number of factors that must be considered and complicates the collection of data.

The Importance of Mobility Aircraft to National Security

Strategic airlift is an important component of the military's ability to carry out United States national policy throughout the world (Stucker, 1998:1). The strategic airlift system must be able to support major deployments delivering the required cargoes on time and safely, while at the same time that it continues to support other national operations (Stucker, 2000:52). The C-17 is an integral part of this mission. It is the military's newest cargo airlifter and has increased the capability to deliver troops and cargo into more austere and remote locations than previous aircraft. Due to recent events and changes in national security policy, the C-17 has become an even larger player in the defense of the nation and enforcement of policy.

> The September 11 attacks and the 2001 Quadrennial Defense Review (QDR) have led the Department of Defense (DoD) leadership to change its terms of reference for sizing its force. Specifically, this approach has shifted from fighting two overlapping major theater wars (MTWs) in Northeast and Southwest Asia to one of (1) defending the United States;

(2) swiftly defeating aggression in overlapping major conflict while preserving the option to call for a decisive victory in one of those conflicts; and (3) conducting a limited number of smaller scale contingency operations.1 Although the new force planning is still being studied, it has become clear that the objectives of U.S. peacetime air mobility operations—to meet peacetime demand and maintain wartime readiness—will remain unchanged. (Chow, 2003:1)

Due to reduction in the number of C-141 mobility aircraft and the steady decline of the C-5 aircraft's mission capability, the C-17 has become a more prominent player in the mobilization of the military shown in Figure 1.

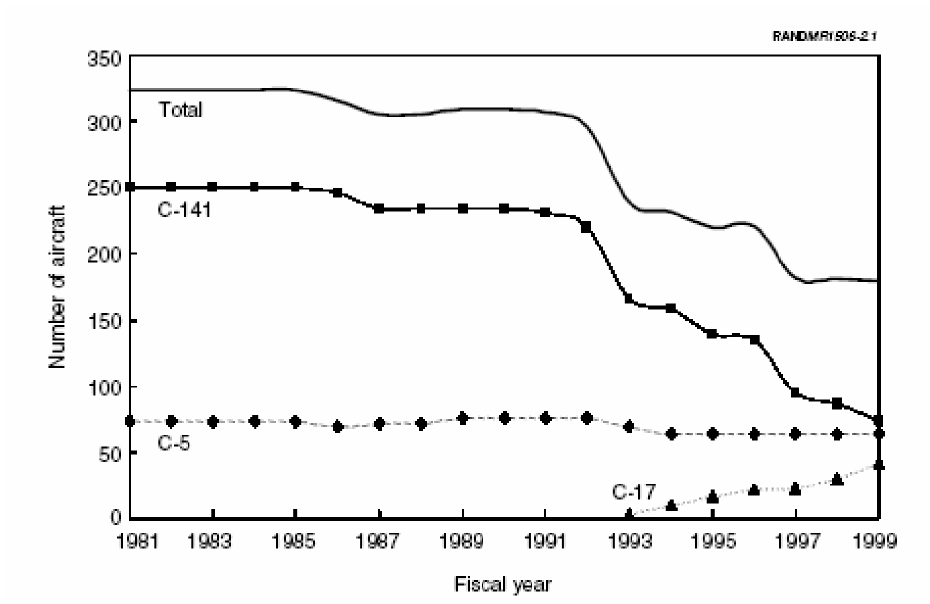


Figure 1. Numbers of Strategic Airlifters has Decreased Sharply since 1992.
(Chow, 2003:8)

As the AF and the military transition away from the C-5 and C-141 as heavy airlifters, the C-17 will become the primary tool for strategic and tactical airlift, to be complemented by the C-130 for tactical airlift.

Capabilities and Limitations of the C-17

The C-17 is to be the core airlifter for the USAF into the future. The C-17 presents a unique capability to USTRANSCOM as the single point manager for DoD transportation and a supported unified commander in theater. The aircraft is designed to airlift substantial payloads over long ranges without refueling (Dicks, 1996:1)Missions can be strategic, employ a direct delivery concept, consist of in-theater missions or a combination (Hershman, 1997:2) All C-17 crews are trained in both strategic and tactical, short field operations. The aircraft can back and maneuver under its own power. Twice as many pallets can be loaded on C-17 logistic rails and vehicles can be loaded side by side for an airland mission, allowing for greater capacity. Actual throughput of cargo can be effectively doubled by airlanding cargo rather than airdropping the cargo into theater (Hershman, 1997:3).

Since the decline of the Soviet Union, the DoD has reduced the number of troops overseas, but still requires troops on the ground during any type of contingency operation. The C-17 allows for rapid response of troops to nearly any overseas location (Hershman, 1997:3). Because it is easier and allows for more cargo/troop throughput, the airland mission is preferred over the airdrop mission. The AMC doctrine even states "airland is the preferred method of deploying forces" (AMMP, 1996: 1-11). The C-17 is capable of landing on a 3000-foot dirt airfield or strip and deliver a M-1 tank. The tank can drive on and off the aircraft without any special loading equipment. Because of this ability to land on a short field, it is possible to land near a battlefield and offload more troops and cargo than possible through a tactical airdrop mission (Hershman, 1997:3).

This ability allows combatant commanders to be able to take the fight to the enemy much faster and efficiently.

The capabilities of the C-17 allow commanders to deploy troops and cargo out of the CONUS, aerial refuel, tactically land in theater and deploy troops and equipment directly to the fight. In the past, improved airfields were required to land mobility aircraft, cargo would arrive in theater, but have to be off-loaded and on-loaded to C-130 aircraft or trucks to be further transported to the tactical battlefield. The C-17 is able to deliver mass where it is needed from anywhere in the world, freeing theater airlift for much needed support in other areas. The C-17 allows for seamless airlift and capability from the CONUS to anywhere in the world (Hershman, 1997:4).

The C-17's ability to haul more cargo and land near the battlefield takes a huge burden off of the aerial ports. If the C-17 had to be off-loaded every time and on-loaded to C-130, the port's capacity may often be exceeded. If a C-17 delivered 18 pallets of cargo, it would require 3 C-130's to haul the cargo further in-theater (Hershman, 1997:4). This off-loading and up-loading takes much more time, use of on-ground resources, manpower and is another link a supply chain that could break. Additionally, by keeping the cargo on one aircraft from point A to final destination, pipeline visibility of the cargo is increased. If a commander knows the cargo got loaded in Dover AFB and the aircraft has not landed anywhere, he knows it must be on the inbound C-17 and not lost at an aerial port somewhere enroute. There is still the chance the aircraft could be lost to enemy action or maintenance diverts, but at least he knows a precise location of the cargo (Hershman, 1997:4).

Future Use and Resource Capacity Constraints on C-17 Operations

According to RAND, the C-17 will soon become the primary aircraft for strategic and tactical airlift, with the C-130 utilized for more combat oriented airlift deliveries of troops and cargo (Killingsworth, 1997:11). The C-17 is especially useful in contingencies where beddown-base capacity is limited. Even when the mix of C-17 and C-130 aircraft is examined, the C-17 is more often favored over the C-130. This is primarily because the C-17 makes the best use of limited parking space per ton of cargo delivered (Killingsworth, 1997:xi). Even when non-outsized cargo was part of the load plan and delivery, the C-17 is still favored over the more agile C-130. The C-17 is critical when M-1 Abrams and Patriot missile batteries needed to be transported to the combat zone, whether it is a strategic or tactical movement. This is an activity the C-130 can not perform and where the need for the C-17 is a positive.

Aircraft parking beddown constraints at contingency bases lend themselves to the utilization of C-17's over the C-130 for tactical airlift (Killingsworth, 1997:31). According to the RAND study by Killingsworth, the more constrained beddown conditions became, the larger the exchange of C-17's for the C-130. Another way this is presented is to consider the overall capacity of the theater to beddown aircraft of all types. By substituting C-17s for C-130s, more ramp space can be made available for parking of other deployed aircraft such as tankers, fighters, and bombers (Killingsworth, 1997:31). This allows a commander to bring more firepower to the battlefield, while not losing cargo capacity.

Another key area RAND discovered in their study was that the more flexible, or soft, delivery timelines were, the smaller the requirement for C-17s in-theater. Because of the higher reliability of the C-17 over the C-130, this time sensitive requirement is essential in planning how many C-17s to bring to the combat arena.

Aircraft Availability

While the air mobility network provides the support needed to satisfy worldwide airlift requirements, perhaps the key factor constraining Mobility Air Forces is the availability of strategic aircraft to perform their assigned missions. AMC's determination of the airlift requirement and the ability of existing strategic airlift resources to meet the requirement are based on the expected availability of aircraft (General Accounting Office, 2000:10). Although aircraft availability is a critical element of air operations, Joint Publication 1-02, the Department of Defense Dictionary of Military and Associated Terms, provides no precise definition of the term. The characterization of aircraft availability has chiefly become dependent upon the organizational setting in which it is used. While a variety of definitions exist, fleet availability indicators typically measure the ability of logistics to provide the aircraft needed to meet mission requirements (Air Force Logistics Management Agency, 2001:14) Some of the more common descriptions of aircraft availability are reviewed in the subsequent discussion.

Air Mobility Command's Aircraft Availability Effort

The AMC Logistics Directorate presently does not possess a capability to quickly and accurately forecast aircraft availability, assess and evaluate the impact of policy changes or limiting factors on aircraft availability, and perform "what-if" type analyses of alternative strategies (e.g. resource allocation) or policies impacting aircraft availability to determine "best" solutions (Vincent questionnaire, 2003). Currently, there are only two ways to equate personnel on the flightline to actual sortie generation capability:

1. Run an LCOM simulation. This is the accepted method, but takes 18 months to complete.
2. Use a wartime deployment package UTC and estimate via "gut check" how that translates to home-station or en route turn capabilities (Briggs questionnaire, 2003)

Both of these methods either take too much time to produce and acceptable answer or the answer provided is not as based on accurate, real-time resources as the LG and Tanker Airlift Control Center (TACC) would like to base future mission planning.

According to Major Raymond Briggs, Chief Manpower and Analysis Branch, when AMC/LGMQ is tasked, each case develops into a "science project" in trying to determine the number of mission ready aircraft available in any 30 day time period. An analytical science project is tailored to each specific case and audience. The AMC/LGMQ office use data in G081 and statistical methods to draw out historical parallels that may or may not build an accurate case of how many mission ready aircraft will be available at any specific point in time. Most projections are simple linear projections of individual variables, not integrated into the whole. Once completed, the project only serves to answer the scenario at hand and has very limited value for the next project (Vincent, 2003:2).

This current method of projecting aircraft availability has worked, but is not as accurate or quick a tool as needed. One key ingredient that is needed to develop a positive working model is to determine the events that go into generating a mission ready C-17, either on the CONUS or deployed. Before a model of events to generate a C-17 is developed, a definition for mission ready aircraft needs to be developed.

Defining Mission Ready Aircraft

How a unit or command defines mission ready aircraft, greatly influences how resources and time are allotted to various functions, maintenance training, spares levels, increase POL capability, etc. There are a few primary methods of measuring perceived availability, but AMC and the MAAF project are looking for a better predictive tool.

Mission Capable Rate

Historically, the Air Force has used aircraft mission capable (MC) rates as the measure by which health of the fleet and availability of aircraft are measured. Joint Publication 1-02 (2003:342) defines mission capability as "the material condition of an aircraft indicating it can perform at least one and potentially all of its designated missions." The MC rate is a lagging indicator and uses historical data to highlight trends related to aircraft mission readiness. Because these rates represent a composite of many processes and measures, other fleet availability indicators must be used to perform root cause analysis when MC rates decline (Air Mobility Command, 2003b:32).

According to AMC/LGMQ, a mission ready aircraft is simply an aircraft that is MC and ready for a mission tasking (Briggs, 2003:5). The AMC definition for an MC aircraft comes from the Metrics Handbook for Mobility Forces:

> Mission Capable Rate is perhaps the best-known yardstick by which to measure a unit. MC rate is very much a "composite metric." That is, it is a broad indicator of many processes and metrics – the tip of the pyramid. A low MC rate may indicate a unit is experiencing many hard (long fix) breaks that don't allow them to turn a jet for many hours or several days. It may also indicate serious parts supportability issues, poor job prioritization, lack of qualified technicians, or poor sense of urgency. The key is to focus on trends and the top systems that lower MC rate. Trends for a well-managed fix rate will indicate good management. In other words, fixes on some systems predictably take longer than 12 hours. A

unit experiencing a poor production effort may show over 12 hour fixes in a wide variety of systems (Briggs, 2003:24).

The calculation for MC rate is shown in Figure 2.

Mission Capable Rate: The Percentage of possessed hours that an aircraft is partially or fully mission capable.

$$\frac{\textbf{FMC Hours + PMCB Hours + PMCM Hours + PMCS Hours X 100}}{\textbf{Possessed Hours}}$$

Figure 2. AMC Calculation for MC Rate.

(Briggs metrics, 2003:24)

For example, low MC rates may be driven by long maintenance repair times, spare parts shortages or MICAPs, personnel training deficiencies, high commitment rates, and/or poor prioritization of needs. Because the faster an aircraft gets repaired and brought back into MC status, the better the MC and availability rate will be for the C-17. By examining a developed hierarchy of generation flow for the aircraft, it is possible to determine a critical path of operations for the manager to analyze and determine if more resources are needed to increase the velocity of repair and return to MC status.

Supply Availability

In contrast to the MC Rate perspective, a supply viewpoint asserts, "an aircraft is operationally available if not waiting for a reparable component to be repaired or shipped" (Kapitzke, 1995:8). This approach views the aircraft as a serial system, and assumes all components must be working for the end item to be considered available. Aircraft availability from a supply standpoint can be estimated by calculating the probability of an aircraft missing an item. Supply availability (A) is expressed mathematically by the following formula:

$$A = \prod_{i=1}^{I} \left[1 - \frac{(EBO(s_i))}{NZ_i} \right]^{Z_i} \qquad (1)$$

Where *i* is the ith item at a random point in time, $EBO(S_i)$ represents the probability of an expected backorder for item i given inventory quantity S, N is the number of aircraft in the fleet, and Z_i stands for the quantity of item *i* per aircraft. The Multi-Echelon Technique for Reparable Item Control (METRIC) family of models used frequently within the Air Force incorporate this mathematical approach to minimize expected backorders or maximize weapon system availability (Zorn, 1996:14). The Aircraft Availability Model, for instance, computes optimal levels of spare parts necessary to attain established aircraft availability goals.

MAAF Availability

While these previous definitions of aircraft availability may adequately serve their intended purpose, they do not properly address the short term, point-in-time status of aircraft necessary to support certain AMC decisions. MC Rate and supply perspectives of aircraft availability are typically more appropriate for supporting strategic decisions related to weapon system acquisition and policy. To support development of the MAAF model, however, a short-term definition of aircraft availability is necessary. This study defines aircraft availability as "the number of aircraft available at any time to perform a specific airlift mission or category of airlift missions based on all pertinent operational and logistics factors" (Goddard, 2003). According to this definition, therefore, an aircraft is considered available if it is capable of performing the mission to which it is currently assigned.

This section has discussed some of the previous approaches by which the concept of aircraft availability has been investigated. MC Rate is a lagging indicator of the health of the fleet. Supply availability is a mathematical approach for determining appropriate levels of reparable spares for a weapon system. Because these perspectives offer a strategic view of aircraft availability, a short-term definition was provided that supports this study and development of the MAAF model. The next discussion discusses Air Mobility Command's current process to determine availability of mobility aircraft. Now that the definition and importance of aircraft availability, MC status, supply status, and MAAF availability goals are known, the current tool used by AMC/LGMQ needs to be defined and any shortfalls it possesses.

Aircrew/Aircraft Tasking System (AATS)

The current aircraft availability tool utilized by AMC/LGMQ is called the Aircrew/Aircraft Tasking System (AATS). It is used to tell the TACC how many aircraft will be available for tasking in the next 30 day period (Briggs, 2003:5). The leaders at AMC describe this tool as a process and not an efficient system. Every month or interval that aircraft availability is requested generates a unique process that is different every time and LGMQ has a difficult time providing an accurate number of aircraft to the TACC. Even though it is burdensome, the AATS is AMCs best method for predicting future capability to USTRANCOM (Briggs, 2003:5).

Problems with Current Availability Process

The current AATS system's main problem is that it is not a refined system that can provide a consistent, predictable answer on a monthly/weekly basis for TACC to assign and fulfill missions for AMC. The calculations for AATS are rather simple and consider very few controllable variables. Figure 3 shows the AATS calculation for the C-17 aircraft.

Start with Forecast of Possessed Tails at a Base
Possessed aircraft or PAA
- Deployed aircraft
x Commitment Rate (AMCI 10-202, V6) 85% for C-17
- Local Training sorties (Determined at wing level; Flying & Mx Training)
- Adjustments (Management inputs)

TACC Taskable Aircraft (C-17s available to TACC for the month)

Figure 3. AMC Calculation for TACC Taskable Aircraft.

(Briggs, 2003:9)

The primary issues with this method of predicting available aircraft are that very few controllable variables are utilized in the determination of the number of available aircraft for the month to TACC. Granted, any number of factors can be implemented under the adjustments factor in the AATS process, but because it is left up to leaders at the wings, it will be different and change from month to month and base to base. Factors that should be considered at every location should include, at a minimum, manning and experience levels, MICAP rates, equipment levels and in-commission rates, and any other specific resources that can be mapped to any location or base and can impact MC rates and repair times of aircraft. By developing the hierarchical structure to show how a C-17 is generated, a maintenance manager or senior leader should better be able to make policy decisions or make manning decisions that can better increase numbers of aircraft able to be generated and allow AMC to determine the best en route planning, based on known resources located at specific bases and locations, to ensure mission success.

Existing Aircraft Availability and Generation Flow Models

The problem AMC/LGMQ is facing is not a new one and has been faced and overcome by other Major Commands and airframes in the past. In addition to prior modeling and simulation on the C-17, several aircraft have models attempting to either predict availability/MC rates or generation timelines. Even though other models analyze different airframes, they all have very similar resources and constraints in common and can lend valuable reference and validation to a hierarchical structure of the C-17 aircraft generation process.

With fewer resources available to the Air Force and the continued emphasis by senior leadership to use resources more efficiently, the Air Force and AMC can not afford to indiscriminately use resources with little knowledge as to how their use will impact mission needs and goals, and more importantly, mission success. AMC needs an analytical tool to identify the key variables to take into account when allocating its resources to generate C-17 aircraft. This tools will assist AMC in forecasting what results might arise from the allocation of its resources in pursuit of mission needs and goals (Oliver, 2001:4). The first model investigates the factors affecting F-16 fighter aircraft availability.

F-16 Fighter Aircraft Availability Model

Captain Steve Oliver developed an aircraft availability model for the F-16, based upon 606 factors, eventually reduced to 12 statistically significant factors that highly correlate to F-16 MC rates (Oliver, 2001:120). The primary objectives of the Oliver research was to identify and demonstrate how different variables in the Air Force have impacted F-16C/D aircraft readiness, as related to mission capable rates. Once those variables are identified, they were used to develop a forecasting model that can be used to predict mission capable rates so that better operations and funding decisions can be made (Oliver, 2001:5).

As shown in Table 1, Oliver grouped the main factors of interest into five distinct categories. From these key categories, specific factors associated with each category were derived from the literature and generated the initial 606 factors utilized in his correlation model for MC rates on the F-16.

Table 1. F-16 Availability Model Factors.

Personnel	Environment	Reliability and Maintainability	Funding	Aircraft and Logistics Operations
Personnel Assigned or Authorized	OPSTEMPO Factors	Mission Capability Hours	Spares Funding	Aircraft Utilization Rates
Number Personnel in Each Skill Level (1,3,5,7,9, and 0)	PERSTEMPO Factors	TNMCM Hours	Repair Funding	Possessed Hours
Number of Personnel in Each Grade (E1-E9)	Number of Deployments	Maintenance Downtime	General Support Funding	Average Sortie Duration
Total Number of F-16 Maintenance Personnel in various AFSCs	Policy Changes	Supply Reliability	Contractor Logisitcs Support Funding	Flying Hours
Total Number of F-16 Maintenance Personnel in various Grades per AFSC		Supply Downtime	Mission Support Funding	Sorties
Reenlistment Rates for F-17 Maintenance Personnel		Code 3 Breaks		Repair Cycle Time
Personnel to Aircraft Ratios		TNMCS Hours		Order and Ship Time

(Oliver, 2001:7)

The choice of using an explanatory model, such as regression, has been shown they can be used with great success for policy and decision making (Makridakis et al., 1998). According to Oliver, there are over 30 different models in use by the Air Force to predict aircraft availability and MC rates, but most of the models are tailored to specific aircraft and specific scenarios, so they can not be readily transferred and utilized on different aircraft (Oliver, 2001: 61-62).

Oliver concluded that the key factors affecting F-16 aircraft MC rates were logistics operations, R&M, personnel, aircraft operations, funding, and environment (Oliver Article:39). These factors were found to explain 95 percent of the "what" behind MC rates (Oliver Article:38). These factors are an excellent starting point and are intuitively part of the MC rates for nearly every airframe, the degree of correlation to MC rate may slightly change, but these factors are the same issues nearly every manager of aircraft is familiar with.

C-130 Aircraft Phase Flow Capacity Model

Captain Mattioda developed attacked the availability of aircraft from the C-130 point of view. He developed the premise that there are two ways to increase aircraft availability, fist is to increase the number of aircraft on the ground with additional purchases. This is a preferred choice by the user/maintainer, but is not a consideration in times of tight budgetary constraints. The second option is to minimize the aircraft down time, or time on the ground and not mission ready. This is the method he chose to model C-130 aircraft availability (Mattioda, 2002:2).

He chose to address the streamlining, or improved management, of scheduled maintenance activities, versus trying to improve routine servicing operations. There appeared to be more room for improvement in scheduled activities and more management flexibility. Mattioda states, "Scheduled inspections are very complex, involving many tasks with multiple sub tasks. It is this area where efficient scheduling of resources (personnel and equipment) can reap the greatest benefits, most importantly reduced downtime, thereby increasing aircraft availability" (Mattioda, 2002:3).

The isochronal inspection of the C-130 was modeled to determine where the critical path and critical chain of activities were located and the best way to achieve a reduced amount of aircraft downtime, while still completing all necessary phases of the isochronal inspection. According to Mattioda:

> Critical Path Method determines which sequential tasks take the longest amount of time and focuses management attention on those tasks. However, the CPM assumption of unconstrained resources does not hold

> and is unrealistic in practice. Goldratt's Critical Chain view of the resource constrained project-scheduling problem points out that not only should managers consider the critical tasks, they need to take resource contention into account "up front" when determining the critical path, and schedule them correctly. This resulted in the Critical Chain method (Mattioda, 2002:40)

Upon completion of the critical chain model, Mattioda found no real improvement could be made over the current isochronal inspection process of nine days, based on manning and shift scheduling constraints. By removing the manning and shift scheduling constraints Mattioda did find the isochronal inspection time could be reduced by 95.22 hours. The best thing the critical chain model did was remove slack time from each isochronal task and aggregated the time. Because the critical chain model made no dramatic finding or improvement, the current critical path model was sufficient for determining completion times and aircraft availability (Mattioda, 2002:73). When constraints were removed from the process, shift requirements and No Early Than completion rules, the critical chain model reduced the isochronal inspection to just over 3 days. Due to the resource trade-off of time and personnel for an inspection, the increased and continuous workload does not justify the speed of the inspection completion.

Mobility Aircraft Generation Model

Captain Charlesworth developed a mobility aircraft generation flow model for Air Expeditionary Force deployments on a no notice warning order. A critical path timeline was developed that included eight key events in the deployment and generation process (Charlesworth, 1999:58). The model was based on the utilization of six C-5s and seven C-17 aircraft. The flowchart diagram of the deployment flow plan for the thirteen aircraft is shown in Figure 4.

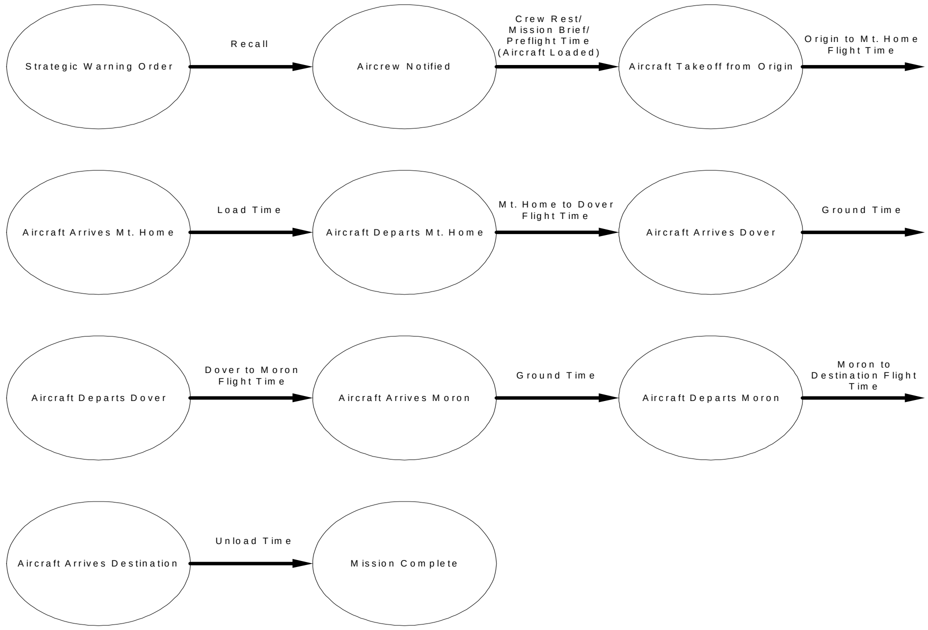


Figure 4. AEW Personnel and Equipment to Destination.

(Charlesworth, 1999:66)

After the flow diagram for the sequence of events was developed, distribution times for the key events were established. These distributions were approximated through the consultation with experts and referencing Air Force instructions (Charlesworth, 1999:80). This is stated as a serious limitation to the study and may impact its validity in practical usage. Experts provided most of the times, in three specific categories (optimistic, pessimistic, and most likely), to establish the triangular distribution used in the simulation (Charlesworth, 1999:81). In actuality, the key events may adhere to a totally different distribution. Charlesworth states the actual distributions are likely more pessimistic than the ones utilized in his model. But using more pessimistic distributions and times would greatly increase the variance of each of the key distributions in the study (Charlesworth, 1999:81).

The distributions used by Charlesworth for airlift operations and generations are shown in Table 2. Ground operations for the C-17 and C-5 were grouped into very general categories of tasks, each of which include several sub-tasks that each have their own specific distributions. By grouping them together under the general category of ground times, the study may be overlooking key opportunities or key events that may change the timeline for meeting the AEW deployment requirement.

Table 2. Approximation of Key Even Time Distributions (hours)

Key Events	Minimum Time	Most Likely Time	Maximum Time
Recall	1	2	4
Crew Rest	12	12	12
Mission Brief/ Preflight C-5	4	4	4
Mission Brief/ Preflight C-17	3	3	3
Load C-5	2	4.25	5.25
Unload C-5	2	3.25	5.25
Load/Unload C-17	1.75	2.25	3.25
Ground Times (Baseline)	2	3	4
Ground Times (Model III)	2	3	7.15

(Charlesworth, 1999:63)

Charlesworth's study lays a good foundation for the development of a timeline for the actual recovery, ground time and launch of a C-17 aircraft during normal mobility operations. Using his events as starting point, or entities, sub-events and tasks can be built into his key events. The triangular distribution of times stated are a starting point, since they are taken from subject matter experts and Air Force instructions and can assist in validating the sum times of all the necessary sub-tasks. The final model to discuss is the RAND C-17 aircraft generation model.

C-17 Mobility Aircraft Mission Capability and Generation Model

Stucker and RAND approached modeling aircraft throughput at airfields by detailing numerous separate activities that go into the generation of a C-17. From visits to over a dozen airfields and interviews with scores of service personnel and technicians, Stucker identified over 40 types of resources that contribute significantly to airfield capacity and that can constrain capacity. Even so, Stucker does not attempt to model all airfield resources. For the three most significant functional areas—aircraft servicing, fueling, and loading—he modeled both an aggregate resource—the package of skills and equipment the Air Force regards as necessary to perform those functions—and he modeled the individual resources that experts have identified as being especially and most visibly associated with airfield capacity: ground-power units, fuel trucks, k-loaders, etc. For three other areas—air traffic control, ground control, and aircrew servicing—we model only the aggregate resources. These procedures are now included in a computer-based model, the Airfield Capacity Estimator (Stucker, 1998:xii).

The key part of Stucker's study that relates to developing a hierarchical structure for generating a C-17 are the 17 ground servicing operations and resources he modeled with data and distributions.

- block in
- post-flight, through-flight, and pre-flight inspections
- general, nitrogen, and oxygen servicing
- repair
- passenger and cargo off-loading and on-loading
- pre-fueling, fuel transfer, and post-fueling

- de-icing
- block out (Stucker, 1998:xiii).

Stucker used average task times for eight of the operations, based upon aircraft type. For five of the tasks, he calculated specific times based upon specific airfield resources; fueling, and passenger and cargo on-loading and off-loading. This ability allows for the visibility of delays due to material handling equipment availability or travel distances to marshalling yard are extensive. Times for the final four tasks—nitrogen servicing, oxygen servicing, repair, and de-icing—vary widely for different aircraft types, type of mission and for individual aircraft landings. The model utilizes the expected value calculations to estimate average resource-use times, aircraft ground times, and airfield capacities for resources (Stucker, 1998:xiii).

The RAND study models two ground-servicing profiles, a quick-turn and a full-service profile, the two most common. The quick turn is when the aircraft are to land, off-load, on-load, and launch as soon as possible. The full-service profile is longer and more detailed. The aircraft may be required to remain on the ground for a longer period of time for repair or awaiting mission. The list of tasks for each profile are shown in Figure 5.

Servicing Operations Determine Aircraft Ground Times	
Full Service	**Quick Turn**
Block In	Block In
Post-flight Inspection	Through-flight Inspection
General Servicing	General Servicing
Nitrogen Servicing	Nitrogen Servicing
Oxygen Servicing	Oxygen Servicing
Repair	Repair
Pre-Fuel	Pre-Fuel
Transfer Fuel	Transfer Fuel
Post-Fuel	Post-Fuel
Off-/on-load passengers	Off-/on-load passengers
Off-/on-load Cargo	Off-/on-load Cargo
Pre-flight Inspection	De-icing
De-icing	Block Out
Block Out	

Figure 5. Servicing Operations that Determine Aircraft Ground Time

(Stucker, 1998:10)

Stucker further develops and shows the structure and resources required for servicing, fueling, and loading in Figure 6. Specific resources and times to the tasks shown are calculated before aggregating the tasks into higher order operations (Stucker, 1998:10).

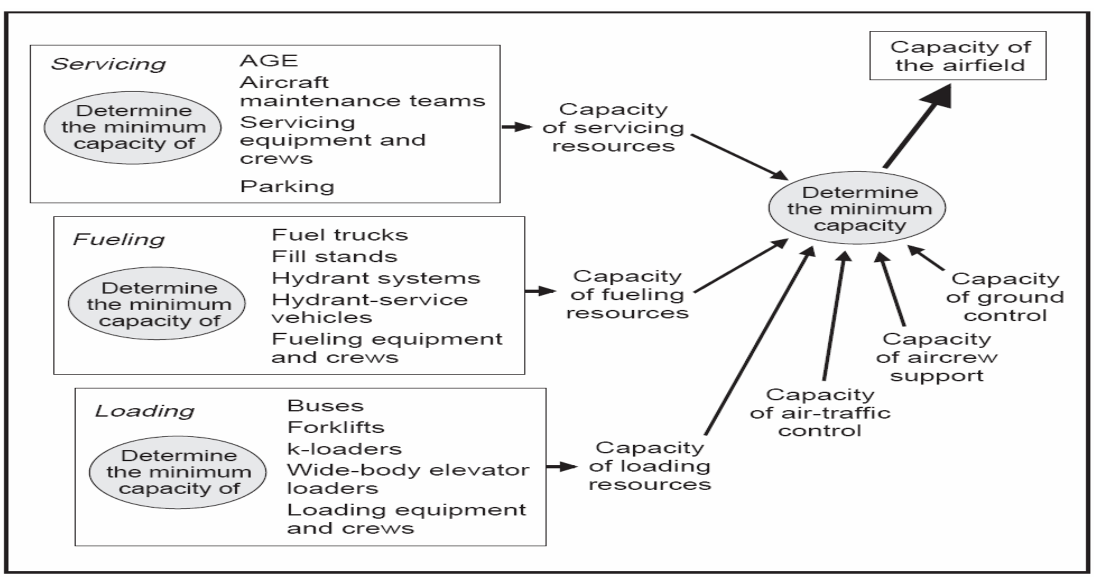


Figure 6. Structure of the ACE model

(Stucker, 1998:11)

An area that does not appear to be covered by this study is the distribution and assignment of specific aircraft necessary repairs. Even though maintenance servicing and repair teams are annotated in the servicing block, the distribution of repair times is not explored beyond an average computed repair time based upon aircraft type. Taking into account the top 25 historical breaks and their repair times, along with spare parts availability can add more fidelity to the aircraft generation model. Also, it is unclear how many and what business rules for C-17 aircraft generation and maintenance are utilized. This research will provide this data and input into the hierarchical model for C-17 generation.

Hierarchical Structure Development for C-17 Operations

The utilization of a hierarchical structure to map the C-17 operations is not a new one. As shown earlier, RAND undertook a project to show C-17 throughput capacity and generated a flow of specific tasks and resources needed. The study lacked utilizing actual break rate data for on-equipment components and assumed an average repair time for all maintenance tasks, lumped together. This study is based on developing a hierarchical structure for the system in question, C-17 aircraft generation.

A hierarchical structure is an excellent tool for analyzing a large system or process. According to Pravin Varaiya, there are good reasons for organizing the control of large systems in a distributed hierarchal structure. Among the reasons are: deeper understanding facilitated by the hierarchical structure, reduction in complexity of communication and computation, modularity and adaptability to change, robustness, and scalability. The fact of the matter is that the control of every large system is organized in a distributed hierarchy, so the question is not whether it is a good idea to control large systems in this way (Varaiya, 1999:1).

1. According to Varaiya, three relationships tie the structures, or entities, of a hierarchy together, as shown in Figure 7.
2. Truth-claim relationship—assertions about syntactical descriptions are *proved* in semantics;
3. Behavior-relevance—relevance of semantic behavior is *experienced* in environment;
4. Granularity-fidelity relationship—details about environment *correspond* to primitive entities in the syntax.

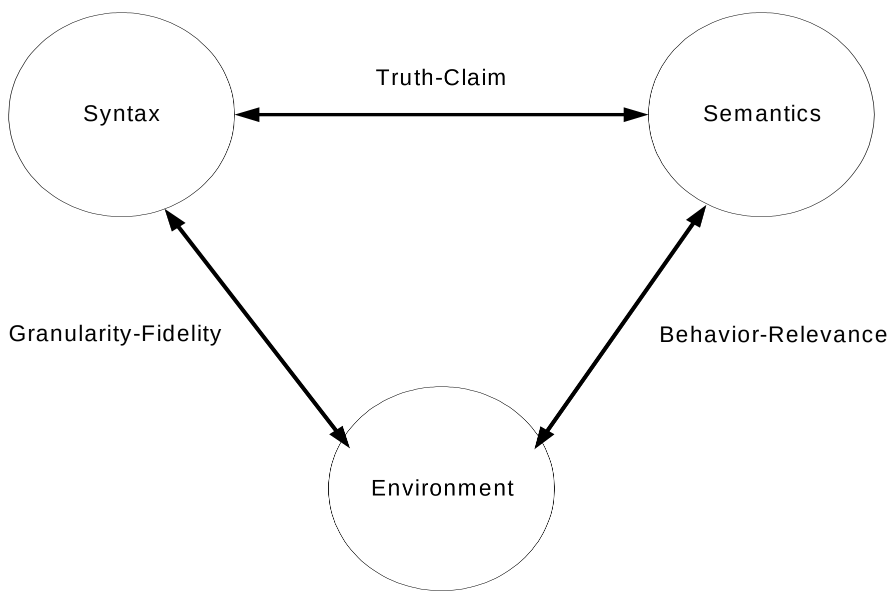


Figure 7. Relationship between structures in a Hierarchical system (Varaiya, 1999:4)

According to Varaiya, in order to describe a distributed, hierarchical system, the syntax needs to be refined to reflect those aspects of distributed hierarchy that we intuitively find to be essential. In terms of Figure 9, this need arises from the granularity-fidelity relationship. The first problem we will face is to circumscribe 'hierarchical, distributed systems' in a usefully precise way.

> The meaning of 'distributed system' is at least initially fairly clear: it refers to a system comprising several components or subsystems that are distinguished from each other by function or merely by identity. Thus, we may have components that function as sensors, actuators, controllers, vehicles, etc. This is functional differentiation. Or we may merely have a collection of functionally identical microbots (agents) distinguished by name or location (identity) (Varaiya, 1999:4).

The term hierarchical system is not a clear term. It can be used in any number of ways to describe goals, concepts, tasks, system make-up, etc. One thing that does hold true is that in a system, safety more often than not is a higher-order goal than total system efficiency. An increased throughput or efficiency should only be achieved or implemented when safety or survival is not threatened (Varaiya, 1999:5).

Current Aircraft Generation Process

According to HQ/AMC, the current C-17 aircraft generation process is defined, but can undergo and accept slight modifications to increase aircraft availability and throughput. The C-17 Weapon System Manager at AMC, MSgt Webster provided the current generation flow that has been mapped by subject matter experts at HQ/AMC and various AMC bases. The flow shown in Figure 8 represents current flightline operations from landing to next take-off.

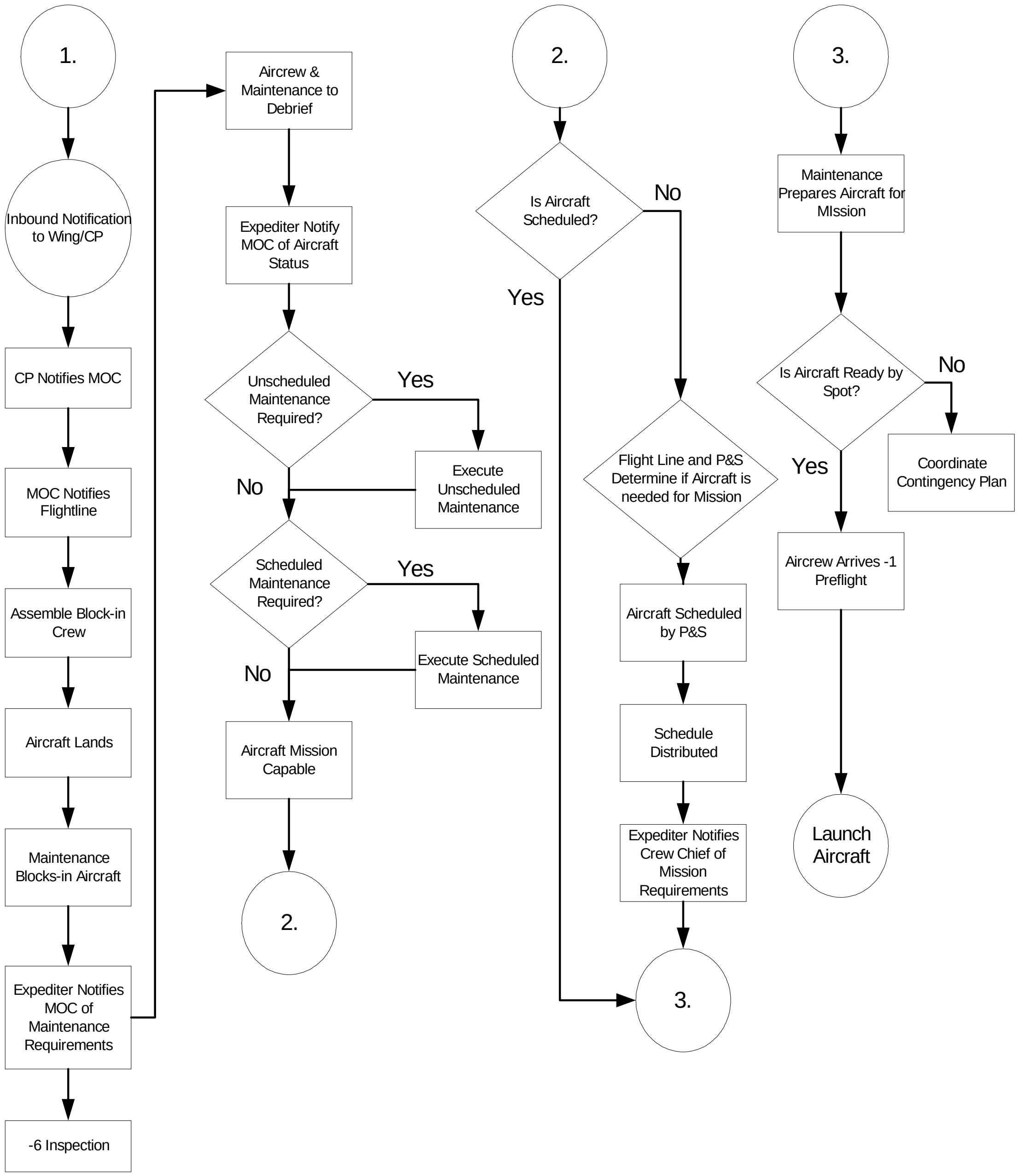


Figure 8. Current AMC flightline operations

(Webster, 2003:1)

The current process flow is currently being looked at and an attempt is being made to redesign the flow of operations on the flightline to streamline activities and produce a C-17 in a shorter amount of time with greater accuracy of maintenance actions.

The proposed maintenance flow begins with airborne data transmissions of aircraft Alpha status, engine status and structural status from on board sensors. This will allow maintenance crews to have early knowledge of maintenance problems and to plan accordingly. In the future, the maintenance crew will take on a new –6 inspection responsibility that will allow AMC flight crews to spend less time on the ground and more time in the air (Webster, 2003:2). This requirement will put more burden on maintenance personnel and resources, but allow for greater flexibility and operational use of aircrew resources.

Resource Requirements

Ramstein AB, Germany is the base to be modeled for the C-17 aircraft generation hierarchical structure and its resources and capacities will be used for the model design. The HQ/AMC Global Reach web database contains all the available resource levels for Ramstein AB, Germany. Data will be pulled from this database as of December 2003 and utilized to determine levels of material handling equipment, re-fuel trucks, manning levels, aerospace ground equipment, and any other supporting equipment that is necessary for flightline operations on the C-17.

In addition, the Occupational Survey Report for the mobility aircraft crew chief will be utilized to determine any specific resources or equipment the crew chiefs have said they use to generate a C-17. The report outlines tasks, durations, and frequency of all crew chief related functions (Occupational Survey Report, 1998:2).

Establishing High Demand Equipment/Aircraft Failures

To establish the probabilities and distributions for the number and type of on-equipment, unscheduled maintenance, the Top 27 NMC drivers for the C-17 will be utilized for the 12-month period ending in October 2003. This data, provided by HQ AMC, will establish the high frequency repair items that maintenance crews have been required to perform repairs on and the amount of time the C-17 fleet has been broken for a specific work unit code (WUC) at the major enroute stop, Ramstein AB. The Top 27 drivers can be seen in Appendix D.

Determining Timeline for C-17 Generation

To create the hierarchical structure, it needs to be known what specific tasks and functions are required to recovery, repair, and generate a C-17 aircraft at Ramstein AB, Germany. Subject matter experts at HQ/AMC, Ramstein AB, McChord AFB, and Hickam AFB were interviewed for what they see as the key steps in generating a C-17 and what resources are required to perform each task. The experts were also asked to provide an educated guess as to task duration. G081 data for the 12-month period ending in November 2003 will be compared with the times provided by the subject matter experts for validation.

The technical orders, job guides, and work cards for the C-17 are sources for the required tasks and their order of precedence. The technical data also establishes certain business rules and policies that impact the flow, duration and necessity of specific tasks.

Project Definition

A project is a temporary endeavor undertaken to create a unique product or service (Guide, 2000; 4). Temporary implies all projects have a definite beginning and end. Unique, in this context, means the product or service is different in some distinguishing way from all other products or services. According to the Guide for Project Management, projects have five major characteristics (Guide, 2000: 4):

1. Projects are performed by people
2. People are from different organizational and functional lines
3. Projects are constrained by limited resources
4. Projects are planned, executed, and controlled
5. Projects have a well-defined objective

Projects are undertaken at all levels of an organization, to include maintenance and aircraft servicing units. They can involve one or more individuals and their duration can have any length (Guide, 1996: 4). Project management is a result of this evolution.

Project Management

According to the Mattioda study, project management in business and industry is defined as managing and directing time, material, personnel, and costs to complete a particular project in an orderly, economical manner; and to meet established objectives in time, dollars, and technical results (Spinner, 1992: 2). Another definition for project management is "the application of knowledge, skills, tools, and techniques to project activities to meet project requirements" (Guide, 2000; 1). Meeting project requirements, successful recovery and launch of a C-17, is the ultimate goal of project management for both definitions. To meet project requirements, numerous project management techniques have been developed. One technique is the Critical Path Method (CPM) of determining a hierarchical structure.

Project Management and the C-17 Aircraft Generation Hierarchy

The C-17 generation process can be defined as a project management problem, set in a maintenance environment. The project has a definite start and end time, and there is a limited number of maintenance personnel (resources) assigned to the project from different organizations. The mission or goal is to provide a fully mission capable aircraft to the aircrews so they can start the next leg of the mission. With these characteristics, project management techniques can be used to optimize the scheduling of resources to improve the process. The goal would be to complete the recovery and generation process no later than the next scheduled take-off time, and sooner if possible. Identification of the critical path would give maintenance leaders the ability to monitor tasks and resources so possible delays in the process could be corrected or adjusted for sooner. By identifying the critical path of the hierarchy, supervision would be able to identify those critical tasks and determine where future improvements can be made.

Underlying Factors

Some factors individually affect TNMCM and TNMCS rates, and some factors, when altered, affect both rates simultaneously. Three underlying factors affecting both TNMCM and TNMCS rates are funding, aircraft operations, and the environment (Oliver, et al, 2001). None of these factors directly affects MC rates, therefore they are hard to quantify. However, they can cause optimization or tradeoff decisions that must be made between the factors discussed previously.

Funding is one of the most common factors associated with any process. As funding increases, MC rates will generally improve. This apparent cause and effect relationship extends from the fact that as more funding is available, the Air Force will be able to purchase more spares, thereby reducing the TNMCS rate. In addition, retention programs (such as bonuses) can be put in place to maintain the skill level of the maintenance work force, thereby reducing the TNMCM rate. However, ample funding is rarely available and tradeoff decisions must be made that will affect both the TNMCM and TNMCS rates. Fully funding spares to accomplish zero backorders will never become a reality because of the phenomena of diminishing rates of return. Like Pareto's Law, a small portion of the spares investment will account for large portions the improvement in MC rates. However, to account for variability in demand and ensure zero backorders, the investment in spares will grow exponentially. This would lead to a case where sufficient spares are available but there are not enough maintenance personnel to install them. Therefore, the Air Force tries to balance its funding by making tradeoffs. A certain number of backorders is planned and maintenance personnel perform cannibalization actions to alleviate some of factors contributing to the TNMCS rate. A cannibalization action is the removal of a serviceable part from an aircraft to replace an unserviceable part on another aircraft (AMC, 2003). However, even cannibalization actions have tradeoffs. Cannibalizing parts doubles the time spent on maintenance and increases the probability of damaging the asset (Oliver, et. al., 2001).

The environment and aircraft operation factors go hand-in-hand. In fact, it could be stated that the environment in which the Air Force is functioning will drive aircraft operations. These environments could include operations during times of peace and war. During peacetime, there is less of a need to push Air Force equipment and personnel. Preventative maintenance functions that schedule downtime in which a well-defined set of tasks, such as inspection and repair, replacement, cleaning, lubrication, adjustment, and alignment (Ebeling, 1997) will occur as scheduled and airframes will generally be tasked to perform missions within the systems design. However, the nature of the military means leaders cannot choose which missions will be supported; when a mission is planned, the Air Force is tasked with fulfilling those mission requirements developed.

During times of war, this could mean foregoing preventative maintenance actions and pushing the airframes beyond their de-rated or even rated capacities. De-rating means to operate the system below its rated stress level (Ebeling, 1997). These factors also have a subtle relationship with the amount of funding provided to the military services. For example, in times of war, funding will generally increase.

Chapter Overview

This chapter reviewed the terminology and concepts concerning this research effort. The Air Mobility Command and its methods of predicting mission ready airlift aircraft were discussed. Next, the existing aircraft availability and generation flow models were discussed. Together, these concepts provide a foundation for development of a hierarchical structure and model development for determining key factors affecting C-17 throughput and turn-time at an enroute location, Ramstein AB, Germany. The next chapter of this thesis explains the methodology followed to develop the hierarchical structure and model to ensure the reader is afforded a clear understanding of the model.

III. Methodology

Introduction

The purpose of this chapter is to discuss the framework for the analysis and present the process used to develop the model utilized in this research effort. The methods used in this study and their relevance will be provided, setting the stage for the presentation of the results. First, the sources of the data and the methods of retrieval used will be introduced. The parameters of the analysis will be discussed next, followed by a description of the variables, entities, and processes in the model. Second, a discussion of the system of interest and the key assumptions utilized to model that system. Next, a discussion on how the problem is formulated and the key performance measures to evaluate the problem are presented. Next, the chapter discusses the use of simulation and Arena simulation software as the appropriate methodology and tools for this research. Finally, the experimental design and statistical methods utilized during the experiment are discussed.

Data Collection

Data was collected for this study by reviewing the post-flight, thru-flight, and pre-flight work cards, and by interviewing subject matter expert from the AMC/LG staff; C-17 Weapon Systems Managers; Superintendent, Aircraft Maintenance, 715th Air Mobility Operations Group, Hickam, HI; Section Chief, 437th Aircraft Generation Squadron, Charleston AFB, SC; Section Chief, 437th Maintenance Squadron, Charleston AFB, SC; Section Chief, Aircraft Generation Squadron, McChord AFB, WA.

The section chiefs are in charge of the maintenance personnel and resources at the various AMC bases that handle C-17 aircraft generation. They have the experience and subject matter expertise to provide and assist in validating generation flow structures and process time for the various tasks encompassing an aircraft recovery, turn, and launch. The HQ AMC/LGM personnel are also subject matter experts and oversee the total force management of the C-17 aircraft and its trained and assigned personnel.

The correspondence was primarily conducted to validate the work card information on times and task requirements. They consisted of an explanation of the research area, followed by a listing of what information was required. The following information was requested:

1. A listing of tasks accomplished during the recovery, repair, load, and launch of a C-17 aircraft in order of occurrence.
2. Type of mechanic and support personnel required for each task along with the number required, to include required skill levels and/or training required.
3. The number of mechanics normally available during each day of normal flying operations at a CONUS location.
4. Task duration.
5. Required task predecessors.
6. Business rules that units follow while generating aircraft.
7. Provided them with list of Top 27 unscheduled maintenance breaks for the C-17 and requested times to repair, provided a spare part was available.

Manpower data was retrieved through manning databases at HQ/AMC for Ramstein AB, Germany, since it is the control base for the hierarchical model. Their manning level was compared to the other AMC bases and overseas en routes and it was determined they were a fair representation of the aircraft generation capabilities of most other bases.

Microsoft Project 2003

The first step in setting up the hierarchical model is to input the various tasks starting at time 0, or aircraft lands. For example, taxi to parking location, block-in, and post-flight inspection will be the main task, with all tasks accomplished during within those primary tasks as subtasks. This procedure was completed for each key process in the C-17 aircraft generation procedure. Once the task was loaded into Microsoft Project 2003, the task and sub-task durations and predecessors were then loaded. Finally, the key resources for each task were input.

The matching of resources to tasks is a three-step process. First, the resources (maintenance personnel and necessary LRU spares) need to be added with their respective, manning and spares levels. Once this was accomplished, individual work schedules could be added as a time constraint to the generation process. Personnel were deemed to work on 8-hour shifts, covering an entire 24-hour day. Manning levels were equal for each of the three respective shifts. The work schedule is the time during the day each resource is available to perform work. Finally, the resource is added to the task with the numbers required to perform that task in the allotted time (duration) (Mattioda, 2002:50).

The initial tasks and durations provided by the RAND C-17 aircraft generation study were used to set the baseline time duration and flow model for the hierarchical structure. Appendix F shows the initial Microsoft Project 2003 hierarchical structure

(H1). H1 reflects the current C-17 aircraft generation process with one exception. The times and types of unscheduled aircraft repair are based upon an average repair cycle for a generic C-17 aircraft break, it does not address specific breaks and their respective times for repair. The study distributes the fix times with an average of 4 hours. This is sufficient for the RAND study, but the underlying factors of the various breaks and spares levels for the repairs may drive the repair times higher than this average, and may impact overall aircraft throughput and turn-time. This issue is addressed in the second structure.

The second hierarchical structure (H2) was developed with the specific repair types and time constraints added. This provided for a more realistic flow of maintenance and generation procedures and durations for specific repair tasks, based upon historical data retrieved from G081 database. The top 27 high occurrence unscheduled maintenance actions were used to determine which specific repairs to focus on and the times to repair them were retrieved from G081 databases and from subject matter experts. The historical data is representative of all C-17 maintenance discrepancies from 1 November 2002 through 31 October 2003 at Ramstein AB, Germany, a key enroute destination. The second Hierarchical Structure (H2) that takes into account the 27 various unscheduled breaks can be seen in Appendix G. This hierarchy actually produces an unscheduled maintenance repair time with and expected duration of nearly 7 hours, 3 hours longer than the RAND study, which is very optimistic.

Once the two hierarchical structure models were built, Microsoft Project 2003 was used to calculate the duration of aircraft generation when high occurrence maintenance actions are taken into account, individually. The model H2 is built with the capability to implement the top 27 high failure items includes a probabilistic nature of determining which of the unscheduled breaks takes place, and therefore dictating which type of repair, personnel, and spare part are needed by the aircraft before it can be re-generated. The other personnel and resources in model H2 are assigned schedules and manpower capacities, allowing them to be utilized in the cargo and passenger function of enroute airlift, but were not a limiting factor in the model.

The H2 model was utilized as a conceptual model for the development of an Arena simulation model for C-17 aircraft generation operations at an enroute location. The H2 model provided the framework to model the generation of a C-17 and the resources necessary to complete the aircraft turn. The simulation allowed for the necessary generation of performance measures and provided the ability to alter the factors of crew chief manning levels and spares fill rates.

Simulation

Since the aircraft were flown based upon a schedule and maintenance requirements were levied, a number of methods and models have been utilized to analyze generation and maintenance processes and solve associated problems. Among the most prominent of the methods, include heuristic based models, linear regression based models, and discrete event simulation models.

The research of Stucker and RAND developed an airlift aircraft generation model that tried to account for over 40 types of resources and constraints that contribute to airfield capacity (Stucker, 1998: xii). The RAND model considered unscheduled aircraft maintenance actions and repairs on the aggregate level and thus did not possess the capability to consider individual breaks or repair processes in the system. As a result, the model is not suited for determining how crew chief manning levels and spares fill rates can affect system throughput and turn-time (Stucker, 1998:10). Other limitations include the models' inability to deal with the stochastic nature of unscheduled maintenance occurrences and task durations and the effect of system delays due to unavailability of spare parts from supply (Bertulis, 2002:12).

Discrete event simulations can address the deficiencies of the regression analysis and heuristic based models. Simulation allows the user to view the flow of the C-17 generation process where entities, C-17 aircraft, progress through processes and queues to become finished goods. Another key advantage of simulation models is the capability to handle stochastic situations (Bowersox:134). Event and process uncertainty and variance are typical considerations in production and logistics systems, and models of the aircraft generation process must be able to incorporate probability into the system. Simulation can effectively model variants such as crew chief manning levels, arrival and processing times, spare component fill rates, and stochastic aircraft equipment failure rates. Finally, since simulations can be built in blocks, breaking down complete processes into manageable and smaller proportions, it allows decision makers to learn about system structure and how individual resources can affect system performance (Disney et al., 1997:176). These factors make simulation modeling an ideal methodology for applying alternative crew chief manning levels and equipment spares levels to an C-17 enroute location and comparing relative levels of performance of throughput and turn-time.

Arena Simulation Software

This study utilizes Arena 5.0 Standard Edition Simulation Software for the development and analysis of the C-17 aircraft generation model. Arena utilizes modeling constructs called modules arranged in a number of templates such as Basic Process and Advanced Process based on different related purposes of each module within the template. In general, models are built by manually inserting modules into a model environment window and connecting them to indicate the flow of entities through the simulated system (Law and Kelton, 2000:215).

Purpose

A simulation model for C-17 generation was developed using the Arena simulation software to describe the relationship between an airfield's crew chief manpower and spares level resources and airfield throughput capacity and turn-time. The output performance measures, or response variables, selected to represent airfield throughput was the number of aircraft, entities, that departed the system, and how long it took to recover and launch an incoming aircraft, on average. In the simulation model, aircraft throughput represents the number of aircraft departing the system after completion of maintenance, cargo, and passenger activities. The independent variables, or factors, in the experimental design were those model parameters crew chief maintenance manpower and supply spares fill rates.

Measures of Performance

The simulation model for this study is primarily concerned with two key performance measures for aircraft generation: (1) Total Project Duration (TD), or aircraft turn-time—which is the total time it takes to recover a C-17 and perform all required maintenance tasks and cargo functions and launch the aircraft for another sortie; and (2) C-17 airlift aircraft throughput—which is the number of C-17s that can be recovered, repaired, and launched again in a 60 day time span. The total project duration measure provides an indication of the efficiency of the maintenance manpower and supply fill rates for key aircraft components.

TD is measured in hours, and based upon a 24-hour clock. TD is measured from the first hour of the C-17 landing at Ramstein AB, Germany, to the time when all required C-17 maintenance is complete, the aircraft is loaded with passengers and cargo, and the aircraft breaks ground for its next mission. For example, if a C-17 lands at 0700 on Friday, 9 November 2003 and all maintenance, cargo and passengers is complete at 1300 on Friday, 9 November 2003, then interim TD equals 6 hours. TD is affected by differing departure times for the aircraft and other airfield restrictions that are not controlled by ground personnel. Outside factors such as ATC problems, incoming aircraft or emergencies in the air or on the ground may delay the actual take-off time for the C-17, and therefore delay, or add time to, the final entity in the hierarchical structure, aircraft taking-off successfully. A take-off time of 1500 on Friday, 9 November 2003, will increase the total TD to 8 hours on the ground. This confounding factor of later take-off times and airfield problems are not addressed in the hierarchical or simulation models. The two hierarchical models produce differing timelines or TDs based on the fact that H2 utilizes variability in determining what, if any, on-aircraft equipment fails and needs repair, while H1 uses an average unscheduled and scheduled maintenance repair times for each aircraft generation. By implementing the probabilities of the top 27 unscheduled maintenance actions, TD changed between the two models. The individual unscheduled maintenance tasks allow for the competition for resources within the simulation. The competition for resources provided for the collection of performance measures and determination of which demand-side factors are significant to C-17 generation.

Experimental Design

The experimental design used for this study was a 3^k full factorial design, for which three levels (low, normal, and high) were chosen for each *k* factor. The Arena simulation was run at each of the 3^k factor-level combinations (treatments). According to Law and Kelton (1991:660), the 3^k factorial design provides an economical means of measuring interaction between important factors, allowing main effects and interactions to be assessed independently. As noted earlier, the two independent variables were grouped into two categories, resulting in a 3^2 factorial design consisting of nine treatments, or design points. The experiment will study two different responses by manipulating the two controllable factors to measure the average performance of the C-17 simulation model and determine which factors significantly affect that performance. Factors are independent variables that can be studied using an ANOVA model. Table 3 shows the factors and their assigned levels for the planned experiment.

Table 3. Factors and Levels

FACTORS	LEVELS
Crew Chief Manning Level	1 - Low (4 workers/shift) 2 - Normal (6 workers/shift) 3 - High (9 workers/shift)
Supply Fill Rate	1 - 1 Low (50%) 2 - 2 Normal (75%) 3 - 3 High (99%)

The factor crew chief manning has 3 levels: low, normal, and high. The model simulates crew chief manning level at Ramstein AB with modules which process the aircraft for a length of time. Once the module completes processing of the aircraft, the aircraft is released from the module and the crew chief is freed to perform another process task elsewhere in the simulation.

The supply fill rate factor has three levels established as low, normal, and high. In general, aircraft reparable assets are expensive and the Air Force attempts to reduce supply stockage levels to the greatest extent possible, while maintaining enough stock to ensure combat readiness. This factor determines the probability of a part needed for an aircraft repair module being available immediately from supply.

For this study, normal level factor values represent baseline values obtained from Air Mobility Command stating current manning levels per shift for crew chiefs and the set level of spares fill rates. Since the enroute location is manned for more than C-17 aircraft, manning levels for the simulation input were obtained by taking current manning levels and determined the proportion of aircraft maintenance work that is done on C-17s versus other arriving aircraft. Aircraft arrival and maintenance data from G081 from 1 November 2002 through 31 October 2003 shows that C-17s accounted for 45% of the maintenance workload for crew chief personnel. The normal level for the crew chief manning factor was set to 45% of the actual manning level at Ramstein AB, Germany. To obtain high-level values, parameters were adjusted up by three personnel to increase capacity of the parameter, and low-level values were obtained by reducing the level by four personnel. For example, a shift for crew chiefs at Ramstein AB is manned at 15 total crew chiefs and taking 45% of that provides a normal manning level of six crew chiefs per 8-hour shift. The hi and low factor levels were determined by subject matter expert opinion of possible ranges for adding manning and worst case manning reductions. The normal level for Supply Fill Rate was taken from Air Mobility Command Analysis Division subject matter experts and data showing an overall fill rate of 75%. The value was utilized as the normal rate and it was adjusted to a high rate of 99% and low rate of 50%, a nearly 25% shift both hi and low of the normal value.

SAS JMP 5.1 statistical software was used to build a two-factor, three-level, balanced design model and conduct a 3^2 factorial experiment. Figure 9 provides a symbolic view of the experiment.

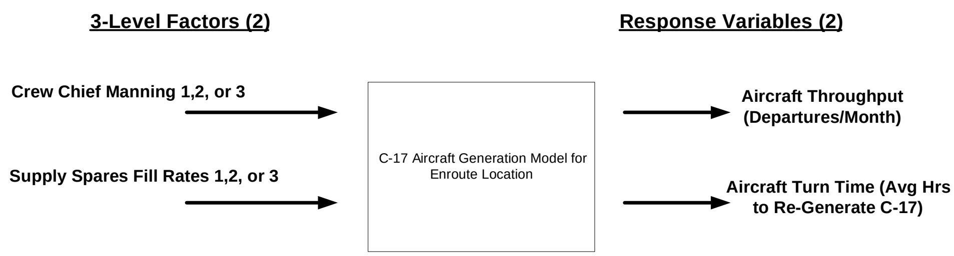


Figure 9. Picture of C-17 Aircraft Generation Simulation

The factors are listed as inputs into the C-17 generation model, while the response variables of interest are depicted as outputs. For the analysis, the two factors were used at three-levels each and the two response variables of interest—Total Average Aircraft Throughput and Average Aircraft Turn-time. Table 4 shows the design matrix that will be utilized to evaluate the complete factorial experiment.

Table 4. Design Matrix for the factorial design

Supply Spares Fill Rate		Low	Norm	Hi
Crew Chief Manning Level	Low	1	2	3
	Norm	4	5	6
	Hi	7	8	9

Validity of the simulation was performed to address the accuracy and generalizability of analysis results. Validity of the simulation model itself has been determined through the comparison of the normal factor level, simulation model output of throughput level to empirical aircraft departure data obtained from HQ AMC/LGMQA on aircraft throughput rates and turn-times. The simulation output an average of 170 departures a month or 2,040 annual departures. The actual historical departure data for the year was 2,045. The model was further validated by the subject matter experts to ensure the activities and processes were an accurate representation of the real-world scenario.

Verification of the model took place by performing initial runs of the developed Arena simulation and monitoring entities as they progressed through the system. The simulation produced performance measure outputs that were realistic and indicative of a functional simulation that processed entities in the desired manner. During initial pilot runs of the simulation, various levels of the two factors were experimented with to determine the sensitivity of the system to change in independent variables. It was found that the initial model was very sensitive to the spares level that was set, versus a manning level that started out arbitrarily high. This initial simulation run produced output data that showed spares level in the system had a significant impact on the two desired performance measures. Because of this, a better specification of the manning level parameter was needed and more accurate and timely manpower data for Ramstein AB was received and the necessary changes to the parameter values were made.

The location selected for this study was Ramstein AB, a major en route location. Additionally, the analysis involved servicing C-17 aircraft only, since these aircraft represent the current and future backbone of strategic airlift capability. It should be noted, however, that this design of experiments represents a "fixed effects" model because factor levels were not randomly assigned, but were purposefully selected. Because of this design, results of the analysis may not be generalized beyond the specific values selected for the simulation experiment (Kachigan, 1991:212).

Data Collection

In order for a simulation model to produce credible results, input data must be representative of the system. Ramstein AB specific information was collected from a variety of sources. Simulation characteristics were grouped into four categories: crew chief maintenance manpower breakdown, repair action/troubleshooting distribution data, repair duration times distribution data, and supply fill rate data. Specific parameters and their locations specific values and distributions are identified in Appendix D. The sources used to collect the data include the following: Core Automated Maintenance System for Mobility (CAMS FM-G081). The G081 Maintenance Information System is the central data source for all unclassified maintenance for mobility tanker and airlift aircraft. Maintenance break rates and repair time distributions for a one-year period starting November 2001 were obtained for Ramstein AB via the G081 break-fix batch report. Additionally, aircraft arrival information for each location was obtained for the same period from historical G081 data.

Subject matter experts provided information relating to maintenance repair times, manpower requirements for specific actions, probability of an action requiring a part from supply or just an on equipment calibration/repair. The subject matter experts were senior non-commissioned officers at Headquarters Air Mobility Command and senior non-commissioned officers at enroute locations that receive C-17 aircraft. This data can be seen in Appendix D.

Analysis of Variance

Analysis of variance is used to analyze the effects of independent variables on the dependent variables (Neter et al., 1985:522). "In multifactor studies, analysis of variance models are employed to determine whether different factors interact, which factors are the key ones, which factor combinations are best (Neter et al, 1985:523). By using analysis of variance (ANOVA), it can be determined what system factor(s) statistically influence or combine to influence the C-17 generation model in terms of the two individual performance measures. Factor influence is made up of main effect and interaction components (McClave et al., 2001:850). One of the important strengths of an ANOVA model is its ability to uncover and measure the impact of any interaction effects. Main effect refers to the direct effect of each factor on the dependent performance measure. Interaction refers to factors combining to affect the dependent performance measure.

For the analysis, we consider the null hypothesis that says that there is no difference in average response as a result of the factors and interactions, and the alternate hypothesis, which proposes that there are some factors or interactions that do influence the average throughput and turn-time. With two different response variables used, two ANOVAs were performed in JMP. The design point values displayed in each ANOVA table are the averages of 40 replications run at each design point. The models should indicate which and how the two factors influence total C-17 throughput and C-17 turn-time.

ANOVA techniques were employed to detect difference of means between treatment groups. The test statistic is defined as:

$$F = MST / MSE \qquad (2)$$

MST represents the Mean Square for Treatments and MSE equals the Mean Square for Error. For the F-test results to be valid, the following assumptions must be satisfied (Benson, McClave and Sincich, 2001:825):

1. The probability distributions of the response variables associated with each treatment must all be normal and possess equal variance.
2. The samples of experimental units selected for the treatments must be random and independent.

Tests for normality and equal variance are shown in Appendix B. The second assumption above is satisfied by the randomized design and multiple replications involved in the experiment.

Prior to discussing the results of our experiments, it is important to note that all ANOVA models were examined for appropriateness using residual analysis. Facilitated by JMP's ability to create the necessary plots, residuals were checked for consistency of error variance, outliers, independence, and normality. Each model was examined to ensure no serious departures from these conditions were encountered using normal probability plots, residual sequence plots, and residual plots against the fitted values. Both the throughput and turn-time measures had residual plots with a mean of zero, but one measure did not conform rigorously to the normality check. Slight non-normality was encountered for the residual tests when measuring turn-time; however, the departure was not extreme and it was decided to proceed with the analysis understanding the robustness of the ANOVA against departures of normality (Neter and others; 1996: 776). For some of the treatments of turn-time measurement, there was not a constant error variance but nearly all of the residuals were within two standard deviations of the mean. See Appendix C for JMP analysis of the residuals.

Output Analysis

Regarding output analysis, simulations are generally referred to as either terminating or non-terminating systems. Procedures for output analysis of the model results may differ depending on the nature of the system. In general, terminating simulations are those in which there is an event that specifies the length of the simulation run; where non-terminating simulations have no natural event to specify run length (Law and Kelton, 2000: 502-503). In terminating systems, the event is a point in which the system is emptied or beyond which there is no useful information to be obtained. In non-terminating systems, we are interested in the behavior of the system in the long-run as opposed to specific time periods or event schedules. In addition to the nature of the system, the objectives of the study may also determine whether the particular simulation may be terminating or non-terminating (Law and Kelton, 2000: 504). Non-terminating simulations generally have steady state performance measures such as the mean throughput of the system or average service time over the long run.

The performance measures of interest in this study are C-17 throughput and C-17 average turn-time. Average turn-time could be a steady state parameter along with the daily-average throughput of the system. In this simulation, the effects of initialization bias are of particular concern because the C-17 generation simulation starts with zero C-17 entities present in the system. Welsh's graphical procedure was used to identify and truncate the transient phase of the simulation models used in this study. Welsh's technique involved determining a warm-up period so the transient mean curve of the response variable flattens out at the steady state mean (Law and Kelton, 1991:545). The procedure was employed for Ramstein AB using 30 replications of the baseline scenario for a period of 30 days. Total aircraft departures per day (throughput) were computed for each iteration, and mean departures per day were plotted. This can be seen in Figure 10.

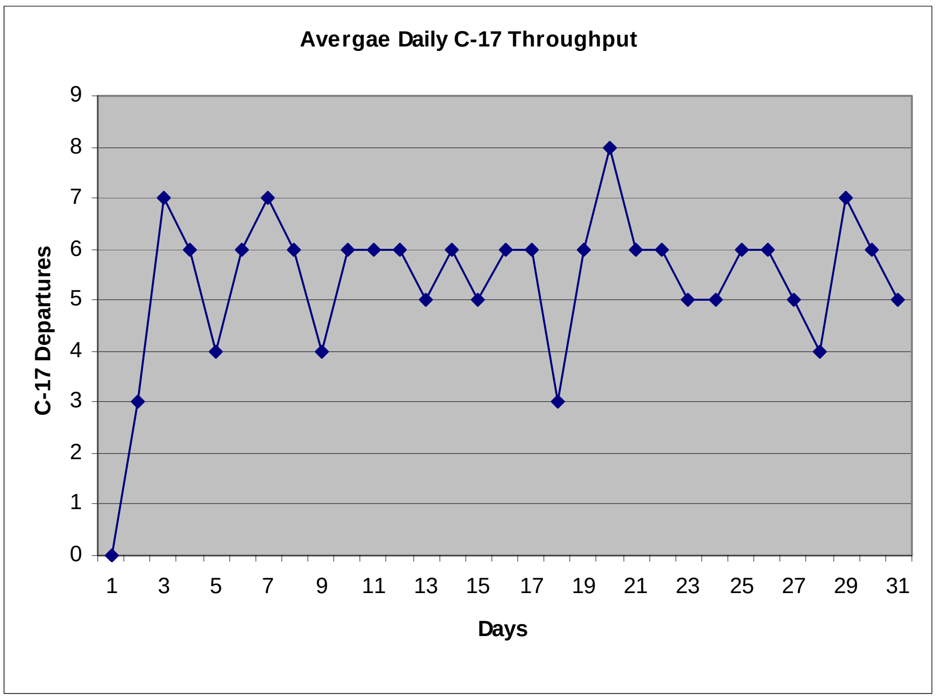


Figure 10. Average Daily C-17 Throughput in Determining Run Length

A moving average of the data was generated using a window of 3 days resulting in a reasonably smooth plot from which an appropriate warm-up period could be determined. Rather than use this warm-up period for the experiment, this value was increased by 100%, up to 6 days, to account for longer transient periods that might occur in other treatments involved in the design. Arena simulation software provides the capability to reset output statistics after a given number of hours, thereby removing initialization bias from reported output results. To determine the length of each simulation, a heuristic approach was used that involves modeling steady-state behavior for a period equal to 10 times the amount of truncated data. A run length of 1440 hours was established, with a simulation warm-up period of 120 hours. This value simulates the C-17 sortie generation operation for 60 days.

Number of Replications

Once the run length was set, the number of replications was determined. Pilot runs consisting of 10 replications were performed on all nine treatments, for both performance measures. For this study, the number of replications was calculated based on a desired level of accuracy for each performance measure. A precision (ε) of 3 departures for the throughput measure and 1 hour for the turn-time measure, both with a 95% confidence interval were set for the determination of total number of runs needed. Sample variance (S_0) associated with the response variables were determined by conducting 10 pilot runs of the models. The number of replications (R) is the smallest integer satisfying calculation 3.

$$R \geq \left(\frac{t_{\alpha/2,R-1} S_0}{\varepsilon} \right)^2 \qquad (3)$$

The number of necessary replications was calculated for performance measures, throughput and turn-time. The runs calculation was performed for each treatment and against each performance measure. The treatment requiring the largest amount of runs was used as the baseline for all treatments and that number was increased as a safety factor. This produced a resulting runs determination of 40 runs for each treatment, results of this calculation can be seen in Appendix A.

Summary

The purpose of this chapter has been to describe the procedures used in this study to investigate the relationship between base crew chief manpower and supply fill rate factors and airfield throughput and aircraft turn-time. First, the sources of the data used and the methods of retrieval employed were introduced. The parameters of the analysis were discussed, followed by a description of the variables (resources and task durations). Calculations of task durations based upon work card data, subject matter expert, and previous RAND research were described, which led into a discussion of Microsoft Project 2003 as the model driver with the resulting two different models. Next, total project duration (TD) time as the measure of performance was discussed. The study makes use of the Arena Simulation Software to model maintenance and servicing activities at Ramstein AB, based upon the task durations and probabilities derived from the Microsoft Project 2003 generated timeline. A 3^2 full factorial design was described that investigates the main effects and interactions between key input factors and the response variables, Total Aircraft Throughput and Average Aircraft Turn-time. The chapter ended with a discussion of the experimental design and manipulation. Chapter 4 will present the experimental results and analysis.

IV. Analysis

Overview

This research began with the objective of developing a hierarchical model of C-17 generation procedures at an enroute location and then proceeded to build a simulation model of the C-17 generation process at Ramstein AB, Germany to predict the aircraft throughput capability of the system and to determine significant factors influencing the system. At this point, our research has answered investigative question one having discussed the background associated with the historical and current methods used for determining aircraft availability and the perceived shortfalls with current aircraft availability methodology. Investigative question two was addressed by reviewing and determining shortfalls with the current AMC aircraft availability tool, AATS. Question three was answered by the development of the H1 and H2 hierarchical models presented in chapter three that compared aggregating vs. disaggregating unscheduled maintenance activities. From that hierarchy, question four was addressed and determined that crew chief manning levels and spares fill rate levels are the key resource requirements that affect aircraft availability.

Next, we introduced the benefits of discrete event simulation and how it can assist leaders by predicting the performance of a system in response to resource level changes before actual costs are incurred. Chapter three addressed the model development process listing the assumptions and input parameters used to construct the C-17 generation process at Ramstein AB we set out to create. The study now continues into answering investigative question five and how the aircraft availability metrics respond to changes in levels of key resources. The research uses statistical analysis tools to predict the throughput capability and turn-time response of the C-17 generation model and determine the significant factors and their sensitivity in influencing C-17 maintenance and generation operations.

Performance Measures for the Throughput Model

Two performance measures are used to study the C-17 aircraft generation simulation for our analysis. These measurements are collected using Arena's ability to gather and record specific data points regarding entity throughput totals and entity total time in the system during the 60-day simulation replications. Table 5 displays the list of both performance measures used for the analysis with values created from the base (normal treatment level) case model.

Table 5. Performance Measures of Interest for Normal Treatment Level for C-17 Generation Model

Rep #(1 rep = 60 days)	C-17 Throughput (Aircraft)	Average Turn Time for a C-17 (hours)
1	296	13.63
2	291	12.25
3	320	13.77
4	276	10.78
5	337	13.25
6	315	13.99
7	320	17.01
8	310	13.38
9	339	15.16
10	308	13.30
11	304	12.49
12	314	13.37
13	330	13.40
14	312	14.02
15	299	11.08
16	317	16.09
17	291	13.76
18	322	17.68
19	301	13.65
20	326	16.56
21	309	13.05
22	327	14.56
23	331	12.70
24	303	16.62
25	298	12.96
26	321	18.89
27	292	14.04
28	288	12.47
29	323	14.02
30	301	15.41
31	349	14.94
32	310	13.61
33	303	15.93
34	344	22.02
35	312	13.85
36	317	12.88
37	330	17.97
38	314	13.76
39	308	12.52
40	320	14.10
Averages	**313**	**14.37**

As a primary metric for system performance, our model measures system throughput in terms of number of C-17 aircraft generated over a 60-day operation. The throughput measure is calculated by averaging the sum of C-17s landing, re-generating, and launching over the 60-day operation.

The second important measurement used to provide information on system effectiveness is average C-17 turn-time over a 60-day operation. To retain effective combat capability and aircraft readiness, maintenance personnel must be able to re-generate and aircraft in an efficient and timely manner, with the assistance of many other organizations and career fields, primarily supply spares level support. The simulation seeks to minimize the amount of time that is needed to repair and re-generate a C-17 aircraft while maintaining as small a footprint of maintenance manpower as necessary, while preserving the ability to service mission and aircrew needs quickly. As such, the amount of time to re-generate a C-17 in the simulation is measured in average time. These calculations are collected using Arena's built-in time weighted average for entities in a system. These performance measures serve as response variable values for each of the design points within our statistical experiments.

The Results – Average Throughput as Response Variable

The first experiment discussed uses average C-17 system throughput as the response variable with both factors at three levels. Results are taken from JMP using an alpha value of .05. Table 6 shows the treatment means for all factor level combinations.

Table 6. Mean C-17 Throughput (60 day period)

Supply Spares Fill Rate		1	2	3
Maintenance Manning Level	1	260.33	258.18	256.58
	2	417.88	413.40	418.30
	3	410.58	424.05	419.00

Figure 11 displays the results of the ANOVA from JMP's output. Looking at the p-values provided, we see that the manning level effects significantly (p-value < 0.05) change the level of throughput achieved in the C-17 simulation model. The R-square for the model is .9343, which is good and the two factors of interest account for 93.5% of the error in the system.

Summary of Fit

RSquare	0.934363
RSquare Adj	0.932867
Root Mean Square Error	20.12216
Mean of Response	364.2528
Observations (or Sum Wgts)	360

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	8	2023143.6	252893	624.5792
Error	351	142120.4	405	Prob > F
C. Total	359	2165264.0		<.0001

Expanded Estimates

Nominal factors expanded to all levels

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	364.25278	1.060531	343.46	0.0000
Manning Level[1 Manning]	-105.8944	1.499817	-70.60	<.0001
Manning Level[2 Manning]	52.272222	1.499817	34.85	<.0001
Manning Level[3 Manning]	53.622222	1.499817	35.75	<.0001
Spares Level[1 Spares]	-1.327778	1.499817	-0.89	0.3766
Spares Level[2 Spares]	0.9555556	1.499817	0.64	0.5245
Spares Level[3 Spares]	0.3722222	1.499817	0.25	0.8041
Manning Level[1 Manning]*Spares Level[1 Spares]	3.2944444	2.121062	1.55	0.1213
Manning Level[1 Manning]*Spares Level[2 Spares]	-1.138889	2.121062	-0.54	0.5916
Manning Level[1 Manning]*Spares Level[3 Spares]	-2.155556	2.121062	-1.02	0.3102
Manning Level[2 Manning]*Spares Level[1 Spares]	2.6777778	2.121062	1.26	0.2076
Manning Level[2 Manning]*Spares Level[2 Spares]	-4.080556	2.121062	-1.92	0.0552
Manning Level[2 Manning]*Spares Level[3 Spares]	1.4027778	2.121062	0.66	0.5088
Manning Level[3 Manning]*Spares Level[1 Spares]	-5.972222	2.121062	-2.82	0.0051
Manning Level[3 Manning]*Spares Level[2 Spares]	5.2194444	2.121062	2.46	0.0143
Manning Level[3 Manning]*Spares Level[3 Spares]	0.7527778	2.121062	0.35	0.7229

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Manning Level	2	2	2018563.4	2492.661	<.0001
Spares Level	2	2	337.8	0.4171	0.6593
Manning Level*Spares Level	4	4	4242.5	2.6195	0.0349

Figure 11. ANOVA Results for Average Throughput as Response Variable

In addition, the main effect of spares level is insignificant when measuring C-17 throughput at Ramstein AB. Using JMP's ability to produce Least Squared (LS) means plots, graphical views of these effects are provided to help explain the individual factors significant effect. Figure 12 shows a set of plots for each of the main effects.

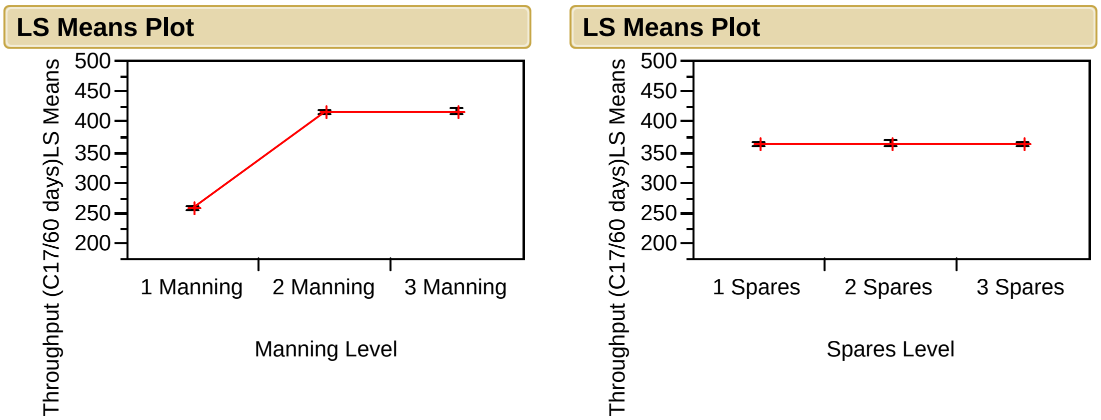


Figure 12. Average Throughput Main Effects Least Squared Means Plots

As shown, the slopes of the lines within each plot graphically demonstrate the interaction and effect tests. These slopes represent the intensity of the effect as its level changes between its assigned levels. The slope concerning the manning level of crew chiefs illustrates its significance to the level of C-17 system throughput. In contrast, the slope associated with spares level is nearly zero. The flatter slope associated with the fill rate level of spares shows its insignificance to total system throughout. This phenomenon is most likely due to the variability in the variety and numbers of different unscheduled maintenance activities and that at even low levels of spares fill rates, there are enough parts on the supply shelf to fill maintenance's demand level throughout a 60-day period.

The interaction effects supplied by JMP provide valuable information. As seen in Figure 13, interaction effects show our system when two factors combine and very little interaction influence is displayed. Looking at the manning level and spares fill level interaction plot, one can see that the level of spares available does not significantly influence throughput at the various manning levels. A possible explanation is that if the supply fill rates, even when at their lowest level (50%), still provide enough aircraft maintenance support to fill the needs of the variable unscheduled maintenance breaks. The graph also shows that normal and high levels of manning have no significant difference in the amount of C-17 being put through the system.

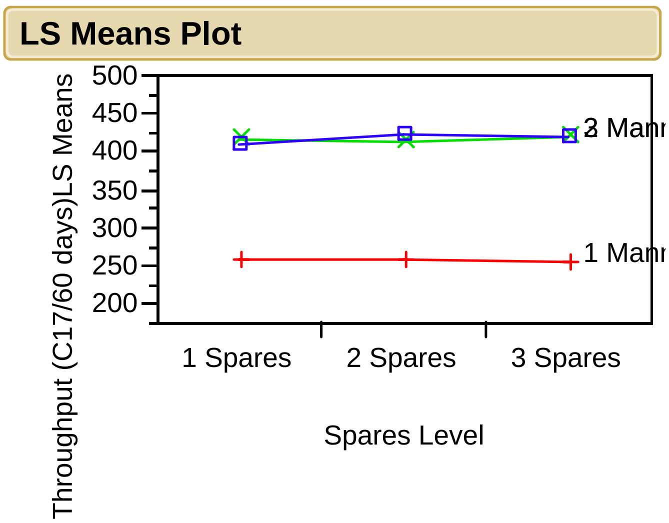


Figure 13. Interaction Plot of Manning and Spares level Least Squares Means Plot

The Results – Average Aircraft Turn-time as Response Variable

The second experiment discussed uses average C-17 turn-time in the system as the response variable, with both factors at three levels. Results are again taken from JMP using an alpha value of .05. Table 7 shows the treatment means for all factor level combinations.

Table 7. Mean C-17 Aircraft Turn-time (60 day period)

Supply Spares Fill Rate		1	2	3
Maintenance Manning Level	1	208.56	214.06	189.74
	2	27.33	27.18	25.57
	3	11.22	10.34	8.97

Figure 14 displays the results of the ANOVA from JMP's output. Looking at the p-values provided, we see that the manning level significantly changes the level of aircraft turn-time achieved in the C-17 simulation model.

Summary of Fit

RSquare	0.91479
RSquare Adj	0.912848
Root Mean Square Error	27.20045
Mean of Response	80.32864
Observations (or Sum Wgts)	360

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	8	2787998.1	348500	471.0318
Error	351	259692.5	740	Prob > F
C. Total	359	3047690.6		<.0001

Expanded Estimates

Nominal factors expanded to all levels

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	80.328637	1.43359	56.03	<.0001
Manning Level[1 Manning]	123.79267	2.027402	61.06	<.0001
Manning Level[2 Manning]	-53.63851	2.027402	-26.46	<.0001
Manning Level[3 Manning]	-70.15417	2.027402	-34.60	<.0001
Spares Level[1 Spares]	2.0408038	2.027402	1.01	0.3148
Spares Level[2 Spares]	3.5308773	2.027402	1.74	0.0825
Spares Level[3 Spares]	-5.571681	2.027402	-2.75	0.0063
Manning Level[1 Manning]*Spares Level[1 Spares]	2.4023974	2.86718	0.84	0.4027
Manning Level[1 Manning]*Spares Level[2 Spares]	6.4109153	2.86718	2.24	0.0260
Manning Level[1 Manning]*Spares Level[3 Spares]	-8.813313	2.86718	-3.07	0.0023
Manning Level[2 Manning]*Spares Level[1 Spares]	-1.404975	2.86718	-0.49	0.6244
Manning Level[2 Manning]*Spares Level[2 Spares]	-3.042104	2.86718	-1.06	0.2894
Manning Level[2 Manning]*Spares Level[3 Spares]	4.4470784	2.86718	1.55	0.1218
Manning Level[3 Manning]*Spares Level[1 Spares]	-0.997423	2.86718	-0.35	0.7281
Manning Level[3 Manning]*Spares Level[2 Spares]	-3.368812	2.86718	-1.17	0.2408
Manning Level[3 Manning]*Spares Level[3 Spares]	4.3662342	2.86718	1.52	0.1287

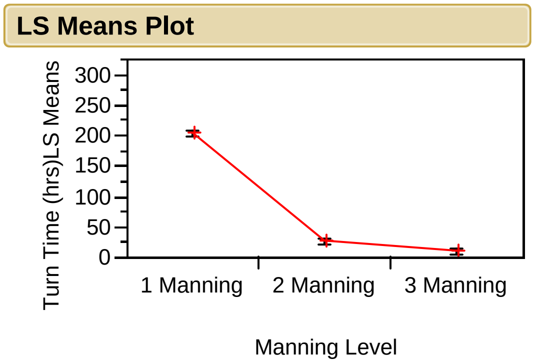
Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Manning Level	2	2	2774798.7	1875.207	<.0001
Spares Level	2	2	5721.1	3.8663	0.0218
Manning Level*Spares Level	4	4	7478.3	2.5269	0.0405

Figure 14. ANOVA Results for Average C-17 Turn-time as Response Variable

In addition, the main effects of spares level, along with interaction between manning and spares level are insignificant when measuring C-17 turn-time at Ramstein

AB. Again, using JMP's ability to produce Least Squared (LS) means plots, graphical views of these effects is provided to help explain the significant effect. Figure 15 shows a set of plots for each of the main effects.



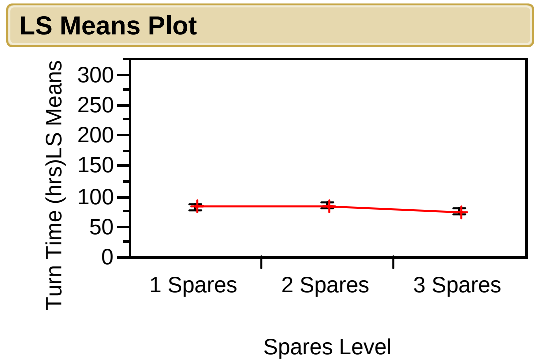


Figure 15. Average C-17 Turn-time Main Effects Least Squared Means Plots

As the plots depict, the slopes of the lines within each plot prove the interaction and effect tests. These slopes represent the intensity of the effect as its level changes between its assigned levels. The slope concerning the manning level of crew chiefs illustrates its significance to the level of C-17 system throughput. As the manning level increases to high, the aircraft turn-time dramatically reduces in value. In contrast, the slope associated with spares level does show some significance, but the slope is not as dramatic as the manning level graph. The flatter slope associated with the fill rate level of spares shows its significance in reducing average C-17 turn-time to total system. This decreased impact is again most likely due to the variability in the variety and numbers of different unscheduled maintenance activities and that at even low levels of spares fill rates, there are enough parts on the supply shelf to fill maintenance's demand level throughout a 60-day period. And when supply has higher levels of spares to fill demands, that has a significant impact on reducing the amount of time needed to turn the aircraft for the next mission.

Again, the interaction effects supplied by JMP provide important information. As seen in Figure 16, interaction effects show our system when the two factors combine and some possible interaction influence is displayed. Looking at the manning level and spares fill level interaction plot, one can see that the level of spares available does significantly influence turn-time at the any manning levels, as slight as it may appear, but a higher supply fill rate possibly impacts a higher manning level and reduces average turn-time significantly. A possible explanation is that if the supply fill rates, even when at their lowest level (50%), still provide enough aircraft maintenance support to fill the needs of the variable unscheduled maintenance breaks.

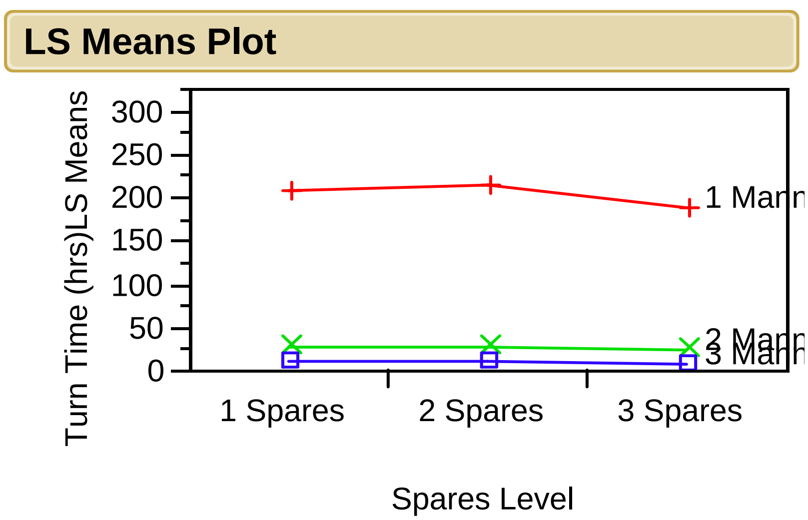


Figure 16. Average C-17 Turn-time Interaction Effects Least Squares Mean Plot

Overall Findings

The experiments accomplished the primary task to predict the enroute location's capability on C-17 throughput and turn-time. As we observed, for the information input into the model, the base case system meets the historical C-17 arrival/departure level for system throughput. We also uncovered the factors and interactions that influence the performance of the enroute system, while verifying that the model is working properly. Our analysis uncovered the important interaction between the levels of crew chief manning on impacting C-17 throughput capability. This important interaction tells us that throughput is very dependent upon the manning level of the enroute location, and that an increased throughput, or aircraft availability for missions can be accomplished if needed by increasing manning levels, even if only on a temporary basis for surge or contingency operations.

The significant operation modeled is the distinct aircraft unscheduled maintenance breaks in the generation process. The results show that by adding three additional crew chiefs, the enroute does not significantly gain an increased aircraft throughput, but by reducing the manning level by two crew chiefs, a significant reduction in combat throughput is encountered. Spares level did not play a statistically significant role in C-17 throughput, but it was shown that as the spares level increased or decreased, the throughput level of C-17s was impacted. Also worth noting is that even at the lowest crew chief manning level and lowest spares fill rate, nearly 270 aircraft could be put through the system in a 60-day period. The issue with this scenario is that the turn time for these aircraft is significantly impacted.

Also revealed from the factor analysis is the significance of crew chief manning level on C-17 turn-time. Since historic unscheduled maintenance breaks were modeled into the system, it can be seen how supply fill rates can affect the turn-time of the aircraft. Some of the unscheduled maintenance actions require LRUs or parts that are not on the shelf at supply and must be ordered, taking anywhere from 24-48 hours on the average. The ability to model the unscheduled breaks allows this interaction to be modeled. Past throughput and availability studies model unscheduled maintenance actions as one process with one standard service time or distribution. If supply can provide a higher fill rate from the warehouse, it was shown how that impacts the ability of the maintenance crews to turn the C-17 in a faster timeline, thus enabling critical missions to continue without extended delays.

These results highlight the significance of the assumptions made for the C-17 throughput model. If these assumptions do not hold true, adjustments should be made to the model and the experiments should be rerun. In addition to providing some insight into the significant factors or interactions of factors associated with C-17 generation operations, the experiments conducted also helped solidify the internal credibility of the model. Considering the assumptions made while developing the C-17 generation model, the results make sense and could be considered realistic outcomes of a real-world enroute aircraft generation system.

A key reason the supply factor was not significant in the model could be attributed to the fact the model was tuned to the real-world nature of unscheduled maintenance breaks. Not all unscheduled maintenance breaks or write-ups require a spare part or LRU. Some actions only require resetting a circuit breaker or recycling power to the system. The model took this trait of actual unscheduled maintenance actions into account and since not all breaks required a spare part, the supply spares factor did not play a part in every aircraft going through the system. But crew chiefs were utilized on every aircraft going through the system, whether there was an unscheduled maintenance break or not. The model turned out to be very sensitive to the level of crew chief manning, but was relatively insensitive to the supply spares level factor.

Overall, the experiments increased our understanding of C-17 aircraft enroute operations and improved our confidence in the model as an approximation to the actual system. The analysis also revealed the dependency of maintenance personnel and activities on the first echelon supply system within the C-17 generation system. The final chapter follows with a recap of our study and a discussion concerning future uses of the C-17 generation model for further system understanding.

V. Discussion, Conclusions and Recommendations

Introduction

The chapter summarizes the results of analysis described in Chapter 4. The analysis is manifested in three forms: evaluation of historical data and subject matter experts, hierarchical structure of C-17 generation events, and controlled Arena simulation events to generate data for an ANOVA on two key factors. The knowledge gained by examining analysis results helped answer the research questions presented in Chapter 1. Those research questions are provided here for review:

1. What is the history regarding the study of aircraft availability within the Air Force?
2. What is the nature of the current process used by AMC to determine aircraft availability?
3. What is the hierarchical structure for the factors affecting generating a mission ready C-17 aircraft?
4. What are the key resource requirements that affect aircraft availability, and what are the associated relationships?
5. How do aircraft availability metrics respond to changes in levels of the key resources required?

Questions #1 and #2 were answered in chapter 2 through a summary of the literature review. Next, question #3 was answered in chapter 4 with a hierarchical structure generated with Microsoft Project 2003. Finally, question #4 was answered through an ANOVA of the two factors and two performance measures replicated in the Arena Simulation of C-17 aircraft generation.

Conclusions and Recommendations

Research Question #1: What is the history regarding the study of aircraft availability within the Air Force?

The literature review in Chapter 2 showed the influence and impact of various forecasting models utilized by the Air Force. Most of the forecasting tools were centered around combat aircraft availability. RAND performed the most comprehensive mobility model, but failed to account for a disaggregated unscheduled maintenance process. They grouped all breaks into one category and gave them all a set, fix time, when in actuality, some unscheduled actions take longer than others take and fidelity of the system is lost when they aggregate for their model. The RAND model is a very optimistic availability model for mobility aircraft.

Research Question #2: What is the nature of the current process used by AMC to determine aircraft availability?

Currently, the AMC Directorate of Logistics analysis section uses the AATS model to predict aircraft availability command wide. The AMC Directorate of Logistics then provides the forecasted numbers from the AATS model to the TACC, which individually tasks each base in order to fulfill AMC mission requirements. The formula used by the AATS model can be seen in Figure 17 below.

Possessed Aircraft
- Deployed Aircraft
x Commitment Rate
- Local Training Aircraft
- Adjustments

TACC Taskable Aircraft

Figure 17. AATS Model Formula

(Briggs, 2003b)

The AATS model is a simplistic formula run monthly on an Excel spreadsheet and, unfortunately, the process uses broad-brushed planning factors. For example, the number of possessed aircraft is based on monthly averages, which are themselves based on estimated values. In addition, the adjustments portion of the formula enables managers to make modifications usually based on intuition or "gut feel." Clearly, a better aircraft availability forecasting solution is needed to accurately predict the number of aircraft that will be available to accomplish the AMC mission.

Research Question #3: What is the hierarchical structure for the factors affecting generating a mission ready C-17 aircraft?

The hierarchical structures of existing availability techniques, H1, and the hierarchical structure of current processed, to include specific unscheduled maintenance actions were discussed in Chapter 3 and are seen in Appendix F and Appendix G. Utilizing unscheduled tasks in the hierarchy, creates a longer possible task duration than by aggregating all unscheduled maintenance tasks together for simplicity.

Research Question #4: What are the key resource requirements that affect aircraft availability, and what are the associated relationships?

Question #4 was answered with and Arena simulation model that attempts to exploit and show how unscheduled maintenance breaks can have varying degrees of impact upon the C-17 sortie generation process at an enroute location. The results revealed that the ability to recover and generate C-17 aircraft is significantly impacted by the number of crew chiefs manned per location. It was shown that the higher the manning level, the faster the aircraft could be repaired and available for the next mission. Throughput rates were slightly impacted by the number of crew chiefs on shift. Supply fill rates appeared to have very little effect on throughput or turn-time for the C-17 at the enroute. Crew chief manning and spares fill rate levels were two of the key demand-side resource requirements found to affect aircraft availability.

Research Question #5: How does aircraft availability metrics respond to changes in levels of the key resources required?

The model responds significantly to changes in crew chief manning levels. The spares fill rate levels were not significant for the performance measures collected for this research. This could be explained by the fact that a proportion of the unscheduled maintenance actions only require some type of reset or calibration, or that the distribution of repair times at an enroute represent very short repair times and very few repairs actually occupy more than 3-4 hours at a time. Enroute locations are manned with advanced technicians; therefore, the repair times may be faster than normally experienced at home station, and return them to the fight could prove crucial in future wartime environments.

Managerial Implications

This study proposes the following managerial implications and recommendations for action. They are not necessarily cost free, but are observations that may help improve readiness or at least help better predict effects to C-17 aircraft availability and how resource use and distribution in the system can impact overall mission success.

Develop a system for tracking personnel

During the data gathering portion of this research, it was discovered that even though the AMC Directorate of Logistics analysis section knew how many individuals were authorized to each base, it had no way of tracking how many maintenance personnel, whether permanently assigned or on temporary duty, are actually at a location. This proved to be problematic when determining how many actual crew chief and maintenance personnel were assigned to Ramstein AB. Due to the transient nature of Air National Guard units working at Ramstein AB and other members arriving and departing station, it was difficult for the analysis section to determine a precise number. This resulted in the accurate personnel data based upon one or two persons manual work to find the number of personnel, when this number should be available to the Headquarters at a moments notice. AMC leaders need some way less cumbersome than going through military personnel flight each time they need a number in order to insert into the MAAF model, or whatever new forecasting tool they use.

Also, knowing how many and locations of your most valuable resource, people, is very important and this research has shown how critical it is to know how many you have and where they are. A drop in personnel at an enroute has been shown to have a significant impact on aircraft availability, and if contingency operations are planned around some notional number, things may not execute as desired.

Possible reduction in spares levels at enroute locations

Since it was shown in the model that spares fill rates did not play a significant role in the throughput and turn-time of C-17s, it may be possible to further look at specific line items and LRUs that may be reduced in quantity on the shelf or moved to a central warehouse. The average time for a MICAP part to arrive was 24-hours, with 36 hours as the longest normal delivery time, and if this timeframe is adequate for most channel and contingency operations, then a possible cost savings or inventory level reduction may be seen. The managerial tradeoff is service level versus inventory level, and with more aircraft passing through Ramstein, of varying airframes, more shelf space for parts for older airframes may be more valuable than storing parts that rarely fail on a C-17 enroute.

Future utilization of new resources and funding

The study also shows if new funding is procured for enroute locations or high-tempo contingency operations, it may be best spent on additional manpower versus additional parts. The manpower billets have shown that they can possibly produce greater aircraft throughput and turn-time, with a normal, and even below normal, level of spares. The additional manpower can also be cross-utilized for other base support functions while not actively generating C-17 aircraft.

Suggestions for Further Study

Some information regarding unscheduled maintenance repair data for the C-17 at enroute locations was unavailable for this analysis. More supply fill rate and stockage level data needs to be collected in order for this model and future supply chain models to maximize their utility. The supply fill rates used in this model were purposely set at the Headquarters approved stockage level and assumed that all necessary parts were filled to that level, no fluctuation in variance of stockage levels among LRUs and parts. Once new, individual LRU consumption information is developed, the model should incorporate those changes and the experiment should be conducted again. To increase the validity of the model, actual process time data should be collected from the enroute location and compared to the activity parameters used within the model, which were provided from historical data and subject matter expert knowledge.

Further research efforts should also be applied toward the integration of airfield, equipment, and distance constraints at the enroute location. This model assumed instantaneous movement of resources and entities from process to process. No account for towing, movement of personnel to various, geographically separated locations, and delivery of supply parts was taken into account. With actual distances, equipment and vehicle levels, and airfield ramp capacity, Arena has the ability to implement this data and add validity to the output. A maintenance-centered model should focus on the parking locations of aircraft and the relative location of all necessary maintenance personnel. This allows for greater control over what actions get a priority and what processes can have resources, manpower, taken away from for a short period of expediting other processes. This study revealed the significance of the C-17 generation process associated with maintenance operations and where specific bottlenecks can occur in a system of this linear nature, an additional study may uncover other sources of problems in the generation process that may affect the global generation and supply chain. There could be ramp restrictions or other capacity limitations that could cause a bottleneck or problem to occur and more detailed modeling can bring that factor to bear.

Distribution of the number of times an unscheduled maintenance action requires an LRU versus troubleshooting and resetting a system was based entirely on subject matter experts. This actual data would be invaluable to increases system validity, but collection of this data posses a hurdle. Any significant change from the expert knowledge currently in use, will have an affect on the demand put on supply, can cause increased pulls from the supply system, and therefore may delay C-17 processing when there are stock-outs, which may now occur more often.

Summary

The purpose was to present research findings that will facilitate in Air Mobility Command Logistics Directorate developing of a Mobility Airlift Aircraft Forecasting tool, especially pertaining to how manning and spares level factors affect aircraft availability. Investigative questions and research propositions were developed to meet the goal of the research. Historical and simulation data was collected and analyzed through implementation of the methodology.

This study was undertaken to determine the hierarchical structure of C-17 aircraft generation at an enroute location and determine how the factors of crew chief manning levels and spares fill rates affect aircraft availability. A study of the literature also provided a framework for the development of past aircraft availability models and heuristics. Aircraft availability has many different meanings, depending on the office or functional area asked. It was determined the Air Mobility Command Logistics Directorate defined aircraft availability as a mission ready aircraft.

The study formulated a hierarchical structure of current C-17 generation procedures and translated the structure into an Arena based simulation model to determine how the factors of crew chief manning and spares levels affect aircraft throughput and turn-time, two key performance measures that reflect overall aircraft availability. The study also utilized data to model unscheduled maintenance actions as individual processes versus being aggregated into one general process with one distribution.

The research concluded that crew chief manning level had a statistically significant impact on aircraft throughput and turn-times, but spares fill rates had no statistical impact, for the levels tested for in the experiment.

This work can be used in conjunction with other simulations studies now ongoing. Because the model utilizes and attempts to model individual unscheduled maintenance actions, the predicted throughput and aircraft turn-times hold the possibility of becoming more accurate than current simulations that aggregate unscheduled maintenance into one process with some standard distribution of repair time. This model attempts to use variability in breaks and supply spares levels to accurately represent the real world at an enroute location. The fact that the model is also in Arena 5.0, should facilitate model integration into other similar simulations.

We hope that future researchers will continue in the efforts already on going in this interesting and important area. We sincerely hope this research adds to the airlift mobility community's efforts towards shaping the Air Force's future needs and missions.

Appendix A. Simulation Runs Calculations

Model 1 Low Manpower Low Supply

Throughput

rep		Theta (rep)	Theta rep - Theta Hat	Squared
1		308	8	64
2		307	7	49
3		305	5	25
4		280	-20	400
5		290	-10	100
6		305	5	25
7		300	0	0
8		291	-9	81
9		306	6	36
10		308	8	64
				844
Theta hat		300		
R	10			
Variance		9.377778		
S squared		93.77778		
S		3.062316		
Runs		6.8875		
alpha	0.05			
precision	3			

Turn Time

rep		Theta (rep)	Theta rep - Theta Hat	Squared
1		89.97	5.01	25.08413
2		76.78	-8.18	66.88666
3		89.78	4.82	23.20181
4		81.69	-3.27	10.67155
5		97.18	12.22	149.2757
6		90.25	5.29	27.9909
7		80.38	-4.58	20.98993
8		82.31	-2.65	7.006872
9		71.29	-13.67	186.8261
10		89.97	5.01	25.08413
				543.0178
Theta hat		84.96109		
R	10			
Variance		6.033531		
S squared		60.33531		
S		2.456325		
Runs		39.88189		
alpha	0.05			
precision	1			

Model 2 Low Manpower Normal Supply

Throughput

rep		Theta (rep)	Theta rep - Theta Hat	Squared
1		318	16.3	265.69
2		288	-13.7	187.69
3		284	-17.7	313.29
4		303	1.3	1.69
5		303	1.3	1.69
6		306	4.3	18.49
7		312	10.3	106.09
8		300	-1.7	2.89
9		298	-3.7	13.69
10		305	3.3	10.89
				922.1
Theta hat		301.7		
R	10			
Variance		10.24556		
S squared		102.4556		
S		3.200868		
Runs		7.524838		
alpha	0.05			
precision	3			

Turn Time

rep		Theta (rep)	Theta rep - Theta Hat	Squared
1		80.46	-1.851042	3.426357
2		73.44	-8.863284	78.5578
3		70.02	-12.29071	151.0616
4		91.25	8.942181	79.9626
5		91.25	8.942181	79.9626
6		84.54	2.227925	4.96365
7		81.70	-0.608197	0.369904
8		80.38	-1.928666	3.719754
9		79.79	-2.51	6.319383
10		90.25	7.94	63.09845
				471.4421
Theta hat		82.30828		
R	10			
Variance		5.238245		
S squared		52.38245		
S		2.288721		
Runs		34.62502		
alpha	0.05			
precision	1			

Model 3 Low Manpower High Supply

Throughput

rep		Theta (rep)	Theta rep - Theta Hat	Squared
1		296	-5.1	26.01
2		309	7.9	62.41
3		319	17.9	320.41
4		306	4.9	24.01
5		287	-14.1	198.81
6		300	-1.1	1.21
7		304	2.9	8.41
8		287	-14.1	198.81
9		320	18.9	357.21
10		283	-18.1	327.61
				1524.9
Theta hat		301.1		
R	10			
Variance		16.94333		
S squared		169.4333		
S		4.116228		
Runs		12.44401		
alpha	0.05			
precision	3			

Turn Time

rep		Theta (rep)	Theta rep - Theta Hat	Squared
1		11.80	-0.21	0.04485
2		11.71	-0.299437	0.089662
3		13.61	1.604268	2.573676
4		13.18	1.175725	1.382328
5		12.27	0.264481	0.06995
6		11.47	-0.534496	0.285686
7		10.93	-1.080546	1.167579
8		10.56	-1.446868	2.093426
9		11.86	-0.15	0.023134
10		12.69	0.68	0.463418
				8.193711
Theta hat		12.00745		
R	10			
Variance		0.091041		
S squared		0.910412		
S		0.30173		
Runs		0.601786		
alpha	0.05			
precision	1			

Model 4 Normal Manpower Low Supply

Throughput

rep		Theta (rep)	Theta rep - Theta Hat	Squared
1		333	25.8	665.64
2		347	39.8	1584.04
3		294	-13.2	174.24
4		319	11.8	139.24
5		312	4.8	23.04
6		313	5.8	33.64
7		298	-9.2	84.64
8		281	-26.2	686.44
9		269	-38.2	1459.24
10		306	-1.2	1.44
				4851.6
Theta hat		307.2		
R	10			
Variance		53.90667		
S squared		539.0667		
S		7.342116		
Runs		39.5917		
alpha	0.05			
precision	3			

Turn Time

rep		Theta (rep)	Theta rep - Theta Hat	Squared
1		13.85	-0.362692	0.131546
2		16.17	1.956828	3.829175
3		14.33	0.113804	0.012951
4		16.70	2.485928	6.17984
5		13.85	-0.36201	0.131052
6		14.85	0.63313	0.400853
7		13.48	-0.730655	0.533856
8		12.60	-1.614656	2.607115
9		11.64	-2.571064	6.610372
10		14.67	0.45	0.203751
				20.64051
Theta hat		14.21533		
R	10			
Variance		0.229339		
S squared		2.29339		
S		0.478894		
Runs		1.51594		
alpha	0.05			
precision	1			

Model 5 Normal Manpower Normal Supply

Throughput

rep		Theta (rep)	Theta rep - Theta Hat	Squared
1		296	-15.2	231.04
2		291	-20.2	408.04
3		320	8.8	77.44
4		276	-35.2	1239.04
5		337	25.8	665.64
6		315	3.8	14.44
7		320	8.8	77.44
8		310	-1.2	1.44
9		339	27.8	772.84
10		308	-3.2	10.24
				3497.6
Theta hat		311.2		
R	10			
Variance		38.86222		
S squared		388.6222		
S		6.233957		
Runs		28.54232		
alpha	0.05			
precision	3			

Turn Time

rep		Theta (rep)	Theta rep - Theta Hat	Squared
1		13.63	-0.03	0.000631
2		12.25	-1.40	1.956431
3		13.77	0.12	0.013977
4		10.78	-2.88	8.270167
5		13.25	-0.41	0.16416
6		13.99	0.34	0.116407
7		17.01	3.36	11.29868
8		13.38	-0.27	0.072305
9		15.16	1.51	2.274966
10		13.30	-0.36	0.126283
				24.294
Theta hat		13.65364		
R	10			
Variance		0.269933		
S squared		2.699334		
S		0.519551		
Runs		1.784271		
alpha	0.05			
precision	1			

Model 6 Normal Manpower High Supply

Throughput

rep		Theta (rep)	Theta rep - Theta Hat	Squared
1		296	-5.1	26.01
2		309	7.9	62.41
3		319	17.9	320.41
4		306	4.9	24.01
5		287	-14.1	198.81
6		300	-1.1	1.21
7		304	2.9	8.41
8		287	-14.1	198.81
9		320	18.9	357.21
10		283	-18.1	327.61
				1524.9
Theta hat		301.1		
R	10			
Variance		16.94333		
S squared		169.4333		
S		4.116228		
Runs		12.44401		
alpha	0.05			
precision	3			

Turn Time

rep		Theta (rep)	Theta rep - Theta Hat	Squared
1		11.80	-0.21	0.04485
2		11.71	-0.30	0.089662
3		13.61	1.60	2.573676
4		13.18	1.18	1.382328
5		12.27	0.26	0.06995
6		11.47	-0.53	0.285686
7		10.93	-1.08	1.167579
8		10.56	-1.45	2.093426
9		11.86	-0.15	0.023134
10		12.69	0.68	0.463418
				8.193711
Theta hat		12.00745		
R	10			
Variance		0.091041		
S squared		0.910412		
S		0.30173		
Runs		0.601786		
alpha	0.05			
precision	1			

Model 7 High Manpower Low Supply

Throughput

rep		Theta (rep)	Theta rep - Theta Hat	Squared
1		315	9.8	96.04
2		300	-5.2	27.04
3		308	2.8	7.84
4		327	21.8	475.24
5		313	7.8	60.84
6		278	-27.2	739.84
7		294	-11.2	125.44
8		307	1.8	3.24
9		307	1.8	3.24
10		303	-2.2	4.84
				1543.6
Theta hat		305.2		
R	10			
Variance		17.15111		
S squared		171.5111		
S		4.14139		
Runs		12.59662		
alpha	0.05			
precision	3			

Turn Time

rep		Theta (rep)	Theta rep - Theta Hat	Squared
1		11.16	0.179148	0.032094
2		11.03	0.049265	0.002427
3		13.63	2.645242	6.997307
4		11.67	0.689289	0.475119
5		10.44	-0.538895	0.290408
6		10.29	-0.697146	0.486012
7		11.14	0.159226	0.025353
8		10.78	-0.200684	0.040274
9		10.21	-0.770847	0.594205
10		9.47	-1.514598	2.294007
				11.23721
Theta hat		10.9837		
R	10			
Variance		0.124858		
S squared		1.248578		
S		0.353352		
Runs		0.825315		
alpha	0.05			
precision	1			

Model 8 High Manpower Normal Supply

Throughput

rep		Theta (rep)	Theta rep - Theta Hat	Squared
1		306	-0.8	0.64
2		338	31.2	973.44
3		317	10.2	104.04
4		292	-14.8	219.04
5		313	6.2	38.44
6		293	-13.8	190.44
7		309	2.2	4.84
8		288	-18.8	353.44
9		321	14.2	201.64
10		291	-15.8	249.64
				2335.6
Theta hat		306.8		
R	10			
Variance		25.95111		
S squared		259.5111		
S		5.094223		
Runs		19.05977		
alpha	0.05			
precision	3			

Turn Time

rep		Theta (rep)	Theta rep - Theta Hat	Squared
1		9.57	0.167489	0.028053
2		10.90	1.497256	2.241775
3		10.40	0.99364	0.98732
4		8.57	-0.833142	0.694126
5		9.50	0.096313	0.009276
6		9.19	-0.209657	0.043956
7		8.49	-0.910419	0.828864
8		10.73	1.330992	1.77154
9		8.83	-0.569265	0.324063
10		7.84	-1.56	2.443613
				9.372584
Theta hat		9.403414		
R	10			
Variance		0.10414		
S squared		1.041398		
S		0.322707		
Runs		0.688369		
alpha	0.05			
precision	1			

Model 9 High Manpower High Supply

Throughput

rep		Theta (rep)	Theta rep - Theta Hat	Squared
1		339	28.7	823.69
2		311	0.7	0.49
3		344	33.7	1135.69
4		302	-8.3	68.89
5		304	-6.3	39.69
6		284	-26.3	691.69
7		326	15.7	246.49
8		317	6.7	44.89
9		287	-23.3	542.89
10		289	-21.3	453.69
				4048.1
Theta hat		310.3		
R	10			
Variance		44.97889		
S squared		449.7889		
S		6.70663		
Runs		33.0347		
alpha	0.05			
precision	3			

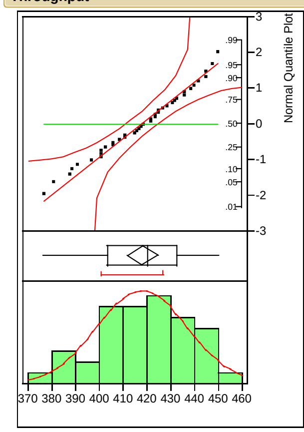
Turn Time

rep		Theta (rep)	Theta rep - Theta Hat	Squared
1		8.63	-0.27051	0.073176
2		8.26	-0.639856	0.409415
3		10.05	1.152891	1.329159
4		9.05	0.146008	0.021318
5		9.40	0.495143	0.245167
6		7.95	-0.945556	0.894076
7		9.28	0.382326	0.146173
8		9.19	0.285873	0.081723
9		8.76	-0.137774	0.018982
10		8.43	-0.468546	0.219535
				3.438724
Theta hat		8.900402		
R	10			
Variance		0.038208		
S squared		0.38208		
S		0.195469		
Runs		0.252557		
alpha	0.05			
precision	1			

Appendix B. JMP Analysis of Treatments for Normality

Normal Manpower, High Spares Level

Throughput



Normal(418.3,18.9847)

Quantiles

100.0%	maximum	450.00
99.5%		450.00
97.5%		449.95
90.0%		444.70
75.0%	quartile	432.75
50.0%	median	420.50
25.0%	quartile	403.75
10.0%		389.20
2.5%		377.10
0.5%		377.00
0.0%	minimum	377.00

Moments

Mean	418.3
Std Dev	18.984744
Std Err Mean	3.0017516
upper 95% Mean	424.37162
lower 95% Mean	412.22838
N	40
Sum Wgt	40
Sum	16732
Variance	360.42051
Skewness	-0.313299
Kurtosis	-0.615243
CV	4.5385475
N Missing	0

Fitted Normal

Parameter Estimates

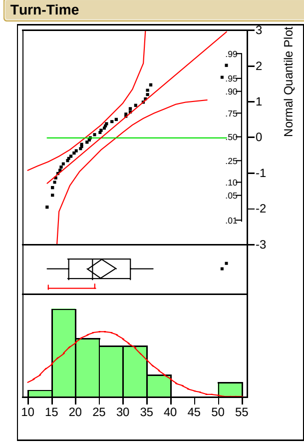
Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	Mu	418.3000	412.2284	424.3716
Dispersion	Sigma	18.9847	15.5516	24.3771

Goodness-of-Fit Test

Shapiro-Wilk W Test

W	Prob<W
0.975455	0.5254

Turn-Time



Normal(25.5655,8.91741)

Quantiles

100.0%	maximum	51.981
99.5%		51.981
97.5%		51.956
90.0%		35.348
75.0%	quartile	31.521
50.0%	median	23.686
25.0%	quartile	18.646
10.0%		15.851
2.5%		14.231
0.5%		14.205
0.0%	minimum	14.205

Moments

Mean	25.565528
Std Dev	8.9174087
Std Err Mean	1.4099661
upper 95% Mean	28.417453
lower 95% Mean	22.713602
N	40
Sum Wgt	40
Sum	1022.6211
Variance	79.520178
Skewness	1.1836629
Kurtosis	1.6724339
CV	34.880597
N Missing	0

Fitted Normal

Parameter Estimates

Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	Mu	25.56553	22.71360	28.41745
Dispersion	Sigma	8.91741	7.30479	11.45027

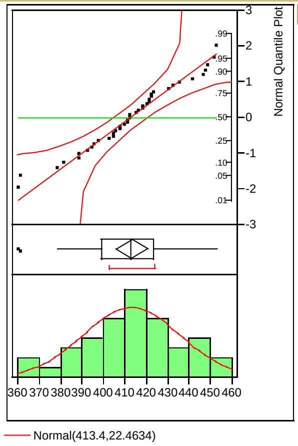
Goodness-of-Fit Test

Shapiro-Wilk W Test

W	Prob<W
0.898514	0.0017

Normal Manpower, Normal Spares Level

Throughput



Quantiles

100.0%	maximum	453.00
99.5%		453.00
97.5%		452.98
90.0%		447.90
75.0%	quartile	423.75
50.0%	median	413.00
25.0%	quartile	399.25
10.0%		382.70
2.5%		361.03
0.5%		361.00
0.0%	minimum	361.00

Moments

Mean	413.4
Std Dev	22.463418
Std Err Mean	3.5517782
upper 95% Mean	420.58415
lower 95% Mean	406.21585
N	40
Sum Wgt	40
Sum	16536
Variance	504.60513
Skewness	-0.261973
Kurtosis	0.0758464
CV	5.4338214
N Missing	0

Fitted Normal

Parameter Estimates

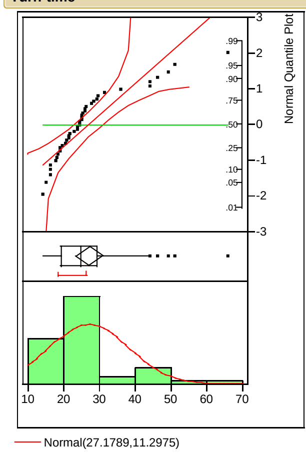
Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	Mu	413.4000	406.2159	420.5841
Dispersion	Sigma	22.4634	18.4012	28.8438

Goodness-of-Fit Test

Shapiro-Wilk W Test

W	Prob<W
0.972432	0.4283

Turn-time



Quantiles

100.0%	maximum	66.072
99.5%		66.072
97.5%		65.707
90.0%		46.194
75.0%	quartile	29.382
50.0%	median	24.726
25.0%	quartile	19.427
10.0%		16.417
2.5%		14.467
0.5%		14.447
0.0%	minimum	14.447

Moments

Mean	27.178904
Std Dev	11.297483
Std Err Mean	1.786289
upper 95% Mean	30.792014
lower 95% Mean	23.565794
N	40
Sum Wgt	40
Sum	1087.1562
Variance	127.63313
Skewness	1.6950711
Kurtosis	2.8696628
CV	41.567104
N Missing	0

Fitted Normal

Parameter Estimates

Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	Mu	27.17890	23.56579	30.79201
Dispersion	Sigma	11.29748	9.25446	14.50637

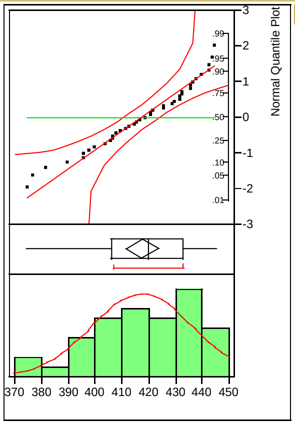
Goodness-of-Fit Test

Shapiro-Wilk W Test

W	Prob<W
0.819624	<.0001

Normal Manpower, Low Spares Level

Throughput



Normal(417.875,18.9062)

Quantiles

100.0%	maximum	445.00
99.5%		445.00
97.5%		444.98
90.0%		442.70
75.0%	quartile	433.00
50.0%	median	420.00
25.0%	quartile	406.25
10.0%		390.60
2.5%		375.05
0.5%		375.00
0.0%	minimum	375.00

Moments

Mean	417.875
Std Dev	18.906229
Std Err Mean	2.9893374
upper 95% Mean	423.92151
lower 95% Mean	411.82849
N	40
Sum Wgt	40
Sum	16715
Variance	357.44551
Skewness	-0.53454
Kurtosis	-0.428181
CV	4.5243744
N Missing	0

Fitted Normal

Parameter Estimates

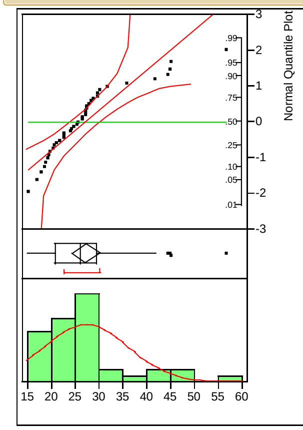
Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	Mu	417.8750	411.8285	423.9215
Dispersion	Sigma	18.9062	15.4872	24.2763

Goodness-of-Fit Test

Shapiro-Wilk W Test

W	Prob<W
0.953696	0.1017

Turn-time



Normal(27.326,8.84895)

Quantiles

100.0%	maximum	57.015
99.5%		57.015
97.5%		56.722
90.0%		44.363
75.0%	quartile	29.609
50.0%	median	26.213
25.0%	quartile	20.831
10.0%		18.735
2.5%		15.384
0.5%		15.339
0.0%	minimum	15.339

Moments

Mean	27.325959
Std Dev	8.8489482
Std Err Mean	1.3991416
upper 95% Mean	30.15599
lower 95% Mean	24.495928
N	40
Sum Wgt	40
Sum	1093.0384
Variance	78.303885
Skewness	1.5260872
Kurtosis	2.5522497
CV	32.382937
N Missing	0

Fitted Normal

Parameter Estimates

Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	Mu	27.32596	24.49593	30.15599
Dispersion	Sigma	8.84895	7.24871	11.36236

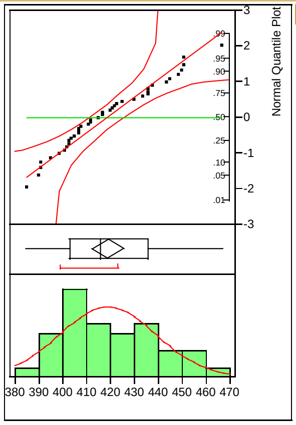
Goodness-of-Fit Test

Shapiro-Wilk W Test

W	Prob<W
0.858594	0.0001

High Manpower, High Spares Level

Throughput



Normal(419,20.2421)

Quantiles

100.0%	maximum	467.00
99.5%		467.00
97.5%		466.60
90.0%		449.90
75.0%	quartile	436.00
50.0%	median	416.00
25.0%	quartile	403.25
10.0%		391.40
2.5%		385.13
0.5%		385.00
0.0%	minimum	385.00

Moments

Mean	419
Std Dev	20.242124
Std Err Mean	3.2005608
upper 95% Mean	425.47375
lower 95% Mean	412.52625
N	40
Sum Wgt	40
Sum	16760
Variance	409.74359
Skewness	0.4245748
Kurtosis	-0.627767
CV	4.8310559
N Missing	0

Fitted Normal

Parameter Estimates

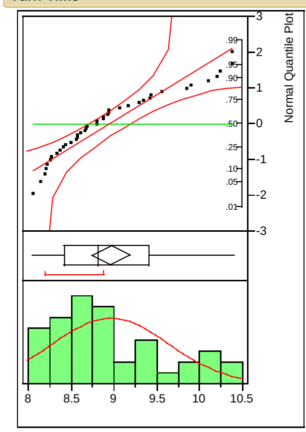
Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	Mu	419.0000	412.5263	425.4737
Dispersion	Sigma	20.2421	16.5816	25.9916

Goodness-of-Fit Test

Shapiro-Wilk W Test

W	Prob<W
0.961975	0.1956

Turn-TIme



Normal(8.96902,0.67649)

Quantiles

100.0%	maximum	10.397
99.5%		10.397
97.5%		10.397
90.0%		10.204
75.0%	quartile	9.418
50.0%	median	8.816
25.0%	quartile	8.432
10.0%		8.226
2.5%		8.071
0.5%		8.068
0.0%	minimum	8.068

Moments

Mean	8.9690235
Std Dev	0.676494
Std Err Mean	0.1069631
upper 95% Mean	9.1853768
lower 95% Mean	8.7526702
N	40
Sum Wgt	40
Sum	358.76094
Variance	0.4576441
Skewness	0.7909114
Kurtosis	-0.420105
CV	7.5425598
N Missing	0

Fitted Normal

Parameter Estimates

Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	Mu	8.969024	8.752670	9.185377
Dispersion	Sigma	0.676494	0.554157	0.868642

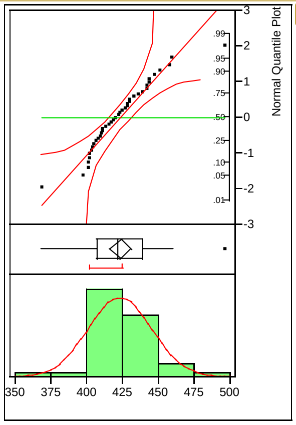
Goodness-of-Fit Test

Shapiro-Wilk W Test

W	Prob<W
0.908099	0.0033

High Manpower, Normal Spares Level

Throughput



Normal(424.05,22.3377)

Quantiles

100.0%	maximum	497.00
99.5%		497.00
97.5%		496.08
90.0%		451.60
75.0%	quartile	439.25
50.0%	median	422.00
25.0%	quartile	407.50
10.0%		402.10
2.5%		369.73
0.5%		369.00
0.0%	minimum	369.00

Moments

Mean	424.05
Std Dev	22.337677
Std Err Mean	3.5318968
upper 95% Mean	431.19394
lower 95% Mean	416.90606
N	40
Sum Wgt	40
Sum	16962
Variance	498.97179
Skewness	0.6935171
Kurtosis	2.0735571
CV	5.2676988
N Missing	0

Fitted Normal

Parameter Estimates

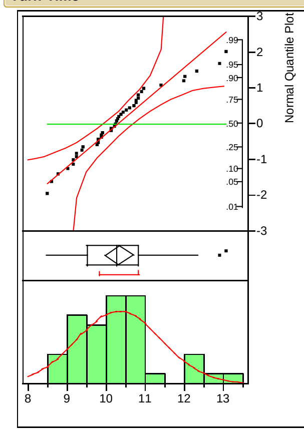
Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	Mu	424.0500	416.9061	431.1939
Dispersion	Sigma	22.3377	18.2982	28.6824

Goodness-of-Fit Test

Shapiro-Wilk W Test

W	Prob<W
0.949295	0.0717

Turn-Time



Normal(10.3365,1.0846)

Quantiles

100.0%	maximum	13.111
99.5%		13.111
97.5%		13.106
90.0%		12.048
75.0%	quartile	10.825
50.0%	median	10.281
25.0%	quartile	9.525
10.0%		9.065
2.5%		8.512
0.5%		8.509
0.0%	minimum	8.509

Moments

Mean	10.336536
Std Dev	1.0845973
Std Err Mean	0.1714899
upper 95% Mean	10.683407
lower 95% Mean	9.989665
N	40
Sum Wgt	40
Sum	413.46144
Variance	1.1763512
Skewness	0.7187278
Kurtosis	0.5345517
CV	10.49285
N Missing	0

Fitted Normal

Parameter Estimates

Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	Mu	10.33654	9.989665	10.68341
Dispersion	Sigma	1.08460	0.888460	1.39266

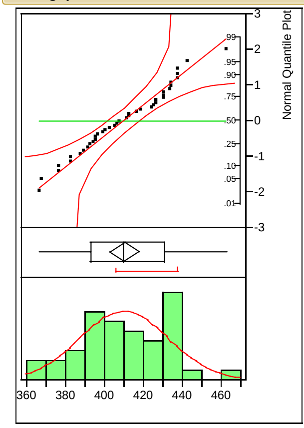
Goodness-of-Fit Test

Shapiro-Wilk W Test

W	Prob<W
0.950723	0.0803

High Manpower, Low Spares Level

Throughput



Normal(410.575,22.864)

Quantiles

100.0%	maximum	463.00
99.5%		463.00
97.5%		462.50
90.0%		438.00
75.0%	quartile	431.00
50.0%	median	410.00
25.0%	quartile	393.50
10.0%		377.60
2.5%		367.02
0.5%		367.00
0.0%	minimum	367.00

Moments

Mean	410.575
Std Dev	22.864021
Std Err Mean	3.6151192
upper 95% Mean	417.88727
lower 95% Mean	403.26273
N	40
Sum Wgt	40
Sum	16423
Variance	522.76346
Skewness	-0.00153
Kurtosis	-0.66325
CV	5.5687806
N Missing	0

Fitted Normal

Parameter Estimates

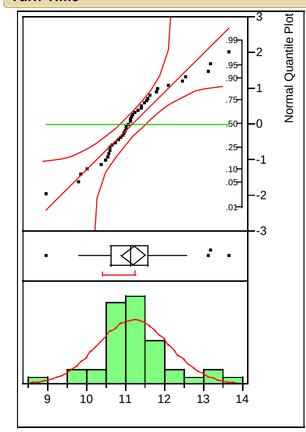
Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	Mu	410.5750	403.2627	417.8873
Dispersion	Sigma	22.8640	18.7293	29.3582

Goodness-of-Fit Test

Shapiro-Wilk W Test

W	Prob<W
0.974142	0.4816

Turn-Time



Normal(11.2179,0.92101)

Quantiles

100.0%	maximum	13.683
99.5%		13.683
97.5%		13.671
90.0%		12.549
75.0%	quartile	11.584
50.0%	median	11.125
25.0%	quartile	10.647
10.0%		10.083
2.5%		9.013
0.5%		8.993
0.0%	minimum	8.993

Moments

Mean	11.217851
Std Dev	0.9210065
Std Err Mean	0.1456239
upper 95% Mean	11.512404
lower 95% Mean	10.923299
N	40
Sum Wgt	40
Sum	448.71406
Variance	0.8482529
Skewness	0.5434208
Kurtosis	1.2351916
CV	8.2101862
N Missing	0

Fitted Normal

Parameter Estimates

Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	Mu	11.21785	10.92330	11.51240
Dispersion	Sigma	0.92101	0.75445	1.18261

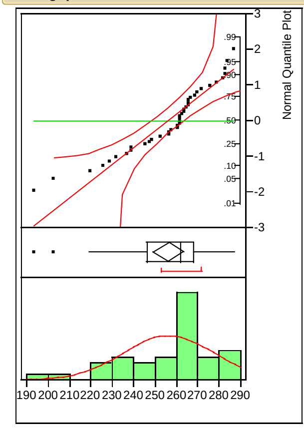
Goodness-of-Fit Test

Shapiro-Wilk W Test

W	Prob<W
0.953748	0.1021

Low Manpower, High Spares Level

Throughput



Normal(256.575,21.2493)

Quantiles

100.0%	maximum	287.00
99.5%		287.00
97.5%		286.92
90.0%		282.90
75.0%	quartile	268.50
50.0%	median	262.00
25.0%	quartile	246.50
10.0%		226.30
2.5%		194.22
0.5%		194.00
0.0%	minimum	194.00

Moments

Mean	256.575
Std Dev	21.249299
Std Err Mean	3.3598091
upper 95% Mean	263.37086
lower 95% Mean	249.77914
N	40
Sum Wgt	40
Sum	10263
Variance	451.53269
Skewness	-1.119256
Kurtosis	1.2893215
CV	8.2819053
N Missing	0

Fitted Normal

Parameter Estimates

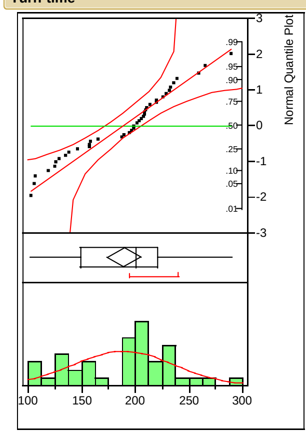
Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	Mu	256.5750	249.7791	263.3709
Dispersion	Sigma	21.2493	17.4066	27.2849

Goodness-of-Fit Test

Shapiro-Wilk W Test

W	Prob<W
0.910378	0.0039

Turn-time



Normal(189.736,47.0808)

Quantiles

100.0%	maximum	290.28
99.5%		290.28
97.5%		289.68
90.0%		239.75
75.0%	quartile	221.03
50.0%	median	201.31
25.0%	quartile	149.92
10.0%		119.88
2.5%		103.58
0.5%		103.50
0.0%	minimum	103.50

Moments

Mean	189.73632
Std Dev	47.080774
Std Err Mean	7.4441239
upper 95% Mean	204.79348
lower 95% Mean	174.67916
N	40
Sum Wgt	40
Sum	7589.4527
Variance	2216.5993
Skewness	-0.219632
Kurtosis	-0.64578
CV	24.813791
N Missing	0

Fitted Normal

Parameter Estimates

Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	Mu	189.7363	174.6792	204.7935
Dispersion	Sigma	47.0808	38.5667	60.4534

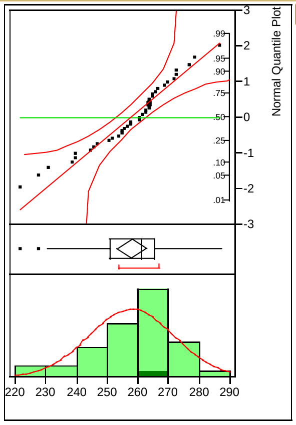
Goodness-of-Fit Test

Shapiro-Wilk W Test

W	Prob<W
0.955686	0.1191

Low Manpower, Normal Spares Level

Throughput



Normal(258.175,13.9153)

Quantiles

100.0%	maximum	287.00
99.5%		287.00
97.5%		286.80
90.0%		273.00
75.0%	quartile	265.75
50.0%	median	261.50
25.0%	quartile	251.25
10.0%		239.10
2.5%		222.15
0.5%		222.00
0.0%	minimum	222.00

Moments

Mean	258.175
Std Dev	13.915289
Std Err Mean	2.2002003
upper 95% Mean	262.62533
lower 95% Mean	253.72467
N	40
Sum Wgt	40
Sum	10327
Variance	193.63526
Skewness	-0.654426
Kurtosis	0.5072592
CV	5.3898668
N Missing	0

Fitted Normal

Parameter Estimates

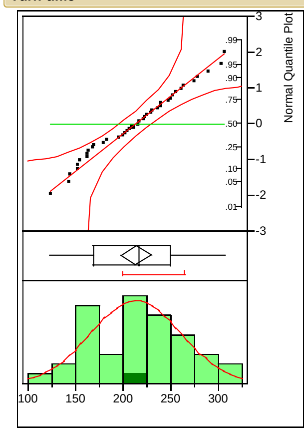
Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	Mu	258.1750	253.7247	262.6253
Dispersion	Sigma	13.9153	11.3989	17.8677

Goodness-of-Fit Test

Shapiro-Wilk W Test

W	Prob<W
0.959458	0.1605

Turn-time



Normal(214.063,47.3454)

Quantiles

100.0%	maximum	306.97
99.5%		306.97
97.5%		306.91
90.0%		278.23
75.0%	quartile	250.46
50.0%	median	216.99
25.0%	quartile	169.18
10.0%		152.60
2.5%		124.80
0.5%		124.33
0.0%	minimum	124.33

Moments

Mean	214.0631
Std Dev	47.345415
Std Err Mean	7.4859674
upper 95% Mean	229.2049
lower 95% Mean	198.92131
N	40
Sum Wgt	40
Sum	8562.5241
Variance	2241.5883
Skewness	0.0732373
Kurtosis	-0.791375
CV	22.117504
N Missing	0

Fitted Normal

Parameter Estimates

Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	Mu	214.0631	198.9213	229.2049
Dispersion	Sigma	47.3454	38.7835	60.7932

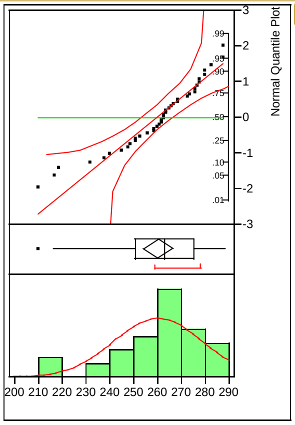
Goodness-of-Fit Test

Shapiro-Wilk W Test

W	Prob<W
0.976194	0.5509

Low Manpower, Low Spares Level

Throughput



Normal(260.325,18.574)

Quantiles

100.0%	maximum	288.00
99.5%		288.00
97.5%		288.00
90.0%		280.00
75.0%	quartile	275.50
50.0%	median	263.00
25.0%	quartile	251.00
10.0%		232.60
2.5%		210.18
0.5%		210.00
0.0%	minimum	210.00

Moments

Mean	260.325
Std Dev	18.57402
Std Err Mean	2.9368105
upper 95% Mean	266.26526
lower 95% Mean	254.38474
N	40
Sum Wgt	40
Sum	10413
Variance	344.99423
Skewness	-0.974361
Kurtosis	0.8345914
CV	7.1349353
N Missing	0

Fitted Normal

Parameter Estimates

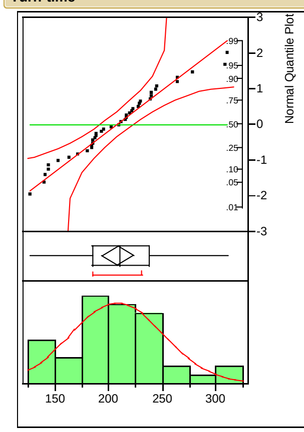
Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	Mu	260.3250	254.3847	266.2653
Dispersion	Sigma	18.5740	15.2151	23.8497

Goodness-of-Fit Test

Shapiro-Wilk W Test

W	Prob<W
0.929307	0.0153

Turn-time



Normal(208.565,43.7339)

Quantiles

100.0%	maximum	310.98
99.5%		310.98
97.5%		310.93
90.0%		265.16
75.0%	quartile	237.64
50.0%	median	211.34
25.0%	quartile	185.41
10.0%		144.25
2.5%		127.95
0.5%		127.64
0.0%	minimum	127.64

Moments

Mean	208.56451
Std Dev	43.73391
Std Err Mean	6.9149383
upper 95% Mean	222.5513
lower 95% Mean	194.57773
N	40
Sum Wgt	40
Sum	8342.5805
Variance	1912.6549
Skewness	0.3065405
Kurtosis	0.0284285
CV	20.969008
N Missing	0

Fitted Normal

Parameter Estimates

Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	Mu	208.5645	194.5777	222.5513
Dispersion	Sigma	43.7339	35.8251	56.1559

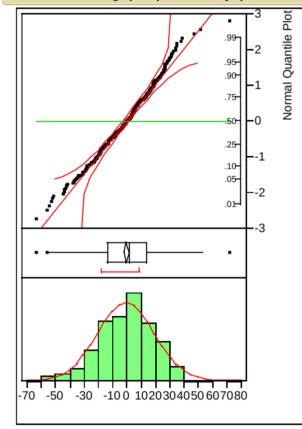
Goodness-of-Fit Test

Shapiro-Wilk W Test

W	Prob<W
0.974107	0.4805

Appendix C. JMP Analysis of Residuals for Normality and Variance

Residual Throughput (C17/60 days)



Normal(-1e-14,19.8967)

Quantiles

100.0%	maximum	72.95
99.5%		56.43
97.5%		34.57
90.0%		25.12
75.0%	quartile	14.35
50.0%	median	1.68
25.0%	quartile	-13.14
10.0%		-27.06
2.5%		-42.87
0.5%		-56.52
0.0%	minimum	-62.57

Moments

Mean	-1.01e-14
Std Dev	19.896695
Std Err Mean	1.0486479
upper 95% Mean	2.0622646
lower 95% Mean	-2.062265
N	360
Sum Wgt	360
Sum	-3.64e-12
Variance	395.87848
Skewness	-0.213953
Kurtosis	0.3391669
CV	-1.969e17
N Missing	0

Fitted Normal

Parameter Estimates

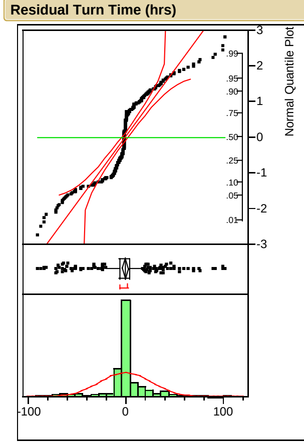
Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	Mu	-1.01e-14	-2.0623	2.06226
Dispersion	Sigma	19.8967	18.5417	21.46695

Goodness-of-Fit Test

Shapiro-Wilk W Test

W	Prob<W
0.992134	0.0541

Residual Turn Time (hrs)



Normal(5e-14,26.8957)

Quantiles

100.0%	maximum	102.4
99.5%		100.9
97.5%		70.3
90.0%		26.3
75.0%	quartile	4.0
50.0%	median	-0.1606
25.0%	quartile	-5.4
10.0%		-24.0
2.5%		-68.2
0.5%		-86.9
0.0%	minimum	-89.7

Moments

Mean	4.974e-14
Std Dev	26.895677
Std Err Mean	1.4175266
upper 95% Mean	2.7876993
lower 95% Mean	-2.787699
N	360
Sum Wgt	360
Sum	1.791e-11
Variance	723.37742
Skewness	0.0791377
Kurtosis	3.7156897
CV	5.4075e16
N Missing	0

Fitted Normal

Parameter Estimates

Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	Mu	4.974e-14	-2.7877	2.78770
Dispersion	Sigma	26.89568	25.0641	29.01829

Goodness-of-Fit Test

Shapiro-Wilk W Test

W	Prob<W
0.836182	0.0000

Appendix D. Simulation Parameters and Distribution Times and Data

ID	Ref Des	Crew Chiefs	Avionics	Electricians	Min (hrs)	Avg (hrs)	Max (hrs)	% Rate Occurance	Probablility needs LRU/Part	Miscellaneous Requirements
1	4711	1	1	1	3	4	5	11.9	50%	
2	3441	1	1	1	1.5	2	2.5	5.3	75%	
3	4910AA001	2	0	1	3	4	5	4.6	50%	
4	4711AA001	2	0	1	3	4	5	4.6	50%	
5	3612	2	0	1	4.5	6	7.5	4	50%	
6	4900	2	0	2	4.5	6	7.5	4	50%	
7	4700	2	0	2	3	4	5	4	50%	
8	3341	1	0	1	0.75	1	1.25	4	100%	
9	2800	2	0	1	2.25	3	3.75	4	50%	3 Fuels
10	3425AA001	2	1	1	1.5	2	2.5	3.3	75%	
11	344600ABV	2	2	1	1.5	2	2.5	3.3	100%	
12	4100	2	0	0	1.5	2	2.5	3.3	50%	1 Structural
13	7321CM004	2	0	1	3	4	5	3.3	50%	
14	7200AA003	2	0	0	4.5	6	7.5	3.3	0%	2 Structural
15	3511FR001	2	0	1	1.5	2	2.5	3.3	50%	
16	3152CM001	1	1	1	1.5	2	2.5	3.3	50%	
17	3152	1	1	2	1.5	2	2.5	3.3	50%	
18	2781	2	0	0	4.5	6	7.5	3.3	0%	2 Structural
19	4962AA001	2	0	1	4.5	6	7.5	2.6	50%	
20	2461SW001	1	0	2	1.5	2	2.5	2.6	50%	
21	2700	2	0	2	4.5	6	7.5	2.6	50%	
22	3441EE001	1	2	1	2.25	3	3.75	2.6	50%	
23	2300	1	2	0	2.25	3	3.75	2.6	50%	
24	3241	3	0	0	2.25	3	3.75	2.6	100%	
25	7800	2	0	0	1.5	2	2.5	2.6	0%	
26	2100	2	0	0	4.5	6	7.5	2.6	100%	2 Structural
27	2821CT001	2	0	1	3	4	5	2.6	50%	1 Fuels
	TOTAL							100		

Rate of Hard Broke	27%
No Unscheduled Mx Needed	73%
C-17 Sorties	2055
TOTAL Ramstein Sorties	4522
% sorties by C-17	45%

Activity/Process	Crew Chiefs	Rate of Occurrence		Min (hrs)	Avg (hrs)	Max (hrs)	Misc
Block In	3			0.20	0.27	0.50	
Through Flight	2			0.50	0.73	1.00	
General Mx/Servicing	2			0.75	1.00	1.25	
Fuel A/C	2			0.60	0.72	1.00	3 Fuels
Oxygen Servicing	2	25%		0.50	0.75	1.00	
Nitrogen Servicing	2	25%		0.25	0.33	0.50	
General Mx, Cont	2			0.50	0.75	1.00	
De-Ice	2	1%		1.75	2.00	2.25	
Block Out	3			0.50	0.75	1.00	
Pax Off-load	1			0.25	0.33	0.50	2 Trans
Cargo Off-load	1			1.75	2.25	2.75	1 Trans
Pax On-load	1			0.25	0.33	0.50	2 Trans
Cargo On-load	1			1.75	2.25	2.75	1 Trans

Appendix E. Simulation Output Data

40 Replications, 60 Days, 5 Day Initialization

Manning Level	Spares Level	Throughput (C-17/60 Days)	Turn Time (hrs)
3 Manning	3 Spares	374	8.40
3 Manning	3 Spares	362	7.93
3 Manning	3 Spares	368	7.76
3 Manning	3 Spares	393	8.55
3 Manning	3 Spares	375	8.21
3 Manning	3 Spares	369	8.31
3 Manning	3 Spares	351	8.33
3 Manning	3 Spares	352	7.57
3 Manning	3 Spares	345	8.85
3 Manning	3 Spares	355	8.23
3 Manning	3 Spares	365	8.16
3 Manning	3 Spares	352	7.42
3 Manning	3 Spares	328	8.24
3 Manning	3 Spares	322	7.78
3 Manning	3 Spares	383	7.73
3 Manning	3 Spares	334	8.63
3 Manning	3 Spares	354	7.88
3 Manning	3 Spares	399	9.04
3 Manning	3 Spares	355	7.38
3 Manning	3 Spares	375	8.12
3 Manning	3 Spares	310	7.82
3 Manning	3 Spares	393	8.05
3 Manning	3 Spares	360	7.97
3 Manning	3 Spares	371	8.31
3 Manning	3 Spares	353	8.05
3 Manning	3 Spares	363	7.82
3 Manning	3 Spares	357	8.68
3 Manning	3 Spares	351	8.81
3 Manning	3 Spares	358	8.04
3 Manning	3 Spares	360	8.18
3 Manning	3 Spares	385	8.35
3 Manning	3 Spares	359	8.58
3 Manning	3 Spares	374	8.73
3 Manning	3 Spares	349	8.59
3 Manning	3 Spares	390	10.11
3 Manning	3 Spares	352	8.19
3 Manning	3 Spares	347	7.84
3 Manning	3 Spares	364	9.54
3 Manning	3 Spares	350	8.36
3 Manning	3 Spares	360	8.26

Manning Level	Spares Level	Throughput (C-17/60 Days)	Turn Time (hrs)
3 Manning	1 Spares	316	12.38
3 Manning	1 Spares	345	9.56
3 Manning	1 Spares	345	12.05
3 Manning	1 Spares	389	10.31
3 Manning	1 Spares	363	10.55
3 Manning	1 Spares	335	9.68
3 Manning	1 Spares	362	10.46
3 Manning	1 Spares	394	10.84
3 Manning	1 Spares	328	10.07
3 Manning	1 Spares	348	10.41
3 Manning	1 Spares	374	11.20
3 Manning	1 Spares	353	10.24
3 Manning	1 Spares	354	11.22
3 Manning	1 Spares	385	10.47
3 Manning	1 Spares	349	10.96
3 Manning	1 Spares	356	12.23
3 Manning	1 Spares	366	10.74
3 Manning	1 Spares	384	11.90
3 Manning	1 Spares	345	12.74
3 Manning	1 Spares	359	12.34
3 Manning	1 Spares	348	10.19
3 Manning	1 Spares	334	11.23
3 Manning	1 Spares	369	9.84
3 Manning	1 Spares	357	9.84
3 Manning	1 Spares	331	9.58
3 Manning	1 Spares	343	10.96
3 Manning	1 Spares	378	10.95
3 Manning	1 Spares	343	10.78
3 Manning	1 Spares	370	10.03
3 Manning	1 Spares	372	10.81
3 Manning	1 Spares	335	10.23
3 Manning	1 Spares	379	12.67
3 Manning	1 Spares	337	10.45
3 Manning	1 Spares	346	9.88
3 Manning	1 Spares	379	11.28
3 Manning	1 Spares	330	11.40
3 Manning	1 Spares	389	10.41
3 Manning	1 Spares	354	10.07
3 Manning	1 Spares	337	10.78
3 Manning	1 Spares	383	11.75

Manning Level	Spares Level	Throughput (C-17/60 Days)	Turn Time (hrs)
3 Manning	2 Spares	366	10.20
3 Manning	2 Spares	370	8.88
3 Manning	2 Spares	341	10.53
3 Manning	2 Spares	342	9.68
3 Manning	2 Spares	354	9.84
3 Manning	2 Spares	327	8.81
3 Manning	2 Spares	381	10.39
3 Manning	2 Spares	373	9.51
3 Manning	2 Spares	355	9.80
3 Manning	2 Spares	338	8.20
3 Manning	2 Spares	351	9.40
3 Manning	2 Spares	362	8.24
3 Manning	2 Spares	359	10.42
3 Manning	2 Spares	327	8.53
3 Manning	2 Spares	340	8.30
3 Manning	2 Spares	345	8.81
3 Manning	2 Spares	352	8.77
3 Manning	2 Spares	356	10.55
3 Manning	2 Spares	350	10.27
3 Manning	2 Spares	361	8.80
3 Manning	2 Spares	319	9.10
3 Manning	2 Spares	381	9.03
3 Manning	2 Spares	384	9.20
3 Manning	2 Spares	367	9.19
3 Manning	2 Spares	348	9.78
3 Manning	2 Spares	343	8.56
3 Manning	2 Spares	408	10.49
3 Manning	2 Spares	360	8.78
3 Manning	2 Spares	383	8.45
3 Manning	2 Spares	371	8.77
3 Manning	2 Spares	335	9.71
3 Manning	2 Spares	382	9.74
3 Manning	2 Spares	361	10.04
3 Manning	2 Spares	372	8.67
3 Manning	2 Spares	361	9.29
3 Manning	2 Spares	399	8.48
3 Manning	2 Spares	385	9.20
3 Manning	2 Spares	353	9.54
3 Manning	2 Spares	347	9.15
3 Manning	2 Spares	341	10.14

Manning Level	Spares Level	Throughput (C-17/60 Days)	Turn Time (hrs)
1 Manning	3 Spares	296	111.70
1 Manning	3 Spares	281	210.28
1 Manning	3 Spares	284	125.41
1 Manning	3 Spares	290	105.25
1 Manning	3 Spares	300	134.39
1 Manning	3 Spares	282	103.32
1 Manning	3 Spares	315	97.57
1 Manning	3 Spares	300	124.48
1 Manning	3 Spares	284	147.63
1 Manning	3 Spares	294	85.63
1 Manning	3 Spares	271	119.10
1 Manning	3 Spares	302	141.96
1 Manning	3 Spares	278	82.92
1 Manning	3 Spares	268	64.38
1 Manning	3 Spares	289	118.92
1 Manning	3 Spares	310	119.40
1 Manning	3 Spares	277	133.65
1 Manning	3 Spares	287	187.31
1 Manning	3 Spares	292	58.23
1 Manning	3 Spares	314	120.48
1 Manning	3 Spares	296	65.98
1 Manning	3 Spares	273	126.00
1 Manning	3 Spares	296	132.40
1 Manning	3 Spares	284	165.48
1 Manning	3 Spares	287	105.59
1 Manning	3 Spares	301	138.02
1 Manning	3 Spares	273	237.92
1 Manning	3 Spares	291	121.81
1 Manning	3 Spares	292	175.97
1 Manning	3 Spares	314	117.58
1 Manning	3 Spares	299	75.19
1 Manning	3 Spares	304	158.93
1 Manning	3 Spares	294	125.99
1 Manning	3 Spares	303	69.99
1 Manning	3 Spares	310	172.55
1 Manning	3 Spares	282	213.04
1 Manning	3 Spares	299	162.02
1 Manning	3 Spares	280	71.11
1 Manning	3 Spares	303	141.30
1 Manning	3 Spares	265	142.88

Manning Level	Spares Level	Throughput (C-17/60 Days)	Turn Time (hrs)
1 Manning	1 Spares	289	145.08
1 Manning	1 Spares	309	105.19
1 Manning	1 Spares	289	143.12
1 Manning	1 Spares	288	155.49
1 Manning	1 Spares	300	114.29
1 Manning	1 Spares	309	76.69
1 Manning	1 Spares	265	174.79
1 Manning	1 Spares	285	62.02
1 Manning	1 Spares	278	58.14
1 Manning	1 Spares	290	103.20
1 Manning	1 Spares	301	144.36
1 Manning	1 Spares	317	128.86
1 Manning	1 Spares	312	103.46
1 Manning	1 Spares	303	115.69
1 Manning	1 Spares	289	52.56
1 Manning	1 Spares	278	125.80
1 Manning	1 Spares	298	86.20
1 Manning	1 Spares	307	142.61
1 Manning	1 Spares	288	166.57
1 Manning	1 Spares	278	115.59
1 Manning	1 Spares	280	68.61
1 Manning	1 Spares	275	204.71
1 Manning	1 Spares	300	133.39
1 Manning	1 Spares	299	58.89
1 Manning	1 Spares	307	123.06
1 Manning	1 Spares	288	112.94
1 Manning	1 Spares	296	137.64
1 Manning	1 Spares	274	106.04
1 Manning	1 Spares	283	84.39
1 Manning	1 Spares	293	128.40
1 Manning	1 Spares	310	95.17
1 Manning	1 Spares	305	110.12
1 Manning	1 Spares	289	139.89
1 Manning	1 Spares	307	63.60
1 Manning	1 Spares	293	113.59
1 Manning	1 Spares	274	126.33
1 Manning	1 Spares	302	181.16
1 Manning	1 Spares	259	117.38
1 Manning	1 Spares	315	84.15
1 Manning	1 Spares	295	169.98

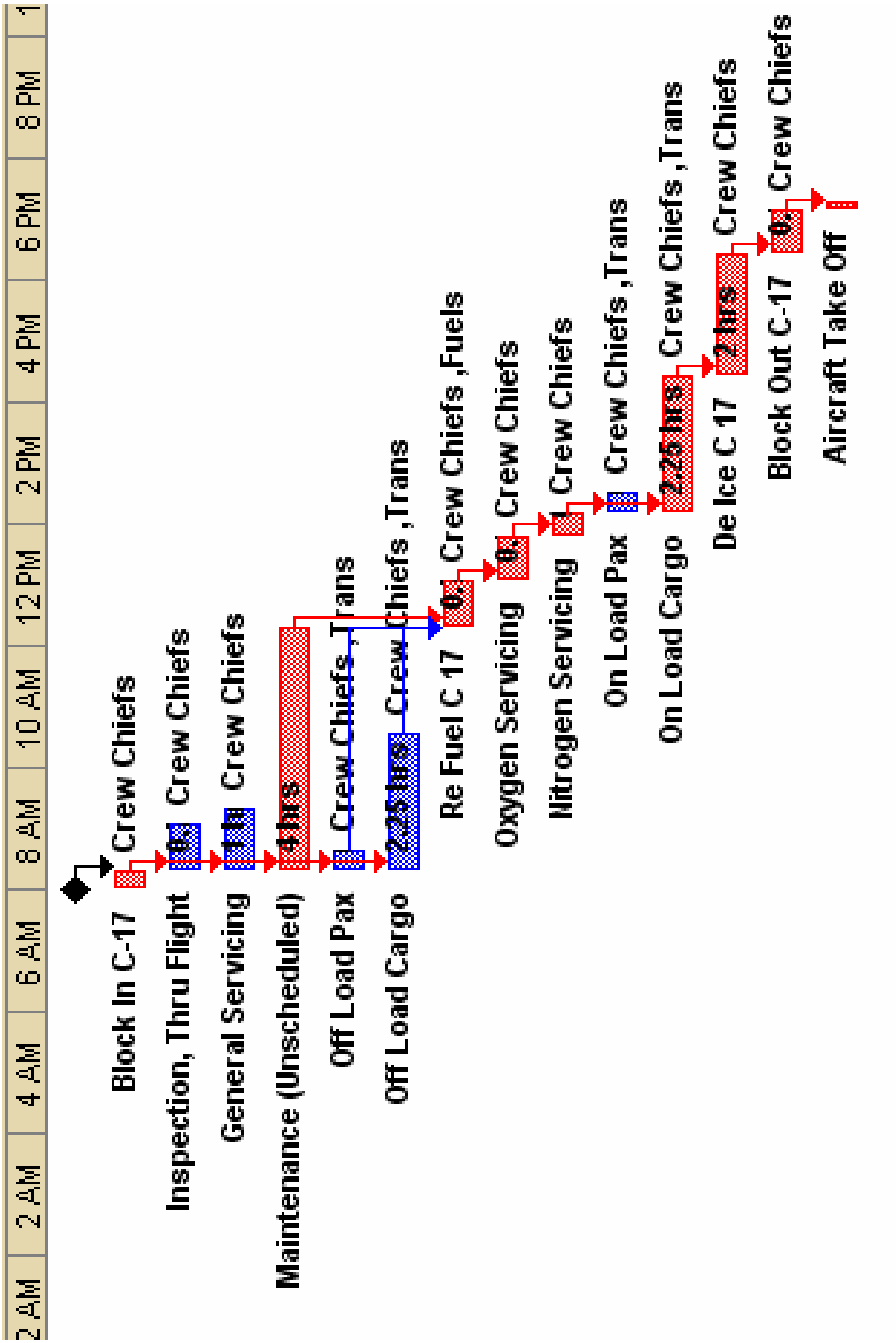
Manning Level	Spares Level	Throughput (C-17/60 Days)	Turn Time (hrs)
1 Manning	2 Spares	282	150.53
1 Manning	2 Spares	283	174.84
1 Manning	2 Spares	310	130.44
1 Manning	2 Spares	295	155.05
1 Manning	2 Spares	287	175.61
1 Manning	2 Spares	282	98.36
1 Manning	2 Spares	278	149.65
1 Manning	2 Spares	289	160.51
1 Manning	2 Spares	282	92.96
1 Manning	2 Spares	288	96.33
1 Manning	2 Spares	281	131.68
1 Manning	2 Spares	264	146.32
1 Manning	2 Spares	306	166.09
1 Manning	2 Spares	274	130.90
1 Manning	2 Spares	282	150.02
1 Manning	2 Spares	270	154.06
1 Manning	2 Spares	253	109.46
1 Manning	2 Spares	249	209.95
1 Manning	2 Spares	308	53.33
1 Manning	2 Spares	290	88.69
1 Manning	2 Spares	286	60.78
1 Manning	2 Spares	307	74.25
1 Manning	2 Spares	286	183.35
1 Manning	2 Spares	295	86.56
1 Manning	2 Spares	298	101.59
1 Manning	2 Spares	289	99.28
1 Manning	2 Spares	302	128.05
1 Manning	2 Spares	275	172.73
1 Manning	2 Spares	251	159.66
1 Manning	2 Spares	260	198.73
1 Manning	2 Spares	299	102.83
1 Manning	2 Spares	289	173.38
1 Manning	2 Spares	298	104.22
1 Manning	2 Spares	280	70.68
1 Manning	2 Spares	302	92.52
1 Manning	2 Spares	287	165.44
1 Manning	2 Spares	300	128.78
1 Manning	2 Spares	302	47.09
1 Manning	2 Spares	300	130.66
1 Manning	2 Spares	293	149.34

Manning Level	Spares Level	Throughput (C-17/60 Days)	Turn Time (hrs)
2 Manning	3 Spares	375	16.95
2 Manning	3 Spares	318	10.59
2 Manning	3 Spares	353	20.26
2 Manning	3 Spares	344	15.70
2 Manning	3 Spares	362	29.90
2 Manning	3 Spares	352	18.37
2 Manning	3 Spares	389	19.84
2 Manning	3 Spares	355	14.59
2 Manning	3 Spares	365	16.19
2 Manning	3 Spares	322	12.25
2 Manning	3 Spares	369	24.62
2 Manning	3 Spares	367	20.40
2 Manning	3 Spares	366	13.33
2 Manning	3 Spares	355	12.97
2 Manning	3 Spares	351	17.16
2 Manning	3 Spares	325	16.33
2 Manning	3 Spares	384	19.87
2 Manning	3 Spares	361	15.37
2 Manning	3 Spares	365	12.64
2 Manning	3 Spares	357	13.27
2 Manning	3 Spares	316	9.84
2 Manning	3 Spares	380	18.44
2 Manning	3 Spares	375	20.10
2 Manning	3 Spares	362	16.68
2 Manning	3 Spares	374	25.39
2 Manning	3 Spares	358	19.75
2 Manning	3 Spares	358	13.33
2 Manning	3 Spares	403	24.46
2 Manning	3 Spares	335	12.96
2 Manning	3 Spares	319	14.82
2 Manning	3 Spares	336	13.00
2 Manning	3 Spares	379	14.40
2 Manning	3 Spares	346	15.47
2 Manning	3 Spares	390	20.47
2 Manning	3 Spares	375	12.62
2 Manning	3 Spares	332	13.56
2 Manning	3 Spares	344	14.29
2 Manning	3 Spares	402	25.74
2 Manning	3 Spares	362	14.08
2 Manning	3 Spares	361	14.68

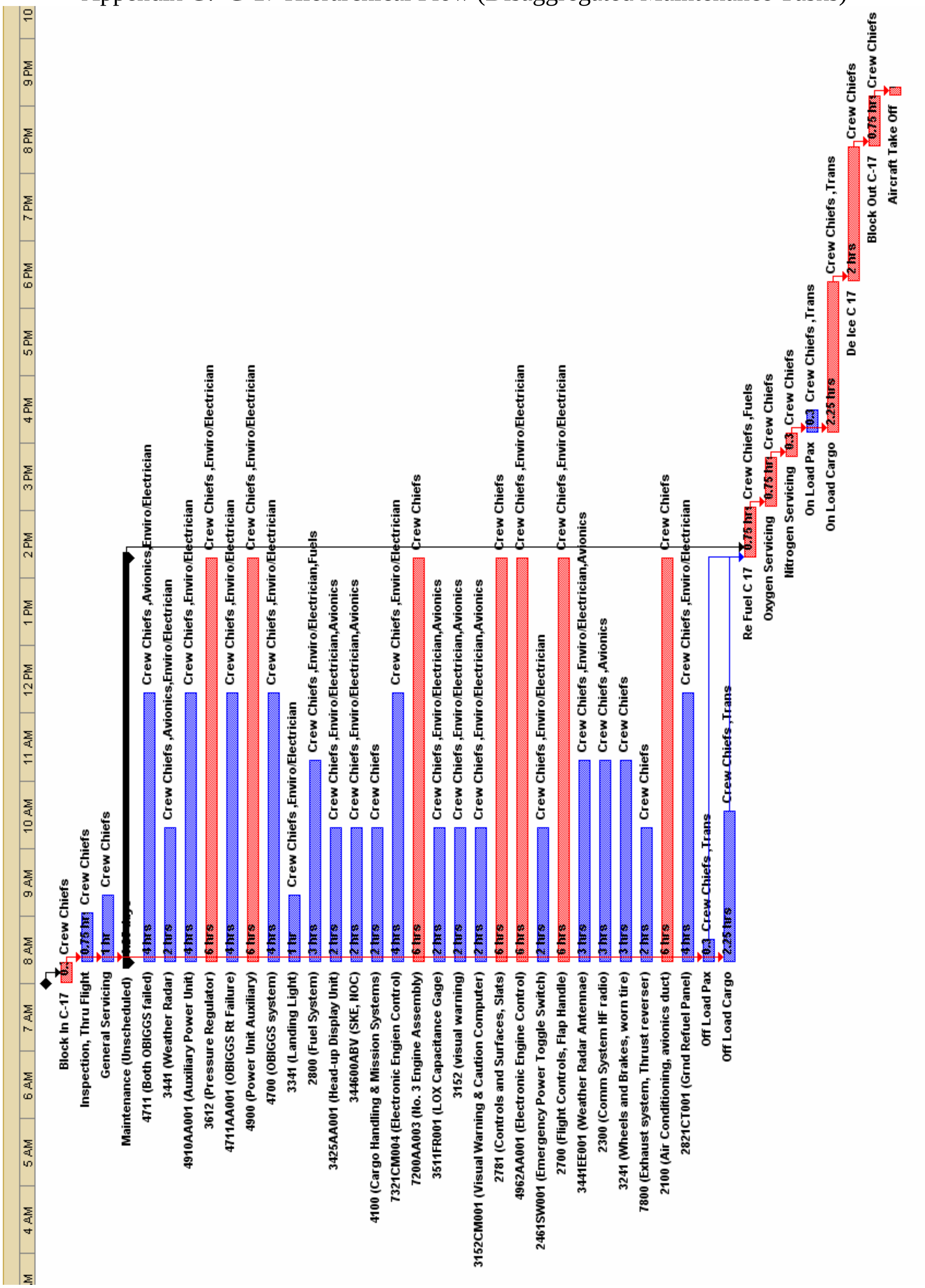
Manning Level	Spares Level	Throughput (C-17/60 Days)	Turn Time (hrs)
2 Manning	1 Spares	394	18.37
2 Manning	1 Spares	345	16.17
2 Manning	1 Spares	353	14.77
2 Manning	1 Spares	334	17.86
2 Manning	1 Spares	342	14.49
2 Manning	1 Spares	344	15.33
2 Manning	1 Spares	380	23.03
2 Manning	1 Spares	364	16.77
2 Manning	1 Spares	324	15.94
2 Manning	1 Spares	340	21.63
2 Manning	1 Spares	364	16.90
2 Manning	1 Spares	346	13.68
2 Manning	1 Spares	354	14.14
2 Manning	1 Spares	312	13.77
2 Manning	1 Spares	340	17.92
2 Manning	1 Spares	333	13.96
2 Manning	1 Spares	373	15.72
2 Manning	1 Spares	326	14.00
2 Manning	1 Spares	354	17.20
2 Manning	1 Spares	412	23.22
2 Manning	1 Spares	320	11.14
2 Manning	1 Spares	370	19.25
2 Manning	1 Spares	334	15.55
2 Manning	1 Spares	333	20.22
2 Manning	1 Spares	364	18.67
2 Manning	1 Spares	356	19.84
2 Manning	1 Spares	379	23.30
2 Manning	1 Spares	369	20.95
2 Manning	1 Spares	387	20.69
2 Manning	1 Spares	365	16.87
2 Manning	1 Spares	385	15.87
2 Manning	1 Spares	379	26.16
2 Manning	1 Spares	335	14.75
2 Manning	1 Spares	370	18.26
2 Manning	1 Spares	390	23.45
2 Manning	1 Spares	342	14.97
2 Manning	1 Spares	374	23.85
2 Manning	1 Spares	370	18.92
2 Manning	1 Spares	326	16.60
2 Manning	1 Spares	358	18.46

Manning Level	Spares Level	Throughput (C-17/60 Days)	Turn Time (hrs)
2 Manning	2 Spares	340	14.84
2 Manning	2 Spares	356	14.19
2 Manning	2 Spares	357	22.02
2 Manning	2 Spares	336	14.78
2 Manning	2 Spares	355	24.02
2 Manning	2 Spares	339	13.20
2 Manning	2 Spares	354	18.11
2 Manning	2 Spares	403	18.74
2 Manning	2 Spares	351	20.19
2 Manning	2 Spares	353	14.95
2 Manning	2 Spares	372	29.60
2 Manning	2 Spares	369	16.14
2 Manning	2 Spares	343	14.41
2 Manning	2 Spares	375	16.67
2 Manning	2 Spares	389	18.24
2 Manning	2 Spares	331	13.80
2 Manning	2 Spares	373	17.47
2 Manning	2 Spares	358	17.61
2 Manning	2 Spares	361	16.36
2 Manning	2 Spares	327	12.85
2 Manning	2 Spares	329	10.45
2 Manning	2 Spares	397	24.47
2 Manning	2 Spares	400	22.92
2 Manning	2 Spares	380	21.56
2 Manning	2 Spares	328	11.48
2 Manning	2 Spares	353	17.46
2 Manning	2 Spares	368	15.60
2 Manning	2 Spares	379	17.85
2 Manning	2 Spares	351	15.45
2 Manning	2 Spares	359	20.97
2 Manning	2 Spares	366	15.62
2 Manning	2 Spares	380	16.17
2 Manning	2 Spares	350	15.82
2 Manning	2 Spares	370	17.36
2 Manning	2 Spares	375	29.48
2 Manning	2 Spares	390	16.13
2 Manning	2 Spares	367	13.45
2 Manning	2 Spares	371	15.67
2 Manning	2 Spares	331	13.98
2 Manning	2 Spares	374	16.13

Appendix F. C-17 Hierarchical Flow (Aggregate Maintenance Tasks)



Appendix G. C-17 Hierarchical Flow (Disaggregated Maintenance Tasks)



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Vita

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His first assignment was at Shaw AFB, South Carolina where he served as Flight Commander, Fabrication Flight, 20th Equipment Maintenance Squadron from June 1994-February 1996. In February 1996, he was then assigned as the Flight Commander, Maintenance Operations Flight, 20th Logistics Support Squadron. He finally served as Sortie Support Flight Commander, 77th Fighter Squadron. In October 1997, he was reassigned to Sheppard AFB, Texas where he served as Flight Commander, Weapons Systems Support Flight, 361st Training Squadron, where he led his flight and squadron to an Outstanding rating during the 1999 Air Education and Training Command Operational Readiness Inspection. In April 2000, he became Flight Commander, Aerospace Propulsion Flight, also in the 361st. In Aug 2000, he was assigned to as Flight Commander, Sortie Generation Flight, 18th Fighter Squadron, Eielson AFB, Alaska. In August 2002, he entered the Graduate School of Engineering and Management, Air Force Institute of Technology. Upon graduation, he will be assigned to the Air Force Logistics Management Agency, Maxwell AFB, Alabama. Capt Huscroft is married.

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14. ABSTRACT

Current aircraft forecasting methods of the Air Mobility Command (AMC) Directorate of Logistics are reliant on the experience of personnel and lead to "after the fact", labor-intensive analysis. These deficiencies led AMC to the development of a Mobility Aircraft Availability Forecasting (MAAF) model. The purpose of the MAAF model is threefold: predict aircraft availability in order to provide the Tanker Airlift Control Center (TACC) with a forecast of aircraft that will be available for AMC mission requirements, provide "what if" capabilities that analyze the effects of tasking and policy changes, and to provide foresight into problems associated with aircraft availability (Briggs, 2003b).
This research uses Arena simulation to model C-17 aircraft generation at a major enroute location to determine how significant the factors of crew chief manning and spares levels affect aircraft throughput and turn-times. From the simulation, ANOVA statistical techniques are applied to determine factor significance. In addition, a hierarchical structure of aircraft generation is generated to include the variability of unscheduled maintenance actions. This provides a more precise analysis of expected turn-time duration, which leads to overall throughput of the system. Ultimately, this research provides an key input to the MAAF project that will enable AMC to predict aircraft availability and provide the TACC with a monthly forecast of the number of aircraft that will be available to fulfill AMC mission requirements.

15. SUBJECT TERMS

Arena Simulation, Aircraft Maintenance, Maintenance, C-17 Aircraft, Aircraft Availability, Mobility Aircraft, Aircraft Throughput, Aircraft Turn-time, Hierarchical Structure

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