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A PERFORMANCE ANALYSIS OF THE AIR FORCE "WAR TIME" LEAN LOGISTICS PIPELINE

THESIS

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Presented to the Faculty of the Graduate School of Logistics and
Acquisition Management
of the Air Force Institute of Technology
Air University
in Partial Fulfillment of the Requirements for the
Degree of Master of Science in Logistics Management

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Preface

The purpose of this research was to determine whether a wartime lean logistics pipeline can maintain acceptable aircraft availability rates in response to induced variations of order and ship time (OST) and flying hours for deployed forces. Consideration of how Lean Logistics would operate in a wartime environment is important because the ability of the logistics infrastructure to support deployed forces is critical to USAF readiness. The results of this research clearly indicate that management attention and further research should be directed towards improving transportation efficiency for shipments to deployed locations and that steps should be taken to minimize variability in the shipment times to these deployed locations.

The completion of this research would not have been possible without the help of several people. We would like to thank our thesis advisor, Major Terrance Pohlen, for his advice, direction, and guidance throughout the process. We would also like to thank Major Mark Kraus for his many insightful and candid comments and the staff at HQ AFMC/XPS for their assistance in comprehending many of the computer programs utilized in this research.

Most of all, we would like to dedicate this thesis to our wives, Carol Gaddis and Julie Haase, because of their unwavering love and support during our entire AFIT experience.

Craig S. Gaddis　　　　David A. Haase

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Glossary

Aircraft Availability:	Aircraft availability is a measure of a flying unit's percentage of fully mission capable aircraft resulting from the total number of expected backorders for that unit (O'Malley, 1983: vi). Aircraft availability directly results from the projected pipeline flow of spares into the deployed theater of operations (Isaacson and Boren, 1993: 33).
Centralized Intermediate Repair Facility:	A Centralized Intermediate Repair Facility (CIRF) is defined as an echelon between bases and depots that provide logistics support (repair and supply) to one or more bases.
Depot:	A centralized repair facility for overhaul and high volume repairs.
Dyna-METRIC	Dynamic Multi-Echelon Technique for Recoverable Item Control (Dyna-METRIC) is a series of capability assessment models developed by RAND to support analytic studying of the logistics system. Version 6, and advanced, hybrid analytic simulation model, the latest version of the Dyna-METRIC series, incorporates the indenture relationship among LRUs and SRUs (Cohen and others, 1991, xxi).
Fully Mission Capable:	Fully Mission Capable (FMC) is an aircraft status indicating that the weapon system can accomplish any of its intended wartime missions (Isaacson and Boren, 1993: xv)
Intermediate-Level Maintenance:	A field activity or facility that performs limited component repairs; includes repair shops on bases and CIRFs (Pyles, 1984: xv).
Lean Levels	Lean Levels are Lean Logistics inventory authorizations that are designed to reduce traditional inventory levels approximately 30-40% by maintaining a system that is much more responsive and efficient (Ramey and Pyles, 1992). These reduced levels of inventory are referred to as Lean Levels.

Lean Production:	A business practice that focuses on the reduction of inventory levels through the utilization of rapid transportation and continuous improvements in all processes (Pyles and Cohen, 1993).
Line-Replaceable Units:	Line-Replaceable Units (LRUs) are components that are removed from aircraft when a discrepancy is suspected (Abell and others, 1192: xx).
Logistics Pipeline:	A network of repair and transportation channels through which repairable and serviceable parts flow as they are removed from their higher assemblies, repaired , and requisitioned from other supply points (Isaacson, and others, 1988: xv).
METRIC:	Multi-Echelon Technique for Recoverable Item Control (METRIC) is a method for estimating requirements for aircraft recoverable spare parts developed by C. C. Sherbrooke (Adams and others, 1993: xii).
Mission Design Series:	A Mission Design Series (MDS) is an alphanumeric designation representing a single USAF aircraft type (e.g. F-15C).
Mobility Readiness Spares Package:	Mobility Readiness Spares Packages (MRSP), a subset of a RSP, are sets of air transportable spare parts that are authorized to help a unit to support its combat operations during the days 1-30 of a deployment (Abell and others, 1992: xxi). MRSPs are packaged for immediate deployment with operational squadrons to support their wartime tasking as outlined in the USAF War Mobilization Plan (Clarkson, 1994: 2).
Monte Carlo Trial:	Replication of an experiment to estimate experimental error in which outcomes are determined purely by chance (Isaacson and Boren, 1993: 2-4).

National Stock Number:	A National Stock Number (NSN) is a unique identification number assigned to spare parts.
Not Repairable This Station:	Not Repairable This Station (NRTS) is a designation given to reparable assets indicating that the item can not be repaired at a specified facility (Isaacson and others, 1988: xv).
Order and Ship Time:	The Order and Ship Time (OST) is the average elapsed time between the initiation and receipt of stock replenishment requisitions from the depot (Christensen and Ewan, 1994: 5).
Readiness Spares Package:	A Readiness Spares Package (RSP) is an additive level of spare parts, above a base's peacetime operating stock, for operational squadrons to support their wartime tasking (Clarkson, 1994: 1). MRSPs, a subset of a RSP, are sets of air transportable spare parts that are authorized to help a unit to support its combat operations during the days 1-30 of a deployment (Abell and others, 1992: xxi).
Reparable Asset:	Those items that can be repaired or reconditioned and returned to a serviceable condition for reuse (Christensen and Ewan, 1985:1).
Remove and Repair:	Remove and Repair (RR) policy implements an organizational structure where a specific component can not be repaired at an intermediate repair facility. Units deploy with only limited component maintenance capability (Pyles, 1984, xvi).
Remove Repair and Replace:	Remove, Repair, and Replace (RRR) policy designates that a specific component can be repaired at an intermediate repair facility (Pyles, 1994: xvi).
Shop-Replaceable Unit:	A Shop-Replaceable Unit (SRU) is a sub-component of an LRU that is typically removed and replaced during intermediate-level repair (Abell and others, 1992: xxi).

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Abstract

Lean Logistics is an innovative proposal designed to reduce the costs associated with reparable inventory management. The purpose of this thesis is to determine whether a wartime lean logistics pipeline can maintain acceptable aircraft availability rates in response to induced variations of order and ship time (OST) and flying hours for deployed forces. The Dyna-METRIC Version 6.4 simulation program was used to evaluate nine different factor-level combinations. The factors, OST and flying hours were varied at three different levels, low, medium, and high. Analysis of the results was accomplished using a two-factor ANOVA. The authors discovered that while increasing OST greatly degraded available aircraft, flying hours did not significantly affect aircraft availability.

A PERFORMANCE ANALYSIS OF THE AIR FORCE "WAR TIME" LEAN LOGISTICS PIPELINE

I. Introduction

Introduction

Lean Logistics is an innovative proposal designed to reduce the costs associated with reparable inventory management. This thesis examines the impact of implementing Lean Logistics in the dynamic environment associated with wartime employment. After providing an overview of the development of the Lean Logistics concept, a research problem statement concerning the application of Lean Logistics to a wartime environment will be discussed. Additionally, this chapter will provide an introduction to the research methodology to be used. Once the research methodology has been addressed, the chapter concludes by providing an overview of the thesis.

Background, Lean Logistics Development

The end of the Cold War has forced the United States Air Force (USAF) to reassess its logistical structure. The demise of the Soviet Union has resulted in nearly a 30 percent reduction in the size of the Air Force. Today, the USAF faces an environment in which units must be able to respond to a wide variety of threats with reduced resources, manpower, equipment, and dollars (Cohen and Pyles, 1992: 1-2). This "new" military environment has challenged the Air Force to develop innovative logistics systems which will ensure the United States maintains a credible defense force (HQ USAF/LGM-2, 1995: 10).

The USAF reparable asset system is currently composed of large base stock levels, high volume depot repair, and long transportation lead times. Because of these characteristics, the system has become too costly and unresponsive for the future needs of a smaller, post Cold War Air Force (Surrey, 1994: 10). Throughout the Cold War era, military planners focused on maintaining high resource levels and developed redundant systems to ensure mission accomplishment (Pagonis and Cruikshank, 1992: 210). In future years, the Air Force will focus on the maintenance of a smaller more flexible force designed to fight major regional conflicts instead of a general engagement against the Soviet Union (HQ USAF/LGM-2, 1995: 11).

The cost conscious nature of the military during the 1990s has encouraged the application of "better" business practices to enhance military operations. The Department of Defense (DOD) began taking a closer look at these potential business applications when Secretary of Defense Cheney implemented the Defense Management Review (DMR) process in the late 1980s. The DMR reevaluated long standing DOD policies and procedures in an attempt to integrate business practices to military operations (Pyles and Cohen, 1992: 1).

In response to Secretary Cheney's initiative, the Air Force and the RAND Corporation began a series of studies in an effort to develop a more effective and efficient concept of logistics operations (Pyles and Cohen, 1993). One of the first initiatives developed was known as Coupling Logistics to Operations to Meet Uncertainty and the Threat (CLOUT). The CLOUT proposal stressed that responsive logistics systems were needed to meet the uncertainties of aircraft spares support through the use of enhanced redistribution systems (Cohen and others, 1991: 20-21). Although CLOUT was never implemented, the proposal identified many important concepts that laid the foundation for additional research that would eventually produce Lean Logistics.

Before Lean Logistics can be defined, the term logistics needs to be properly defined. The term logistics, as it applies to this research, can be defined as:

> The science of planning and carrying out the movement and maintenance of forces. In its most comprehensive sense, those aspects of military operations which deal with design and development, acquisition, storage, movement, distribution, maintenance, evacuation, and disposition of materiel. (Joint Chiefs of Staff, 1994: 221)

Lean Logistics is the conversion of a business practice known as "Lean Production" to the operational readiness and support objectives of military logistics (Russell, 1994: 32). Lean Production focuses on the reduction of inventory levels through the utilization of rapid transportation and continuous improvements in all processes (Pyles and Cohen, 1993).

The implementation of a lean logistics reparable management system represents a departure from traditional logistics practices (HQ USAF/LGM-2, 1995: 11). The success of a streamlined and cost efficient logistics management system will depend on the ability of logistics planners to forecast peacetime as well as wartime reparable requirements (Ramey and Pyles, 1992: 1-3). The USAF began considering Lean Logistics as an approach to reduce costs while maintaining force readiness (HQ USAF/LGM-2, 1995: 11). Initial research on Lean Logistics has explored the possibility of improving the efficiency of peacetime operations. However, this research is still in the early stages and much discord exists on the exact methodology to employ when approaching problems associated with Lean Logistics. Additionally, the dynamic and unpredictable nature of contingency operations could severely strain or overwhelm a "lean" peacetime logistics network. This research will focus on taking the projected lean logistics pipeline and altering key factors to mimic the stresses that result from wartime deployments.

Objectives of Lean Logistics

Lean Logistics can be categorized into three broad objectives: streamlining logistical processes through continuous improvement, reducing operational costs by implementing rapid and flexible repair and distribution concepts, and increasing unit readiness through empowering operational commands.

Streamlining Logistical Processes. Enhancing efficiency at all levels of the Air Force logistics system is at the heart of Lean Logistics. Lean Logistics research has pointed to efficiency within the storage, redistribution, and repair subsystems as a key to reducing logistical costs (Ramey and Pyles, 1992: 2-4). A major focus within the Air Force logistics system is the management of spare parts (HQ USAF/LGM-2, 1995: 7). All USAF reparable inventory is managed through the operation of a perpetual repair cycle system. Decision points within the repair cycle determine if an item is to be repaired and whether that item should be repaired at base level or shipped to a depot repair facility. Delays or inefficiencies at any processing point in the repair cycle can cause a significant portion of the recoverable and reparable inventory to be unavailable for operational use (Cohen and Pyles, 1992: 2-7). As a result, longer lead times or repair times equate to higher reparable inventory levels. Currently, the average length of the pipeline, or the time required for a item to complete the depot repair process and transportation process, is estimated at 58 days: each day equates to an approximately $50.9 million dollar investment in reparable assets (Peterson, 1992: 1).

Air Force policy requires sufficient inventory levels to be maintained at both base and depot level to buffer against uncertainty in demand and lead-times. Uncertainty in demand occurs because spare part failure rates are random over time. Uncertainty in lead times often result from unforeseen events in the repair process. Buffer or protective stock levels are required to ensure acceptable support levels (Tersine, 1994: 205-210). Inventory levels are also driven by inefficiencies in processing reparable items. In many lean logistics scenarios, intermediate-level maintenance requirements would be removed from the processing cycle to expedite the processing of items requiring depot repair (Morrill, 1994: 8). Air Mobility Command (AMC) is currently testing a Lean Logistics plan aimed at eliminating many base level processes that slow the processing of spare parts (Surrey, 1994: 1).

Lean Logistics may significantly impact the repair processes employed within the Air Logistics Centers (ALCs). Instead of operating in a mode of large scale batch repair with many processing queues, Lean Logistics could explore using a more direct and efficient repair of critical assets using techniques such as Distribution and Repair in a Variable Environment (DRIVE) (HQ USAF/LGM-2, 1995: 8). The goal imbedded within

DRIVE is to repair assets in such a way as to achieve a desired Mission Design Series (MDS) aircraft availability rate across multiple bases and commands (Abell and others, 1992: vi-vii). Lean Logistics would totally overhaul the system of mass production for repair and assign individual repair priorities to each part based on real world needs. Depots and contract repair facilities would repair mission impacting items first and enable a quick turnaround of these assets. Additionally, Lean Logistics would introduce a higher degree of managed competition between the depots and contractors to increase efficiency and reduce costs (Camm, 1993: 1-2).

The two main factors that work to accelerate pipeline times under Lean Logistics are reduced transportation times and decreased depot repair time (Pyles and Cohen, 1993: 5). Within this relationship, the transportation times can be viewed as deterministic because of the reliability of commercial overnight package services. Many uncertain factors influence depot repair; therefore, the depot repair component of this relationship presents itself as the probabilistic or unknown element. Successful implementation of a lean depot repair system would be crucial to the effectiveness of a lean logistics system. The task of employing this new method of responsive repair within the ALC system will be challenging. However, under Lean Logistics, robust mission capable weapon systems would depend more heavily than ever before on the depot repair system (Cohen and Pyles, 1992: 4).

A lean logistics system would rely heavily on rapid commercial transportation and next day delivery of spare parts. Instead of transporting assets in days or weeks, the Air Force would be able to redistribute parts nationwide in less than 24 hours (Surrey, 1993).

Due to the speed, flexibility, and consistency in commercial transportation, the opportunity exists to considerably reduce active inventories. The present commercial system could distribute assets very quickly and enable a reduction in movement times of spare parts between bases and repair facilities. This increased speed of spares redistribution could result in lower inventories due to the higher availability of assets within the system (Morrill, 1994: 9). One view of Lean Logistics involves the placing of serviceable stocks at forward storage locations near major air freight distribution hubs. This action is designed to further contribute to providing Air Force managers real time availability of assets worldwide (Surrey, 1994).

Cost Reduction. Streamlining base level processes, enhancing depot repair, and utilizing rapid transportation should reduce operational costs (HQ USAF/LGM-2, 1995: 14). An operational cost is the cost to the government to maintain a weapon system or sub-system in serviceable condition in order to perform its assigned mission. Streamlining processes at both base and depot level could eliminate the waste of large and slow moving inventories resulting from improper management of repair processes (Ramey and Pyles, 1992: 2-3). As stated earlier, the average pipeline time is approximately 58 days, and eliminating even a small portion of this time could result in a greatly reduced need for inventory.

A lean logistics depot repair system could more effectively ensure the assets having the greatest impact on mission readiness would be repaired first. Scheduling tools (such as DRIVE) would direct or prioritize repair of high priority assets (Abell and others, 1992: 87-88). In essence, the depot system would focus on repairing items needed to satisfy specific needs rather than filling shelves. Rapid transportation could result in higher transportation costs, but the overall cost savings from reduced inventory levels should produce significant long term savings (HQ USAF/LGM-2, 1995: 14). The lean logistics concept is designed to eliminate inefficient processes at all levels. At the ALC level, Lean Logistics should eliminate redundant and non-value added processes which could produce large savings for the Air Force. Rapid transportation would act as a multiplier of the benefits gained from these improved depot repair processes.

The Air Force plans to further reduce costs by decentralizing control of weapon system and inventory management by delegating the responsibility to Major Commands (MAJCOMS). The decentralization of asset management will allow Air Force Materiel Command (AFMC) to focus on repairing broken parts. The cost reductions realized from weapon systems management decentralization will result from the increased responsiveness of the system and making better use of available assets. The operational commands would direct which assets are repaired, thus increasing mission capability from a given asset pool. The using command would be more informed on the real world needs and more able to align repair priorities with mission requirements. Therefore, repair would more closely match mission requirements and contribute to increased efficiency in the depot repair system. Rand's CLOUT research found increased responsiveness between the depots and operational commands could increase the efficiency within the repair system (Cohen and others, 1991: 42). Decentralization would put the user in better contact with the source of supply and repair. The desired result of decentralizing weapon system management is increased mission capability from a given asset level, which would result in lower cost for the Air Force.

The overall cost reduction goal of Lean Logistics could be achieved by cutting inventories by over one third (Ramey and Pyles, 1992: 6). Timely and efficient repair of the "lean" asset pool is key to the systems approach of reparable asset management. Additionally, improved depot performance could reduce the need for contract repairs and additional acquisitions, thus further reducing operational costs. A recent study by RAND simulated the operations of the F-16 fleet under a lean logistics system using a computer model. The researchers combined the total cost of transportation, warehousing, and outlays for new spares between the current logistics system and Lean Logistics. The resulting data suggested that Lean Logistics could operate at half the cost of the current system with significantly lower inventory levels (Ramey and Pyles, 1992: 4).

Readiness and Mission Capability. Lean Logistics planners must ensure that the potential cost savings of Lean Logistics do not produce negative results by allowing mission capability and readiness to fall below acceptable levels (Russell, 1994: 32). RAND research, simulating support for the F-16 force, demonstrated that Lean Logistics could adequately support peacetime flying programs. RAND researchers used Dyna-METRIC Version 6 program to simulate 474 F-16s at 10 different CONUS bases during peacetime operations under both the current logistics system and the proposed lean logistics system (Ramey and Pyles, 1992: 4). The results demonstrated that reductions in inventory levels associated with Lean Logistics did not degrade performance of the weapon system. Their research further showed that the lean logistics concept proved to be more responsive to fluctuating demand than the current system.

Decentralized Asset Management. Another important component of the proposed lean logistics system is the decentralization of asset management to operational commands (Cohen and Pyles, 1992: 3). MAJCOM involvement in the daily decisions concerning the logistical support of a weapon system should enhance command awareness of the needs and current capabilities of that system. Currently, several major evaluations of expanded MAJCOM involvement have been completed. AMC conducted a successful lean logistics test of support for the C-5 aircraft (Surrey, 1994). Air Combat Command (ACC) implemented lean logistics concepts to respond to a congressionally mandated test of the B-1B's ability to maintain acceptable mission capable rates (Clarkson, 1994). The success of these two tests established Lean Logistics as a viable concept under controlled peacetime conditions. The concept of decentralized weapon system management is a major change from the past when AFMC item managers determined where and when to redistribute assets. Under Lean Logistics, operational units can ideally have more control over the management of assets that directly impact mission accomplishment.

Lean Logistics Research

Currently, Lean Logistics research is still in the initial stages of development (HQ USAF/LGM-2, 1995: 19). The basic premise for approaching the simulation and study of lean logistics problems is a matter of debate between MAJCOMS and agencies within the USAF. This research presents one of the first attempts to evaluate lean logistics support in a wartime environment. The assumptions made in the process of conducting this research were made in a effort to both match conventional thought toward lean logistics issues and enable the experiment to be conducted within the framework of the Dyna-METRIC computer simulation model.

Problem Definition

This research looks the level of support Lean Logistics would provide deployed wartime forces. The term support and supportability in the context of this research refer to the aircraft availability levels achieved by deployed flying unit under the constraints of a wartime scenario. The problem faced by the USAF is determining the impact of transitioning from peacetime to wartime in a lean logistics scenario. This problem is important to the USAF because Lean Logistics is a system that is designed on the premise of a stable pipeline environment. Wartime deployments may not always produce stable predictable pipeline times or resource consumption rates. The current view toward Lean Logistics is focused on reducing costs in a peacetime environment. The initial drive to conceptualize Lean Logistics has not yet addressed many important questions on the operations of the reparable asset system during wartime.

Research Objective.

The research will determine how a lean logistics system will operate and react in a wartime scenario. The primary measurement for this research will be aircraft availability levels at deployed operational locations. Aircraft availability is a measure of a flying unit's percentage of fully mission capable aircraft resulting from the total number of expected backorders for that unit (O'Malley, 1983: vi). Aircraft availability directly results from the projected pipeline flow of spares into the deployed theater of operations (Isaacson and Boren, 1993: 33). More specifically, the objective of this research is to determine the impact of induced variability in Order and Ship Time (OST) and flying hours on aircraft availability.

Scope of the Research

Lean Logistics encompasses a broad range of factors in its attempt to reduce costs and improve management and efficiency within the reparable assets system. Many factors will influence the system implementation and operation. This study will concentrate on several specific characteristics of the proposed lean logistics pipeline model and its performance. An analysis of aircraft availability will be conducted by examining the main effects and interaction of OST and flying hour variability on the performance of an assumed lean logistics pipeline in a wartime scenario. These two factors were selected because they were both deemed to have a significant impact on deployed operations. Both OST and flying hours would be expected to fluctuate as a result of the dynamics of a wartime environment. OST is the elapsed time, in days, between the initiation and receipt of stock replenishment requisitions from depot and represents the efficiency of the transportation network (Christensen and Ewan, 1994: 5). Flying hours represent the cumulative number of flying hours resulting from the execution of a planned flying program. The selection of the three levels for both of these factors will be based on a range of values that the researchers would expect to observe in a wartime scenario.

The analysis will use the Dyna-METRIC Version 6.4 computer simulation model. The simulation model will be used to produce data for a two factor at three levels analysis of variance experiment. This simulation will utilize the F-15C Mission Design Series (MDS) to measure the effectiveness of lean logistics support. The attributes of a deployed fighter squadron matched the ideal conditions desired for this research. Fighter squadrons deploy with large 30 day spares kits and a remove and replace (RR) maintenance concept. Once the decision was made to select a fighter MDS for this research, the F-15C was an arbitrary choice. Other MDS considerations such as bombers, cargo, and tanker aircraft did not fit as well into the conceptual design of this research because the mission of these aircraft did not provide for multiple sortie generation from and deployed location.

Research Question

Can a wartime lean logistics pipeline maintain acceptable aircraft availability rates in response to induced variations of OST and flying hours for deployed forces? This will be measured through the use of Dyna-METRIC Version 6.4 to produce aircraft availability rates. An aircraft availability rate of 85 percent or higher will be considered adequate to support mission requirements. Inability to achieve a 85 percent or higher aircraft available rate will demonstrate combinations of OST and flying hours that result in degraded mission support.

Limitations of Research

Although this research will attempt to be comprehensive in all aspects of the subject matter, there are limitations to the applicability of the results of this research.

This research is limited by the following factors:

1. The results of this research should be applied only to fighter aircraft operations. This experiment is configured around a deployed fighter operations environment. The results of this research should not be extrapolated to other aircraft types such as bomber, cargo, and tankers with deployed missions and spares support that are different from a typical fighter unit.

2. It is assumed in this research that item failure rates are strictly correlated to flying hours. The computer simulation model, Dyna-METRIC Version 6.4, used in this research generates item failures on the basis of total flying hours. The results should not be applied to systems where failure rates are not strictly correlated to flying hours.

3. The results of this research should be generalized only within the time frame of this wartime simulation and within the parameters of the mission constraints placed upon the simulation model constructed for this research. The results of this research apply only to situations where the experimental conditions are the same as those applied to this research.

Assumptions

Due to the working nature of the Lean Logistics concept, this research will make several assumptions concerning its final form. Also, the uncertain nature of wartime scenarios and the systems of support for deployed forces will require additional assumptions. The assumptions made in this research effort are:

1. Initial spares availability and their location within the modeled pipeline network will be determined through the application of the Aircraft Sustainability Model (ASM). This action is necessary to ensure that the proper initial conditions are set for the computer simulation model. This assumption will not allow the application of lean stock levels to this research. Lean Levels are unconstrained in nature and do not account for depot repair; however, calculation of system stock levels using the ASM method can build stock levels to reflect a desired aircraft availability goal and a constant depot repair time.

2. Depot repair times will be assumed constant. Within lean logistics, depot repair times are an important factor in determining the support level of the system; however, the issue of depot repair processes in a lean logistics environment is very large and beyond the scope of this research. This assumption will limit this research in that we will not be able to measure the impact of variation in depot repair time on a lean logistics wartime analysis.

3. The variable factors our analysis will consider include the variability of OST and flying hours resulting from wartime deployment scenarios. All other relevant input factors will be held constant throughout the experiment.

Methodology

Design. The aircraft support environment that this research will evaluate reflects the uncertainty and variability in a wartime scenario. This type of environment does not lend itself to analytical model analysis because induced constraints result in deterministic outcomes rather than the desired probabilistic outcomes (Isaacson and Boren, 1993: 1-3). That is, analytical models produce the same results on successive runs due to the fact that there are no randomized factors in the model. The design of this research involves the use of a computer simulation model, Dyna-METRIC Version 6.4, to simulate the processes of a wartime lean logistics pipeline. This simulation model was selected because it utilizes Monte Carlo sampling, which allows probabilistic outcomes at critical decision points such as repair and distribution (Isaacson and Boren, 1993: 3-4). Additionally, Dyna-METRIC was specifically designed by RAND to simulate USAF logistics pipeline performance in a dynamic wartime environment (Isaacson and Boren, 1993: 1).

The basic design of our research experiment is a factorial design, with two factors at three levels. The two factors within this research are OST and flying hours. Each factor has three levels which will represent a range of low, medium, and high values. This 3^2 factorial design will produce 9 treatments which allow for all possible combinations of factor levels.

Implementation. The Dyna-METRIC model will simulate the logistical support for four deployed F-15C squadrons flying under a wartime scenario. The sample data used to assess this MDS will include the top 25 demanded LRUs assigned to the F-15C's Mobility Readiness Spares Package (MRSP). HQ AFMC/XPS has conducted studies verifying that the top 25 problem LRUs will provide nearly identical results to running a Dyna-METRIC analysis using all authorized MRSP items (Nicklas, 1995). The required National Stock Number (NSN) data will include the demand rates and total asset position in the logistics pipeline. Factors internal to the Dyna-METRIC Version 6.4 program will be designed to simulate a wartime lean logistics pipeline environment.

Analysis. The data generated from this research will be evaluated through the analysis of variance (ANOVA) technique. The ANOVA technique will be used to test for differences between treatment means, the main effect of each factor, and possible interaction between main effects. The ANOVA hypothesis testing will allow conclusions to be drawn on the impact of the individual factors and the interaction of the factors on aircraft availability levels in a wartime lean logistics scenario.

Management Implications

The issue of wartime support under a lean logistics concept is a very important issue for the USAF to consider. Determining whether a system designed for streamlined and cost effective peacetime operations can provide adequate support to deployed wartime forces could be critical to the long-term viability of Lean Logistics. This research will attempt to evaluate this issue and identify important factors in determining the viability of Lean Logistics in a wartime scenario.

Thesis Overview

This chapter presented the reasons underlying the need for a Lean Logistics wartime study. Chapter II will summarize the literature that addresses the relevant issues concerning Lean Logistics activities as they relate to a wartime environment. The topics covered in Chapter II will include: current reparable pipeline and reparable item policy, RSPs, the support of deployed forces, an analysis of Dyna-METRIC, and a comprehensive analysis of lean logistics proposals.

Chapter III will describe in detail the methodology that will be utilized in this research. The research design will be detailed using the information compiled in Chapter II. In addition, all issues relative to statistical analysis will be discussed. This discussion will include a detailed explanation of the ANOVA process, ANOVA model, and underlying assumptions that must be met. Furthermore, Chapter III will address factors concerned with setting the initial conditions of the experiment.

Chapter IV will present the analysis results of the experiment that is outlined in Chapter III. Chapter V will summarize the research, draw conclusions, recommend management action, identify the implications of the findings, and provide recommendations for future research.

II. Literature Review

Introduction

During the early 1990s and into the foreseeable future, the Air Force faces reduced resources, manpower, equipment, and dollars (Cohen and Pyles, 1992: 1-2). Lean Logistics is a concept the Air Force is considering to improve the way scarce logistics resources are managed (HQ USAF/LGM-2, 1995: 10). This chapter provides a comprehensive review of the literature relevant to conducting a wartime analysis of the proposed lean logistics system. The main components of both the current logistics system and proposed lean logistics innovations will be explored. This chapter will begin by defining the characteristics of a logistics pipeline and analyzing the Air Force reparable asset pipeline by defining its major components. The impact of RSPs on logistics support will then be addressed due to the important role RSPs play in wartime mission support. The Dynamic Multi-Echelon Technique for Recoverable Item Control (Dyna-METRIC) assessment model and its impact as a management tool on unit assessments will be discussed to show how logistical resources can be expressed in terms of measurable mission capability. Finally, a comprehensive review of the concepts behind Lean Logistics will be presented.

Reparable Items

The Department of Defense (DOD) measures capability in terms of mission readiness (Russell, 1994: 32). Readiness is defined by the Joint Chiefs of Staff as: "the ability of forces, units, weapon systems, or equipment to deliver the output for which they were designed" (Joint Chiefs of Staff, 1994: 221). One important way the Air Force evaluates its mission readiness is in terms of aircraft availability, which is a measure of the mission capability resulting from available logistical assets. The assets of primary importance in determining mission readiness are aircraft reparable spares.

Reparable spare parts, unlike high volume consumables, are typically complex, expensive, and in low demand. Thus, the management of reparable assets requires intense scrutiny. To clarify the term reparable asset, Christensen and Ewan define reparables as: "...those items that may be repaired or reconditioned and returned to a serviceable condition for reuse. The term reparable denotes the logistics status of an item rather than the condition of an item" (Christensen and Ewan, 1985: 1). In common practice, the term repairable is used to describe the condition of a reparable item. Reparables repaired at a depot require complete rebuild or major overhauls using more extensive facilities and equipment than are available at the base or at intermediate levels (Peterson, 1992: 1). This situation is representative of a multi-echelon systems. The two primary echelons in this system are base level organizations and depots. Figure 2.1 demonstrates the echelon relationship between bases and a depot.

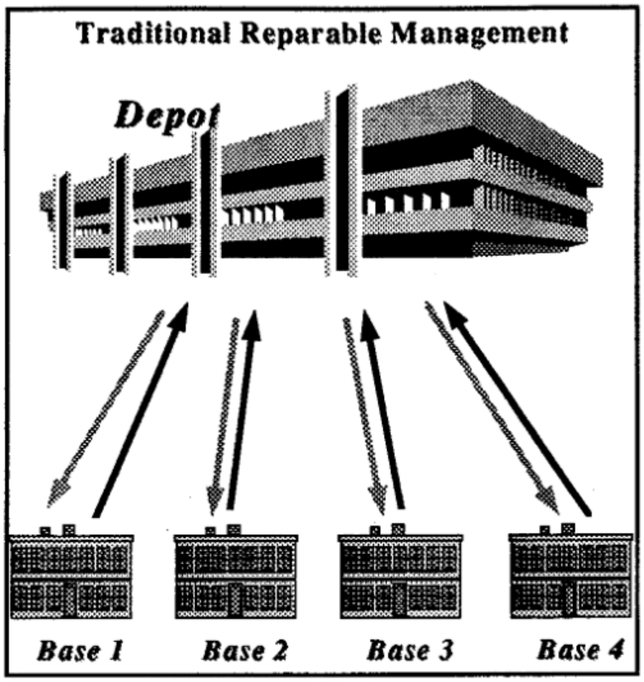


Figure 2.1 Traditional Reparable Management Interface

LRUs and SRUs. A major class of Air Force reparable items are categorized as Line Replaceable Units (LRU). An LRU is defined as: "a component that can be removed from the aircraft and replaced on the flight line" (Isaacson and Boren, 1993: xv).

When an LRU fails, base-level maintenance personnel replace the entire unit with an identical unit from base stock. LRUs that can not be repaired at the field level are classified as Not Repairable This Station (NRTS). All NRTS items are processed through base supply and sent to a higher echelon for repair. Each LRU is made up of Shop Replacement Unit (SRU) components that are typically removed and replaced during intermediate level repair (Abell and others, 1992: xxi). This is what is known as an indenture relationship; that is one LRU is composed of several SRUs. An SRU is "a sub-component of an LRU, it can be removed from the LRU in the shop" (Isaacson and Boren, 1993: xv).

USAF Stockage Policy. Stockage policy determines how much inventory an organization holds or accumulates. Stockage policies generally consider: purchase economies, transportation savings, safety stock, speculative purchases, and maintenance of supply sources (Coyle and others, 1992: 194-195). The USAF uses an (S-1,S) inventory policy for reparable asset management because it is a policy designed "for reparable items which typically are expensive and have low demands rates" (Christensen, 1994: 3). (S-1,S) is a continuous review reorder policy with an order quantity of one. This reorder policy implies that whenever the base's stock on hand plus due-ins minus due-outs fall below the stock level, a replenishment requisition is sent to the depot by the base (Gaver, 1993: 3).

At the base-level, the Repair Cycle Demand Level (RCDL) inventory model incorporates the (S-1, S) inventory policies. RCDL is implemented via the Standard Base Supply System (SBSS) and applies to reparable items ordered on a one-for-one basis. The following definition describes of the objectives of the RCDL:

> The RCDL model calculates spare stocks, or repair cycle demands levels, tailored to individual base repair capabilities as a result of the application of the stockage policies used by base-level managers. The RCDL model does not attempt to minimize or maximize any measure of supply performance. Simply, the stock levels are set to fill pipelines for both the time an asset is in the repair and depot-to-base replenishment cycles, with a set safety quantity added for protection against stock-out. (Military Logistics, 1990: 7-32)

The Repair Cycle Demand Level Model (RCDL) as shown below takes into account the not reparable this station quantity (NCQ), base repair cycle quantity (RCQ), order and ship time quantity (OSTQ), safety levels quantity (SLQ), and a constant factor (K) to compute the necessary stock on hand (s) to meet current demand (Christensen and Ewan, 1994:4). The RCDL model which constitutes the Standard Base Supply System (SBSS) method of computing the base reparable stock level (s) is shown as below in equation (1):

$$s = RCQ + OSTQ + NCQ + SLQ + K \qquad (1)$$

The individual quantities of the RCDL model are computed as follows:

$$RCQ = DDR * PBR * RCT$$

$$OSTQ = DDR * (1\text{-}PBR) * OST$$

$$NCQ = DDR * (1\text{-}PBR) * NCT$$

$$SLQ = C * \sqrt{3 * (RXCQ + OSTQ + NCQ)}$$

K = .5 if unit cost is greater than $750, or .9 if unit cost is $750 or less

Table 2.1 presents the formulas for calculating each component of the RCDL model.

TABLE 2.1

RCDL INDIVIDUAL COMPONENT FORMULAS (Christensen and Ewan, 1994: 4-5)

Quantity	Definition	Formula
DDR	Daily Demand Rate	$\frac{\text{Cumulative recurring demands}}{\text{max of (180 days, current Julian date - DOFD)}}$
PBR	Percent Base Repair	$\frac{\text{number repaired units x 100}}{\text{sum of unit repaired, NRTS, condemned}}$
RCT	Repair Cycle time	$\frac{\text{sum repair days}}{\text{number repaired}}$
NCT	NRTS Condemned Time	$\frac{\text{sum NRTS/condemned stock}}{\text{Number NRTS/condemned}}$
OST	Order and Ship Time	$\frac{\text{Sum of base to depot ship days}}{\text{number of receipts}}$
C	C factor, or number of standard deviations to protect against stockouts	N/A

Current USAF Reparable Status. Ninety-five percent of the investment in supplies stocked at a typical base supply organization is spent on reparable items (Christensen and Ewan, 1985: 3). Reductions in defense spending over the past decade have made efficient management of this significant portion of the Air Force's operational costs very important. From the Air Force perspective, mission readiness is a direct result of spare part levels and aircraft availability. Maintaining large stores of spare parts has been an expensive but necessary requirement for the Air Force.

Recently, the Air Force has made some important changes in the area of reparable management. Depot Level Reparables (DLRs) are no longer centrally funded for use by operational units. Organizational commanders must fund for these items out of budgeted Operations and Maintenance funds. Also, the Air Force is converting some units to a Two-Level Maintenance (2LM) concept (Morrill, 1994: 8). 2LM is a concept in which units maintain minimal on-base repair capability. As a result, when a failed LRU is removed from an aircraft, it is generally identified as NRTS except in situations when repair is authorized at base level. The aircraft is returned to fully mission capable status by replacing the failed LRU with an identical asset from base stocks (DeGroot, 1988: 8-10). Minimizing on-base repair highlights the importance of this multi-echelon relationship. Under 2LM, transportation and repair times are a larger factor in spare parts management because base-level maintenance functions no longer maintain SRU repair capability.

Logistics Pipeline Characteristics

The concept of a logistics pipeline provides the foundation for the understanding the reparable asset system. All logistics pipelines have the attributes of length, diameter, and volume (Bond and Ruth, 1989: 5). The characteristics of a typical reparable asset system, as defined by Bond and Ruth, include:

1. Length: The length of the pipeline represents the time assets are in the reparable asset pipeline. For example, length could include the number of days required to take an item from when it fails on the aircraft, process it through supply, transportation, and repair channels, and then returned it to active stock.

2. Diameter: The pipeline diameter represents the maximum number of items that may flow through the pipeline or be held in any one segment. For example, the number of units that can be repaired at the depot in one day or the number of assets a base submits as NRTS during one week.

3. Volume: The pipeline volume represents the number of assets in the system.

When the dimensions of a pipeline are combined with the processes that must occur for a repairable asset to be repaired, the pipeline takes form in a shape that can easily be modeled. Following is an analysis of the Air Force pipeline to include base and depot-level interfaces and transportation links between echelons.

Air Force Reparable Asset Pipeline. The Air Force logistics pipeline can be defined as the expected number of items of a particular type in resupply (Gaver, 1993: 4). In simplest terms, the Air Force logistics pipeline is a system of supply, repair, and transportation activities that together form a distribution network for unserviceable and serviceable spares. The following is a pictorial depiction of the Air Force reparable asset pipeline. The numbers represented in Figure 2.2 do not represent a single asset, instead they represent the average values for all assets.

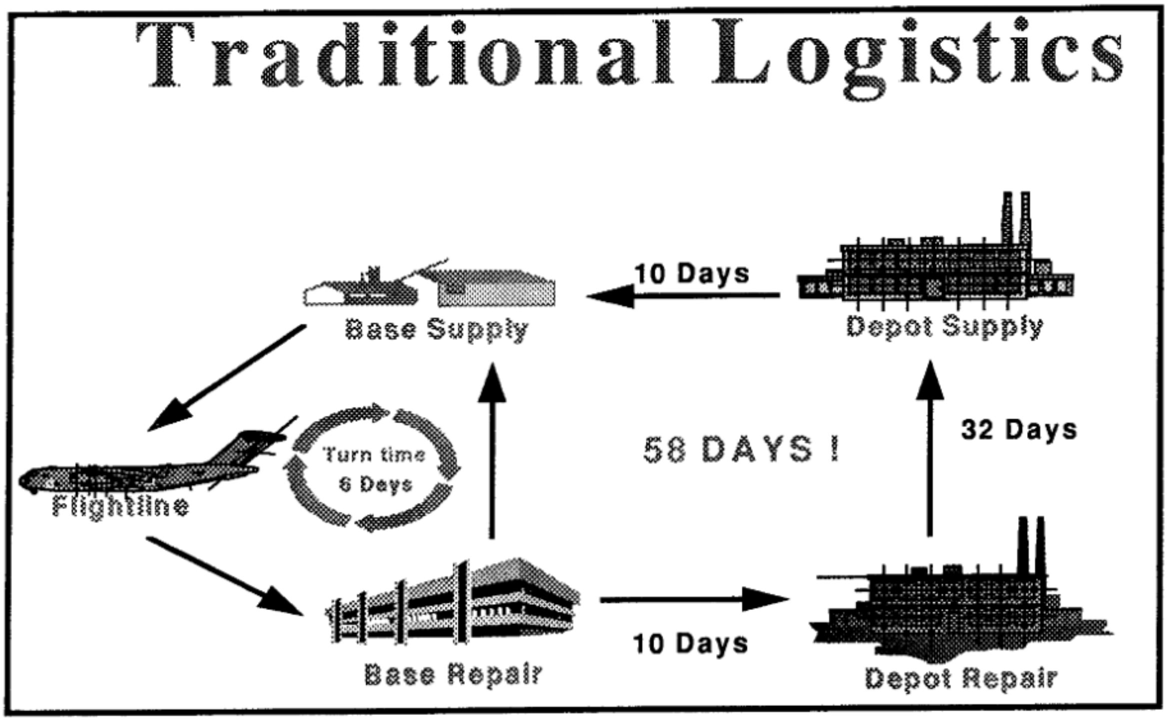


Figure 2.2 Traditional Reparable Asset Pipeline (HQ AMC Slide Package, 1994)

Base-Level Interface. When an aircraft reparable part fails, base level maintenance personnel initiate action in the reparable asset pipeline. Maintenance personnel determine whether or not the LRU is repairable at their echelon. If the item is determined to be NRTS, it begins the process characteristic of the reparable asset pipeline. First, the asset is sent from base maintenance to base supply. Second, base supply personnel request disposition instructions from the depot item manager. Third, the asset is prepared for transportation. Finally, base transportation arranges transportation for the failed asset to the servicing depot (Peterson, 1992: 2). Figure 2.3 is a representation of the base/depot interface in the reparable asset repair process.

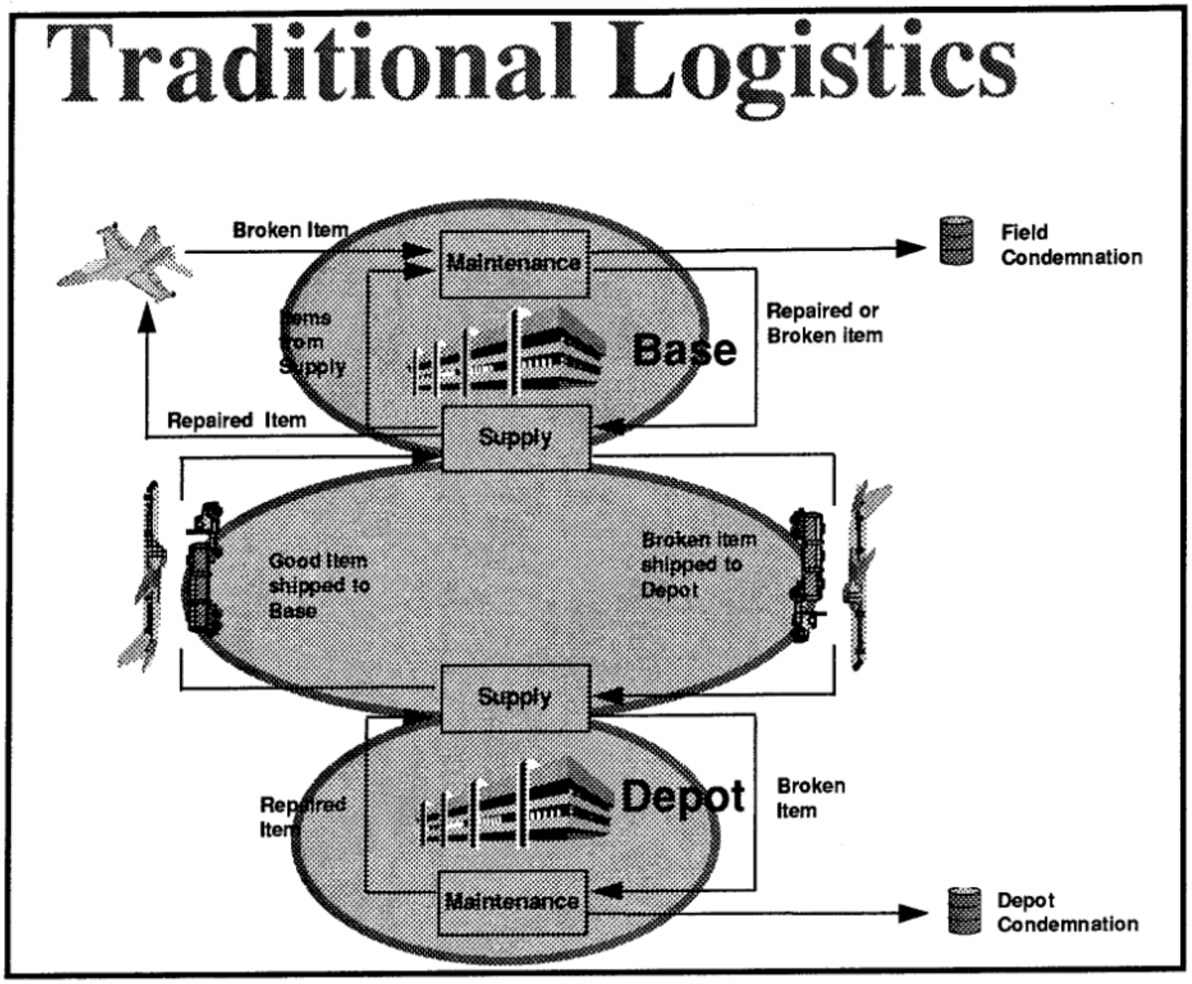


Figure 2.3 Base/Depot Interface

Another characteristic of how a base interacts with the reparable asset pipeline is the employed repair concept. The Air Force currently implements two different maintenance organizational concepts. These maintenance organizations are either configured as Remove, Repair and Replace (RRR) or Remove and Replace (RR) operations.

RRR maintenance policy, which is also know as Three Level Maintenance (3LM), assumes that each unit possesses an on-base repair capability. RRR reduces dependence on the logistics pipeline, because the on-base repair capability inherent in RRR represents a self-sufficient portion of the overall pipeline process. Base-level processing of reparables tends to be slower because of the base repair process. The two results of a RRR concept are higher base repair percentages and longer NRTS processing times. As a result of external constraints such as reduced manpower and budgets, the Air Force is examining alternatives to the manpower intensive RRR concept. The main alternative to RRR is the implementation of a RR maintenance concept (Morrill, 1994: 8).

RR is a process where most base-level repair capability is eliminated in favor of a streamlined and responsive depot repair process. RR is an effort by the Air Force to minimize cost and manpower in support of daily aircraft operations by centralizing repair at depot facilities. The conversion from RRR to RR concepts is designed to reduce the infrastructure of flying units. However, this action also places an increased emphasis on the performance of the reparable asset pipeline. Approximately 80 percent of the Air Force's major weapon systems are converting to RR maintenance (Cox, 1993). An RR maintenance organization will rely on base stocks and depot responsiveness rather than internal repair capabilities. As a result, maintenance personnel will remove failed LRUs from the aircraft, and replace them with spare LRUs from supply. The broken LRU is placed in the reparable asset pipeline and repaired at a depot.

Depot-Level Interface. Under both RR and RRR maintenance concepts, items requiring repair beyond the capability of the base enter the depot portion of the Air Force reparable asset pipeline. When a defective LRU is removed from an aircraft, a reparable generation occurs (Abell and others, 1993: 6). Maintenance activities confirm the status of the reparable asset, and either repair it or forward it to supply identified as a NRTS item. Supply personnel then forward the unserviceable NRTS asset to the applicable depot. The NRTS unserviceable asset en route from the base to the depot is said to be in retrograde.

Transportation. Transportation is the link between the bases and the depots within the reparable asset pipeline. This link plays an important role in management decisions because of potential trade-off between inventory and transportation costs (Coyle and others, 1992: 9). The term trade-off refers to the process of investing resources in transportation in anticipation of achieving greater savings in inventory costs. In the Air Force, transportation times are commonly associated with OST (Christensen and Ewan, 1994: 4). The retrograde portion of the transportation link refers to the movement of unserviceable assets between base and depot level. The OST begins when the base submits a request to the depot to repair or replace a NRTS item and lasts until a replacement unit is received at the originating base (Peterson, 1992: 3). Air Force stockage policy is designed to not only satisfy demands, but also provide support during OST (Christensen and Ewan, 1994: 4). Therefore, since OST constitutes a significant portion of the transportation time, it has a significant impact on stockage levels. A detailed discussion of how OST effects reparable inventory levels is addressed later in this chapter in the section on Lean Logistics. While the USAF transportation system effectively supports extremely diverse organizations, it is generally characterized by slow transportation, long lead-times, large inventories, and high costs (Surrey, 1994: 12).

Summary. The Air Force reparable asset pipeline consists of an extensive network of interrelated systems. The effectiveness of this pipeline is essential if the Air Force is to continue achieving a high state of readiness. Additionally, wartime deployments can disrupt the normal operations of the extended logistics pipeline. To ensure deployed units can operate effectively when decoupled from the traditional pipeline environment, the USAF has implemented programs where assets categorized as War Reserve Material (WRM) are maintained as a separate entity apart from the pipeline. The most important WRM asset maintained is the Readiness Spares Package (RSP).

Readiness Spares Packages

This section will begin by providing a background on USAF wartime concepts. Additionally, this section will introduce the major systems related to RSP development and operations. Following the background information, RSP development and computation procedures will be discussed. Finally, the impact of RSPs on deployed forces will be discussed.

Overview of USAF Wartime Concepts. RSPs are a major factor for ensuring the reliability and maintainability of deployed combat forces. RSPs are additive levels of spare parts above a base's peacetime operating stock. Mobility Readiness Spares Packages (MRSP), a subset of RSPs, are packaged for immediate deployment with operational squadrons to support their wartime tasking as outlined in the USAF War Mobilization Plan (WMP) (Clarkson, 1994: 2). MRSPs provide the range and depth of spare parts required to support deployed forces. The Air Force reparable asset pipeline must support both wartime and peacetime scenarios with the same physical infrastructure. Also, MRSPs enable deployed forces to achieve desired aircraft availability goals in dynamic wartime situations by temporarily decoupling the deployed unit from the supply and transportation functions of the reparable asset pipeline. MRSPs give units the ability to sustain operations and allow deployed forces to operate independently from the reparable asset pipeline.

The Vietnam War prompted the development of War Readiness Spares Kit (WRSK), a sub-component of War Reserve Materiel (WRM), as a means of providing aircraft spare parts support for combat aircraft until a routine supply system could be established (Lee, 1993: 29). In the early 1990s, the WRSKs were renamed Mobility Readiness Spares Packages (MRSP). MRSPs contain both consumable and reparable parts.

The RR maintenance process is used in both home station operations and deployment scenarios. Maintenance technicians practice RR techniques and support aircraft requirements from deployed MRSP packages. RR MRSPs have a computed quantity of each authorized LRU necessary to support flying operations for a specified period of time. Currently MRSP computations assume no resupply of any kind takes place for 30 days.

RSP Computing Formulation. The following sections introduce the major Air Force objectives, systems, and techniques related to RSP development and operations. The techniques discussed are: marginal analysis, Direct Support Objective (DSO), Recoverable Item Consumption Requirements Computation System (D041), and the Weapon System Management Information System (WSMIS).

Marginal Analysis. In an attempt to find the least-cost mix of spares needed to attain a specific capability, the Air Force uses a technique called marginal analysis (King and Mattern, 1989: 7). Marginal analysis allows the Air Force to take a systems approach to stockage decisions. Marginal analysis is a mathematical technique that enables the Air Force to take expected backorder values and determine the implications on aircraft availability of adding the next unit of an item to a specific inventory system. In other words, for every stockage decision, marginal analysis considers the systems implications of adding the next unit of an item to inventory to get the "most bang for the buck".

Direct Support Objective (DSO). The DSO is outlined in the USAF WMP and indicates the acceptable number of aircraft not mission capable for supply (NMCS) on a specified day of a wartime scenario (Clarkson, 1994: 2). The original Dyna-METRIC model accurately modeled the indenture relationships between LRUs and SRUs; however, it did not find the least cost mix to meet given weapon system availability (Blazer and Rippy, 1988: 2). RAND modified the Dyna-METRIC model to minimize the cost of achieving an 80 percent probability of meeting the Air Force directed aircraft availability target. The modified model finds the least cost mix of LRUs and SRUs in provisioning weapon systems (Blazer and others, 1988: 2).

The Recoverable Item Consumption Requirements Computation System (D041). The D041 is a management information system designed to collect peacetime demand rates and other item factors for all spare parts in the Air Force. The D041 uses an eight-quarter moving average to compute the worldwide average requirements on the basis of data contained in the item record. Item-specific data include factors such as base repair rate, condemnation rate, and total demands. The system is updated each quarter by adding the current quarter's item factors data and dropping the oldest quarter of data (Department of the Air Force, 1986: 9-1). The D041 reporting system predicts future requirements by accumulating data on spare parts as they circulate through the reparable spare parts pipeline (Jones and Turco, 1993: 9). The D041 system is designed and intended for use in a peacetime environment. Wartime item requirements computations are completed through the Weapon System Management Information System.

Weapon System Management Information System (WSMIS). In 1981 WSMIS was developed by Air Force Logistics Command to assess the Air Force's capability to deploy on a sustain combat operations (Jones and Turco, 1993: 16). WSMIS is the primary system in AFMC that provides the capability to view the impact of the worldwide asset position on our potential wartime capabilities. In 1990, Air Force policy required that all RSP reparable item requirements be computed using the WSMIS model (Department of the Air Force, 1990: 33). WSMIS contains five separate but interactive elements:

> (1) Readiness Assessment Module (RAM), which assesses current aircraft availability; (2) Sustainability Assessment Module (SAM), which projects combat capability with available resources over time; (3) Get Well Assessment Module (GWAM), which provides information to resolve logistics problems; (4) Requirements Execution Availability Logistics Module (REALM), which provides the capability to compute requirements

> and identifies budget priorities bases on those requirements; and (5) Distribution and Repair In Variable Environments (DRIVE), which provides information to manage the depot repair and distribution process in both peacetime and war. (Jones and Turco, 1993: 16-17)

RSP Development. The overall source of USAF WRM authorizations is the HQ USAF WMP document. The guidance contained in the WMP establishes the need for WRM levels designed to support forces executing their wartime missions (AFI 25-101, 1994: 39). WMP 1, Logistics Annex, contains the guidance each MAJCOM needs to determine their WRM requirements as well as assess their current WRM capability and existing shortfalls (DeGroot, 1988: 12). HQ AFMC is responsible for computing the WRM spares requirements for every weapon system. Although AFMC performs the requirement computation, each MAJCOM plays a significant role in computing requirements (Stone, 1990: 1). RSP requirements are updated yearly based on user inputs and MAJCOM review.

RSP Computations. The RSP is designed to provide a maximum of thirty days of dedicated support until resupply can be established (Department of the Air Force, 1990: 32). RSPs contain the repair components and spare parts needed to sustain contingency operations (without resupply) until normal supply actions are resumed. Follow-on support spares are designed for continued support after the 30 day RSP window.

Each RSP is computed to support a specific sortie and flying hour program. The WMP specifies the sortie rate and average sortie duration for the tasked unit. The sortie rate is the total number of sorties per day divided by the total number of aircraft on-station. The average sortie duration is the total hours flown per time period divided by the total numbers of sorties flown (Department of the Air Force, 1990: 33). This information enables logistics planners to compute an RSP that supports a unit's sortie requirements in accordance with the established DSO.

The first MRSPs were designated "conventional" kits and were built with simple computations. The conventional kits were computed by determining the average number of demands for each item. The item demand determined how many of each item was included in the RSP. These primitive computations ignored variability in both demand and repair capability (King and Mattern, 1989: 7). The Air Force approach to authorizing MRSPs was not based on scientific methods, but on a non-optimal procedure. A non-optimal procedure was nothing more than user developed heuristics designed to provide acceptable aircraft performance

RSP Support of Deployed Forces. The concept of deployed supply support involves each unit deploying with its own cadre of supply personnel for management of the RSPs. Supply personnel in conjunction with deployed maintenance personnel would establish a repair cycle system at the deployed location. During the initial stages of the deployment, repair capability is limited and most reparables would be shipped to either a Centralized Intermediate Repair Facility (CIRF) located in the deployed theater or stateside depots for repair. All spares requirements not satisfied by the MRSP would be backordered through a centralized supply support activity.

The logistical support of deployed forces is accomplished through the operations of a multi-echelon system of repair and resupply. The first echelon in the system is the peacetime maintenance of RSPs. The act of deployment is a relocation of this first echelon. A possible second echelon is the CIRF and lateral supply sources within the deployed theater. The third echelon is the depot repair system and available assets at stateside bases. Each echelon of support is an important processing loop in the reparable pipeline. The efficient management of this pipeline is crucial to meeting established DSOs for the execution of operational plans.

Dyna-METRIC Assessment Models

This section discusses the Dyna-METRIC model. After providing an overview of the model, the version important to this research effort, Version 6.4, will be analyzed and its output measure, aircraft availability, will be defined. This section concludes by describing how Dyna-METRIC models the Air Force logistics pipeline.

Pipeline Simulation. The Air Force makes extensive use of computer models to solve management problems. In logistics, the Dyna-METRIC series, which includes both analytical and simulation models, can be used to compute wartime requirements and to model the operations of real world logistics systems. The latest release of the program series is Version 6.4, which is designed to assess and model the processes of a dynamic wartime logistics pipeline (Isaacson and Boren , 1993: 1). All Dyna-METRIC programs are based upon the development of the METRIC concept.

METRIC. In the 1960s, the Air Force began researching new ways of measuring combat capability relative to logistical resources. During this time, the Air Force developed a philosophy of providing the end users of the logistics resupply systems with a forecast of expected support. The goal of this research was to ensure necessary corrective actions could be taken prior contingency operations (Pyles, 1984: 3). This research lead to the development of the initial METRIC analytical model. METRIC also brought to the forefront of logistics planning the concept of a systems approach (Sherbrooke, 1968: 1). The systems approach differed from traditional management techniques in that it set "optimal" inventory stockage levels by location with the overall goal of achieving a pre-determined level of system-wide performance. METRIC gave the USAF the ability to determine both requirements and distribution of recoverable items in a two-echelon inventory system (Muckstadt, 1973: 472). The evolution of METRIC led to the development of assessment programs in the 1980s.

Dyna-METRIC. The METRIC concept as applied through the Dyna-METRIC programs provided the Air Force with the ability to accurately assess mission capability resulting from a given volume of aircraft spares. Dyna-METRIC applications are used to measure readiness in peacetime as well as combat capability in wartime scenarios. The Dyna-METRIC series of programs were initially developed in the early 1980s to enhance the modeling of logistics support in a dynamic wartime environment. The key characteristic of a dynamic environment is the uncertainty found in both logistical and operational areas. Some of the elements that contribute to the uncertainty in a dynamic pipeline environment are component demand variation resulting from changes in flying hours, repair capacity constraints, and information lags (Isaacson and Boren, 1993: 2). Dyna-METRIC predicts the availability of aircraft at one or more bases located in one or more theaters given a planned operating scenario and dynamic constraints. It is designed to model aircraft availability as a direct function of the accessibility of the aircraft's components (Isaacson and Boren, 1993: 5). Aircraft availability is a flying unit's percentage of fully mission capable (FMC) aircraft resulting directly from supply support. Dyna-METRIC forecasts future aircraft operational performance through a mathematical evaluation of the available wartime logistics resources and associated support processes. Dyna-METRIC provides the Air Force with many user-selected capabilities that model the effects of both repair constraints and priority repair management.

The two currently used variants of Dyna-METRIC are Versions 4 and 6.4. These two models differ greatly in that the former is an analytical model and the latter is a simulation model. In order to clearly define the differences between the two versions and the original METRIC model, Table 2.2 is provided.

TABLE 2.2

MODEL COMPARISON (Isaacson and Boren, 1993: v-3)

MODEL	**Type of Model**	**Outcome Analysis**	**Demand Environment**	**Indenture Relationships**
METRIC	Analytical	Requirements	Steady	Single
Dyna-METRIC Version 4	Analytical	Requirements/ Assessment	Dynamic	Multiple
Dyna-METRIC Version 6.4	Simulation (Monte Carlo sampling)	Assessment	Dynamic	Multiple

The information in Table 2.2 illustrates that Version 4 is best suited for requirements computation and peacetime performance assessments. This fact is due to the analytical and deterministic nature of Version 4's output results. The use of analytical models for requirements computations enables researchers to generate reproducible results that are deterministic and result directly on the input parameters assigned to a model. The implementation of Monte Carlo or random sampling procedures in Version 6.4 results in this model being better suited for dynamic wartime scenarios.

Implementing Dyna-METRIC. Dyna-METRIC can be configured to assess weapon system performance based on user determined constraints. These constraints include sortie duration and frequency, range of parts used by the flying units, and the depth of stock available to support flying operations. Using this information, "Dyna-METRIC assesses the effects of wartime dynamics, produces operational performance measures, and identifies potential problems" (Isaacson, 1993: iii). Figure 2.4 is a pictorial representation of the logistics support network modeled by Dyna-METRIC.

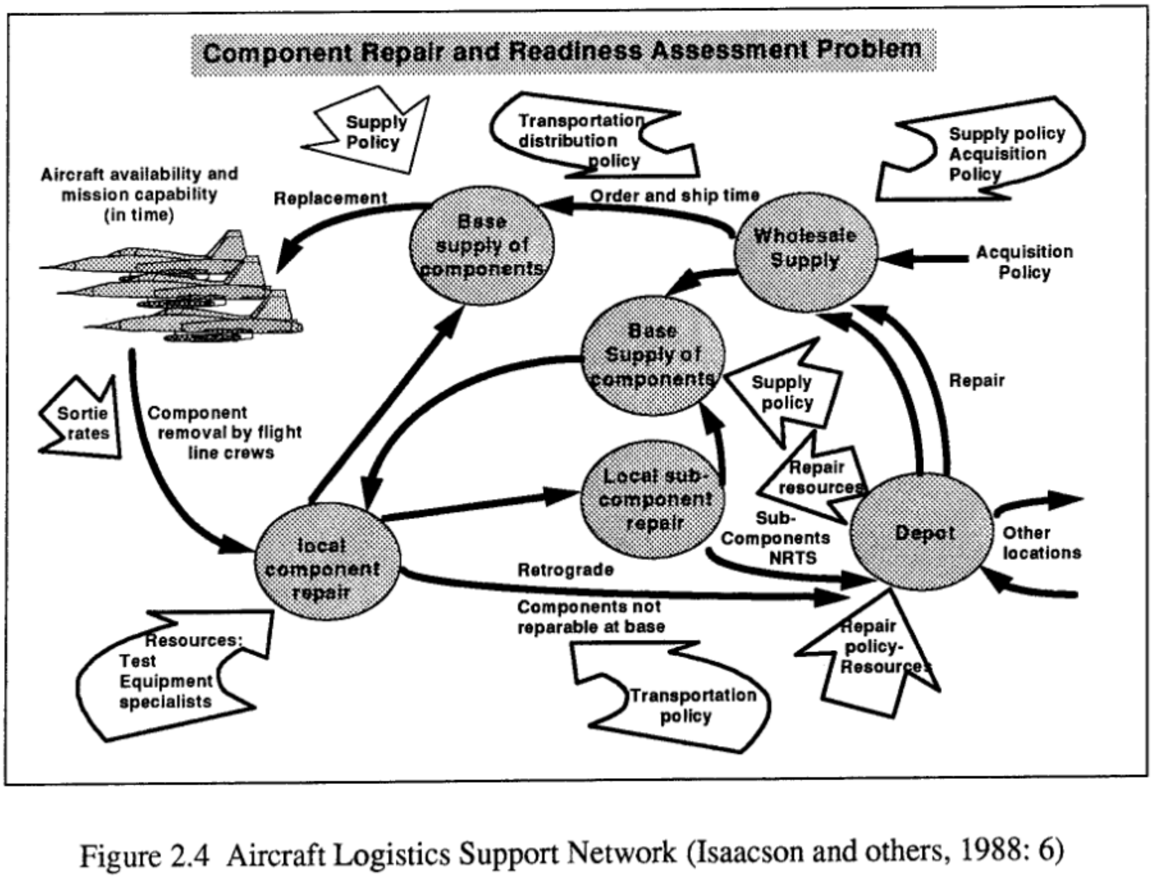


Figure 2.4 Aircraft Logistics Support Network (Isaacson and others, 1988: 6)

Dyna-METRIC Version 6.4 Dyna-METRIC Version 6.4 is a simulation tool used to assist Air Force personnel in determining assets needed to support a wartime or deployment scenario. This model uses a Monte Carlo simulation to forecast how asset support processes will affect wartime capability as measured by aircraft availability (Isaacson and others, 1988: 1-10). Monte Carlo sampling was added to version 6.4 because "management adaptations in repair and distribution could not be addressed analytically," and "some of the assumptions made to solve the mathematics underlying the analytic version limit the accuracy of the model's results" (Isaacson and others, 1993: 2-3). Dyna-METRIC Version 6.4 views a base as a collection of aircraft made up of spare parts. Version 6.4 uses traditional measures of supply performance such as resource counts (on-hand WRM) and support process delay times (repair time, pipeline time, order and ship time) to forecast how these factors affect the capability of an aircraft weapon system (DeGroot, 1988: 25). The different echelons in Dyna-METRIC include the base, the consolidated intermediate repair facility (CIRF), and the depot. The pipeline segments can flow both away from and towards the aircraft. As LRUs fail during operations, they are removed from the aircraft and replaced with a serviceable spare from supply stock. If a serviceable LRU is immediately available, the aircraft is returned to readiness in a minimal amount of time. However, if a spare LRU is not available, the LRU is placed in a back-order status and repair of the aircraft is delayed. Dyna-METRIC can model all LRU repair possibilities while assessing the indenture relationship of LRUs and their subcomponent SRUs (Pyles, 1984: 14-15).

Aircraft Availability. Logistics pipeline models, such as Dyna-METRIC Version 6.4, focus on the aircraft availability reports. Aircraft availability is the percentage of assigned aircraft a unit has available for duty based strictly on the factors of supply support. In other words, aircraft availability is a direct result of the on-hand assets, OST, and repair capability which provide resources to satisfy sortie execution demands. Aircraft availability can be defined as:

> An aircraft is considered to be unavailable if it is missing any of its LRUs (i.e. if it has a hole for an LRU). At the conclusion of pipeline segment processing, we have for each LRU the total number tied up in the base pipeline (i.e. in the base's administrative, maintenance, awaiting parts, and on-order segments). The number of holes for a given LRU is simply the amount by which the base pipeline exceeds the base stock level. If the base pipeline is less than the base stock level, there are no holes. (Isaacson and Boren, 1993: 33)

Aircraft availability can also be represented mathematically. Sherbrooke outlines the mathematical equation for aircraft availability as follows:

> Availability (A), the expected percent of the aircraft fleet that is not down for any spare is given by the following product:
>
> $$A = 100 \prod_{i=1}^{I} \{1 - EBO_i(s_i)/(NZ_i)\}^{Z_i}$$
>
> with the constraint that $EBO_i(s_i) \leq NZ_i$ for every item *i*. Z_i is the number of occurrences on an aircraft of the *i*th LRU (quantity per aircraft) and N is the number of aircraft. The logic is that there are NZ_i locations of LRU *i* in the fleet of aircraft, the probability of a hole in any of these locations is $EBO_i(s_i)/NZ_i)$ (the probability cannot exceed one). An aircraft will be available only if there is no hole for any of the Z_i occurrences of LRU *i* (which accounts for the exponent), or for any other LRU (which accounts for the product over *i*). (Sherbrooke, 1992: 38)

In the equation above, the symbol $EBO(s_i)$, used by Sherbrooke, represents the expected backorders for a given stock level for a specific LRU. In Sherbrooke's formula, an EBO is synonymous with a failed LRU which grounds an aircraft. Thus, in simplistic terms, the aircraft availability formula measures the expected number of failures for a given LRU divided by the total number of that LRUs multiplied by 100. The resulting percentages for each individual LRU are used to calculate a multiplicative summation of all the LRUs assigned to an aircraft to produce an aircraft availability measure.

Dyna-METRIC Assumptions. Although Dyna-METRIC is an extremely advanced and flexible model, it makes many assumptions regarding the real world environment. See Table 2.3 below for the assumptions embedded in Dyna-METRIC (Pohlen, 1994).

TABLE 2.3

DYNA-METRIC ASSUMPTIONS

LRU demands are proportional to either flying hours or sortie rate
Demands arrive randomly, with a known mean and variance according to either Poisson or negative binomial distribution
Demands and service process (repair & transportation)times are independent
Repair and transportation times have known probability distributions
Unconstrained repair capability Version 4
Constrained repair capability Version 6.4
All aircraft deployed to a single base are identical
Additive pipeline segments
Aircraft performance measures computed after attrition
Under full cannibalization policy, holes instantly consolidated on as few as aircraft as possible (Version 4). Version 6.4 provides results for: No cannibalization, full cannibalization, and a partial cannibalization rate
Ability to cannibalize a given LRU is all or nothing
Repair Times vary by component, transportation times vary by base

Dyna-METRIC Pipeline. Dyna-METRIC models the main components of the Air Force reparable pipeline. Dyna-METRIC computes each aircraft's spare parts volume expected in the pipeline. Or equivalently, the quantity of each spare's components that should be expected in each segment of the pipeline. The computation is based on the modeled time-dependent flying activity, the flying-dependent spares failures caused by that activity, the time-dependent availability and delays associated with transportation, the probability a spare cannot be repaired at each echelon, and the time delay for depot resupply. Dyna-METRIC then totals these time dependent pipeline quantities to arrive at the overall expected pipeline size. The model can use the expected pipeline size as a forecast for the number of spare components that will be required to sustain aircraft operations (DeGroot, 1988: 28). With the ability to vary parameters such as number and length of sorties and turn rate, Dyna-METRIC is able to accommodate most conceivable peacetime and wartime scenarios (Isaacson, 1993: 5). Once all initial parameters have been set, Dyna-METRIC produces day specific performance reports for designated performance characteristics.

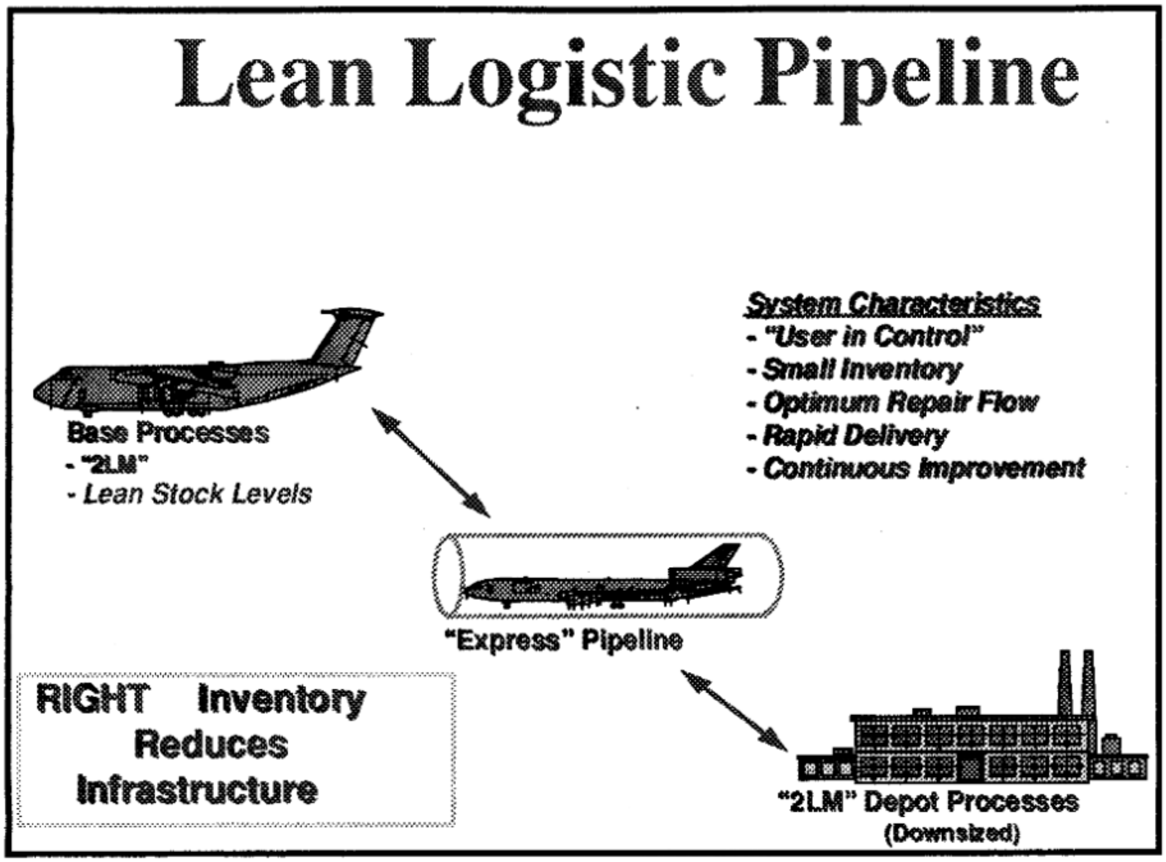
Lean Logistics

Lean Logistics is an application of modern business practices to enhance cost effectiveness of logistical operations in the USAF (HQ USAF/LGM-2, 1995: 7). Lean Logistics can be characterized by three main components that will impact current pipeline functions: reduced inventory levels, fast transportation links, and streamlined depot repair processes. This section defines the concept of Lean Logistics and describes its development. The systems theory underlying Lean Logistics will then be discussed to point out the trade-offs imbedded in the concept. Then each of the three major sub-characteristics that comprise the Lean Logistics system will be fully explored. The inventory concepts and stockage policy of Lean Logistics will be detailed first. Next, the expanded use of rapid or fast transportation introduced by Lean Logistics will be examined to determine its impact on the overall logistics system. Proposed changes to depot repair practices will also be discussed to demonstrate how Lean Logistics would revamp that system to make it more responsive. In addition to analyzing proposed changes to the current logistics framework, this section will also discuss how Lean logistics intends to empower MAJCOMs through the decentralization of weapon systems management.

Background. As a result of a shrinking DOD budgets and personnel reductions, the Air Force began in the early 1990s to seek alternative methods of providing logistical support. The goal of this effort was to develop a system that would both reduce costs and avoid degradation of logistics support. Working in conjunction with RAND, the Air Force developed an inventory management, redistribution, and repair system called Lean Logistics (HQ USAF/LGM-2, 1995: 17). This innovative concept allows the Air Force to take advantage of leading edge practices in the management of inventory, transportation, and reparable asset repair (Surrey, 1994).

In 1992, the Air Force initiated an in-depth examination of modern business practices to determine how they could be applied to the Air Force (HQ USAF/LGM-2, 1995: 17). This effort was directed toward minimizing resource investments required for the maintenance of the reparable pipeline. RAND was chosen to conduct the research under Project Air Force (HQ USAF/LGM-2, 1995: 17). In January 1993, RAND briefed a concept of using rapid and flexible inventory practices and lean production policies to improve depot repair processes and to streamline pipeline activities to senior members of the Air Staff (HQ USAF/LGM-2, 1995: 17). During this process, the term "Lean Logistics" originated, and the Air Force began to explore the application of this new method of managing reparable spare parts (Pyles, 1994).

Historically, the focus of military and business logisticians has been quite different. While military logisticians focus on internal customers and concentrate on system readiness and sustainability, business logisticians have been concerned with differentiating their firms in the market by providing the best product and customer service (Russell, 1994: 32). Although military logisticians are not forced to reduce costs based on outside competition for their product, they must do so in response to constraints placed upon the DOD due to decreasing budgets. The implementation of modern business practices through the concept of Lean Logistics may provide the Air Force with a means of becoming more cost efficient. Figure 2.5 presents the general characteristics of a conceptual Lean Logistics system.



Lean Logistic Pipeline

System Characteristics
- *"User in Control"*
- *Small Inventory*
- *Optimum Repair Flow*
- *Rapid Delivery*
- *Continuous Improvement*

Base Processes
- **"2LM"**
- *Lean Stock Levels*

"Express" Pipeline

RIGHT Inventory
Reduces
Infrastructure

"2LM" Depot Processes
(Downsized)

Figure 2.5 Characteristics of a Lean Logistics Pipeline (HQ AMC Slide Package, 1994)

Lean Logistics: A Systems Approach. Lean Logistics takes a comprehensive view of the logistics pipeline and makes trade-offs to maximize responsiveness in the system. The Lean Logistics initiative seeks to apply rapid and flexible logistics practices to the military environment with the two-fold purpose of reducing costs and maintaining readiness. This comprehensive approach will effect three major sub-systems of the logistics system: inventory management, transportation, and the repair process.

Inventory Management. Lean Logistics is concerned with inventory throughout the entire reparable asset pipeline. This includes inventory on the shelf at base and depot level, in transportation channels, and inventory that has been inducted for repair at some level within the repair system (Bond and Ruth, 1989: 3). The current pipeline process is cumbersome and layered with many levels of processing and connected by multiple transportation links. This system represents a large investment of Air Force assets. The traditional Air Force logistics pipeline has an average turnaround time of 58 days for reparable assets, and has a one day inventory value approximately equal to \$50.9 million (Peterson, 1992: 1). The inventory policies called for under Lean Logistics targets this high volume of inventory in the pipeline for reduction.

The first change in inventory practices proposed by Lean Logistics concerns the way the Air Force computes reparable requirements. The Repair Cycle Demand Level Model (RCDL) as shown below takes into account the not reparable this station quantity (NCQ), base repair cycle quantity (RCQ), order and ship time quantity (OSTQ), safety levels quantity (SLQ), and a constant factor (K) to compute the necessary stock on hand (s) to meet current demand (Christensen and Ewan, 1994:4). For the reader's convenience, the RCDL model presented initially in equation (1) is repeated in equation (2) to support the discussion of Lean Levels.

$$s = \mathrm{RCQ} + \mathrm{OSTQ} + \mathrm{NCQ} + \mathrm{SLQ} + \mathrm{K} \qquad (2)$$

The individual quantities of the RCDL model are computed as follows:

$$\mathrm{RCQ} = \mathrm{DDR} * \mathrm{PBR} * \mathrm{RCT}$$

$$\mathrm{OSTQ} = \mathrm{DDR} * (1\text{-}\mathrm{PBR}) * \mathrm{OST}$$

$$\mathrm{NCQ} = \mathrm{DDR} * (1\text{-}\mathrm{PBR}) * \mathrm{NCT}$$

$$\mathrm{SLQ} = \mathrm{C} * \sqrt{3*(RXCQ + OSTQ + NCQ)}$$

K = .5 if unit cost is greater than \$750, or .9 if unit cost is \$750 or less

Table 2.4 presents the formulas for calculating each component of the RCDL model.

TABLE 2.4

RCDL FORMULAS (Christensen and Ewan, 1985: 4-5)

Quantity	Definition	Formula
DDR	Daily Demand Rate	$\frac{\text{Cumulative recurring demands}}{\text{max of (180 days, current Julian date - DOFD)}}$
PBR	Percent Base Repair	$\frac{\text{number repaired units x 100}}{\text{sum of unit repaired, NRTS, condemned}}$
RCT	Repair Cycle time	$\frac{\text{sum repair days}}{\text{number repaired}}$
NCT	NRTS Condemned Time	$\frac{\text{sum NRTS/condemned stock}}{\text{Number NRTS/condemned}}$
OST	Order and Ship Time	$\frac{\text{Sum of base to depot ship days}}{\text{number of receipts}}$
C	C factor, or number of standard deviations to protect against stockouts	For the purposes of this thesis default to a value of1

Lean Logistics inventory practices are designed to reduce inventory levels by maintaining a system that is much more responsive and efficient. These reduced levels of inventory are referred to as Consolidated Serviceable Inventory (CSI) or as it will be referred to in this research, Lean Levels. More specifically, the term Lean Levels within the context of this research will refer to reduced stockage levels at base level. Ultimately, the main characteristic of CSI or Lean Levels, will be lower calculated stock levels for the logistics pipeline (HQ USAF/LGM-2, 1995: 30). Lean Levels will result from the manipulation of all the major variables within the RCDL model. Conceptually, the RCDL computes an unconstrained stock level (Pohlen: 1994). However, Lean Level computations will result in lower outcomes for these unconstrained levels through the application of reduced input factors. Some of these factors in the RCDL model will be reduced as a result of the implementation of a Lean Logistics support system. Additionally, management can reduce selected factors to produce stock levels in response to USAF or DOD policy directives. The OSTQ factor will be reduced considerably under Lean Logistics through the use of rapid commercial transportation. Also, the expected reliability of rapid transportation could provide the opportunity the reduce safety levels by reducing or eliminating variability in transportation lead times. Additionally, improvements in repair processes and prioritization of base and depot level repair could produce a significant decrease in the RCQ and NCQ. Lean Levels would take a comprehensive approach to reducing inventory and thus produce significant cost savings (Ramey and Pyles, 1992: 1-7).

Transportation Management. Lean Logistics has a "high velocity" pipeline under which 2LM organizations and lean stock levels could combine to produce a greatly reduced asset investment. Large inventories at both base and depot could be reduced by eliminating slow pipeline times through the use of overnight commercial carriers, and thus negate the need for massive inventory levels (HQ USAF/LGM-2, 1995: 14). This relationship is shown in Figure 2.6.

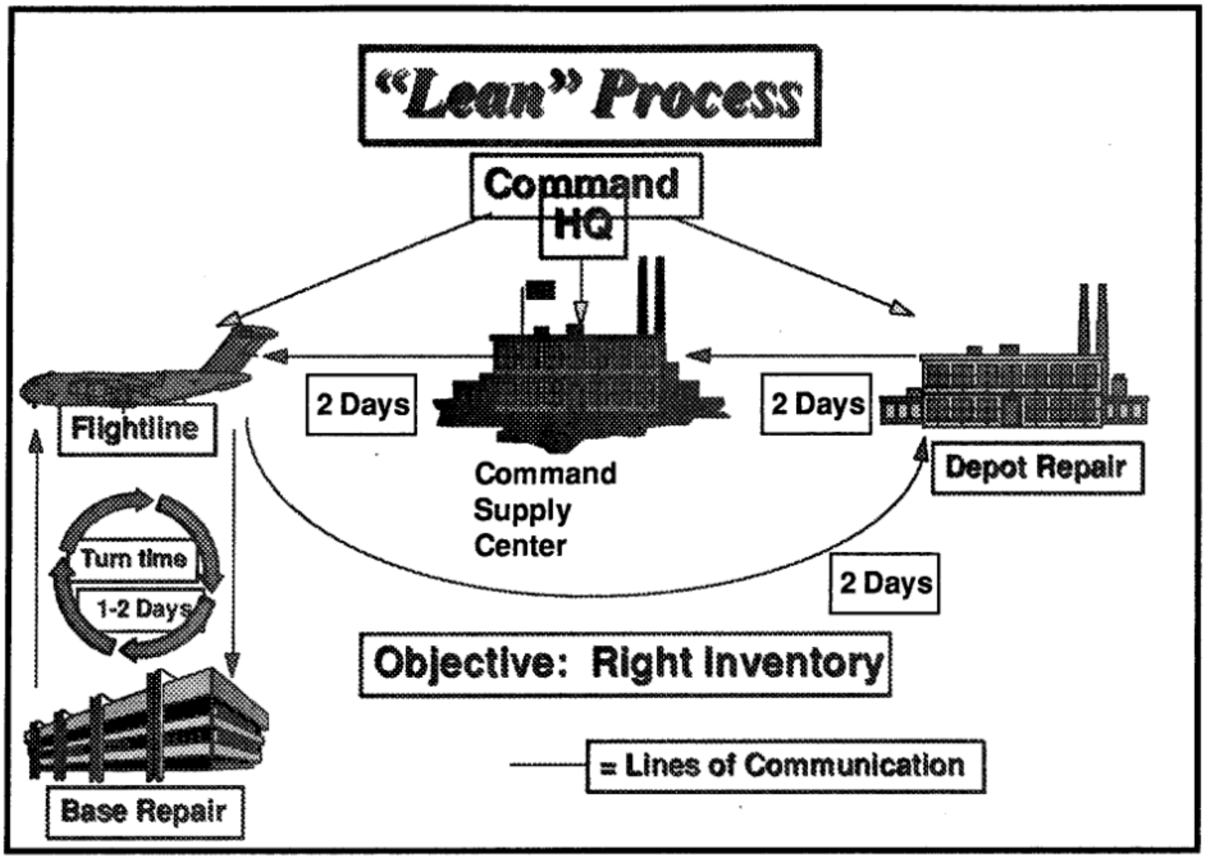


Figure 2.6 Lean Process (HQ AMC Slide Package, 1994)

Rapid Transportation. In the past, slow, unresponsive transportation links have contributed to the establishment of a large logistics infrastructure to support worldwide operations. The pressures of reduced budgets forced the Air Force to reevaluate the effectiveness of its operating procedures. The advent of fast, reliable, and inexpensive overnight commercial carriers presented the USAF and the DOD with an opportunity to revise its practices. As stated earlier, the average length of the pipeline, or the time required for an item to complete all segments of the logistics pipeline, is estimated at 58 days (Peterson, 1992: 1). These segments include transportation to the depot, repair at the depot, and transportation back to the base. This relationship is shown in Figure 2.7.

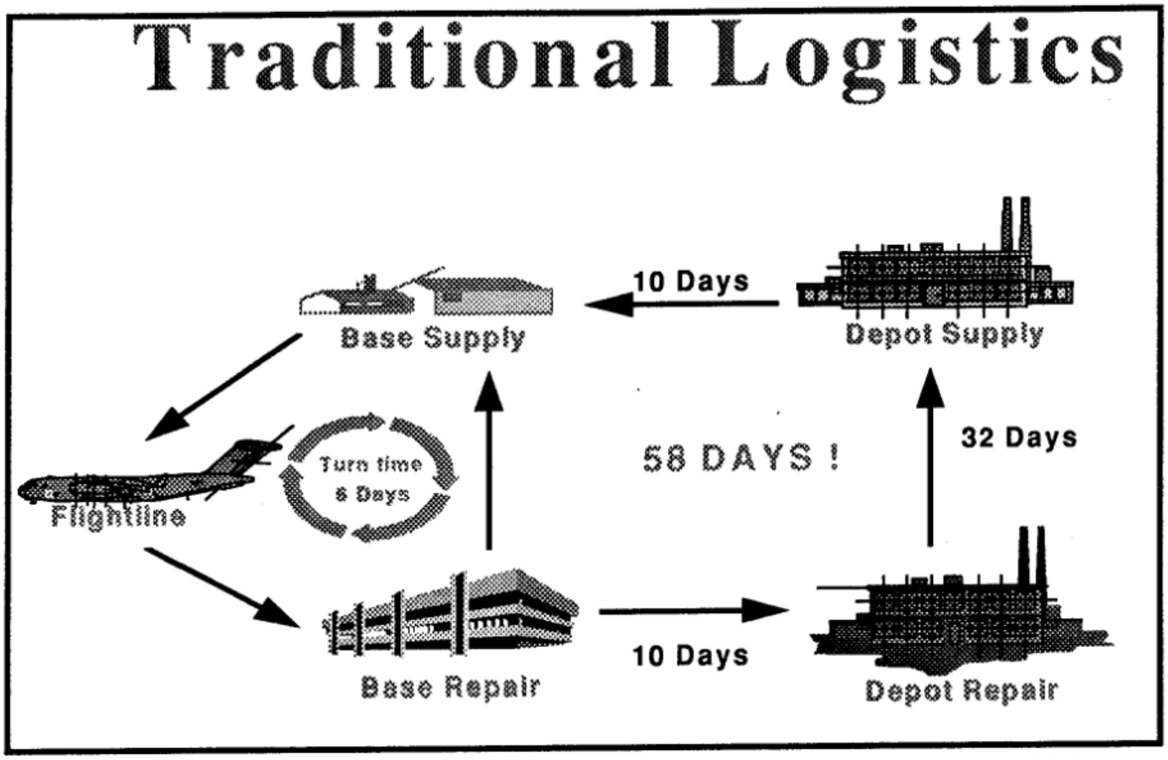


Figure 2.7 Traditional Reparable Asset Pipeline (HQ AMC Slide Package, 1994)

The use of rapid transportation focuses on reducing the OSTQ portion of the RCDL model. The potential of Lean Logistics in terms of reducing the transportation time element within the pipeline is to reduce OST to between 2-4 days (HQ AMC Slide Package, 1994). This time reflects overnight shipments from servicing depots to the base requiring the item. Traditional pipeline OSTs can account from 20 to over 90 days of the total pipeline time; however, as presented in Figure 2.7, the average pipeline time for all reparable items is estimated at approximately 58 days (Nicklas, 1995).

The use of overnight commercial transportation would be much more expensive then the use of conventional transportation channels. Ramey and Pyles, of the Rand Corporation, estimate that the transition from traditional transportation channels to express service would increase costs to $1.60 per pound from $0.60 per pound for

CONUS shipments (Ramey and Pyles, 1992: 6). Conventional transportation refers to the use of routine transportation. Figure 2.8 presents the characteristics of a typical reparable inventory system. However, lean logistics planners expect the cost savings resulting from reduced inventory costs and reduced warehousing costs to outweigh the increased cost of rapid transportation (Ramey and Pyles, 1992: 6). To enhance the operations of this proposed rapid transportation system, a new framework of redistribution and storage has been developed.

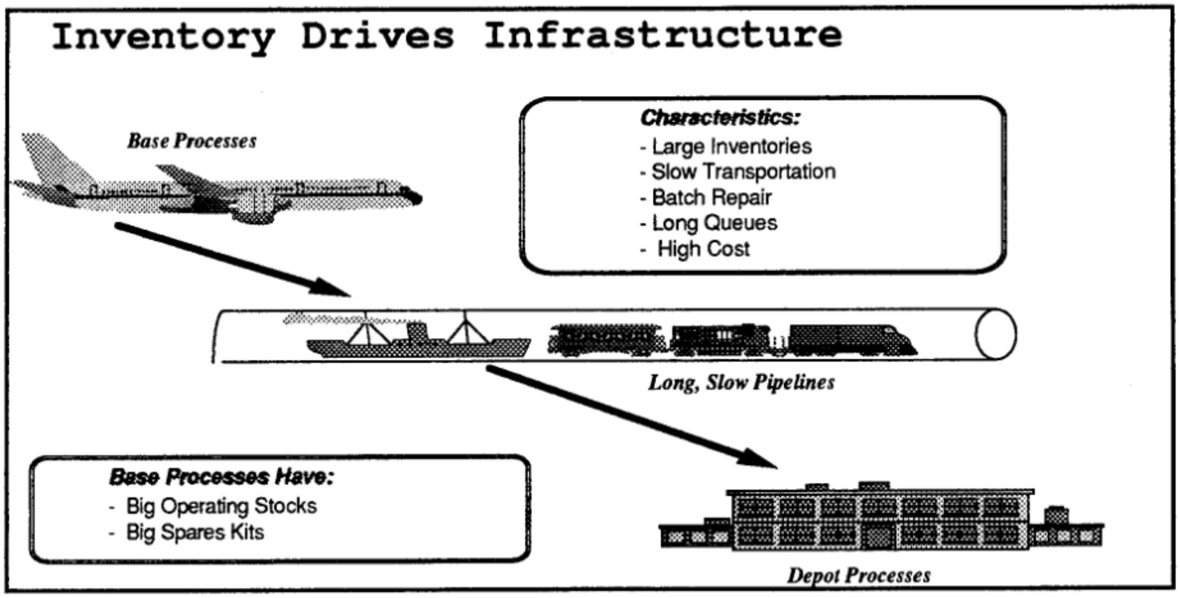


Figure 2.8 Traditional Reparable Inventory

Strategic Positioning. The strategic positioning of serviceable spares under the lean logistics concept could contribute to the impact of rapid transportation on the reparable pipeline. The establishment of intermediate storage points (ISPs) will increase the accessibility of critical assets to a commercial carrier's hub of operations. By collocating these parts with the carrier's main hub, the USAF could successfully redistribute assets by next-day air.

The ISPs would be operated by either AFMC or a using MAJCOM (Surrey, 1994). AFMC could use these ISPs to facilitate the redistribution of high cost, low volume assets to customers worldwide. The main advantage to be gained from the use of the ISP is an elimination of transportation time (from depot stocks to carriers hub) that is reflected in the OSTQ portion of the RCDL model. By collocating the assets with a freight hub, the time required to ship from the depot to the hub would be eliminated, so the total transportation time would be reduced.

The using MAJCOMs would use the ISPs as Command Storage Facilities (CSFs) to control redistribution and asset management. The CSF is designed as a consolidated storage and distribution site for command controlled parts. The CSF would be controlled and operated by the using MAJCOM (Surrey, 1994: 5). Developing ISPs or CSFs may allow the Air Force to minimize the number of reparable assets in the system by reducing the number of stocked reparables at any given base and positioning the ISP at a place where it can respond to base demands more rapidly than before (Ramey and Pyles, 1992: 5).

Lean Logistics is designed to reduce the number of LRUs within the pipeline. This reduced number of spares and a more responsive transportation system could be maximized if operations were centralized. This centralization could be based on geography or sole management/control of a MDS by a MAJCOM. In either case, centralization should be a value-added aspect of the redistribution system where ISPs and CSFs provide an operational advantage over traditional depot management and distribution of reparable spares.

Depot Repair. The repair process plays an important role in determining the required levels of spares based on the total time the repair processes consumes. Lean Logistics attempts to reduce inventory through the application of streamlined repair procedures. The streamlining and elimination of redundant processes and the use of priority repair procedures in place of batch repair at the depots are designed to reduced the time required to process and repair assets.

Priority vs. Batch Repair. Traditionally, the depot system has operated in a batch repair mode (HQ USAF/LGM-2, 1995: 8). This method of operation was based historically upon the need to repair large volumes of spares to support the large aircraft inventories of the Cold War. Traditionally, depot repair has been scheduled through quarterly negotiation sessions designed to maximize depot resources, such as repair stations, by scheduling repair for backordered requirements and forecasted demands (Abell and others, 1992: 14).

Under Lean Logistics, the concept of priority repair would replace batch repair . The use of computer programs such as DRIVE would direct repairs of unserviceable assets to match worldwide requirements (Abell and others, 1992: 16). This system is designed to replace the process of negotiating quarterly repair quotas and then inducting these assets into the batch repair system (Abell and others, 1992: 14-17). The DRIVE program would direct item specific repairs at the depot-level in response to predesignated aircraft availability rates assigned to the various bases (Abell and others, 1992: 44). The spares posture that would result from such a repair and redistribution philosophy would differ greatly from the current resource allocation and redistribution practices. The use of

DRIVE to schedule repair verses negotiated quotas is geared toward repairing the best mix of assets. This philosophy may actually result in under utilization of some depot processes; however, when using the DRIVE logic, desired aircraft availability is the driver instead of optimal utilization of the depot infrastructure.

Continuous Improvement. The concept of continuous improvement imbedded in lean logistics is very similar to that found in Total Quality Management (TQM) (Pyles and Cohen, 1993, 2-7). Lean Logistics encourages managers to view improvements and streamlining as an ongoing process. Lean Logistics would require the logistics managers of the future to constantly perform process review and evaluation to ensure efficient operations are always maximized.

Management Approach of Lean Logistics. Lean Logistics implementation would have a major impact on traditional weapon system management. In the past, the Air Force managed its logistics infrastructure under centralized item management and repair. Lean Logistics planners have identified several advantages to decentralizing weapon system management to the operational commands.

Decentralized Weapon System Management. Some lean logistics planners believe decentralizing control of weapon systems to MAJCOMs will enhance mission capability by allowing operators of weapon systems a greater degree of control over resources (Cohen and Pyles, 1992: 1-8). Furthermore, lean logistics would also allow using commands to provide inputs to the depot system on repair priorities. This input would most likely take the form of predetermined aircraft availability rates designated for individual bases within a command (Abell and others, 1993: 42-44). By allowing the MAJCOMS to redistribute assets and set repair priorities, Lean Logistics assumes the entire depot repair process would be more responsive to customer needs (Pyles and Cohen, 1993: 5).

Summary of Lean Logistics.

Lean Logistics is a multi-faceted concept that strives to produce system savings throughout the Air Force logistics infrastructure. The systems approach is designed to produce cost savings through reduced inventories, fast transportation channels, reduced depot repair times, and better informed management decisions gained through decentralization of item management duties. Table 2.5 below gives a comparison of the characteristics current logistics pipeline and the Lean Logistics pipeline and suggest possible areas where cost trade-offs can be realized.

TABLE 2.5

PIPELINE COMPARISONS

Characteristics	Current Logistics Pipeline	Lean Logistics Pipeline
Transportation	Slow	Fast
Transportation Costs	Low	High
Transportation Time (OST)	19 days	2 days
Strategic Positioning	Decentralized (Base Level)	Centralized (ISP)
Depot Repair	Batch Repair	Priority Repair
Inventory	Large	Small
Inventory Cost	High	Low
Asset Visibility	Low	High
Pipeline Velocity	Slow	Fast

Chapter Summary

This chapter provided a comprehensive review of the factors relevant to a wartime analysis of the lean logistics concept. The chapter provided detailed information on the following: the traditional reparable pipeline, RSPs, Dyna-METRIC assessment model, and the fundamental concepts of the lean logistics reparable asset pipeline. Chapter III will describe the methodology that will be used in this research and discuss how variable inputs will be managed and how resulting data will be analyzed.

III. Methodology

Introduction

The purpose of this chapter is to identify a process for determining the impact of transitioning from an assumed stable lean logistics pipeline to a wartime scenario by varying the factors of OST and flying hours. This chapter will begin by restating the general problem. Then the method employed to execute this research will be addressed. The inputs to the simulation model used in this research, Dyna-METRIC, is also presented. This chapter also identifies the experimental design and includes the techniques used to gather and analyze the data necessary to answer the research question. Finally, the input parameters and initial conditions for both the initial spares conditions and the Dyna-METRIC program are described.

Problem Definition

The problem faced by the USAF involves the uncertainty encountered when transitioning from peacetime to wartime under the parameters of a lean logistics pipeline scenario. The uncertainty involved in this transition is important because Lean Logistics is a system designed on the premise that the logistics support pipeline operates in a predictable environment. Wartime deployments may not always produce stable or predictable pipeline times. As stated in Chapter I, Lean Logistics focuses on reducing costs, shortening pipeline times, and reducing uncertainty in a peacetime environment. The initial drive to conceptualize Lean Logistics has not yet addressed many important questions on the operations of the reparable asset system during wartime.

General Method

This research will evaluate a scenario where four F-15C squadrons are deployed to four separate locations in an overseas theater. This research will simulate lean logistics pipeline support for these deployed units for days 1-120 of a wartime scenario. Since Lean Logistics is still theoretical in nature, the initial conditions that represent the peacetime period prior to deployment of these four units will have to be established through the development a peacetime lean logistics system. The lean logistics system that will be modeled for this research will focus primarily on the redistribution aspects of the pipeline. Depot repair will be treated as a constant due to the large scope of depot operations in a lean logistics scenario. OST will be used as a primary variable to measure variability within the lean logistics pipeline that results from wartime employment. Flying hours will be used as a variable to effect change upon the spares requirements of the pipeline resulting form changes in flying schedules that could be encountered during wartime.

Once a peacetime system has been established, the variable factors of OST and flying hours will be altered at three levels each in the simulation model to reflect the uncertainty of a wartime environment. Because direct observation of both the peacetime and wartime lean logistics systems is not possible, a computer simulation model will be utilized. The simulation model to be used in this research is Dyna-METRIC Version 6.4. The data used to facilitate the simulation will be selected NSN data for the F-15C.

Simulation Model

The methodology to be employed in this research involves the application of the Dyna-METRIC program to model the flow of aircraft spares through a wartime reparable asset pipeline. Dyna-METRIC is a discrete simulation model that models a system based upon describing the changes that occur in the system at discrete points in time (Pritsker, 1986: 381). Pritsker further defines discrete models as:

> a discrete simulation model can be formulated by: (1) defining the changes in state that occur at each event time, (2) describing the activities in which the entities in the system engage; or (3) describing the process through which the entities in the system flow. (Pritsker, 1986: 55)

As related to this research, an entity is a reparable asset and the system is the logistics pipeline. All simulation experiments will be conducted on an AT&T 486 DX/50 notebook computer.

The decision to use a simulation program instead of an analytical program was based on the need to produce an environment where outcomes are random. While analytical models would produce the same results on successive runs due to the lack of a randomized element in their design, a simulation model can allow for probabilistic outcomes at critical decision points. Since the aircraft support environment that this research evaluates reflects the uncertainty and variability in a wartime scenario, a simulation model is deemed most appropriate to represent the uncertain elements found in a wartime scenario.

The Dyna-METRIC Version 6.4 program was chosen for this research because it was designed especially for simulating and assessing USAF logistics pipeline performance in a dynamic wartime environment. Dyna-METRIC uses planned usage of aircraft spares, the failure characteristics of aircraft components, and wartime dynamics to produce operational performance measures for deployed aircraft (Isaacson and Boren, 1993: iii). Additionally, Dyna-METRIC Version 6.4 uses Monte Carlo sampling techniques which produce probabilistic outcomes at critical decision points (Isaacson and Boren, 1993: 3-4).

Model Verification. Model verification is the process of determining if the model's program code exactly implements the system being modeled. Normally, verification of a model's code could involve several detailed processes such as: manual comparisons, static and dynamic comparisons, and verification through output analysis. Currently, no known official documentation exists for the formal verification of the Dyna-Metric Version 6.4 program. Earlier versions, such as Version 4, have been accepted and even incorporated into AFMC's Weapon System Management Information System (WSMIS) to produce assessments of stock level support (Isaacson and Boren, 1993: 1) Additionally, RAND extensively uses Version 6.4 to conduct USAF directed research, including large scale lean logistics simulations (Ramey and Pyles, 1992: 4). Therefore, since Dyna-METRIC has been extensively used by RAND and AFMC, the code for the Dyna-METRIC program is considered acceptable for all operations within the context of the model's design. Since documentation of this model's verification has not been completed, this research is limited by the assumption that Version 6.4 provides accurate results for this study.

Model Validation. The issue of model validation addresses whether or not the model used in the simulation experiment adequately represents the system. Dyna-METRIC was designed for simulating pipeline performance in a dynamic wartime environment. This research is designed to conducted a pipeline performance assessment in a dynamic wartime environment within the framework of the Dyna-METRIC program. Therefore, since Dyna-METRIC has been deemed valid for experimentation by RAND and AFMC the program is valid for this research. HQ AFMC Management Science Division (AFMC/XPS) will be consulted to ensure model inputs are correct for each scenario. Validation will be addressed in Chapter IV due to the need to analyze research results to ensure outputs are consistent with model construction.

Dyna-METRIC Version 6.4 Validation. Validation for the Dyna-METRIC input parameters utilized in this research were accomplished primarily through two sources. First, the experiment performed in this research is similar to the experiment conducted by Ramey and Pyles in their 1992 article titled, "Would "Just in Time" Improve Logistics Responsiveness and Cost?". Consultation with Ray Pyles, of the Rand Corporation, has further confirmed that the hypothesis and methodology of this research as evaluated by Dyna-METRIC are both within the capabilities of the Version 6.4 program. Additionally, further consultations with AFMC Management Sciences Division (AFMC/XP) has validated the construction of the model used in this research. It should be noted that the model constructed was designed to represent a hypothetical environment. Thus, efforts to validate focused on whether or not the model represents the system described in Chapter III. The results of the computer simulations, as will be presented in this chapter, are consistent with the expected performance of the model and further contribute to the validation of this model.

Experimental Design

The focus of this research is the measurement of aircraft availability levels resulting from the variation of OST and flying hour inputs to the Dyna-METRIC simulation program. Based on this focus, the response variable for this research will be the aircraft availability level resulting from changes in the factors of OST and flying hours. These two factors were selected because they were both deemed to have significant impact on deployed operations. OST is the elapsed time, in days, the initiation and receipt of stock replenishment requisitions from a depot (Christensen and Ewan, 1994: 5). Flying hours represent the cumulative number of flying hours resulting from the execution of a planned flying program.

OST and flying hours will be varied at three levels (low, medium, and high). The medium value will represent an estimated average value for a typical employment scenario. The low and high values will represent a range of expected values that could be encountered in a deployed wartime scenario. The actual values used in this research are shown in Table 3.1. The combination of levels between OST and flying hours represents the treatments that will be compared after the simulation runs. The combination of three levels for each of two factors results in nine possible treatments. The treatment combinations and their representative values are shown in Table 3.1.

TABLE 3.1

COMBINATIONS/LEVELS/TREATMENTS

	Peacetime Baseline	**OST**		
	OST/Flying Hrs. (2 days/1.0 Hrs).	**Low (3 days)**	**Medium (5 days)**	**High (7 days)**
FLYING	**Low (1.0 hours)**	Treatment #1	Treatment #2	Treatment #3
HOURS	**Medium (1.5 hours)**	Treatment #4	Treatment #5	Treatment #6
(per sortie)	**High (2.0 hours)**	Treatment #7	Treatment #8	Treatment #9

Peacetime Baseline. The peacetime baseline will represent a possible combination of peacetime values for the lean logistics pipeline. The actual values of the peacetime baseline are provided in Table 3.1. These values represent an approximation of peacetime OST and flying hour levels. This baseline will provide an aircraft availability rate that will establish a performance level for the model in a peacetime environment. Although this value will not be used in the statistical analysis of this experiment, the baseline provides a good starting point to observe changes in aircraft availability levels that occur throughout the experiment. It is our expectation, based upon assumptions made, that the aircraft availability levels in wartime will be less than the peacetime baseline due to the increased values of OST and flying hours.

Statistical Measures

Analysis of Variance (ANOVA). This experiment will utilize the ANOVA technique to analyze the mean response value of the nine treatment means. The goal of this process is to determine if the treatment values differ from each other, differ based upon the effects of individual factors, or differ based upon the interaction of the two main factors. By answering this series of questions, this experiment will provide insight on whether or not OST and/or flying hours effect the aircraft availability levels for the nine treatments which represent nine different deployed wartime scenarios. It is expected, that the treatment means, which represent the aircraft availability levels, will decrease in value as the values of OST and flying hours increase. Ultimately, the results of these statistical tests will allow for the determination of whether or not a lean logistics pipeline can effectively support a deployed wartime scenario.

An ANOVA for a two factor factorial experiments will be used to evaluate the experimental results. The ANOVA process can be represented as a mathematical model. The model illustrates the possible interaction that may occur to produce the value of the response variable. The ANOVA model can also be described as, "an equation written in such a way as to represent the actual real world process that produces the data," (Iverson and Norpoth, 1987: 54-55) The ANOVA model for this experiment is shown in equation 3.

$$\mathrm{Y}_{ijk} = \mu + A_i + B_j + (AB)_{ij} + \varepsilon_{ijk} \qquad (3)$$

where

Y_{ijk} = the response of the kth replication (k = 1 to n) with flying hours set at level i and OST set at level j.

The value of "n" will be determined by analyzing research results to identify the number of replications necessary to satisfy the assumption of normality.

μ = the grand mean of all replications under all factors

A_i = fixed effect of flying hours (i = 1 to 3)

B_j = fixed effect of factor OST (j = 1 to 3)

$(AB)_{ij}$ = interaction effect of factor A and B

ε_{ijk} = error term

The above ANOVA model will be used to evaluate the impact of changes in OST (A_i) and flying hours (B_j) on the resulting aircraft availability level (Y_{ijk}). The formal ANOVA model will aid in determining the nature of the treatment effects, if any, on the response variable in the 3^2 factorial experiment to be used in this research. In order to determine these effects, the response variable value will need to be divided into four components: main effect of factor A, main effect of factor B, interaction between factors A and B, and random error (McClave and Benson, 1994: 881). This partitioning is necessary to identify the sum of squares for error (SSE) for each treatment combination. Correctly calculating the SSE for each treatment is critical to the ANOVA process. Accurately identifying the SSE enables the calculation of an F statistic which will eventually determine rejection or failure to reject the null hypotheses (McClave and

Benson, 1994: 860-863). The series of tests to be conducted for this ANOVA are as follows:

1. Test for differences between treatment means: This test will be conducted to determine if variations of OST and flying hours produces changes in observed aircraft availability levels. This test will determine if differences in mean aircraft availability exists among the nine treatments we will test:

H_o: $A_i = B_j = (AB)_{ij} = 0$, for all i,j

H_a: At least two treatment means differ

2. Test for main effects of flying hours: The hypothesis test for main effect of flying hours is conducted to determine whether or not flying hours effects aircraft availability under the parameters of this experiment.

H_o: $A_i = 0$, for all i

H_a: At least two factor A mean levels differ

3. Test for main effects of OST: The hypothesis test for main effect of OST is conducted to determine whether or not OST effects aircraft availability under the parameters of this experiment.

H_o: $B_j = 0$, for all j

H_a: At least two factor B mean levels differ

4. Test for factor interaction: The interaction component tests whether the factors combine to affect the response. Within the context of this research, this test determines whether or not flying hours and OST interact to affect aircraft availability.

H_o: $(AB)_{ij} = 0$, for all i and j

H_a: Factors A and B do interact to affect the response mean

The ANOVA technique is a powerful tool for determining the impact variations of input factors can have on the response variable. However, ANOVA is restrictive in that it must conform to the following assumption (McClave and Benson, 1994: 886):

1. The response distribution for each factor-level combination (treatment) must be normal.

2. The response variance for all treatments must be equal.

3. Random and independent samples of experimental units are associated with each treatment.

Verification of ANOVA Assumptions. All assumptions applicable to the particular test utilized will be verified. Independence can be assured in the ANOVA test by changing the number stream for each replication. While a random number stream can be generated in a variety of ways, the specific method used for this experiment is presented in Chapter IV. Normality of distributions will be tested by the Wilk-Shapiro test, and testing for equality of variance will be accomplished through the use of Bartlett's test of equal variance.

Wilk-Shapiro Test for Normality. The Wilk-Shapiro test is a procedure that examines whether a response distribution conforms to a normal distribution. The approximate Wilk-Shapiro test statistic calculated by the Statistix computer package calculates the square of the linear correlation between the residuals resulting from a linear regression analysis and the order statistic (Siegel, 1992: 246-247). For the purposes of this research, a critical Wilk-Shapiro value of 0.918 will be used to establish the approximate normality of the 25 observations for each factor-level (treatment) combination, giving a 95% level of confidence (Conover, 1995: 468).

Bartlett's Test of Equal Variance. Equality of variances will be tested using the Bartlett's feature of Statistix (Siegel, 1992: 122-123). The Bartlett test of equal variance will be used to determine if the response variance is constant for all treatments. Under this test, an alpha level of .05 will be used to test the hypothesis that the variances are equal.

Data Generation

By varying the input factors from the assumed stable peacetime environment to three different wartime levels, the experiment will produce aircraft availability rates for a lean logistics wartime scenario. The variability of aircraft availability rates among the different levels of OST and flying hours will establish the degree of sensitivity or difference that exists. Basic NSN data is required to facilitate Dyna-METRIC Version 6.4 execution. HQ AFMC maintains an Air Force wide database which allows for easy identification of critical assets. This database at HQ AFMC will provide the necessary information for input into Dyna-METRIC (Isaacson and others, 1988: 1-10).

Data Sample. The data sample will be the top 25 demanded spare parts or Line Replaceable Units (LRU) contained in the F-15C's MRSP. HQ AFMC/XPS has conducted studies verifying that the top 25 problem parts, LRUs, will provide nearly identical results as running a Dyna-METRIC analysis using the entire compliment of LRUs in a MRSP (Nicklas, 1994). Simply put, of the approximately 1000 line items contained in an MRSP, the top 25 items produce aircraft availability rates reflective of the entire MRSP (Nicklas, 1994). Thus, the use of the top 25 failing items will maintain the database at a manageable level and produce aircraft availability rates that are highly correlated to the availability rates resulting from assessments of the entire MRSP population. Appendix A details information for each NSN in the data sample.

Initial Conditions

The initial condition is the state of the system prior to beginning the experiment. The nature of this research places a premium importance on the starting or initial conditions. In order to effectively simulate a wartime pipeline, the condition of the pipeline prior to the start of the war must accurately reflect a peacetime pipeline. "The ideal initial condition setting would be to sample from the steady state distributions that underlie the simulation model and set the initial conditions based on the sample values obtained" (Pritsker, 1986: 751). However, since Lean Logistics is only a theoretical system, such actions are not possible. Therefore, to set the initial conditions in this experiment, the Aircraft Sustainability Model (ASM) will be used to calculate system wide stock levels necessary to obtain a desired aircraft availability level. The goal of this effort will be to establish initial conditions that produce a modeled peacetime environment where approximate "steady state" performance can be expected.

Stock Levels and Placement. Key to ensuring proper starting conditions is the allocation of stock between the four F-15C bases and the servicing depot prior to starting the wartime analysis. Within the context of this research, authorized stock levels will refer to the total available assets within the modeled environment. These assets will be maintained in one of four different conditions: Peacetime Operating Stock (POS), depot level repair, MRSPs, and in-transit. Dyna-METRIC will model the entire logistics pipeline to determine the availability of spare parts at the deployed location based upon the pipeline constraints. The resulting asset position at the deployed location will be used to calculate an aircraft availability rate for each of the flying units.

The decision on the initial condition of the spares can be broken down into determining how much stock is authorized and where it should be located. The conventional wisdom in lean logistics planning is to determine the authorized stock level by calculating Lean Levels through manipulation of the unconstrained RCDL model (Surrey, 1994). This was accomplished for the 25 NSNs in the data sample and the results are in Appendix B. However, the calculation of Lean Levels through the RCDL method presents two major problems. First, the RCDL formula seeks to fill the average expected number of assets in the pipeline on an item-by-item basis, which runs counter to the systems approach of Lean Logistics (Pohlen, 1995). Secondly, the RCDL methodology does not account for depot repair time. The RCDL views the depot as an infinite source of supply that is order and ship time away (Pohlen, 1995).

To solve this problem, the Aircraft Sustainability Model (ASM) will be used to calculate the necessary spares distribution at each base and within the pipeline to maintain a designated aircraft availability goal for the peacetime flying mission over a 365 day time frame. The use of ASM is designed to estimate a volume of spares necessary to maintain "steady state" performance in a peacetime environment. ASM has the ability to balance two or more objectives at one time. "It provides a true LRU/SRU trade-off logic and a better treatment of constrained funding for budget allocation" (King and Mattern, 1989: 5). For the purposes of this research, ASM will determine a "constrained" initial allocation of the LRU's, based on a aircraft availability goal, for input into Dyna-METRIC. This process will enable the Dyna-METRIC simulation runs to begin with the assets required to maintain 85% aircraft availability rather than the possibly inflated aircraft availability levels resulting from the calculation of Lean Levels resulting from the manipulation of the RCDL model. ASM builds stock levels to fill the pipeline to achieve desired aircraft availability goals by balancing the expected number of item failures with the specified limitations of the pipeline parameters. In this manner, the logic of the ASM method is more closely correlated to the goals of Lean Logistics than the RCDL method.

Current Lean Level methodology computes an unconstrained authorization level from the RCDL. The ASM method is not a widely used or discussed means of computing on-hand levels for lean logistics simulations; however, for the purposes of this research establishing a measurable benchmark of 85% availability in peacetime operations is beneficial in measuring the impact of the induced variability on the wartime pipeline. The benchmark of 85 percent represents an arbitrarily selected goal. Appendix C provides the documentation of the methodology for the calculation of the ASM levels used in this research. Additionally, Appendix C provides a comparison of the calculated ASM levels and RCDL Lean Levels.

WRM Levels. The problem of determining initial stock conditions for the spares at the four CONUS bases for the peacetime assessment must also address WRM/MRSP authorized for each squadron. The WRM levels for each flying squadron will be a direct result of MRSP authorizations for each of the 25 selected NSNs. During peacetime operations, the WRM/MRSP stocks will be available for use. However, when the individual units deploy the appropriate WRM stocks will be extracted and deployed. The configuration of the MRSPs will reflect authorizations to support 30 days of wartime operations. During the process of determining the initial conditions, the WRM stocks will play an important role because they will be considered available to satisfy demands. Appendix E provides the configuration of a standard MRSP which is maintained at each of the four bases during this experiment. The MRSP information for each base is contained in the stock level section of Appendix E under the authorized stock at each base.

Dyna-METRIC Version 6.4 Configuration. The Dyna-METRIC Version 6.4 configuration requires values to be entered for various elements that constitute the characteristics of a wartime scenario. Variations in the aircraft availability rates among the nine treatment means will be used to isolate the impact of the wartime flying schedule and extended OST on the performance of the lean logistics reparable asset pipeline functioning in a wartime scenarios. The actual values for Dyna-METRIC input parameters, for the wartime scenario, are located in Appendix D. The input parameters for the Dyna-METRIC program are grouped into four major categories: Administrative Data, Location Description, Scenario Data, and Component Data.

Chapter Summary

This chapter has detailed the methodology design to be utilized in this research. In addition to laying out the experimental design, it discussed statistical considerations and the initial conditions of the experiment. The input parameters for both the initial spares condition and the Dyna-METRIC program were briefly described and the complete input parameters referenced in appendices. This chapter has provided all the information necessary to conduct the Dyna-METRIC computer simulation. Chapter IV will present the results of the research by statistically analyzing the data. Chapter V will provide conclusions and suggested future research.

IV. Results and Analysis

Introduction

The purpose of this chapter is to present and analyze the results of the experiment outlined in Chapter III. The results are designed to address the thesis research question: Can a wartime lean logistics pipeline maintain acceptable aircraft availability rates in response to induced variations of OST and flying hours for deployed forces? Next, the results of the simulation runs for each of the nine treatments will be analyzed to determine if each of the three ANOVA assumptions are satisfied. Once the ANOVA assumptions are verified, hypothesis tests will be conducted for each of the following areas: equality of treatment means, main effect of flying hours, main effect of OST, and factor interaction.

Data Computation Summary

Appendix F provides the results of the Dyna-METRIC Version 6.4 simulation runs for the nine factor-level combinations (treatments). The runs were conducted for 25 individual trials because of the need to satisfy the normality assumption which will be discussed later in this chapter.

Verifications of Assumptions

Tests conducted to analyze a factorial experiment (ANOVA) requires the satisfaction of three assumptions (McClave and Benson, 1994: 886).

1. The response distribution for each factor-level combination (treatment) must be normal.

2. The response variance for all treatments must be equal.

3. Random and independent samples of experimental units are associated with each treatment.

A discussion of how each of the three assumptions were satisfied is presented in this section.

Normality. The Wilk-Shapiro test for normality was used to evaluate this assumption. The statistical software package Statistix generated the results of the Wilk-Shapiro test (Statistix, 1992: 246). Recall from Chapter III, that a value of 0.918 was determined to be sufficient to establish the approximate normality of the data collected for each factor-level combination. Table 4.1 presents the results of the "Wilk-Shapiro" tests for each of this experiment's nine individual treatment sample populations.

TABLE 4.1

WILK-SHAPIRO TEST RESULTS

Treatment	**Wilk-Shapiro Statistic**
1	.9736
2	.9630
3	.9756
4	.9685
5	.9455
6	.9708
7	.9802
8	.9759
9	.9676

As demonstrated by the results presented in Table 4.1 above, the assumption of normality of the data collected for each treatment of this 3^2 factorial experiment is satisfied.

Equal Variance. Bartlett's test of equal variance was used to test for equality of variance between the treatment cells. An alpha value equal to a 0.05 level of significance was used to conduct the following hypothesis test:

H_o: all nine treatment variances are equal

H_a: above not true for at least one treatment

The test statistic for Bartlett's test of equal variance is chi-square (χ_0^2). H_o is rejected on values of χ_0^2 that are greater than $\chi^2_{\alpha,a-1}$, ($\chi_0^2 > \chi^2_{\alpha,a-1}$). $\chi^2_{\alpha,a-1}$ is the upper α percentage point of the chi-square distribution with α -1 degrees of freedom (Montgomery, 1991: 102). Using Table XIII of Statistics for Business and Economics, the reject region for alpha = .05 and (25-1) degrees of freedom ($\chi^2_{.05,24}$) = 36.4151 (McClave and Benson, 1994: 1138-1139).

The Statistix software package produced a chi-square value of 8.44 for Bartlett's Test of Equal Variances. Since $8.44 \leq 36.4151$ we fail to reject the null hypothesis and conclude that at alpha = .05 level of significance all nine treatment variances are the same.

Random and Independent Samples. To ensure independence among the treatment cells, unique random number seeds were used for each of the nine simulation runs. These random number streams represent 20 random number seeds of four columns each. The various random number seeds "control the generation of removals, repair times, transportation times, NRTS actions, etc." (Isaacson and Boren, 1993: 86). In addition, Dyna-METRIC Version 6.4 uses the Monte Carlo sampling technique to randomize the distribution of assets to fill requisitions and repair scheduling decisions for all assets in the pipeline (Isaacson and Boren, 1992: 30-31). This characteristic also supports the assumption of independence between treatment cells.

The method chosen to generate our random number seeds was to take advantage of the random number table, Table I, in Statistics for Business and Economics (McClave and Benson, 1994: 1113). The treatment random number selection process began at the beginning of row one, and all the required numbers were selected horizontally across the table. The process was repeated for each Dyna-METRIC run by beginning with a random number seed that begins with the next odd numbered row. Table 4.2 presents the random number seeds utilized in this research.

TABLE 4.2

RANDOM NUMBER SEEDS

Treatment	Random Number Seeds
1	10480150110153602011816479164669179141946259036207209699957091291907002236846573
2	24130483602252797265763936480915179248304934032081306801965563348586294216793093
3	37570399758183716656061219178260468813054968460672141100692701263546137792106907
4	99562729055642069994988723101671194187384401348840632132106910634129529630191977
5	89579143426366110281174531810357740843782533112566586784494705585569418547536857
6	63553409614823503427496266944518663726955218020847122349051133703903220942993969
7	10365611298752985689482375226767689933940151126358851042028529975898680711997336
8	51085127655182151259774521630860756921444944253900709606399075601407190236821382
9	01011540923336294904312730414618594298527158585030511320191592747649515216253916

Hypothesis Testing

This research is focused around the use of the ANOVA technique to analyze a 3^2 factorial experiment. In order to determine the nature of the treatment effect, if any, on the dependent variable in a factorial experiment, the treatment variability must be broken down into identifiable components. The hypothesis testing that will be conducted to complete this ANOVA includes four hypothesis tests: equality of treatment means, main effect of factor A (flying hours), main effect of factor B (OST), and interaction of main effects. In order to conduct an ANOVA on the dependent variable (aircraft availability), a Microsoft Excel spreadsheet was used to produce a two-factor with replication ANOVA table which provided statistics on the main and random effects. Table 4.3 presents the mean values for each treatment. Each treatment mean was calculated from the results of 25 individual replications. These 225 observations used as inputs to analyze the results of this experiment are outlined in Appendix F. Table 4.4 presents the ANOVA table for aircraft availability.

TABLE 4:3

ANOVA RESULTS
(TREATMENTS REFLECT INDIVIDUAL AIRCRAFT AVAILABILITY RATES)

	Peacetime Baseline	**OST**		
	86.88	**Low (3 days)**	**Medium (5 days)**	**High (7 Days)**
FLYING	**Low (1.0 hours)**	72.586	66.588	58.922
HOURS	**Medium (1.5 hours)**	72.380	66.374	59.110
(per sortie)	**High (2.0 hours)**	72.918	66.118	57.208

TABLE 4.4

ANOVA TABLE FOR AIRCRAFT AVAILABILITY

Source	**DF**	**SS**	**MS**	**F**	**P**
Flying Hrs.	2	16.98833	8.494164	.171256	.84272
OST	2	7612.589	3806.294	76.74097	0.0000
Interaction	4	44.36022	11.09006	.223593	.925041
Error	216	10713.44	49.59925		
Total	224	18387.38			

Test: Equality of Treatment Means. To determine if differences in mean aircraft availability exits among the nine treatments we test:

Ho: $A_i = B_j = (AB)_{ij} = 0$, for all i,j

Ha: At least two treatment means differ

The format of Microsoft Excel ANOVA procedure used in this analysis did not produce an F statistic for this test. Therefore, the F statistic for this test was calculated manually using procedures outlined in Statistics for Business and Economics (McClave and Benson, 1994: 860). The F statistic for this test is equal to mean square for treatments (MST) divided by mean square for error (MSE). These manual calculations produces a F test statistic of 19.34. Since the rejection region requires $\alpha = .05$ in the upper tail of the F distribution with numerator degrees of freedom (ν_1) = ab - 1 = 9 -1 = 8, denominator degrees of freedom (v_2) = ab(r-1) = 225 -9 = 216 and where n = abr (a = number of levels for factor A; b = number of levels for factor B; and r = number of replications per treatment). From Table VIII, Statistics for Business and Economics, $F_{.05,8,216} \approx 1.94$ (McClave and Benson: 1994, 1130). Therefore, the rejection region is F > 1.94. Since the observed value of the test statistic does fall in the rejection region, Ho is rejected. There is sufficient evidence to indicate differences in the mean aircraft availability among the nine treatments at $\alpha = .05$.

Test: Main Effect Factor A (Flying Hours). The hypothesis test for main effect of flying hours is conducted to determine whether or not flying hours effects aircraft availability under the parameters of this experiment. Table 4.5 summarizes the results of this hypothesis test.

TABLE 4.5

HYPOTHESIS TEST FOR FLYING HOURS MAIN EFFECT

Test	Hypothesis	Test Statistic	Reject Region	Results
Main Effect: Flying Hours (Factor A)	Ho: $A_i = 0$, for all i Ha: At least two factor A mean levels differ	$F = \frac{MS(A)}{MSE}$ Therefore: F= 0.171256	$F \geq 3.00$ based on: $\nu_1 = 2$ $\nu_2 = 216$	Not enough evidence to reject Ho at $\alpha = .05$

Test: Main Effect Factor B (OST). The hypothesis test for main effect of OST is conducted to determine whether or not OST effects aircraft availability under the parameters of this experiment. Table 4.6 summarizes the results of this hypothesis test.

TABLE 4.6

HYPOTHESIS TEST FOR OST MAIN EFFECT

Test	Hypothesis	Test Statistic	Reject Region	Results
Main Effect: OST (Factor B)	Ho: $B_j = 0$, for all j Ha: At least two factor B mean levels differ	$F = \frac{MS(B)}{MSE}$ Therefore: F = 76.74097	$F \geq 3.00$ based on: $\nu_1 = 2$ $\nu_2 = 216$	$76.74097 \geq 3.00$ therefore, reject Ho at $\alpha = .05$

Test: Factor Interaction. The interaction component tests whether the factors combine to affect the response. Within the context of this research, this test determines whether or not flying hours and OST interact to affect aircraft availability. Table 4.7 summarizes the interaction hypothesis test.

TABLE 4.7

HYPOTHESIS TEST FOR INTERACTION

Test	**Hypothesis**	**Test Statistic**	**Reject Region**	**Results**
Interaction of Flying Hours (Factor A) and OST (Factor B)	Ho: $(AB)_{ij} = 0$, for all I and j Ha: Factors A and B do interact to affect the response mean	$F = \frac{MS(AB)}{MSE}$ Therefore: F= 0.223593	$F \geq 2.37$ based on: $\nu_1 = 4$ $\nu_2 = 216$	Not enough evidence to reject Ho at $\alpha = .05$

Summary of Hypothesis Testing. The hypothesis testing conducted above answered some basic questions concerning the results of this experiment. The rejection of the null hypothesis when testing for the equality of treatment means indicated that at the 95 percent confidence level there is sufficient evidence to indicate differences in the mean aircraft availability levels among the nine treatments. Furthermore, the hypothesis tests on the main effect of OST rejected the null hypothesis that OST, at its three levels, did not effect the outcome of the model. However, the test on the main effect of flying hours failed to reject the null hypothesis that flying hours, at its three levels, did not effect the outcome of the model. Additionally, the results of the hypothesis test for interaction between OST and flying hours failed to reject the null hypothesis that the two factors do not interact to effect the response mean.

In brief, these tests suggest that aircraft availability varies because of changes in OST, but not because of the demand rate. OST was shown to have an impact of the output of the factor-level combinations as represented by the treatment means. However, both the main effect of flying hours and the interaction of flying hours and OST were discounted as having a major impact of the results of the ANOVA model. These results suggest that, in the modeled environment produced by this research, OST is the primary determinant of output results.

Chapter Summary

This chapter discussed the results obtained for each of the analytical approaches to answer the research question addressed by this experiment. The assumptions of the ANOVA analysis and statistical tests are discussed and verified. The statistical techniques used to analyze the output data from the simulation model are presented in both tabular and narrative form. Chapter V will list conclusions and provide recommendations for future research.

V. Conclusions and Recommendations

Introduction

This chapter provides a summary of the research performed during the course of investigating whether a wartime lean logistics pipeline can maintain acceptable aircraft availability rates in response to induced variations of OST and flying hours for deployed forces. The chapter begins by providing a general review of the thesis, and then presents findings and conclusions that can be drawn based upon the analysis of the data obtained from the simulation experiment. This chapter concludes by providing a list of topics encountered during the course of this research that would be suitable candidates for further study.

Research Summary

This research was designed to evaluate how a lean logistics reparable asset pipeline may function under the conditions inherent to a deployed combat scenario. An analysis of aircraft availability was conducted by examining the effects of OST and flying hour variability on the performance of an assumed lean logistics pipeline in a wartime scenario.

Due to the working nature of the lean logistics concept, this research made several assumptions concerning its final form. OST was utilized in the experiment to represent the rapid transportation variable for Lean Logistics in a wartime scenario. In addition, the uncertain nature of a wartime scenario and the systems of support for deployed forces required additional assumptions. Flying hours was selected as a primary variable in the experiment because fluctuations in flying hours would directly result in fluctuating demand for aircraft spares within the pipeline based upon the assumption that flying hours and failures were strictly correlated. Another important assumption was that initial spares availability within the pipeline network could be determined through the application of ASM. This assumption did not allow the application of lean stock levels, calculated via the RCDL method, to this research. Refer to Appendix B for information on Lean Levels.

The research utilized the F-15C MDS to measure the effectiveness of lean logistics support in a wartime scenario. The attributes of a deployed fighter squadron reflected the ideal conditions desired for this research. Four identical fighter squadrons composed of 24 aircraft each were deployed with 30 day MRSPs to four separate locations in an overseas theater. The sample data used to assess the deployed aircraft included the top 25 demanded LRUs assigned to the F-15Cs MRSP.

The methodology employed in this research involved the application of Dyna-METRIC Version 6.4 to model the flow of aircraft spares through a wartime reparable asset pipeline. Dyna-METRIC was chosen for this research because it was designed especially for assessing USAF logistics pipeline performance in a dynamic wartime environment. The basic design of this research experiment was a factorial design with two factors. These two factors, OST and flying hours, were varied at three levels each which represented low, medium, and high values. This 3^2 factorial design produced 9 treatments which allowed for all possible combinations of factor levels.

Dyna-METRIC Version 6.4 was used to simulate the first 120 days of the logistics support provided for the four F15-C squadrons flying under a wartime scenario. ASM was used to establish the initial spares distribution at each base within the pipeline to achieve a 85% aircraft availability goal.

The data generated from this research was evaluated using an ANOVA. The data collected satisfied all assumptions required of the ANOVA. The ANOVA was used to test for difference between treatment means, the main effect of each factor, and possible interaction between main effects. The ANOVA hypothesis testing allowed conclusions to be drawn on the impact of the individual factors and the interaction of the factors on aircraft availability levels in a wartime lean logistics scenario.

Summary of Findings

The hypothesis testing conducted in Chapter IV answered some basic questions concerning the results of this experiment. The hypothesis test for the equality of treatment means rejected the null hypothesis that the treatment means were equal. The results of this test suggest that the ANOVA model used in this research produced different results at varying levels of OST and flying hours. Furthermore, the results of this ANOVA experiment demonstrated the following:

1. Impact of OST on aircraft availability rates: OST does impact aircraft availability rates at a 95% level of significance. This hypothesis test evaluated whether or not the three varying levels of OST produced different aircraft availability levels. The test for main effect of OST rejected the null hypothesis that the three levels of OST produced the same experimental results.

2. Impact of flying hours on aircraft availability rates: The hypothesis test for the main effect of flying hours failed to reject the null hypothesis that the aircraft availability results were the same at each of the three levels of flying hours.

3. Impact of interaction on aircraft availability: The test for interaction evaluated whether or not OST and flying hours interacted to effect the dependent variable response. In this case, the null hypothesis that interaction did not effect the experimental results was not rejected.

Table 5.1 provides a summary of the achieved aircraft availability rates for all nine treatments, and Figure 5.1 provides a bar chart of the nine individual treatment means across the horizontal axis and observed aircraft availability rates along the vertical axis.

TABLE 5.1

OBSERVED AIRCRAFT AVAILABILITY

		OST		
		Low (3 days)	**Medium (5 days)**	**High (7 Days)**
FLYING HOURS (per sortie)	**Low (1.0 hours)**	treatment 1 72.586	treatment 2 66.588	treatment 3 58.922
	Medium (1.5 hours)	treatment 4 72.380	treatment 5 66.374	treatment 6 59.110
	High (2.0 hours)	treatment 7 72.918	treatment 8 66.118	treatment 9 57.208

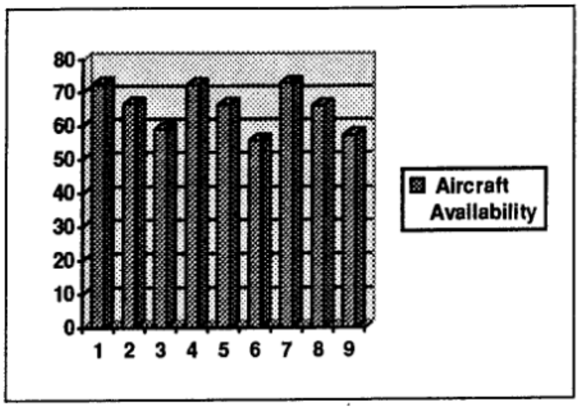


Figure 5.1 Bar Chart of Observed Aircraft Availability

As demonstrated in Figure 5.1, this research resulted in a wide range of aircraft availability rates based on the nine individual factor-level combinations. The main effect of OST was identified to be the main source of variation in the value of the dependent variable, and flying hours was shown to have little impact on the dependent variable. Additionally, the results of this research indicated that the interaction between OST and flying hours does not significantly effect the aircraft availability rates for the lean logistics pipeline portrayed in this research. These facts can be easily seen by examining the ANOVA results in table 4.4. The mean square for error (MSE) for OST is 3806.294 and the MSE for flying hours is 8.494164. The MSE represents the amount of variation in the model resulting from each individual factor. The large difference between the MSE of OST and flying hours suggests OST is the main driver in this model. Also, the MSE of the interaction term was only 11.09006 which further suggests that interaction of the two terms has minimal impact on the value of the dependent variable.

Conclusions Drawn From Research

This section will discuss the results of the research to answer the research question: Can a wartime lean logistics pipeline maintain acceptable aircraft availability rates in response to induced variations of OST and flying hours for deployed forces? The main conclusion drawn from this research is that a wartime lean logistics pipeline can not maintain acceptable aircraft availability levels in response to variation of OST and flying hours. In Chapter I the acceptable aircraft availability level was established at 85 percent, and in Chapter IV the aircraft availability level obtained by the peacetime baseline simulation was 86.88 percent. Each of the nine treatments in this experiment failed to achieve an 85 percent aircraft availability rate. The range of mean treatment values in this research, 72.918 percent to 57.208 percent, were well below the 85 percent acceptability level. Evaluation of the hypothesis tests and ANOVA results identified OST to be the primary source of variation in the model; therefore, the conclusion can be drawn that OST variation is the primary cause of the unacceptable aircraft availability levels. Further observation of the observed aircraft availability levels, Table 5.1, clearly shows that in this model as OST increases aircraft availability decreases. When OST is at 3, 5, and 7 days, aircraft availability is approximately 72 percent, 66 percent and 58 percent respectively. Since flying hours and the interaction between OST and flying hours were both determined to have little impact on the outcome of the experiment, OST is identified as the primary determinant of the results of this model. An increasing level of OST appears to produce decreasing aircraft availability, which suggests that consistently controlling and minimizing OST provides the main area for potential improvements in this model's performance.

Management Implications

This research has attempted to evaluate whether or not a lean logistics system can support the mission requirements for a wartime deployment. The conclusions drawn from this research point to potential shortfalls in a wartime lean logistics pipeline. The inability of the lean logistics pipeline modeled in this research to produce acceptable aircraft availability levels should be viewed as unacceptable by USAF logisticians regardless of the savings and efficiencies produced by a peacetime lean logistics system. The USAF must focus on decreasing the OST and developing a system which can deliver reparable assets within two days or less and do so consistently. Consideration of how Lean Logistics would operate in a wartime environment is important because the ability of the logistics infrastructure to support deployed forces is critical to USAF readiness. The results of this thesis clearly indicate that management attention and further research should be directed toward improving transportation efficiency for shipments to deployed locations and that steps should be taken to minimize variability in the shipment times to these locations.

Suggestions for Future Research

During the course of this research, many other areas of potential future research were identified. These issues were generally beyond the scope of this research, but merit further investigations. Four suggestions for future research are discussed below.

Lean Logistics Stock Levels. Calculating stock levels for lean logistics systems considers only OST; however, when modeling wartime pipeline systems the retrograde time is an equally important player in the total transportation pipeline time. For Lean Logistics to truly become a systems operation all aspects of the system must be considered. The OST pipeline time is not the only pipeline transportation time that must be considered. The retrograde time from base to depot represents an equally important time lag in the pipeline. Suggest future research centered around the development of a methodology that considers both retrograde time and OST in the calculation of Lean Levels. The design of the experiment could involve adding an element to the RCDL model that accounts for retrograde transportation time. An experiment could be conducted by comparing the performance of RCDL stock levels both with and without the retrograde component.

Depot Repair. The issue of depot performance in a lean logistics system can be critical to the success of the system. The subject of depot operations and its relationship to Lean Logistics is a very broad and diverse subject field. In this research depot time was held constant, future research could conduct a similar ANOVA experiment to determine what impact variation in the depot repair times may have on the performance of a lean logistics system. A model of the lean logistics depot repair system could be constructed and an a experiment conducted to determine the capacity, responsiveness, average through-put time, and impacting factors of the system. Additionally the performance of the depot model could also be combined with a pipeline performance experiment similar to the one conducted in this research. An effort along these lines would produce a truly comprehensive view of the lean logistics pipeline network.

Validation of Dyna-METRIC Version 6.4. Although Dyna-METRIC Version 6.4 is a widely accepted and used model, no known documentation exists on the programs validation. Documented validation of the Version 6.4 program would enhance the uses of the model for academic research. Future research, in conjunction with RAND or AFMC/XPS, would be valuable to fully validate the Dyna-METRIC Version 6.4 program.

Thesis Summary

Lean Logistics is an innovative proposal designed to reduce the costs associated with reparable inventory management. This thesis was undertaken to highlight the potential problems Lean Logistics could encounter during a wartime scenario. More specifically, the purpose of this thesis was to determine whether a wartime lean logistics pipeline can maintain acceptable aircraft availability rates in response to induced variations of OST and flying hours for deployed forces. After a comprehensive review of the available literature related to this research was completed, the Dyna-METRIC Version 6.4 simulation program was used to evaluate an ANOVA experimental design with nine factor-level combinations. The methodology of this experiment was based upon the variation of the two main factors, OST and flying hours, which were each varied at three levels; low, medium, and high. The results of the ANOVA experiment identified OST as the primary factor that influenced observed aircraft availability levels across the nine treatment means. An analysis of the results indicated as OST increased aircraft availability rates tended to decrease, thus it was determined that maintaining OST at a low level is one of the keys to the success of a deployed lean logistics scenario. The conclusions drawn from this research clearly showed that the uncertainties of a wartime environment could invalidate Lean Logistics as a viable concept for the USAF. While many aspects of the proposed lean logistics pipeline concept could prove to be a significant improvement over traditional reparable pipeline management, USAF logistics planners must not overlook the possible impact dynamic factors could have on combat operations.

Appendix A: F15-C Research Data

TABLE A.1

F15-C RESEARCH DATA

National Stock Number (NSN)	Nomenclature	Quantity Per Aircraft (QPA)	Demand Rate Per Flying Hour
1270010405948XX	Converter	1	0.00227
1270010469884XX	Gyro, Lead	1	0.00156
1560012713543XX	Raydome	1	0.02102
1620002671046XX	Damper	1	0.00081
2835010912433XX	Engine, Gas	1	0.00467
2915011800246XX	Control, EN	1	0.00234
2915012648648XX	Fuel Controller	1	0.00275
2915012913072XX	Exhaust Nozzle	1	0.00014
4320013327070XX	Oil Pump	1	0.00199
5841011007363XX	Transmitter	1	0.00788
5841010486312XX	Radar, Rec	1	0.00522
5841011356194XX	Processor	1	0.00689
5841012348535XX	Processor	1	0.00706
5841013093064XX	Processor	1	0.00523
5865010891745XX	Processor	1	0.00104
5865011003768XX	Oscillatin	1	0.00298
5865011449320XX	Receiver, C	1	0.00708
5865012112335XX	Receiver-T	1	0.00182
5865012876182XX	Receiver, C	1	0.00412
5895010456276XX	Amplifier	1	0.00272
5895010891808XX	Tuner, Radio	1	0.00460
5895012731990XX	Receiver-T	1	0.00423
5985012778913XX	Antenna AS	1	0.00664
6130011234126XX	Power Supply	2	0.00394
6610012238179XX	Controller	1	0.00128

Appendix B: Lean Level Computations

The reduced levels of inventory that will be encountered under the confines of a lean logistics reparable asset system are referred to as Lean Levels. The main characteristic of Lean Levels, when implemented, will be lower authorized stock levels. Lean Levels will result from the manipulation of all the major variables within the Repair Cycle Demand Level Model (RCDL). Lean Level computations will result in depressed or constrained levels through the application of reduced input factors. Some of these factors will be reduced as a result of the implementation of a lean logistics support system, or the artificial reductions of these factors to produce a level in response to management decisions. The main factors that impact inventory levels as reflected in the RCDL are transportation time, repair time, and the associated variability (safety stock). Lean Logistics would strive to significantly reduce transit times through the use of rapid transportation and reduce repair time by streamlining depot and base-level repair processes. Additionally, the expected responsiveness and reliability of the proposed lean logistics process would reduce system variability. Lean Levels would take a comprehensive approach to reducing inventory and thus produce significant cost savings.

Conceptually, the RCDL computes an unconstrained stock level (Pohlen: 1994). However, Lean Level computations should result in depressed or constrained levels through the application of reduced input factors.

In reality, the calculation of base Lean Levels reflects a sub-optimization of the logistics pipeline. The calculation of Lean Levels must address in-transit inventory and assets currently within the depot repair system. Following is the input data and results of the RCDL Lean Level calculations for each of the NSNs used in this research.

Base Lean Levels (Input parameters shown in Bold)

Lean Levels reflect the following standards inputs:		**actual values apply for inputs to the RCDL**	
OST=	**7 days**	**DDR=**	**actual**
NCT=	**0 days**	**PBR=**	**actual**
C Factor=	**1**	**RCT=**	**actual**

FSC	NIIN	NOMEN			
2915	'012913072	EXHAUST,NO		System stock levels for the four bases in the experiment (valuex4)	
DDR	0.0018	RCQ	0	S= 0.736654	System stock level = 2.946616
PBR	0	OSTQ	0.0126		
RCT	2.5	NCQ	0.0036		
NCT	2	SLQ	0.220454		
OST	7	K	0.5		
C	1				
5841	'011356194	PROCESSOR,			
DDR	0.0893	RCQ	0.40694	S= 2.142011	System stock level = 8.568044
PBR	0.93	OSTQ	0.043757		
RCT	4.9	NCQ	0.012502		
NCT	2	SLQ	1.178812		
OST	7	K	0.5		
C	1				

5865 '011003768 OSCILLATIN

DDR	0.043	RCQ	0.051428	S= 1.079544	System stock level = 4.318176
PBR	0.92	OSTQ	0.02408		
RCT	1.3	NCQ	0.00688		
NCT	2	SLQ	0.497156		
OST	7	K	0.5		
C	1				

5841 '013093064 PROCESSOR,

DDR	0.0541	RCQ	0.109066	S= 1.249529	System stock level = 4.998114
PBR	0.96	OSTQ	0.015148		
RCT	2.1	NCQ	0.004328		
NCT	2	SLQ	0.620987		
OST	7	K	0.5		
C	1				

1560 '012713543 RADOME

DDR	0.1513	RCQ	0.11983	S= 2.227204	System stock level = 8.908815
PBR	0.72	OSTQ	0.296548		
RCT	1.1	NCQ	0.084728		
NCT	2	SLQ	1.226098		
OST	7	K	0.5		
C	1				

5895 '010456276 AMPLIFIER,

DDR	0.0391	RCQ	0.043714	S= 1.121127	System stock level = 4.484508
PBR	0.86	OSTQ	0.038318		
RCT	1.3	NCQ	0.010948		
NCT	2	SLQ	0.528147		
OST	7	K	0.5		
C	1				

2835 '010912433 ENGINE, GAS

DDR	0.0604	RCQ	0.123578	S= 1.825355	System stock level = 7.301418
PBR	0.62	OSTQ	0.160664		
RCT	3.3	NCQ	0.045904		
NCT	2	SLQ	0.995208		
OST	7	K	0.5		
C	1				

5841 '012348535 PROCESSOR,

DDR	0.0914	RCQ	0.150719	S= 1.400786	System stock level = 5.603144
PBR	0.97	OSTQ	0.019194		
RCT	1.7	NCQ	0.005484		
NCT	2	SLQ	0.725389		
OST	7	K	0.5		
C	1				

1270 '010469884 GYRO,LEAD

DDR	0.0224	RCQ	0.017472	S= 0.992489	System stock level = 3.969954
PBR	0.78	OSTQ	0.034496		
RCT	1	NCQ	0.009856		
NCT	2	SLQ	0.430665		
OST	7	K	0.5		
C	1				

5865 '012112335 RECEIVER-T

DDR	0.0261	RCQ	0.022968	S= 0.942906	System stock level = 3.771624
PBR	0.88	OSTQ	0.021924		
RCT	1	NCQ	0.006264		
NCT	2	SLQ	0.39175		
OST	7	K	0.5		
C	1				

5865 '012876182 RECEIVE R,C

DDR	0.0593	RCQ	0.18549	S= 1.555567	System stock level = 6.222269
PBR	0.92	OSTQ	0.033208		
RCT	3.4	NCQ	0.009488		
NCT	2	SLQ	0.827381		
OST	7	K	0.5		
C	1				

5985 '012778913 ANTENNA AS

DDR	0.0955	RCQ	0.28077	S= 1.743412	System stock level = 6.973649
PBR	0.98	OSTQ	0.01337		
RCT	3	NCQ	0.00382		
NCT	2	SLQ	0.945452		
OST	7	K	0.5		
C	1				

5841 '011007363 TRANSMITTE

DDR	0.102	RCQ	0.504594	S= 2.295622	System stock level = 9.182488
PBR	0.97	OSTQ	0.02142		
RCT	5.1	NCQ	0.00612		
NCT	2	SLQ	1.263488		
OST	7	K	0.5		
C	1				

5895 '012731990 RECEIVER-T

DDR	0.0608	RCQ	0.259738	S= 1.799618	System stock level = 7.198471
PBR	0.89	OSTQ	0.046816		
RCT	4.8	NCQ	0.013376		
NCT	2	SLQ	0.979688		
OST	7	K	0.5		
C	1				

```
      5865 '011449320    RECEIVE
                         R,C

DDR              0.1018 RCQ      0.324233    S= 2.01126     System stock level = 8.045041
PBR                0.91 OSTQ     0.064134
RCT                 3.5 NCQ      0.018324
NCT                   2 SLQ      1.104569
OST                   7 K             0.5
C                     1

      1620 '002671046    DAMPER,
                         SHI

DDR              0.0117 RCQ      0.000702    S= 1.089745    System stock level = 4.35898
PBR                 0.2 OSTQ      0.06552
RCT                 0.3 NCQ       0.01872
NCT                   2 SLQ      0.504803
OST                   7 K             0.5
C                     1

      6610 '012238179    CONTRO
                         LLER

DDR              0.0099 RCQ      0.023255    S= 0.887391    System stock level = 3.549562
PBR                0.81 OSTQ     0.013167
RCT                 2.9 NCQ      0.003762
NCT                   2 SLQ      0.347206
OST                   7 K             0.5
C                     1

      2915 '012648648    FUEL
                         CONTR

DDR              0.0301 RCQ      0.004064    S= 1.617616    System stock level = 6.470465
PBR                0.09 OSTQ     0.191737
RCT                 1.5 NCQ      0.054782
NCT                   2 SLQ      0.867034
OST                   7 K             0.5
C                     1
```

2915 '011800246 CONTROL,EN

DDR	0.0255	RCQ	0	S= 1.559259	System stock level = 6.237036
PBR	0	OSTQ	0.1785		
RCT	1.9	NCQ	0.051		
NCT	2	SLQ	0.829759		
OST	7	K	0.5		
C	1				

5895 '010891808 TUNER,RADI

DDR	0.0584	RCQ	0.119545	S= 1.406801	System stock level = 5.627202
PBR	0.89	OSTQ	0.044968		
RCT	2.3	NCQ	0.012848		
NCT	2	SLQ	0.72944		
OST	7	K	0.5		
C	1				

1270 010469884

DDR	0.022464	RCQ	0.035044	S= 1.026711	System stock level = 4.106843
PBR	0.78	OSTQ	0.034595		
RCT	2	NCQ	0		
NCT	0	SLQ	0.457072		
OST	7	K	0.5		
C	1				

2835 010912433

DDR	0.06047	RCQ	0.074983	S= 1.576963	System stock level = 6.30785
PBR	0.62	OSTQ	0.16085		
RCT	2	NCQ	0		
NCT	0	SLQ	0.84113		
OST	7	K	0.5		
C	1				

6130 011234126 POWER SUPP

DDR	0.05106	RCQ	0.099056	S= 1.183658	System stock level = 4.734632
PBR	0.97	OSTQ	0.010723		
RCT	2	NCQ	0		
NCT	0	SLQ	0.573879		
OST	7	K	0.5		
C	1				

4320 013327070

DDR	0.028584	RCQ	0.004573	S= 1.44096	System stock level = 5.763839
PBR	0.08	OSTQ	0.184081		
RCT	2	NCQ	0		
NCT	0	SLQ	0.752305		
OST	7	K	0.5		
C	1				

1270 01-040-5948

DDR	0.0201	RCQ	0.039396	S= 1.298061	System stock level = 5.192244
PBR	0.98	OSTQ	0.002814		
RCT	2	NCQ	0		
NCT	0	SLQ	0.355851		
OST	7	K	0.9		
C	1				

5841 01-048-6312

DDR	0.0314	RCQ	0.061544	S= 1.41071	System stock level = 5.642838
PBR	0.98	OSTQ	0.004396		
RCT	2	NCQ	0		
NCT	0	SLQ	0.44477		
OST	7	K	0.9		
C	1				

5865 01-089-1745

DDR	0.02145	RCQ	0.040326	S= 1.334049	System stock level = 5.336197
PBR	0.94	OSTQ	0.009009		
RCT	2	NCQ	0		
NCT	0	SLQ	0.384714		
OST	7	K	0.9		
C	1				

Appendix C: Aircraft Sustainability Model

Background

The Aircraft Sustainability Model (ASM) was designed to enable USAF planners to compute the minimum cost and the associated optimal spares mix to achieve a prescribed set of probabilities for a pre-determined flying schedule (Slay and King, 1987:, 1-2). ASM uses the marginal analysis technique to build the best mix of assets from a given pool to achieve a desired aircraft availability goal. The model is component specific, multi-echelon, and multi-indentured: it distinguishes between line replaceable units (LRUs) and shop replaceable units (SRUs) installed directly on an aircraft (Eichorn, 1989: 1-1). ASM uses component specific data such as item failure rates, resupply times and depot repair time to compute the necessary quantity of spares to both fill the pipeline and achieve desired flying goals.

The execution of the ASM program is very straight forward. Component data for each National Stock Number (NSN) is loaded into the program via ASM data files. Next, the programmer inputs the planned flying scenario and the desired aircraft availability goal to be achieved. Additionally, a parameter file must be loaded which identifies the composition of the multi-echelon environment (number of bases) to be modeled. The program logic primarily operates by marginal analysis to get the lowest cost mix of spares necessary to achieve the aircraft availability goal. Once the program has been run, output files or "shopping lists" identifying the optimal mix of spares are easily obtainable.

The ASM method is more consistent with the system optimization goals of Lean Logistics. ASM builds stock levels to fill the pipeline to achieve desired aircraft availability goals by balancing the expected number of item failures with the specified limitations of the pipeline parameters. In this manner, the logic of the ASM method is more closely correlated to the goals of Lean Logistics than the RCDL method.

Design of Experiment

The calculation of ASM levels for this thesis research was completed in a manner so that the assumptions of the experiment and the assumptions made in the ASM model were correlated with each other. Provided below, in table C.1, is a summary of assumptions used and results of the ASM level computations.

Data Sample. The data sample for this exercise is the top 25 demanded items for the F-15C Mission Design Series. These top 25 items were screened from the AFMC/XP worldwide critical item management program for the F-15C.

Assumptions. To increase the effectiveness of this experiment, several assumption are made:

(1) Only LRUs will be considered in this experiment

(2) Cost of the individual LRUs will not be considered in this experiment. This assumption is made so that the only constraint placed upon the ASM parameter file will be the achievement of an aircraft availability goal. Asset costs would place another constraint on the model. The differing costs of LRUs provides an additional basis for selection of the optimal spares mix.

(3) The flying program assigned to the ASM model is the same flying program that would be loaded into the Dyna-METRIC Version 6.4 program.

(4) Readiness Spares Package (RSP) assets will not be considered in this experiment.

(5) Modeled environment will reflect zero base repair capability.

(6) No condemnations will be allowed in the modeled system.

(7) Stock levels will be computed based on a seven day OST.

(8) Dyna-METRIC will assess the stock levels based on two day retrograde time and two day OST.

TABLE C.1

LEAN LEVEL COMPUTATION DATA

National Stock Number (NSN)	Percent Base Repair	Repair Cycle Time (days)	Demand Rate Per Flying Hour	Lean Stock Level
1270010405948XX	0.78	2.0	0.00227	5
1270010469884XX	0.78	1.0	0.00156	4
1560012713543XX	0.72	1.1	0.02102	9
1620002671046XX	0.2	0.3	0.00081	4
2835010912433XX	0.62	3.3	0.00467	7
2915011800246XX	0.0	1.9	0.00234	6
2915012648648XX	0.09	1.5	0.00275	7
2915012913072XX	0.0	2.5	0.00014	3
4320013327070XX	0.08	2	0.00199	6
5841011007363XX	0.97	5.1	0.00788	3
5841010486312XX	0.98	2.0	0.00522	6
5841011356194XX	0.93	4.9	0.00689	9
5841012348535XX	0.97	1.7	0.00706	6
5841013093064XX	0.96	2.1	0.00523	5
5865010891745XX	0.94	2.0	0.00104	5
5865011003768XX	0.92	1.1	0.00298	4
5865011449320XX	0.91	3.5	0.00708	8
5865012112335XX	0.88	1.0	0.00182	4
5865012876182XX	0.92	3.4	0.00412	6
5895010456276XX	0.86	1.3	0.00272	5
5895010891808XX	0.89	2.3	0.00460	6
5895012731990XX	0.89	4.8	0.00423	7
5985012778913XX	0.98	3.0	0.00664	7
6130011234126XX	0.97	2.0	0.00394	5
6610012238179XX	0.81	2.9	0.00128	4

TABLE C.2

STOCK LEVEL INPUT PARAMETERS

Parameter	RCDL	ASM
OST	7 Days	7 Days
Base repair time	Actual (based on item data)	Actual
Percent base repair	Actual	Actual
Depot repair time	N/A	15 Days
NTRS condemn time	Actual	Actual

Table C.3. illustrates the difference in stock levels between unconstrained Lean Level computation and ASM levels. If Lean Levels had been utilized in this experiment, 39 units of unnecessary stock would have been included in the simulation and possibly could have distorted the results.

TABLE C.3

SYSTEM-WIDE STOCK LEVELS

NSN	**Lean Level**	**ASM level**	**Lean Level-ASM Level**
1270-01-040-5948	5	2	**3**
1270-01-046-9884	4	2	**2**
1560-01-271-3543	9	12	**-3**
1620-00-267-1046	4	3	**1**
2835-01-091-2433	7	8	**-1**
2915-01-180-0246	6	7	**-1**
2915-01-264-8648	7	8	**-1**
2915-01-291-3072	3	1	**2**
4320-01-332-7070	6	8	**-2**
5841-01-100-7363	9	8	**1**
5841-01-048-6312	6	7	**-1**
5841-01-135-6194	9	3	**6**
5841-01-234-8535	6	6	**0**
5841-01-309-3064	5	2	**3**
5865-01-089-1745	5	2	**3**
5865-01-100-3768	4	1	**3**
5865-01-144-9320	8	2	**6**
5865-01-211-2335	4	6	**-2**
5865-01-287-6182	6	2	**4**
5895-01-045-6276	5	4	**1**
5895-01-089-1808	6	3	**3**
5895-01-273-1990	7	4	**3**
5985-01-277-8913	7	5	**2**
6130-01-123-4126	5	2	**3**
6610-01-223-8179	4	1	**3**
Totals	148	109	**39**

Appendix D: Dyna-METRIC Input Parameters

Notes: (1) The options used for this research are highlighted in bold print.

(2) Only the Dyna-METRIC Header records and columns used in this research are addressed in this appendix. Further information can be obtained by referencing Dyna-METRIC Version 6, An Advanced Capability Assessment Model (Isaacson and Boren, 1993).

(3) Header records and column definitions direct quotations from the Dyna-METRIC Version 6 handbook (Isaacson and Boren, 1993).

(4) Appendix E contains the actual input parameter record for this experiment.

ADMINISTRATIVE DATA

Header Record: none

Definition: Provides general information about the run, including a heading, number of trials, wartime start, days of analysis, and seeds for the random number generator. Also provides the administrative delay times for each echelon. Table D-1, D-2, and D-3 will summarize the data inputs for the second, third, and fourth record of this input file. The first record is simply a heading for the entire input data file.

TABLE D.1

INPUT RECORD: ADMINISTRATIVE DATA (SECOND RECORD)

Column	Description
20-30	Data set version. Must contain "Version 6.4" to correctly identify the input data set. **For this research, "Version 6.4" was input for all simulation runs.**
67-70	Number of Trials. The number of model iterations to run. More trials take more computer time but yield more precise results. Limited by parameter DMTRIES. **Twenty-five (25) trials were accomplished for each of the nine simulation runs.**
79	Depot distribution policy. 1 = depot fills requirement on a priority basis (distributed to the base with the greatest need for the component) 0 = depot fills requisition on a random basis (similar to first come, first served. **For this research, a value of "1" was always input.**

TABLE D.2

INPUT RECORD: ADMINISTRATIVE DATA (THIRD RECORD)

Column	Description
1-80	Random Number Seeds. Random number seeds are needed for the various random number streams that control the generation of removals, repair times, transportation times, NRTS actions etc. **For this research, the random numbers were altered for each treatment. Refer to discussion in chapter 4 for the exact input parameters.**

TABLE D.3

INPUT RECORD: ADMINISTRATIVE DATA (FOURTH RECORD)

Column	Description
1-4	First day of war. Independent of the first day of analysis and must be greater than 0. Wartime resupply times and demand rate changes go into effect on this day. **For the purpose of this research, a value of "1" is always entered.**
5-8	First day of analysis. The first day for which output reports are requested. **For the purpose of this research, values of 30, 60, 90, and 120 were entered.**

OPTION SELECTION

Header Record: OPT

Definition: Defines the options that generate Dyna-METRIC reports and controls lateral supply.

TABLE D.4

INPUT RECORD: OPTION SELECTION

Column	Description
5-7	Option number (requests output reports). **For this research, the following option was used:** **11 -- Performance report: Produces an output called *data.out* showing each base's performance for each day of analysis. Performance measures include expected available aircraft, number of sorties, and the probability of achieving them under three assumptions: dedication cannibalization, full cannibalization, and no cannibalization.**

DEPOT DESCRIPTION

Header Record: DEPT

Definition: Provides characteristics about each depot, including its resupply availability and when unconstrained repair of LRUs and SRUs starts. The number of depots may not exceeds DMDEPOTS.

TABLE D.5

INPUT RECORD: DEPOT DESCRIPTION

Column	Description
1-4	Depot name. The name of the depot. May not be a header (such as "DEPT") or the name of another location. **For this research, the one depot was be named "DEPO"**
35-39	Resupply start. Day resupply of parts ordered from an outside supplier becomes available. Blank or 0 implies day 1. **For this research, a value of "0" was used.**

BASE DESCRIPTION

Header Record: Base

Definition: Provides characteristics about each base, including its link to a CIRF (if any), resupply availability, and when unconstrained repair of LRUs and SRUs starts. A record is required for each base. The number of bases may not exceed DMBASES.

TABLE D.6

INPUT RECORD: BASE DESCRIPTION

Column	Description
1-4	Base name. The name of the base. May not be a header (such as "BASE") or the name of another location **For this research there are four (4) bases. The names of the bases are as follows: "BS01", "BS02", "BS03", and "BS04".**
35-39	Resupply Start. Day resupply of parts ordered from a supplier other than the CIRF or depot first becomes available. Blank or 0 implies day 1. **For this research, a value of "0" was chosen for each of the four bases.**

DEPOT TRANSPORTATION

Header Record: TRNS

Definition: Describes the transportation resource connecting bases and CIRFs with depots. If a record in not entered for some location directly connected to a depot, transportation between the two it is assumed to be instantaneous and never cut off.

TABLE D.7

INPUT RECORD: DEPOT TRANSPORTATION

Column	Description
1-4	Base name. **For the purpose of this research the base names indicated in table D-6 were used.**
6-9	Depot name. **For the purpose of this research all bases use the services of a single depot (DEPO) for all 25 NSN's.**
11-15	Transportation time to depot. Number of days to ship unserviceable part from the deployed location to the depot. **For the purpose of this research, transportation times to the depot will be held constant across the treatment levels. Refer to Chapter III for exact input parameters.**
17-21	Transportation time from depot. Number of days to ship serviceable part from the depot to the deployed location. **Within this research, the transportation times from the depot to the base will vary in accordance to the factor-level combination of treatment.**
25-29	Transportation start. Day that transportation from the depot first becomes available. Blank or 0 implies day 1. **For the purpose of this research a value of "0" is always used.**

AIRCRAFT LEVELS

Header Record: ACFT

Definition: Specifies the number of aircraft assigned to each base. A base with no ACFT record is assigned no aircraft.

TABLE D.8

INPUT RECORD: AIRCRAFT LEVELS

Column	Description
1-4	Base name. Enter at most one record per base. **For the purpose of this research each of the four bases identified in Table D.6 were used.**
5-8	First aircraft level. Number of aircraft at the base. **For the purpose of this research, each of the four identical bases begins with 24 aircraft.**

Base Deployments

Header Record: DEPL

Definition: Allocates aircraft and stock to bases deployed form existing bases.

TABLE D.9

INPUT RECORD: BASE DEPLOYMENTS

Column	Description
1-4	New Base. Base to which aircraft and/or stock are being deployed. **For the purpose of this research, each of the original bases is deployed to one of four deployed bases. The deployed bases are identified as: "DBS1", "DBS2", "DBS3", and "DBS4".**
6-9	Parent Base. Base from which aircraft and/or stock are being deployed. **For the purpose of this research each original base is deployed to the deployed base having the same number.**
11-14	Deployment Start. Day of deployment. **For the purpose of this research, the deployment begins on day "1".**
16-17	Deployment Priority. **For the purpose of this research, a value of 1, 2, 3, or 4 was given to each of the original bases indicating the base deployment priority. Since our bases are identical, deployment priority does not matter and values were assigned in sequential order.**
19-21	Aircraft share. Percentage of available aircraft at the parent base that are deployed to the new base. **For the purpose of this research, 100% of the aircraft are deployed from each of the four bases.**

SORTIE RATES

Header Record: SRTS

Definition: Specifies the average daily number of sorties per aircraft at each base. Aircraft at bases with no associated SRTS record do not fly.

TABLE D.10

INPUT RECORD: SORTIE RATES

Column	Description
1-4	Base name. Enter at most one record per base. **For the purpose of this research a record is established for BAS1, BAS2, BAS3, and BAS4.**
5-8	First sortie rate. The number of daily sorties per aircraft, which may not exceed the turn rate on the base's TURN record. Rates may change DMCHANGE times during the scenario. Not all rates must be used. The last rate specified carries throughout the rest of the scenario. **For the purpose of this research, a max sortie rate of "2" is used for all bases.**

MAXIMUM SORTIE RATES

Header Record: TURN

Definition: Specifies the maximum number of sorties a mission capable aircraft can fly per day at each base. Aircraft at bases with no TURN records do not fly

TABLE D.11

INPUT RECORD: MAXIMUM SORTIE RATES

Column	Description
1-4	Base name. Enter at most one record per base. **For the purposes of this research a record will be established for each of the four bases.**
5-8	First maximum sortie rate. The maximum number of daily sorties per mission capable aircraft. Should be larger than the sortie rates on SRTS record. Rates may change as many as DMCHANGE times during the scenario. Not all "turn rates" must be used; the last rate specified remains throughout the scenario. **For the purpose of this research, a value of "4" is used for all bases over all simulation runs.**

FLYING HOURS PER SORTIE

Header Record: FLHR

Definition: Specifies the number of flying hours per sortie at each base. Aircraft at bases with no FLHR record fly sorties of one hour each.

TABLE D.12

INPUT RECORD: DATA FLYING HOURS PER SORTIE

Column	Description
1-4	Base name. **For the purpose of this research all four of the bases will be given identical flying hour times.**
5-8	First flying hour level. The number of flying hours per sortie per day. Flying hour levels may change as many as DMCHANGE time during the scenario. Not all levels must be used; the last level specified carries throughout the rest of the scenario. **For the purpose of this research flying hour values will vary based on the treatment level. Refer to Chapter III for clarification.**

LRU DESCRIPTION

Header Record: LRU

Definition: Describes the failure, repair, and resupply characteristics of each LRU. A pair of these records is required per LRU. The number of LRUs may not exceed DMLURS.

TABLE D.13

INPUT RECORD: LRU DESCRIPTION (FIRST RECORD)

Column	Description
1-16	LRU name. Unique LRU identifier, such as NSN. May not be the name of another part and may not begin with a header word (such as "LRU"). **For this research the twenty-five (25) highest failing items were selected. Reference Appendix E for clarification of the 25 NSNs used in this research.**
18-21	Depot Name. The name of the depot that repairs the LRU. Leave blank if the LRU is not repaired by a depot. **For this research, the depot is referenced by "DEPO".**
23	Level of repair. 1 = LRU can be repaired at a base, CIRF, or depot 2 = LRU can be repaired only as a CIRF or depot 3 = LRU can be repaired only at a depot **For this research, a value of "3" is always entered.**
25	CIRF reparability switch. Allows the CIRF to be a special facility that repairs only a subset of LRUs in analyses where both base and depot have repair capabilities. 1 = CIRF can repair the LRU (if level of repair not 3) 0 = CIRF cannot repair the LRU **For this research, a value of "0" always entered.**

26-28	Quantity per aircraft (QPA). Number installed per aircraft. **All NSNs used in this research have a QPA of "1" except for NSN 6610012238179XX which has a QPA of "2". Refer to Appendix A for clarification**
29-31	Minimum quantity. Minimum quantity of the LRU required for the aircraft to be mission capable (i.e., the QPA less the number that may be broken without impairing the aircraft's capability). **For the purpose of this research the minimum quantity is always equal to the value in column 26-28 of this record.**
32	Sorties/flying hours indicator 1 = demand rates are per sortie 2 = demand rates are per flying hour **For the purpose of this research a value of "2" is always used.**
33	Maintenance procedure. Determines when decision is made to NRTS or condemn the LRU and when its failed SRUs are detected. 1 = before attempt repair, make decision 0 = wait until after attempt repair to make decision (in effect, delay the decision one repair time + time awaiting maintenance). **For the purpose of this research, a value of "1" is always used.**
41-47	Demand rate. The expected demands per sortie or flying hour. **Refer to Appendix E.**
54-57	Lone base NRTS rate. Proportion of LRUs arriving for repair at bases not served by a CIRF that are sent to a higher echelon for repair. **For this research, a value of "1.0" was used.**

TABLE D.14

INPUT RECORD: LRU DESCRIPTION (SECOND RECORD)

Column	Description
1-16	LRU name. Must match LRU name given on first record of pair. **See column 1-16 of the first record of LRU description.**
32-36	Depot Repair Time. Number of days to repair the LRU at the Depot **For this research a value of "15" is used.**
75	No cannibalization. 1 = LRU cannot be cannibalized 0 = LRU can be cannibalized **For this research, a value of "1" is always used.**

STOCK LEVELS

Header Record: STK

Definition: Specifies each part's stock level at each location.. A stock level for a location reflects the number of serviceable and unserviceable and unserviceable on-hand and in transit to the location, less the number due out (or committed) to a forward location; it is not simply the number on the shelf. If all stock levels for a component were summed across all locations, the resulting number would be the number of assets in the entire system minus those installed on aircraft. Refer to Appendix E for a presentation of the initial stock levels.

Appendix E: Sample Dyna-METRIC Input File for Treatment 1

```
Gaddis/Haase Thesis Data Set for Treatment 1
           Version 6.4                          25      1
 104801501101536020118164791646691791419462590362007209609957091291901002236846573
  1  30  60  90 120
OPT
   11
DEPT
DEPO                              0
BASE
BS01                             0
BS02                             0
BS03                             0
BS04                             0
TRNS
BS01 DEPO  7.0  3.0
BS02 DEPO  7.0  3.0
BS03 DEPO  7.0  3.0
BS04 DEPO  7.0  3.0
ACFT
BS01  24
BS02  24
BS03  24
BS04  24
DEPL
DBS1 BS01   1  1 100 1 100 1
DBS2 BS02   1  2 100 1 100 1
DBS3 BS03   1  3 100 1 100 1
DBS4 BSO4   1  4 100 1 100 1
SRTS
BS01  2.
BS02  2.
BS03  2.
BS04  2.
TURN
BS01  4.
BS02  4.
BS03  4.
BS04  4.
FLHR
BS01 1.0
BS02 1.0
BS03 1.0
BS04 1.0
```

```
LRU
1270010405948XX DEPO 3 0  1 121      .00227 2.0 1.0
1270010405948XX           15      0 0.  0.          1
1270010469884XX DEPO 3 0  1 121      .00156 2.0 1.0
1270010469884XX           15      0 0.  0.          1
1560012713543XX DEPO 3 0  1 121      .02102 2.0 1.0
1560012713543XX           15      0 0.  0.          1
1620002671046XX DEPO 3 0  1 121      .00081 2.0 1.0
1620002671046XX           15      0 0.  0.          1
2835010912433XX DEPO 3 0  1 121      .00467 2.0 1.0
2835010912433XX           15      0 0.  0.          1
2915011800246XX DEPO 3 0  1 121      .00234 2.0 1.0
2915011800246XX           15      0 0.  0.          1
2915012648648XX DEPO 3 0  1 121      .00275 2.0 1.0
2915012648648XX           15      0 0.  0.          1
2915012913072XX DEPO 3 0  1 121      .00014 2.0 1.0
2915012913072XX           15      0 0.  0.          1
4320013327070XX DEPO 3 0  1 121      .00199 2.0 1.0
4320013327070XX           15      0 0.  0.          1
5841011007363XX DEPO 3 0  1 121      .00788 2.0 1.0
5841011007363XX           15      0 0.  0.          1
5841010486312XX DEPO 3 0  1 121      .00522 2.0 1.0
5841010486312XX           15      0 0.  0.          1
5841011356194XX DEPO 3 0  1 121      .00689 2.0 1.0
5841011356194XX           15      0 0.  0.          1
5841012348535XX DEPO 3 0  1 121      .00706 2.0 1.0
5841012348535XX           15      0 0.  0.          1
5841013093064XX DEPO 3 0  1 121      .00523 2.0 1.0
5841013093064XX           15      0 0.  0.          1
5865010891745XX DEPO 3 0  1 121      .00104 2.0 1.0
5865010891745XX           15      0 0.  0.          1
5865011003768XX DEPO 3 0  1 121      .00298 2.0 1.0
5865011003768XX           15      0 0.  0.          1
5865011449320XX DEPO 3 0  1 121      .00708 2.0 1.0
5865011449320XX           15      0 0.  0.          1
5865012112335XX DEPO 3 0  1 121      .00182 2.0 1.0
5865012112335XX           15      0 0.  0.          1
5865012876182XX DEPO 3 0  1 121      .00412 2.0 1.0
5865012876182XX           15      0 0.  0.          1
5895010456276XX DEPO 3 0  1 121      .00272 2.0 1.0
5895010456276XX           15      0 0.  0.          1
5895010891808XX DEPO 3 0  1 121      .00460 2.0 1.0
5895010891808XX           15      0 0.  0.          1
5895012731990XX DEPO 3 0  1 121      .00423 2.0 1.0
5895012731990XX           15      0 0.  0.          1
5985012778913XX DEPO 3 0  1 121      .00664 2.0 1.0
5985012778913XX           15      0 0.  0.          1
6130011234126XX DEPO 3 0  1 121      .00394 2.0 1.0
6130011234126XX           15      0 0.  0.          1
6610012238179XX DEPO 3 0  2 221      .00128 2.0 1.0
6610012238179XX           15      0 0.  0.          1
```

VTM

1270010405948XX	1.00	1.00	1.0	1.0
1270010469884XX	1.00	1.00	1.0	1.0
1560012713543XX	1.00	1.00	1.0	1.0
1620002671046XX	1.00	1.00	1.0	1.0
2835010912433XX	1.00	1.00	1.0	1.0
2915011800246XX	1.00	1.00	1.0	1.0
2915012648648XX	1.00	1.00	1.0	1.0
2915012913072XX	1.00	1.00	1.0	1.0
4320013327070XX	1.00	1.00	1.0	1.0
5841011007363XX	1.00	1.00	1.0	1.0
5841010486312XX	1.00	1.00	1.0	1.0
5841011356194XX	1.00	1.00	1.0	1.0
5841012348535XX	1.00	1.00	1.0	1.0
5841013093064XX	1.00	1.00	1.0	1.0
5865010891745XX	1.00	1.00	1.0	1.0
5865011003768XX	1.00	1.00	1.0	1.0
5865011449320XX	1.00	1.00	1.0	1.0
5865012112335XX	1.00	1.00	1.0	1.0
5865012876182XX	1.00	1.00	1.0	1.0
5895010456276XX	1.00	1.00	1.0	1.0
5895010891808XX	1.00	1.00	1.0	1.0
5895012731990XX	1.00	1.00	1.0	1.0
5985012778913XX	1.00	1.00	1.0	1.0
6130011234126XX	1.00	1.00	1.0	1.0
6611012238179XX	1.00	1.00	1.0	1.0

```
STK
1270010405948XX DEPO  2 BS01  0 BS02  0 BS03  0 BS04  0
1270010469884XX DEPO  2 BS01  1 BS02  1 BS03  1 BS04  1
1560012713543XX DEPO 12 BS01  1 BS02  1 BS03  1 BS04  1
1620002671046XX DEPO  3 BS01  2 BS02  2 BS03  2 BS04  2
2835010912433XX DEPO  8 BS01  2 BS02  2 BS03  2 BS04  2
2915011800246XX DEPO  7 BS01  2 BS02  2 BS03  2 BS04  2
2915012648648XX DEPO  8 BS01  2 BS02  2 BS03  2 BS04  2
2915012913072XX DEPO  1 BS01  2 BS02  2 BS03  2 BS04  2
4320013327070XX DEPO  8 BS01  2 BS02  2 BS03  2 BS04  2
5841011007363XX DEPO  7 BS01  2 BS02  2 BS03  2 BS04  2
5841010486312XX DEPO  3 BS01  2 BS02  2 BS03  2 BS04  2
5841011356194XX DEPO  6 BS01  2 BS02  2 BS03  2 BS04  2
5841012348535XX DEPO  2 BS01  2 BS02  2 BS03  2 BS04  2
5841013093064XX DEPO  2 BS01  1 BS02  1 BS03  1 BS04  1
5865010891745XX DEPO  1 BS01  0 BS02  0 BS03  0 BS04  0
5865011003768XX DEPO  2 BS01  1 BS02  1 BS03  1 BS04  1
5865011449320XX DEPO  6 BS01  1 BS02  1 BS03  1 BS04  1
5865012112335XX DEPO  2 BS01  0 BS02  0 BS03  0 BS04  0
5865012876182XX DEPO  4 BS01  2 BS02  2 BS03  2 BS04  2
5895010456276XX DEPO  3 BS01  2 BS02  2 BS03  2 BS04  2
5895010891808XX DEPO  4 BS01  1 BS02  1 BS03  1 BS04  1
5895012731990XX DEPO  5 BS01  2 BS02  2 BS03  2 BS04  2
5985012778913XX DEPO  4 BS01  2 BS02  2 BS03  2 BS04  2
6130011234126XX DEPO  2 BS01  1 BS02  1 BS03  1 BS04  1
6610012238179XX DEPO  1 BS01  1 BS02  1 BS03  1 BS04  1
END
```

Appendix F: Data Run Summary

TABLE F.1

DATA RUN SUMMARY: OBSERVED AIRCRAFT AVAILABILITY

Trial	Trt #1	Trt #2	Trt #3	Trt #4	Trt#5	Trt #6	Trt #7	Trt #8	Trt #9
1	82.292	70.833	54.167	66.667	67.771	43.750	71.875	55.208	64.583
2	65.625	71.875	58.333	72.917	68.750	54.167	76.042	65.625	50.000
3	71.875	67.771	48.958	77.083	67.771	60.417	63.542	67.771	63.542
4	66.667	61.458	43.750	82.500	70.833	64.583	72.917	69.792	69.792
5	75.000	70.833	56.250	65.625	80.208	68.750	84.375	64.583	65.625
6	65.625	56.250	63.542	70.833	70.833	57.292	68.750	69.792	50.000
7	60.417	68.750	53.125	77.003	84.375	70.833	70.833	63.542	45.833
8	72.917	60.417	63.542	78.125	55.208	73.958	75.000	62.250	57.292
9	77.083	68.750	58.333	70.833	61.458	62.250	73.958	66.667	51.042
10	61.458	64.583	56.250	79.167	57.292	66.667	77.083	64.583	59.375
11	70.833	69.792	68.750	61.458	62.250	54.167	78.125	66.667	44.792
12	59.375	75.000	59.375	73.958	71.875	67.771	77.083	69.792	63.542
13	72.917	65.625	60.417	79.167	56.250	50.000	73.958	66.667	63.542
14	81.250	77.083	48.958	73.958	62.250	67.771	68.750	76.042	53.125
15	71.875	61.458	51.042	65.625	61.454	59.375	71.875	51.042	61.458
16	86.458	67.771	51.042	68.750	62.250	62.250	77.083	58.333	59.375
17	86.458	71.875	69.792	76.042	72.917	55.208	59.375	59.375	51.042
18	77.083	69.792	75.000	73.958	60.417	61.458	80.208	79.167	45.833
19	67.771	64.583	56.250	73.958	60.417	51.042	73.985	72.917	56.250
20	69.792	53.125	64.583	72.917	60.417	51.042	71.875	71.875	55.208
21	85.415	61.458	67.771	71.875	73.458	63.542	64.583	65.625	59.375
22	68.750	70.833	53.125	73.958	60.417	59.375	83.333	61.458	57.292
23	81.250	65.625	67.771	75.000	68.750	57.292	65.625	65.625	64.583
24	63.542	56.250	53.125	63.542	73.958	57.292	63.542	73.958	59.375
25	72.917	72.917	69.792	64.583	67.771	37.500	79.167	64.583	58.333
$\bar{X}_D$	72.586	66.588	58.922	72.380	66.374	59.110	72.918	66.118	57.208
S_D	8.0374	6.0743	7.9678	5.4185	7.3714	8.4773	6.3006	6.3154	6.8036
$(S_D)^2$	64.599	36.897	63.486	29.360	54.337	71.865	39.697	39.884	46.289
Wilk-Shapiro	0.9736	0.9630	0.9756	0.9685	0.9455	0.9708	0.9802	0.9759	0.9676

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Lean Logistics is an innovative proposal designed to reduce the costs associated with reparable inventory management. The purpose of this thesis is to determine whether a wartime lean logistics pipeline can maintain acceptable aircraft availability rates in response to induced variations of order and ship time (OST) and flying hours for deployed forces. The Dyna-METRIC Version 6.4 simulation program was used to evaluate nine different factor-level combinations. The factors, OST and flying hours were varied at three different levels, low, medium, and high. Analysis of the results was accomplished using a two-factor ANOVA. The authors discovered that while increasing OST greatly degraded available aircraft, flying hours did not significantly affect aircraft availability.

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