3-9-2009

Quantification of Mandatory Sustainment Requirements

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QUANTIFICATION OF MANDATORY SUSTAINMENT REQUIREMENTS

THESIS

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AFIT/GLM/ENS/09M-01

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Wright-Patterson Air Force Base, Ohio

AFIT/GLM/ENS/09M-01

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THESIS

Presented to the Faculty

Department of Operational Sciences

Graduate School of Engineering and Management

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Logistics Management

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March 2009

AFIT/GLM/ENS/09M-01

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AFIT/GLM/ENS/09M-01

Abstract

To emphasize the importance of sustainment, the DoD Joint Requirements Oversight Council addressed sustained Materiel readiness and established a mandatory Key Performance Parameter (KPP) for Materiel Availability; it also established supporting Key System Attributes (KSAs) for Materiel Reliability and Ownership Cost (Chairman of the Joint Chiefs of Staff Manual (CJCSM) 3170.01C, 2007).

Current guidance requires two numbers: a threshold value and an objective value (Chairman of the Joint Chiefs of Staff Manual (CJCSM) 3170.01C, 2007). No distinction is made between the approaches in establishing these values for major system acquisitions, versus smaller, modification-focused efforts for existing systems. The Joint Staff proposed guidance to assist in determining these values for major acquisition programs, but the guidance has yet to be tested on modification contracts. To assess its applicability, we performed a case study of a recent acquisition program under consideration by Air Mobility Command. We sought to apply the principles put forth in this draft guide prepared by the Office of the Secretary of Defense in Collaboration with the Joint Staff.

This research seeks to assist the combat developer and program manager to develop an objective, standard, repeatable method for quantifying the mandatory Materiel Availability KPP and the associated Materiel Reliability KSA values established by the Joint Requirements Oversight Council.

To my wife and two children

Acknowledgements

I would like to take this time to thank my sponsor; Headquarters Air Force Air Mobility Command, Directorate of Plans and Programs. It was through their vision and desire to use AFIT resources to assist in operational decision making that provided the foundation for this research.

I would like to express my sincere appreciation to my faculty advisor, Dr. Alan W. Johnson, for his guidance and support throughout the course of this thesis effort. His insight and experience was certainly appreciated. Special thanks are also in order for my thesis reader, Lieutenant Colonel Pamela S. Donovan, who offered time and guidance reviewing my thesis drafts.

I also thank my wife and children for the encouragement and support they have provided during my time at AFIT. Your level head and words of hope have been a guiding light for me throughout this difficult process.

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I. Introduction

Background

The May 2003 version of DoD Directive (DoDD) 5000.1, "The Defense Acquisition System," references program objectives for total life-cycle systems management, to include sustainment (DoDD 5000.1, 2003). To emphasize the importance of sustainment, the DoD Joint Requirements Oversight Council addressed sustained Materiel readiness and established a mandatory Key Performance Parameter (KPP) for Materiel Availability; it also established supporting Key System Attributes (KSAs) for Materiel Reliability and Ownership Cost (Chairman of the Joint Chiefs of Staff Manual (CJCSM) 3170.01C, 2007). KPPs are those system attributes considered most critical or essential for an effective military capability. KSAs are those system attributes considered most critical or essential for an effective military capability but not selected as a KPP. KSAs provide decision makers with an additional level of capability prioritization below the KPP but with senior sponsor leadership control (generally 4-star level, Defense agency commander, or Principal Staff Assistant) (Chairman of the Joint Chiefs of Staff Manual (CJCSM) 3170.01C, 2007). The values used to describe each KPP and KSA are defined by a threshold value and an objective value. The threshold value for an attribute is the minimum acceptable value considered achievable within the available cost, schedule, and technology at low-to-moderate risk. Performance below the threshold value is not operationally effective or suitable. The objective value for an attribute is the desired operational goal achievable but at higher risk in cost, schedule, and technology. Performance above the objective does not justify additional expense.

Current guidance requires both threshold and objective value (Chairman of the Joint Chiefs of Staff Manual (CJCSM) 3170.01C, 2007). No distinction is made between the approaches in establishing these values for major system acquisitions, versus smaller, modification-focused efforts for existing systems. In some cases a range of stated values may be appropriate, but in other cases the best approach may be to specify the value as a percentage change or as a function of other variables. The Joint Staff proposed guidance to assist in determining these values for major acquisition programs, but the guidance has yet to be tested on modification contracts. To assess its applicability, we performed a case study of a recent acquisition program under consideration by Air Mobility Command. We sought to apply the principles put forth in this draft guide prepared by the Office of the Secretary of Defense in Collaboration with the Joint Staff.

Problem Statement

Air Mobility Command (AMC) lacks a standardized method to establish these mandatory threshold and objective values for the Materiel Availability KPP and Materiel Reliability KSA for modifications to existing weapons systems. A draft guide is proposed by the Joint Staff with the purpose of assisting program decision makers, but its applicability to the AMC problem is unclear.

Research Objective/Questions

In order to address this issue the following research question was investigated:

Research Question: Is the draft Reliability, Availability, Maintainability and Cost Guide (RAM-C) that the Office of the Secretary of Defense in Collaboration with the Joint Staff prepared applicable for use on modification program?

To answer this research question we established five investigative questions:

Question 1: What portions of the guide are applicable to this study and what portions do not apply? Initial review of the RAM-C guide appeared to provide the rationale behind the development of the sustainment requirements for new weapon systems. This research sought to determine whether all or portions of this document would be useful in developing sustainment requirements for modifications of existing weapon systems. We evaluated this document in a comparative manner to determine program requirement differences.

Question 2: What modification program would be a viable candidate for the use in this study? Some of the decision criteria we examined were modification size, timing and current acquisition phase. Another area of interest we considered would be the type of support and sustainment contract, whether it is a Performance Based Logistics (PBL) contract or a traditional government sustainment contract.

Question 3: If the guide is deemed applicable for use in modification or upgrade programs what areas within the guide requires changes and what changes are recommended?

Question 4: How should historical reliability and maintenance data information systems be utilized to establish availability and reliability estimates? We attempted to determine the feasibility of current Air Force data collection systems such as Reliability and Maintainability Information System (REMIS), the Supply Management Analysis Reporting Tool (SMART), and Global Combat Support System (GCSS) as viable candidates for data analysis and model creations.

Question 5: Does the current body of literature concerning Performance Based Logistics support our efforts to establish sustainment performance parameters?

Research Focus

The Air Force Air Mobility Command's Directorate of Plans and Programs approached us with a request for help in quantifying their KPPs for several ongoing major aircraft modifications, and will support our research. Therefore, we initially focused our research on recommending a standardized method for quantifying Materiel readiness sustainment metrics for Air Force Air Mobility Command's modification efforts but we designed our approach and methods to be applicable to all major system modifications and upgrades.

Methodology

To achieve this objective, we used an ongoing AMC major aircraft modification as a case study. We also engaged in bi-lateral discussions with program and subject matter experts, and conducted a review of applicable literature to develop a model that incorporates multiple factors impacting each sustainment metrics. This model was based on the concepts and principles put forth in the draft guide developed by the Office of the Secretary of Defense in Collaboration with the Joint Staff.

The important purpose of sustainment metrics was to ensure that system performance and program cost were properly balanced leading to the Materiel capability developed being operationally effective, suitable, and affordable for the warfighter. We utilized input from the program office, Headquarters Air Mobility Command, industry, and subject matter expert to assist in performing sensitivity analysis on the contributing factors that affected overall system readiness levels and effectiveness. These factors included but were not limited to reliability, maintainability, supportability and ownership cost analysis. By evaluating the effects of trade-offs performed on these factors we attempted to develop a repeatable solution for the readiness requirements mandated by the DoD Joint Requirements Oversight Council.

Assumptions and Limitations

Multiple reliability and maintainability metrics may be applicable to a given program. For simplicity, this discussion used the metrics applicable to the Air Force Air Mobility Command. The combat developer, with technical support from the program manager (especially in the evaluation of existing technological capabilities), evaluated the achievability of the minimum Materiel reliability (reliability required by analyzing the ability of mature or developing technologies to provide needed capabilities). This analysis included historical trending for predecessor systems and extrapolation of trending results to applicable new replacement technologies (Maintenance Division Joint Staff Logistics Directorate (JS/J4/MXD), 2008). The accuracy of the values set forth in this research depended largely on the completeness and accuracy of the data information system used in this research.

The requirements development process concludes when all inputs are translated into Materiel Availability, Materiel Reliability, and Ownership Cost (OC) with supporting rationale (Maintenance Division Joint Staff Logistics Directorate (JS/J4/MXD), 2008). For the purposes of this research we only focused on the Materiel Availability KPP and Materiel Reliability KSA. We did not address costs during this study. It is reasonable to argue that the values achieved within this research do not necessarily hold the most optimal values possible. Optimization requires an exploration of all three of these factors in combination. Also, because the processes and procedures in this study were focused directly towards modifications, the results achieved in this study may not be applicable to new weapon systems acquisitions.

Implications

The purpose of this research is to help develop a better understanding of the processes involved in developing reasonable and balanced requirements. In achieving this we hope to increase the ability of the Combat Developer and Program Manager to identify realistic threshold and objective values for Materiel readiness sustainment. This research seeks to assist the combat developer and program manager develop an objective, standard, repeatable method for quantifying the mandatory Materiel Availability KPP and the associated Materiel Reliability KSA values established by the Joint Requirements Oversight Council. This will help improve management oversight and lead to more cost-effective acquisition programs.

II. Literature Review

Introduction

Sustainment concerns regarding acquisition programs are not new. As early as 1971, DoDD 5000.1 stated that "logistics support shall be considered as a principal design parameter" in acquisition programs (DoDD 5000.1, 1971). The 1982 version of the directive specifically referenced the concept of sustainability when stating, "improved readiness and sustainability are primary objectives of the acquisition process (DoDD 5000.1, 1982)." In 1996, this same philosophy was stated as, "acquisition programs shall be managed to optimize total systems performance and minimize the cost of ownership (DoDD 5000.1, 1996)." the total systems approach is addressed in the current version of the directive and states that "the PM shall be the single point of accountability for accomplishing program objectives for total life-cycle systems management, including sustainment." Furthermore, key defense documents (e.g., National Defense Strategy and Quadrennial Review) stress life-cycle issues as well (i.e., reduced footprint, reduced cycle times, reduced ownership costs). Thus, the focus of DoD acquisition strategies has evolved from an initial reliance on detailed military specifications and performance specifications and to a life-cycle systems view. The Sustainment KPP approach is the next iteration in this evolution and refines the process even further.

A technical report sponsored by the Boeing Aerospace Company entitled "Maintainability/Reliability Impact on System Support Costs", (Johnson et al, 1973), highlighted the increasing emphasis placed on the reduction of total life cycle cost on both new and existing systems. In this report data derived from specific equipment/system programs (F-111, F-4, and A-7D) showed that design efforts to increase reliability and reduce maintenance requirements per failure can significantly reduce equipment/system life cycle costs. Therefore, they offer a major opportunity for support cost savings, especially on equipment that is mission essential. Consequently, improved engineering design analysis techniques, insight, and cost consciousness are needed (Johnson et al, 1973). This report provided a methodology for estimating life cycle cost, primarily during the operational phase and addressed quantifiable savings that could be determined during early design.

In another technical report entitled “Category II FB-111A Reliability and Maintainability Evaluation”, (Chamblee et al, 1972) results were presented from the Category II test program. The aircraft demonstrated a dismal 1.6-hour mean time between failures and a 1.5-hour mean time between aircrew write-ups. The overall aircraft reliability was significantly degraded by the low reliability of flight controls and most avionics subsystems. The contractor predicted that 23.8 maintenance man-hours per flying hour would be required, and 48.0 man-hours were actually measured. The results from the performance of the F-111 series of aircraft demonstrated how important the factors of reliability and maintainability analysis early-on in the acquisition of weapons systems can impact total life cycle cost.

In a memorandum dated August 16, 2004, the Deputy Secretary of Defense directed measuring performance in terms of Operational Availability, Mission Reliability, Cost per Unit of Usage, Logistics Footprint, and Logistics Response time. For consistency, this memorandum provided specific definitions of those metrics for use across the Department. Current guidance directs their use as the standard set of metrics for evaluating overall Total Life Cycle Systems Management (TLCSM) Metrics (Under Secretary of Defense, 2005).

In a memorandum (Under Secretary of Defense, 2005) to the Secretaries of the Military Departments, recommendations from the Defense Business Board were presented to the Deputy Secretary of Defense that the Departments aggressively pursue implementation of

Performance-Based Logistics, for all its weapons, new and legacy (Under Secretary of Defense, 2005). This is relevant because PBL concepts stress reliability, maintainability and supportability as the drivers of operational effectiveness of a system and play a crucial role in procurement decision making (Kumar, 2007).

In an interview with "Government Executive" magazine May, 2006 Chief of Naval Operations, Admiral Michael G. Mullen stated “We have a tendency to look at what it takes to get a program out the door. We don't think too much about what the life cycle [cost] is. It's 'Can I build it?' I would like us all to be mindful of what it costs to operate whatever we are building for whatever its life is going to be because I have to pay that bill every single year” (Chief of Naval Operations, Admiral Mullen, 2006).

The specific genesis for the current sustainment focus is the Joint Requirements Oversight Council (JROC) Memorandum 161-06 entitled “Key Performance Parameter Study Recommendations and Implementation,” dated 17 August 2006. Through this memo, the JROC established a mandatory warfighter Materiel Availability Key Performance Parameter and identified Materiel Reliability and Ownership Cost as related Key System Attributes for new acquisitions (Chairman of the Joint Chiefs of Staff Manual (CJCSM) 3170.01C, 2007). The following four life cycle sustainment outcome metrics were subsequently established by the Deputy Under Secretary of Defense for Logistics and Materiel Readiness (DUSD (L&MR)): Materiel Availability, Materiel Reliability, Ownership Cost, and Mean Downtime. Furthermore, CJCSM 3170.01C, “Operation of the Joint Capabilities Integration and Development System,” was modified and reissued on 1 May 2007 to include these sustainment metrics.

Metrics

Key Performance Parameters are those system attributes considered most critical or essential for an effective military capability. The Capabilities Development Document (CDD) and the Capabilities Production Document (CPD) must contain sufficient KPPs to capture the minimum operational effectiveness, suitability, and sustainment attributes needed to achieve the overall desired capabilities for the system (or systems if the CDD/CPD describes an system of systems) during the applicable increment. Failure to meet a CDD or CPD KPP threshold may result in a re-evaluation or reassessment of the program or a modification of the production increments (Chairman of the Joint Chiefs of Staff Manual (CJCSM) 3170.01C, 2007).

Key System Attributes are those system attributes considered most critical or essential for an effective military capability but not selected as a KPP. KSAs provide decision makers with an additional level of capability prioritization below the KPP but with senior sponsor leadership control (generally 4-star level, Defense agency commander, or Principal Staff Assistant). In the case of the mandated Sustainment KPP (Materiel Availability), the supporting Materiel Reliability and Ownership Cost KSAs require any changes to be documented in the subsequent update to the acquisition program baseline (Chairman of the Joint Chiefs of Staff Manual (CJCSM) 3170.01C, 2007).

Materiel Availability

Materiel Availability is a measure of the percentage of the total inventory of a system operationally capable (ready for tasking) of performing an assigned mission at a given time, based on Materiel condition. This can be expressed mathematically as a proportion of the number of operational end items to the total population of end items. Materiel Availability indicates the percentage of time that a system is operationally capable of performing an assigned mission and can also be expressed as the proportion of uptime (operational time) to total time (uptime + downtime). Determining the optimum value for Materiel Availability requires a comprehensive analysis of the system and its planned use, including the planned operating environment, operating tempo, reliability alternatives, maintenance approaches, and supply chain solutions. Materiel Availability is primarily determined by system downtime, both planned and unplanned, requiring the early examination and determination of critical factors such as the total number of end items to be fielded and the major categories and drivers of system downtime. The Materiel Availability KPP must address the total population of end items planned for operational use, including those temporarily in a non-operational status once placed into service (such as for depot-level maintenance). The total life-cycle timeframe, from placement into operational service through the planned end of service life, must be included (Chairman of the Joint Chiefs of Staff Manual (CJCSM) 3170.01C, 2007).

Materiel Availability is a number between 0 and 100 that provides the average percentage of time that the entire population of systems is materially capable for operational use during a specified period. Operational means in a Materiel condition such that the end item is capable of performing an identified mission. Materiel Availability measures the percentage of the entire population that is operational (Chairman of the Joint Chiefs of Staff Manual (CJCSM) 3170.01C, 2007).

Materiel Reliability

Materiel Reliability is a measure of the probability that the system will perform without failure over a specific interval. Reliability must be sufficient to support the warfighting capability requirements. Materiel Reliability is generally expressed in terms of a mean time between failures (MTBF), and once operational can be measured by dividing actual operating hours by the number of failures experienced during a specific interval. Reliability may initially be expressed as a desired failure-free interval that can be converted to MTBF for use as a KSA (e.g., 95 percent probability of completing a 12-hour mission free from mission-degrading failure; 90 percent probability of completing 5 sorties without failure). Specific criteria for defining operating hours and failure criteria must be provided together with the KSA. Single-shot systems and systems for which other units of measure are appropriate must provide supporting analysis and rationale (Chairman of the Joint Chiefs of Staff Manual (CJCSM) 3170.01C, 2007).

$$\text{Materiel Reliability} = \text{Mean Time Between Failure}$$

$$\text{Materiel Reliability} = \frac{\text{Total Operating Hours}}{\text{Total Number of Failures}}$$

Mean Down Time

Mean Downtime (MDT) is the average total downtime required to restore an asset to its full operational capabilities. MDT includes the time from reporting of an asset being down to the asset being given back to operations/production to operate. MDT includes administrative time of reporting, logistics and materials procurement and lock-out/tag-out of equipment, etc. or repair or preventive maintenance (Chairman of the Joint Chiefs of Staff Manual (CJCSM) 3170.01C, 2007).

$$\text{Mean Down Time (MDT)} = \frac{\text{Total Down Time for All Failures}}{\text{Total Number of Failures}}$$

Reliability, Availability, Maintainability and Cost Guide (RAM-C)

The current guidance regarding life cycle sustainment is relatively new. Although policy has been established, there is very little guidance published to help program managers develop and quantify particular threshold and objective values for the relevant metrics discussed above. The only document is the RAM-C guide (Maintenance Division Joint Staff Logistics Directorate (JS/J4/MXD), 2008). The associated guidance notes that determining the optimum value for Materiel Availability requires a comprehensive analysis of the system and its planned use. The guide provides a series of questions to consider for each metric. Furthermore, discussions with Air Force headquarters planners suggest that current methods for developing particular threshold and objective values for the Materiel availability KPP are ad-hoc, at best. The particular relationship between the Materiel Availability KPP and the Materiel Reliability & Ownership Cost KSAs isn't clear. Finally, it is often questionable whether the values used for these measures by headquarters planners are contractually enforceable or even measureable. Therefore, holistic consideration of these metrics provides the trade-space to optimize their achievement and provide a balanced solution. It also enhances the end-to-end Materiel readiness value chain perspective being promoted throughout the DoD.

Performance Based Logistics

While the research literature on KPP constructs appears to be nonexistent, significant research has been done in the context of Performance Based Logistics (PBL) support concepts. This is relevant because a weapon system's key performance parameters should possess linkage to the metrics used to assess a contractor's PBL success. Mahon (2007) states the stakeholder team's job is to develop performance criteria and metrics that are straightforward, measurable, achievable, and are tied to requirements provided by the warfighter. Metrics are typically effectiveness driven, such as assured system availability (percent) and assured component availability (percent); or efficiency-driven, such as assured number of flying hours, assured number of sorties, etc. Not all metrics will be objective measures. Some aspects of product support—for example, customer satisfaction may be subjective measures. The top-level metric objectives established by USD (AT&L) include:

- Operational Availability - percent of time a system is available for a mission or the ability to sustain operations tempo.
- Operational Reliability - measure of a system meeting mission success objective; e.g. a sortie, tour, launch, or destination reached (Mahon, 2007).
- Cost Per Unit Usage - total operating costs divided by the unit of measurement for a given system; e.g. flight hour, launch, or miles driven.
- Logistics Footprint - size or presence of deployed logistics support required to deploy, sustain, or move a system.

Measurable elements include inventory, equipment, personnel, facilities, transportation assets, and real estate. Mahon argues that the Air Force can't justify PBL savings on the basis of cost savings or reduced logistics footprints, because few PBL strategies simultaneously focus on availability, reliability, cost, and logistics metrics. Some focus on availability, or reduced cost, or reduced cycle time (Mahon, 2007).

Kumar (2007) insists that reliability, maintainability and supportability drive the operational effectiveness of a system and play a crucial role in procurement decision making. Due to the inherent criticality of reliability, maintainability and supportability in the defense industry, several procurement strategies have been evolved to influence decision making in the design of products, systems, and most recently, system of systems. PBL strategies focus on product support for large-scale, repairable systems such as fighter aircraft and similar weapon systems (Kumar, 2007).

Performance Based Logistics uses reliability, maintainability and supportability metrics to evaluate effectiveness of a product. For example, measures such as operational availability (OA) and total cost of ownership (TCO) are used to evaluate the overall impact of the system design. Apart from OA and TCO, measures such as Total Operation and Maintenance Cost and Logistics Footprint are used to evaluate maintainability and supportability of the system respectively. Kumar states that it is commonly perceived that performance based logistics is likely to improve product availability, reliability, maintainability and supportability at a lower cost through leveraging commercial best practices. It is reported that in the Iraq and Afghanistan engagements the overall availability of the F/A-18E/F, which has components that incorporate PBL, has been 85% compared to the older F/A-18C/D which is supported under the traditional logistics practices and achieved only 73% availability. Thus, there is evidence that PBL contracts have benefited the customers and has influenced the customers to use PBL contracts instead of the traditional logistics practices under which the customer either purchased or leased all the resources required to support the system (Kumar, 2007).

Simultaneous optimization of reliability, maintainability and supportability is a challenging task since improving one aspect of the design may deteriorate another aspect. Procurement strategies such as PBL, used by defense and public sector organizations, focus on achieving high reliability, maintainability and supportability. Successful PBL contracts require suppliers to find the optimal mix of competing resources that will simultaneously achieve multiple, performance metrics. Total cost of ownership, availability, reliability, maintainability and supportability are all goals that are considered simultaneously when determining the optimal compliment of competing support resources (Kumar, 2007).

Many definitions of PBL exist. In the Defense Acquisition University's 2005 publication entitled *Performance Based Logistics: A Program Manager's Product Support Guide*, the following definition can be found:

> Performance Based Logistics (PBL) is the purchase of support as an integrated, affordable, performance package designed to optimize system readiness and meet performance goals for a weapons system through long-term support arrangements with clear lines of authority and responsibility. Simply put, performance based strategies buy outcomes, not products or services.

Berkowitz et al., (2005) developed this comprehensive definition to capture the essence of this new strategy:

> An integrated acquisition and sustainment strategy for enhancing weapon system capability and readiness where the contractual mechanisms will include long-term relationships and appropriately structured incentives with service providers, both organic and non-organic to support the end user's (warfighter's) objective.

As can be seen in both of these definitions, long-term relationships are integral to the concept of PBL. While many different types of business relationships exist, significant long-term relationships are often referred to as partnerships (Gardner, 2008).

The goal of both acquisition and sustainment is to gain the most efficient and effective performance for a weapon system throughout its life cycle. In doing so, it is important to realize that acquisition and sustainment are not separate but simultaneous and integrative issues that require analysis and synthesis throughout the product life cycle (Berkowitz et al., 2005).

Performance Based Acquisition (PBA) and PBL research is mainly based on systems' performance which is necessary to provide mission capable assets for the warfighters to accomplish their mission. The main purpose of the PBA and PBL is linking the defense acquisition and support activities with the warfighters' needs in the long term agreements with the support providers, both organic and non-organic. Successful PBL implementation provides the same level of support within lower costs while diminishing logistics footprints.

It can be argued that the DoD's compelling reasons to partner with its contractors are to improve service to its customers, the warfighters, and to improve asset performance and cost efficiencies. By employing the PBL strategy, the DoD aims not only to better meet the needs of the operational end-users by improving system performance and readiness (as indicated in the aforementioned definitions of PBL), but also to minimize the total system life cycle costs and logistics footprints associated with those systems (DoDD 5000.1, 2003).

Reliability Improvement

Smith (2004) proposes a process for planning and estimating the cost of a reliability improvement program under a PBL construct that accommodates the effect of equipment aging and associated reliability degradation. The process is a structured methodology utilizing past field performance information as a basis for predicting future reliability performance. The methodology makes use of the predictive results as a basis for estimating the level of effort required to satisfy the PBL contract's reliability and availability goals. The user will enter into a solicitation for a system reliability performance improvement program requesting a desired future state that may or may not be based on knowledge of the system's historical performance. The supplier will negotiate with the user the terms of the goal with respect to the cost of improving the present demonstrated reliability of the system to the desired goal in terms of redesigns and support. The present demonstrated field reliability of the system must be used as a baseline and a point of departure in defining the level of effort toward attaining the future goal. The user may not be satisfied with the present demonstrated reliability and may demand improvement through a Request for Quality Improvement term. The supplier then must develop and present his level of effort estimates for improving the system reliability (Smith, 2004).

The 2001 Quadrennial Review (QDR) stated, "DoD will implement PBL to compress the supply chain and improve readiness for major weapon systems and commodities." Research was conducted at AF/A-IL's request to discover the best practices and lessons learned from the AF's progress in PBL implementation. There were five objectives of this study:

1. Provide a common understanding of PBL.
2. Evaluate AF regulations/guidance to determine they are consistent with the intent of existing DoD guidance.
3. Identify and study PBL implementation "best practices" within the C-17, F-117, JSTARS, and selected programs.
4. Identify and study PBL implementation "lessons learned" within the C-17, F-117, JSTARS, and selected programs.
5. Determine how well the selected programs met the intent of guidance assessed in objectives 1 & 2.

Pettingill and Knipper (2004) and their colleagues found that the F-117, C-17, and JSTARS programs being studied are not using high-level performance metrics (e.g., mission capability rate, improved product affordability, system reliability, and logistics footprint) that measure their success in meeting PBL performance goals (Pettingill, 2004).

According to the Defense Acquisition University Program Managers Guide, PMs are using metrics tied to the systems and subsystems managed by the Product Support Integrator(s) under contract, but not to the weapon system as a whole, just as pointed out by Pettingill and Knipper. PBL success meeting lower-level metrics for these programs did not necessarily translate to improved weapon system availability, because no direct correlation existed between lower- and upper-level metrics. The PM works with the user/warfighter to establish system performance needs and then works with the product support providers to fulfill those needs through documentation of the requirements (including appropriate metrics) in Performance Based Agreements (PBAs). An effective PBL implementation depends on metrics that accurately reflect the user's needs and can be an effective measure of the support provider's performance. Linking metrics to existing warfighter measures of performance and reporting systems is preferable. Many existing logistics and financial metrics can be related to top-level warfighter performance outcomes. Although actual PBL strategies, as implemented, may delineate metrics at levels lower than the warfighter top-level measures (e.g., system availability), it is important that the initial identification of performance outcomes be consistent with the key top-level metric areas (Defense Acquisition University, 2005).

Landreth (2005) and his colleagues examined the PBL contract for a naval aircraft auxiliary power unit, and reached conclusions similar to those by Mahon and Pettingill et al. The contract meets best commercial practices by applying PBL at the component level where appropriate system performance data were available to establish cost effective contract arrangements. The contract is not a true PBL application in that the contract buys availability and reliability improvements at a fixed price with required improvement schedules. The contract does not provide positive incentives for the contractor to provide greater reliability, but rather specific reliability improvement deliverables (Landreth, 2005). Pecht and Thomas (2006) illustrate the relationship between warranty and reliability (Pecht, 2006), (Thomas, 2006). Thomas and Richard also propose a method to establish reliability goals, or targets for creating quality improvement strategies, through reliability improvements of the components (Thomas, 2006).

Other relevant research includes the work by Kang et al (2005) who presents a suite of spreadsheet and discrete-event simulation models that collectively estimate the value of system-level responses to improvements in component reliability. Providing reduced lifecycle cost and, at the same time, improving operational availability are fundamental goals of the Performance-based Logistics (PBL) and other logistics initiatives of the US Department of Defense. In many PBL contracts, the contractual arrangements are typically stipulated at the level of individual components (such as a fuel cell) or a logistic element (such as inventory of certain spare parts). While achieving component-level performance goals is certainly important, what really matters to a warfighter is the operational availability of the weapon system. Hence, there is a need to develop a methodology and an apparatus for estimating the operational availability (A_O) of a weapon system based on the component-level reliability and maintainability data (Kang, 2005).

Some research has focused attention on the method of predicting requirements as opposed to the metrics themselves. According to a study to document improving the Materiel readiness of the Marine Corps, as requested by the Marine Corps Logistics Command (MCLC) Materiel Readiness Integrated Process Team (MRIPT) Lead, reliability, maintainability, and availability simulation models provide a time-continuous reconstruction of a weapons system's "average" mission, which involves simultaneous consideration of the system and other events. The primary means of evaluating Materiel readiness within the Marine Corps relies on deterministic equations. However, as a system's complexity increases, so do the number of variables necessary to define the system, and the number of associated equations to be solved through deterministic methods. Variables such as in repair, re-supply, partial degradation, duty factors, operating factors, allowed downtime events, and all the other complexities of real-life system operations or the complete list of the potential Materiel readiness drivers make evaluating Materiel drivers circumspect and more difficult to write the probability of success formula required by deterministic methods. Use of a simulation model versus deterministic equations would enable these issues to be addressed (Concurrent Technologies Corporation, 2007).

Reliability vs Maintainability

Dellert (2001) examined the impact of reliability and maintainability on the Operations and Support (O&S) costs and Operational Availability (A_O) of the Comanche helicopter. The research focused on the question of where the Comanche program office should allocate resources to minimize O&S costs and maximize A_O. The research indicated that the best allocation of resources was to the improvement of system reliability. The negative impact to both O&S costs and A_O was significant if the predicted reliability goals were not met. The primary goal of this research was to determine the sensitivity of O&S costs to variations from the predicted reliability and maintainability values. The biggest concern in this analysis was on the impact of not meeting the predicted goals vice the cost savings possible if the goals were exceeded. It was determined that O&S costs were more sensitive to reliability levels below predictions than maintainability levels below predictions.

For each increment of 10% below predicted levels, up to 40%, the O&S cost increases by approximately 3%. Beyond a level of 40% below the predicted reliability goals, the O&S costs will begin to increase at an exponential rate. In comparison, failure to reach maintainability goals only caused a 1% increase in O&S costs for each 10% below predicted levels. This rate of increase remained constant throughout all values of maintainability below predicted. The impact on O&S costs from reliability values greater than 20% below predicted was much more severe than that experienced from similar maintainability levels.

The greater impact of reliability on O&S costs was attributable to the higher costs associated with acquiring repair and replacement parts. As the reliability decreased the number of failures will increase. This will result in a substantial increase to the total cost for consumables items. Conversely, the actual labor cost makes up a very small amount of the total maintenance cost. Since labor performed by military maintenance personnel is covered indirectly through their annual salary, the only labor costs are for depot level labor and any contract labor that is required. Hence, decreases in maintainability will have a much smaller affect on maintenance costs and O&S costs as a whole.

Summary

The key objective of this research seeks to develop an objective, standard, repeatable method for quantifying the Materiel Availability KPP and associated Materiel Reliability and Ownership Cost KSA values for defense weapon system requirements documents. We examined possible solutions that would provide a launch pad for program managers to utilize in the weapon systems acquisition process.

This chapter examined the genesis behind the mandatory sustainment requirements metrics associated with each. This chapter provided a review of current literature concerning Performance Based Logistics support concepts and how these concepts have a direct impact on weapons systems sustainment efforts and desired performance parameters. We also discussed some of the literature pertaining to issues such as reliability improvement, maintainability and personnel support. While discernable gaps exists on the development and quantification of specific KPP constructs and related KSAs, the information gained through review of this pertinent body of knowledge is very insightful of the linkage that exists between PBL and reliability, availability, and maintainability.

III. Methodology

The objective of this research is to recommend a standardized method for quantifying Materiel readiness sustainment metrics in military acquisition requirements documents. To achieve this objective, we utilized a case study of a projected aircraft systems modification, discussions with subject matter experts, and a review of the literature to develop an appropriate decision model that incorporates multiple factors impacting each sustainment metric. The decision model included components of predictive modeling and sensitivity analysis of the subsystem components that are incorporated within the projected upgrade to determine the overall affect on Materiel readiness values.

Research Design

In order to gain an adequate perspective on contract length issues throughout DoD, this study included discussions with knowledgeable personnel associated with a variety of organizations and programs. Based on recommendations from the thesis sponsor, Headquarters Air Mobility Command, ideas for a currently ongoing acquisition program were solicited for this study. One of the initial points of contention was which modification program would be a suitable candidate for this research. Some of the areas considered for this program were the age of the platform. The platform must be mature enough to provide the needed historical level of stability but also has enough existing life span remaining to be cost effective. This platform also needed to be one that was early in its requirements development phase in order to get the welcomed support of the program decision makers.

Headquarters AMC had two major aircraft modifications programs in the early phases of acquisition. Both programs under consideration were based on a traditional in-house maintenance and support contract. First, there is the C-5 Reliability Enhancement and Re-

Engining Program (RERP). The C-5 RERP was undertaken to remedy some deficiencies identified in the current C-5 fleet and to close the gap requirements for on-time airlift delivery of oversize and outsize cargo. At the heart of RERP acquisition strategy is an Initial Reliability, Maintainability, and Availability evaluation of modified C-5B and C-5A aircraft. The C-5 RERP will achieve the required wartime 75% MCR by integrating a new commercial-off-the-shelf (COTS) propulsion system, upgrading 70 subsystems and components (including 50 reliability enhancements), providing proper spares levels necessary for an 85% issue effectiveness rate, and improving the efficiency of C-5 phased inspection and maintenance programs. The C-5M climb performance will ensure access to preferred air traffic routings between North America and Europe or Northeast Asia, and provide the capability to operate with wartime planning factor loads from shorter runways on hot days. The C-5M engines will meet worldwide aircraft noise and pollution emission standards. RERP does not change the communications, navigation, and surveillance architecture of the C-5 Avionics Modernization Program (AMP), and does not communicate with external systems (Capability Production Document for C-5 Reliability Enhancement & Re-Engining Program (RERP), 2008).

The second modification program underway for Headquarters AMC is the Communications, Navigation and Surveillance/Air Traffic Management (CNS/ATM) program. The CNS/ATM program is primarily a safety of flight modification. The CNS/ATM program is an acquisition effort to extend the KC-135 as a viable weapon system through fiscal year (FY) 2040. It supports mitigating capability gaps identified in the Initial Capabilities Document for Air Refueling and the Air Force Integrated-Capability Review and Risk Assessment (I-CRRA), anticipated airspace restrictions within the global CNS/ATM System, and overall KC-135 shortcomings in reliability, maintainability, and supportability. With current capabilities, the combatant commanders lack sufficient worldwide capable AR assets to accomplish all requested future joint operations. The KC-135 CNS/ATM program includes an integrated digital flight director (DFD), radio altimeter (RA), and autopilot (AP) systems and Angle of Attack (AOA) (Capability Development Document (CDD) for KC-135 CNS/ATM Program Version 4.4 ACAT: III, 2008).

Through careful consideration by Headquarters AMC the KC-135 CNS/ATM program was deemed the best fit for this study. This aircraft system upgrade consists of multiple subsystem modifications/component replacement and access to a wide array of historical performance and maintenance data would be readily available. This modification is still in the requirements document development phase which makes it a viable platform for study. Also, contact with subject matter experts, program personnel, and industry would be available where necessary. Most importantly, because challenges posed by access to test data on the C-5 RERP upgrade components, AMC felt that the KC-135 CNS/ATM program provided a better scale in both size and complexity as a starting point.

Sustainment Requirements

As defined in the Department of Defense Reliability, Availability, Maintainability and Cost Rationale Report Handbook, the mandatory KPP and two supporting KSAs are:

- ***Materiel Availability KPP* –** Measures the percentage of the total inventory of a system that is operationally capable (ready for tasking) of performing an assigned mission, at a given time, based on Material condition. Materiel Availability also indicates the percentage of time that a system is operationally capable of performing an assigned mission and can be expressed as the proportion of the number of operational end items to the total population of end items.

- ***Materiel Reliability KSA –*** Measures the probability that the system will perform without failure over a specified interval.
- ***Ownership Cost KSA –*** Provides balance to the sustainment solution by ensuring that the Operations and Support (O&S) costs associated with Materiel Readiness (eg. maintenance, spares, fuel, support, etc.) are considered in making program decisions. The Ownership Cost KSA is ultimately based on O&S Cost Estimating Structure elements as specified in the OSD Cost Analysis Improvement Group (CAIG) "Operating and Support Cost-Estimating Guide." Appropriate sections of this document cover the specific elements involved in cost estimation (Maintenance Division Joint Staff Logistics Directorate (JS/J4/MXD), 2008).

Sustainment Requirements Development

The logical process of developing sustainment requirements has well-defined activities to arrive at values that are realistic, achievable, measurable, documented, and therefore defendable. The activities are summarized below:

- The first step in developing sustainment requirements is the preparation of a Draft Concept of Operations (CONOPS) by the combat developer. The CONOPS identifies the role of the system in providing the capability needed by the warfighter in terms of how it will be used operationally (Maintenance Division Joint Staff Logistics Directorate (JS/J4/MXD), 2008).
- Following the development of the CONOPS, the combat developer must articulate the mix of ways the system performs its operational role in an Operational Mode Summary and Mission Profile (OMS/MP). This includes the relative frequency of the various missions, which systems will be involved in those missions, and the types of

environmental conditions the system will be exposed to during the system life. The OMS/MP describes the tasks, events, durations, operating conditions, and environment of the system for each phase of a mission (Maintenance Division Joint Staff Logistics Directorate (JS/J4/MXD), 2008).

- Following the development of the CONOPS and OMS/MP the combat developer must decide what minimal operational tasks the system must be able to perform in order to accomplish its mission and what the associated mission essential functions are in order to identify and classify potential failures. This information is documented in the Failure Definition and Scoring Criteria (FD/SC). The combat developer should receive assistance in developing the FD/SC from the program manager including sustainment and T&E activities (Maintenance Division Joint Staff Logistics Directorate (JS/J4/MXD), 2008).
- The combat developer uses the OMS/MP and FD/SC to conduct an analysis to determine the maintenance and support concepts describing the levels of maintenance and the maintenance activities that will be conducted at each level. All of this information is used to draft initial Materiel Availability, Materiel Reliability, and Ownership Cost goals and document supporting rationale and assumptions (Maintenance Division Joint Staff Logistics Directorate (JS/J4/MXD), 2008).
- The program manager takes the above information from the combat developer and determines what is achievable based on technology maturity and other factors. The combat developer and program manager must enter into a continuous dialogue so that appropriate trade studies can be completed, further analysis conducted, and appropriate

trade decisions made (Maintenance Division Joint Staff Logistics Directorate (JS/J4/MXD), 2008).

- Once the combat developer and program manager have reached agreement on a balanced solution with acceptable trade-offs based on the state of the possible, the combat developer needs to identify the appropriate sustainability requirements for inclusion in the Capability Development Document (CDD)and Capability Production Document (CPD) (Maintenance Division Joint Staff Logistics Directorate (JS/J4/MXD), 2008).
- In the end, the sustainment requirements must enable warfighter functional requirements and be measurable and obtainable. Unrealistic, missing, ambiguous, and/or conflicting requirements affect the development process, result in unacceptable or unachievable performance levels, and drive acquisition and sustainment costs. All requirements must carefully balance technological feasibility with operational needs and desires, and are subject to trade-off in order to optimize Materiel Availability (Maintenance Division Joint Staff Logistics Directorate (JS/J4/MXD), 2008).
- The requirements development process concludes when all inputs are translated into Materiel Availability, Materiel Reliability, and Ownership Cost (OC) with supporting rationale. The resulting lower level requirements, as identified by the combat developer and rationale are documented in the CDD and the CPD depending on the program phase. The lower level requirements, such as Mean Time To Repair, Administrative Delay Time, and Logistics Delay Time, are used in evaluating the resulting Sustainment Requirement values (Maintenance Division Joint Staff Logistics Directorate (JS/J4/MXD), 2008).

For the purposes of this research we will only focus of the Materiel Availability KPP and the Materiel Reliability KSA. With this fact in mind it will be reasonable to argue that the values achieved within this research will not necessarily hold the most optimal values possible since a the most optimal value requires an exploration of all three of these factors in combination. We will not focus on the development of a CONOPS, OMS/MP, and FD/SC for this system because there will be no differentiation in use between the legacy system and the upgraded system.

Maintenance Concept and Support Plans Consideration

The maintenance concept is a general description of the maintenance tasks required in support of a given system or equipment and the designation of the maintenance level for performing each task. The maintenance concept is implemented through a Product Support Plan (Maintenance Division Joint Staff Logistics Directorate (JS/J4/MXD), 2008).

Product Support is the management/technical activities and resources needed to implement the maintenance concept and establish and maintain the readiness and operational capability of a weapon system, its subsystems, and its sustainment infrastructure. Product Support encompasses Materiel management, distribution, technical data management, maintenance, training, cataloging, configuration management, engineering support, repair parts management, failure reporting and analyses, and independent logistics assessments. While the provider of the support may be Public, Private, or a Public-Private Partnership, the focus is to achieve maximum weapon system availability at the lowest total ownership cost. Product Support Plans detail how the sustainment requirements and resources are managed over the life cycle (Maintenance Division Joint Staff Logistics Directorate (JS/J4/MXD), 2008). The product support plans for the legacy system will be utilized for the modified platform.

Warfighter Capability Needs

Warfighter needs are the basis for development of Materiel systems. These needs are usually framed by the combat developer as a required capability to perform a mission. For example, a typical requirement for a system might be that it has a "95-percent chance of completing a 12 hour mission with no mission affecting failures." The program manager translates the combat requirements into specific Materiel Availability, Materiel Reliability, and Ownership Cost metrics. The resulting metrics must fully define warfighter requirements from a contract perspective (Maintenance Division Joint Staff Logistics Directorate (JS/J4/MXD), 2008).

Table 1- Metric Definitions

Metric	Nomenclature	Definition
A_M	Materiel Availability	Percentage of total systems available for operational use
A_O	Operational Availability	Percentage of time a system is available for operational use
R_M	Materiel Reliability	The probability that the system will perform its intended function over a specified time period
MTBF	Mean Time Between Failures	The average time between system failures under specified conditions
MTBM	Mean Time Between Maintenance	The average time between system maintenance activities under specified conditions
MDT	Maintenance Down Time	The average down time for maintenance actions (includes MTTR, LDT, and ADT)
MTTR	Mean Time To Repair	The average time required to repair the system after failure
LDT	Logistics Delay Time	All non-administrative maintenance delays involved in repair actions—including transportation of the system to the repair location, time required to obtain necessary spares, time waiting for repair personnel availability, etc.
ADT	Administrative Delay Time	Times associated with processes not directly involved in restoration or repair activities, such as processing of requests, short term non-availability of repair facilities, or delays due to establishment of higher priorities.

One important purpose of the sustainment metrics is to ensure that system performance and program cost are properly balanced leading to the Materiel capability developed being operationally effective, suitable, and affordable for the warfighter.

The balanced solution will determine the optimal points for reliability and sustainment cycle time early in program development thus ensuring an acceptable life cycle cost for the system consistent with needed mission functional performance.

Supportability and maintainability concepts considered should include system Mean Down Time (MDT) optimization and ease of system maintenance. MDT is reduced by limiting Logistics Delay Time (LDT) through pre-positioning sufficient spares and an efficient supply system ensuring the spares are available at the right place at the right time. Limiting Administrative Down Time (ADT) is another way to limit overall system down time. ADT is time required to initiate a maintenance action after an issue surfaces. Designing maintainability into the system will reduce Mean Time To Repair (MTTR) again reducing MDT (Maintenance Division Joint Staff Logistics Directorate (JS/J4/MXD), 2008).

Materiel Availability

Materiel Availability (A_M) is the sustainment KPP for applicable systems as defined previously. A_M is a characteristic of the system's design, support structure, and operational use profile. When the system capability is fully fielded, A_M is defined by the following equation:

$$A_M = \frac{\text{number of operational end items}}{\text{total number of end items acquired}}$$

These point estimates are based on the following equivalent definition of A_M:

$$A_M = \frac{(\text{uptime})}{(\text{uptime}) + (\text{downtime})} = \frac{(MTBF)}{(MTBF + MDT)}$$

Where:

Uptime = Time the system is available to perform designated mission

Downtime = Total time – Uptime = Time system is unavailable for tasking

MDT = Total system downtime expected given the anticipated support structure

The first step in determining Materiel Availability requirements would be to establish the baseline availability and reliability of the legacy system to be upgraded. The baseline metric for comparison will be the actual MTBF of the CNS/ATM -replaced systems collected over a 12 month period. Legacy baseline rates can be derived from the Reliability and Maintainability Information System (REMIS) to the subsystem level.

Materiel Reliability

Materiel Reliability is a characteristic of the final system design and is designated a KSA. Materiel Reliability is defined by the MTBF of the system. Key to determining the MTBF for any system or subsystem is to first determine that system's failure time distribution. For this study the failure time distribution was determined by taking the historical data retrieved from a PRP-4126 report in REMIS and utilizing software such as ARENA® or JMP® to fit the most applicable distribution. This report contains data representing actual failure and repair historical data used to determine the mean times between failures and mean time to repair. These MTBF and MTTR values will be considered the equilibrium for all distributions that are fitted in this research.

Data Collection and Analysis

Determining which of the maintenance data reporting and collection systems would be appropriate for this study was critical in establishing a baseline metric for analysis. There were three data sources under consideration for this research. The Reliability and Maintainability Information System (REMIS) is an on-line source of unclassified maintenance and supply data for all USAF aircraft. The maintenance information consists of reliability and maintenance factors at the two through five digit Work Unit Code (WUC) level. REMIS is the primary Air Force data system for collecting, validating, editing, processing, integrating, standardizing, and reporting equipment maintenance data, including reliability and maintainability data, on a global, world-wide basis. REMIS provides authoritative information on weapon system availability, reliability and maintainability, capability, utilization, and configuration. REMIS consists of an integrated database containing weapon system and equipment inventory, operational status, configuration management, Time Compliance Technical Order (TCTO) data, and reliability and maintainability analysis data (REMIS Program Management Office, 2008).

Next, we considered the Global Combat Support System-Air Force (GCSS-AF), an Air Force (AF) family of systems (FoS) that is an integral part of GCSS, the Joint Combat Support Command and Control FoS. The GCSS-AF mission is to provide timely, accurate, and trusted Agile Combat Support information to Joint and AF commanders, their staffs and ACS functional personnel at all ranks and echelons. In addition, GCSS-AF is the means by which ACS Automated Information Systems will be modernized and integrated to improve business processes (Frye, 2004).

The Supply Management Analysis Reporting Tool (SMART) provides users with a broad range of AF field and depot supply chain visibility, including demand forecasting, aircraft availability, organic and contract (repair and new buy) past delivery, in work and due-in, requisition visibility, etc. SMART includes 120 plus analyses, designed to provide supply chain personnel needed visibility to answers most questions (Knight, 2008).

Discussions with the Logistics Branch Requirements Division, Headquarters Air Mobility Command and the 135th Aircraft Availability Improvement Program Analysis, Logistics Integration Flight, 550th Aircraft Sustainment Squadron, 827th Aircraft Sustainment Group were undertaken to utilize the wealth of data analysis and program experience that exists among personnel with an extensive working knowledge of the KC-135 aircraft historical performance data. Through these discussions we determined that REMIS would be the best source for the historical data needed in this research. REMIS tools for more tailor configured reports and request allowing less navigation of undesirable data. REMIS also allows for user specified report formats such as PDF, Excel, and Delimited Text. This provides for ease of data analysis and reporting of output. The REMIS Program Management Office is located at Wright-Patterson Air Force Base, Ohio allowing for face to face consultation when necessary. Having direct access to the REMIS system management personnel and close proximity to an operational KC-135 unit that utilizes REMIS as to satisfy its analytical needs was extremely helpful considering the limited amount of time available to learn a complex data collection system. Information pertaining to the reasonable and achievable performance of COTS equipment was obtained from industry through Headquarters Air Mobility Command.

Legacy System Baseline Establishment

The following steps illustrate how the draft guide is used to establish the baseline performance measures.

Step 1: Determine the baseline reliability measure

A working relationship was established with the 121st Air Refueling Wing (ARW) for the purpose of determining the best tools and reports embedded within REMIS that would benefit this research. The 121st ARW is an Air National Guard unit based near Columbus, Ohio. They were contacted to assist with this research because of the close proximity of their location to Wright-Patterson Air Force Base, Ohio. Also, the National Guard represents a population that brings a different experience level and stability that is not normally present in most active duty units due to normal change in permanent duty cycles and movement to different weapons systems. For this purpose, the 121st was chosen as one of two KC-135 aircraft operations unit in this study. The 100th Air Refueling Wing based out of RAF Mildenhall Air Base, England was chosen as the second unit for study in this research because it represents an active duty component and an overseas unit. An overseas unit was chosen because it presents a different variable in possible LDT than was would be present in a stateside organization.

The MTBF totals were determined by extracting historical maintenance data from REMIS. This data encompassed actual failure and repair history of 40 aircraft over a 12-month time period. The 12-month time span in this study is due to a limitation within the REMIS system that only allows for only a 12-month look-back from time of request in the PRP -4126 On/Off Equipment Maintenance Detail Reports. The PRP-4126 On/Off Equipment Maintenance Detail Report contains chronological failure and maintenance data for weapons systems that are in the U. S. Air Force inventory.

REMIS is accessed via the Air Force portal. Authorization to REMIS is limited to U.S. government use only and performance of official duties is a requirement for access. An evaluation of reliability and availability of these aircraft was done with respect to possessed flight hours during this operational range. Utilizing statistical tools available in ARENA® and JMP® software and basic statistics embedded in Microsoft Excel®, the baseline aircraft reliability measures stated as MTBF hours can be established for the entire aircraft system minus the subsystem to be upgraded. The same process can be utilized to determine the MTBF for each upgrade system. This allows for the evaluation of the aircraft as a complete system and allows for segregation of upgrade systems for later sensitivity analysis.

Once the decision was made about which reports would be appropriate for this study retrieval of the data was the next step. Through coordination with the REMIS office at Wright-Patterson Air Force Base, Ohio it was determined that for ease of use, the data would be downloaded directly into Excel® spreadsheets for statistical analysis and charting, and further analysis in ARENA®. Figure 1 represents a sample of the critical data used in this study. One of the main requirements in determining time between successive failures is the operating time of the equipment being evaluated. With the aid of the REMIS office and the Analysis Branch of the 121st ARW it was immediately evident that a key field in the PRP-4126 was not reported. This field should have contained current operating time reported in flight hours for each work unit code failure. After discussions with the REMIS office, we determined that this was a known anomaly within the REMIS system that would require at minimum 12 months of software rewrite to correct.

Equipmen	Block Number	Serial Numbe	Current Oper	Job Control	Command	Geograpl	Organization	Work Unit Code	Transaction Da	Start Time	Stop Time	Performin
KC135R	120	5700001440	0.00E+00	81772851	ANG	NLZL	0121 ARF WG	4199	15-Jul-08	1630	1800	NLZL
KC135R	120	5700001440	0.00E+00	81772850	ANG	NLZL	0121 ARF WG	4199	9-Jul-08	1200	1300	NLZL
KC135R	120	5700001440	0.00E+00	81772852	ANG	NLZL	0121 ARF WG	4210	17-Jul-08	1500	1800	NLZL
KC135R	120	5700001440	0.00E+00	81912855	ANG	NLZL	0121 ARF WG	14AAE	10-Jul-08	1200	1400	NLZL
KC135R	120	5700001440	0.00E+00	81912856	ANG	NLZL	0121 ARF WG	14BD0	11-Jul-08	1800	2200	NLZL
KC135R	120	5700001440	0.00E+00	81772853	ANG	NLZL	0121 ARF WG	14BEG	3-Jul-08	1400	1800	NLZL
KC135R	120	5700001440	0.00E+00	81912850	ANG	NLZL	0121 ARF WG	14CBA	9-Jul-08	1200	1300	NLZL

Figure 1- PRP-4126 On/Off Equipment Maintenance Detail Report

Further engagement with the 121st ARW and Headquarters Air Mobility Command led to a solution that was determined to be feasible and a reasonable work-around. This work-around involved the basic assumption that as a failure occurred and post-flight write-ups were entered, maintenance actions proceeded immediately. First, we noted that a start maintenance action time is recorded when a maintenance crew begins work to correct a write-up and a stop time is recorded when all work has complete that results in a return to operational available status. After sorting all data by aircraft serial number, start date, and then start time, the time between successive failures for each subsystem was determined using the stop time of the previous failure to the start time of the next failure. A twenty four hour clock was used to determine this time between failures. The assumption was that these aircraft would be available for operational use during times between failures. Data received from Headquarters Air Mobility Command in coordination with industry was utilized to validate the measures obtained from this work-around. We determined that this method provided a level of accuracy that was consistent with the numbers that were provided by Headquarters Air Mobility Command.

All subsystems identified for modification in KC-135 CNS/ATM program are required for flight in-accordance with the Minimum Essential Systems List (MESL) for MDS KC135 as of December 01, 2008. A critical failure reported on any one of these system causing that system to be non-mission capable causes a non-mission capable status for the aircraft system as a whole. Also, independence between the subsystems is exists. That is a failure in one subsystem has no impact on another subsystem. The series relationship between the Digital Flight Director (DFD), Radio Altimeter (RA), Auto Pilot (AP), and Angle of Attack (AOA) is represented by the reliability block diagram in Figure 2.

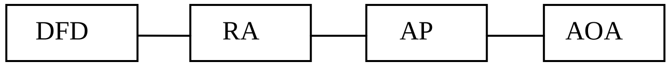

Figure 2– Subsystem Reliability Block Diagram

Step 2: Associate average times to repair

The maintainability metrics will be determined in the same manner as the MTBF. These metrics will include MTTR, ADT, and LDT. Where ADT and LDT historical measures are not specified as a segregated value in REMIS, they are incorporated in the repair time; hence, MTTR times are MDT.

The Headquarters AMC has required that the KC-135 CNS/ATM system shall not shorten the interval for scheduled depot maintenance for the aircraft. Also, The KC-135 CNS/ATM system shall not increase the KC-135 scheduled maintenance downtime. Since upgrade requirements pose no impact to system overhaul interval scheduled and scheduled maintenance downtime, it will not be required to determine sustainment requirements for this upgrade program.

ADT measures the administrative delays in initiating maintenance. Examples of ADT related delays are those required to initiate a request for repair, process paperwork related to the repair, or approve the repair. LDT measures logistics delays related to repairs. Examples of LDT delays are delays in spares availability, maintenance personnel shortages, transportation delays (to/from maintenance locations), etc (Maintenance Division Joint Staff Logistics Directorate (JS/J4/MXD), 2008).

Step 3: Calculate the resulting Baseline Materiel Availability

$$A_M = \frac{(\text{uptime})}{(\text{uptime}) + (\text{downtime})} = \frac{(MTBF)}{(MTBF + MDT)}$$

$$A_M = \frac{r}{r+\lambda} = \frac{MTBF}{MTBF + MDT}$$

where r = MTTR, and λ = MTBF

Step 4: Determine Spares Requirement

Spares may include the number of spare systems as well as the number of removable components and parts spares. Establishing adequate spares support can have as much impact on system availability as the inherent reliability and maintainability.

Sensitivity Analysis

In addition to recommendations brought forth by the draft guide, sensitivity analysis was performed on the recommended values established by industry to ensure first, that the values represent achievable measures. Also, through sensitivity analysis, program officials can see the impact that some variables established from historical performance achievements may have on reliability and availability. This evaluation provides the trade space in which decisions can be made about optimal reliability improvement measures versus costs.

IV. Data Analysis

The data retrieved from REMIS represents actual failure and repair history for the two units of study over a 12 month flying period. This data was analyzed utilizing the ARENA Input Analyzer "fit all" tool to determine the MTBFs for each legacy subsystem that is to be upgraded in addition to the rest of the systems that make of the aircraft minus the four upgrade systems. For the DFD, RA, AP, and AOA subsystems, while the p-values reject the null hypothesis that the data sampled is that of a Weibull distribution, information presented by Banks et al (2005) suggest that a large sample size, such as those present in this study may causes a rejection of all candidate distributions. Because of this the associated histograms in appendix 3 were utilized to present evidence that the Weibull distribution does provide an appropriate fit. The same holds true for the remaining aircraft systems minus the upgrade systems. This data is of an Exponential distribution. The MTBF values and failure distributions are shown in Table 2.

Determine Baseline Reliability and Availability

Table 2– Failure Time Distribution Data

Subsystem	**Distribution**	**MTBF (Flt Hrs)**	**Kolmogorov Smirnov p-value**	**Sample Size**
Aircraft	Exponential	12	< 0.01	5082
DFD	Weibull	717	< 0.01	154
RA	Weibull	370	< 0.01	134
AP	Weibull	417	< 0.01	352
AOA	Weibull	398	< 0.1	49

Except for the AOA subsystem, we used histograms to determine the appropriate repair time distributions. The MTTR for each subsystem is represented by the data in Table 3. The associated histograms are shown in Appendix 4.

Table 3– Repair Time Distribution Data

Subsystem	Distribution	MTTR (Hours)	Kolmogorov Smirnov p-value	Sample Size
Aircraft	Beta	1.08	< 0.01	5083
DFD	Lognormal	1.83	< 0.01	155
RA	Lognormal	1.56	< 0.01	135
AP	Beta	1.93	< 0.01	353
AOA	Exponential	2.28	> 0.15	50

The next step in determining the system baseline availability is to calculate the MTBF for the system.

In general, for the fitted failure rate values obtained from Input Analyzer in ARENA®

$$MTBF_{System} = \frac{1}{\sum_{i}^{n} 1/MTBF_i}$$

where $MTBF_i$ = mean time to failure of the *i*th component/subsystem.

The system MTBF is therefore given by:

$$MTBF_{System} = 1/[(\frac{1}{12}) + (\frac{1}{717}) + (\frac{1}{370}) + (\frac{1}{417}) + (\frac{1}{398})] = 10.83 \text{ Hours} \qquad (4.1)$$

The system MTBF for just the subsystems that are to be upgraded would be extrapolated and calculated using the same method. The subsystems to be upgraded system MTBF value was determined to be:

$$MTBF_{Upgrade-System} = 1/[(\frac{1}{717}) + (\frac{1}{370}) + (\frac{1}{417}) + (\frac{1}{398})] = 111.01 \text{ hours} \tag{4.2}$$

Next, determine the system MTTR. This is accomplished as follows:

$$MTTR_{System} = [(\frac{1}{1.08}) + (\frac{1}{1.83}) + (\frac{1}{1.56}) + (\frac{1}{1.93}) + (\frac{1}{2.28})] = 3 \quad . \text{Hours} \tag{4.3}$$

Resulting Materiel Availability:

$$A_M = \frac{(\text{uptime})}{(\text{uptime}) + (\text{downtime})} = \frac{(MTBF)}{(MTBF + MDT)}$$

$$A_M = \frac{r}{r+\lambda} = \frac{MTBF}{MTBF + MDT}$$

where $r = 1/\text{MTTR}_{\text{System}}$ and $\lambda = 1/\text{MTBF}_{\text{System}}$.

The Baseline Materiel Availability for the 12 month historical data is therefore:

$$A_M = \frac{.3257}{.3257 + .0923} = .7791 \tag{4.4}$$

To ensure the validity of this process, performance measures output by the 135th Aircraft Availability Improvement Program Analysis, Logistics Integration Flight, 550th Aircraft Sustainment Squadron, 827th Aircraft Sustainment Group were cross-referenced. The values they reported for the specific time period of this research was an approximate match to our measures.

Resulting Minimum Number of Spares Required

Assuming instantaneous replacement of failed subsystem component with spares and that all failed subsystem components are repairable (in order to simplify the example), the minimum number of spares required can be determined by:

$$A_M = percentage\ of\ aircraft\ operational = \frac{40arcft}{X} = 0.7791 \tag{4.5}$$

Solving for X:

$$X = \left\lceil \frac{40arcft}{0.7791} \right\rceil = 52\ after\ rounding\ up$$

Number of spares = 52 - 40. To keep 40 aircraft operational on average for 1 year, 12 spares are required.

Reliability Sensitivity Analysis

The first step was to evaluate the sensitivity of the model to changes in multiple variables that play a factor in overall reliability and availability. For this research we only evaluated the effect of changing one variable at a time, not focusing on interactions between variables. A key variable to consider when determining how changes to individual and system reliability may be affected, would be to perform sensitivity analysis on the individual subsystem scale parameters (θ). This will enable the developer to determine what impact that different characteristic life values will have on the reliability of the subsystem/components and the system reliability. Each of the subsystems to be upgraded in this study was determined to have a Weibull failure distribution. We performed this evaluation using the shape parameters (β) established from failure data obtained in the baseline measures.

We began by establishing values based on the recommended objective values provided by industry's COTS measures. This would enable us to determine the probability of meeting these objective measures. Table 4 shows industry recommended threshold and objective values.

Table 4– Industry Threshold and Objective Values

	THRESHOLD	OBJECTIVE	Beta
DFD	1545 hrs	2705 hrs	43.4
RA	773 hrs	1352 hrs	14.3
AP	657 hrs	966 hrs	35.3
AOA	927 hrs	1159 hrs	6.69

We began our analysis by using a value that is 1 percent higher than industry's recommended objective value and increased that measure incrementally by 1 percent through 95 percent above that recommended objective value to determine the influence that it has on system reliability. Except for the AOA threshold, all values at 1 percent and above objective have at least a 100 percent probability of meeting threshold levels so we will only evaluate achieving the objective values. As shown in the calculations below the one percent above objective value achieves an 81 percent probability of meeting the AOA threshold value.

$$R = e - (t/\theta)^{\beta}$$

where t = $MTBF_{Threshold}$ and θ = one percent above $MTBF_{Objective}$.

$$R_{AOA} = e - (927/1171)^{6.69} = .8111$$

where t = $MTBF_{Objective}$ and θ = one percent above $MTBF_{Objective}$.

$$R_{DFD} = e - (2705/2732)^{43.2} = .5214$$

One percent incremental increases above recommended objective values for each subsystem are shown in Table 5.

Table 5– Subsystem Reliability at Different percentages Above MTBF Objective Values

% Above	.01	.02	.03	.04	.05	.06	.07	.08
DFD	.5214	.6544	.7574	.8329	.8862	.9230	.9481	.9650
RA	.4218	.4706	.5208	.5649	.6091	.6472	.6847	.7166
AP	.4990	.6048	.7033	.7809	.8348	.8801	.9134	.9355
AOA	.3932	.4161	.4406	.4627	.4861	.5089	.5292	.5506

Since system reliability is a probability, the system reliability may be determined from subsystem/component reliabilities. Components within a system may be related or configured to one another in two primary ways: in either a serial or a parallel configuration. In series all components must function for the system to function. In a parallel, or redundant, configuration, at least one component must function for the system to function. All components in this system are considered critical for operation. Under this concept a failure in any one component or subsystem would render the aircraft inoperable. All components must be functional for the system to be operational. This series relationship is represented by the reliability block diagram of figure 3.

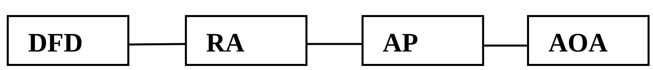

Figure 3- System Reliability Block Diagram

The Upgrade System Reliability is therefore:

$$R_{Upgrade\ System} = \prod_{i=1}^{n} R_i$$

where i = the ith subsystem/component.

The System Reliability at one percent above the objective value is therefore:

$$R_{Upgrade\ System} = .5214 \times .4218 \times .4990 \times .3932 = .0432$$

Table 6 shows the upgrade system reliability increases at one percents incremental increases above the recommended objective values.

Table 6 – Upgrade System Reliability Increase versus Scale Parameter (Ɵ) Increase

Ɵ Increase	.01	.02	.03	.04	.05	.06	.07	.08
$\mathbf{R_{System}}$	.0432	.0775	.1222	.1700	.2190	.2676	.3138	.3562

In establishing the system level reliability requirements, both system performance and the cost associated with system performance must be considered. The trade space for the sustainment requirements is determined by the threshold and objective values determined for Materiel Availability, Materiel Reliability, and Ownership Cost. Internal trade-offs are made to develop the optimal system for the given acquisition/sustainment approach (for example, increasing or decreasing the Materiel Reliability values to reduce the overall LCC). Even though cost analysis will not be thoroughly explored during this study, figures 4, 5, 6, 7, and 8 clearly demonstrate the trade space that exists between reliability improvement and characteristic life that is associated with reliability improvements. For this research we are only considering the impact of the factors that affect achieving quantifiable and reproducible sustainment metrics.

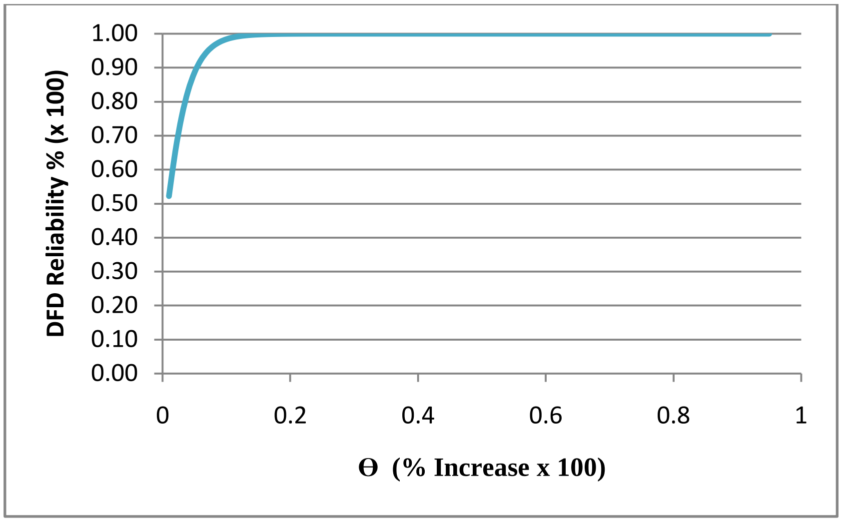

Figure 4- DFD Reliability vs ϴ Increase

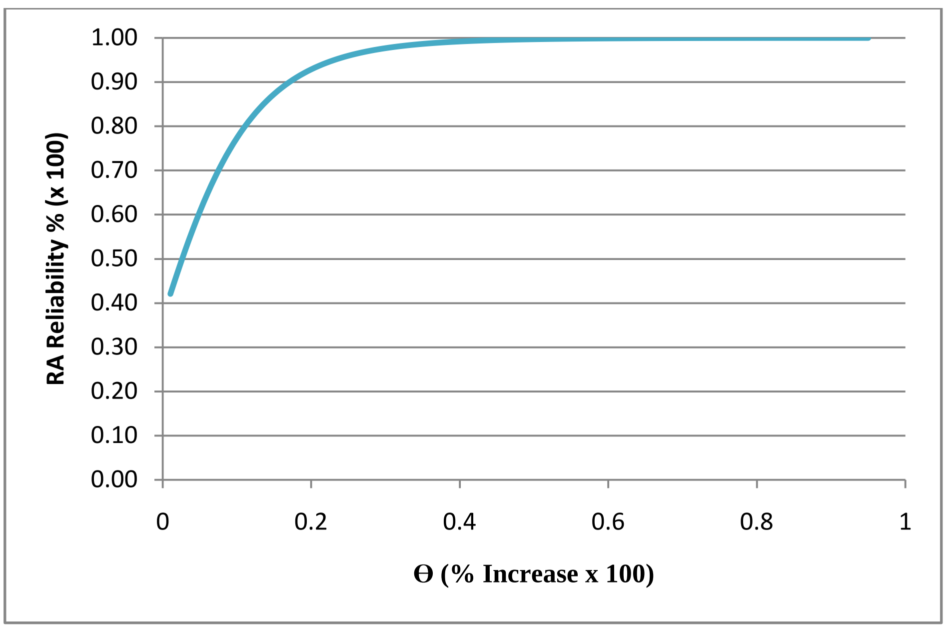

Figure 5- RA Reliability vs ϴ Increase

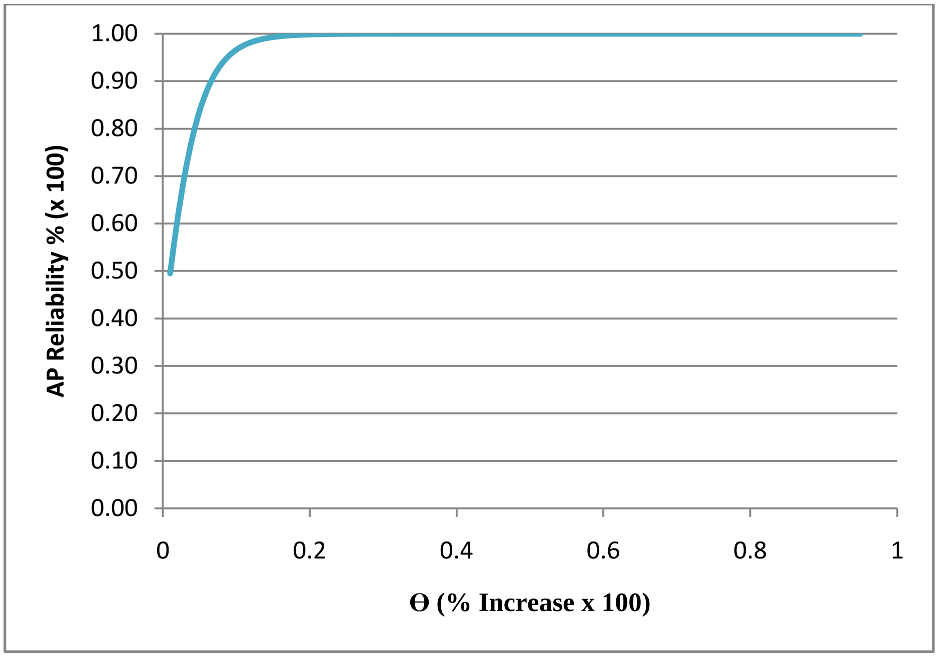

Figure 6– AP Reliability vs ϴ Increase

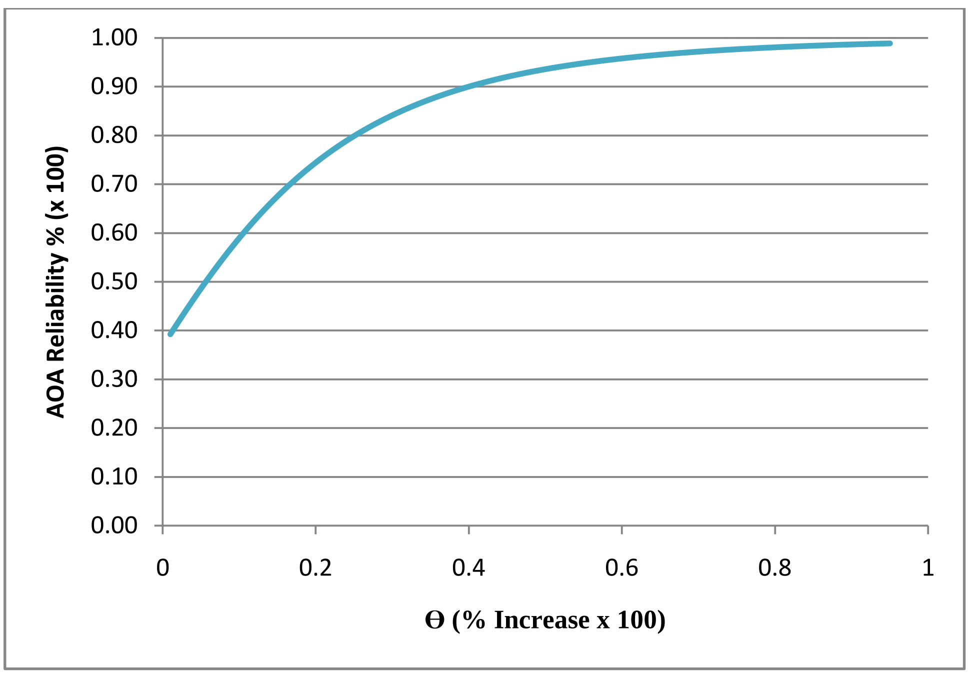

Figure 7– AOA Reliability vs ϴ Increase

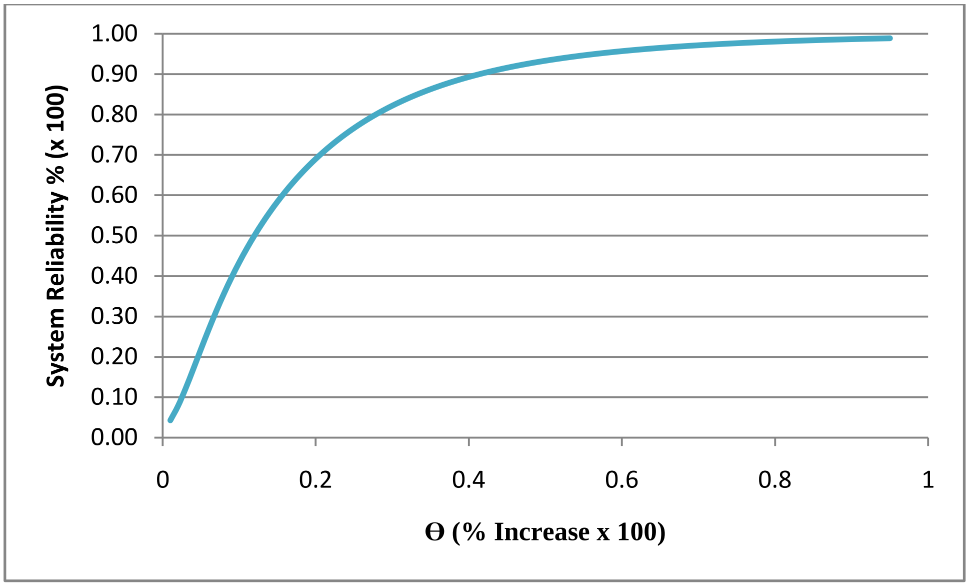

Figure 8– System Reliability vs ϴ Increase

The sensitivity analysis performed demonstrates the ability of the procedures utilized in the study to provide decision makers with additional tools that provide visibility of the trade-offs that may be capitalized upon. For example, the rate of return on additional investment to improve the reliability of the DFD, RA, and AP would provide a much better dollar for dollar return than would be realized if additional funds were allocated toward improving the reliability of the AOA subsystem. The concepts in this guide would allow developers to meet the warfighters requirements in a realistic manner while simultaneously minimizing costs.

Materiel Availability Sensitivity Analysis

Once analyses pertaining to reliability measures were completed, the next sustainment measure of interest was availability. Just as accomplished with the reliability measures, we first evaluated the impact that the industry recommended values had on availability. The system threshold and objective MTBF values of 220 hours and 333 hours respectively, were evaluated to determine what noticeable impact is recorded from the baseline availability measures compare to the values recorded from equation 4.4. Following this, we evaluated availability at 10 percent incremental increases above the recommended objective value. The impact on overall availability was examined from the 10 percent above the recommended value continuing through a 500 percent increase.

Availability at industry recommended threshold values would be determined by:

$$A_M = \frac{r}{r + \lambda_{System\ -\ upgrade}} * \frac{r}{r + \lambda_{Subsystem\ upgrade}}$$

The Threshold Materiel Availability is therefore:

$$A_M = \frac{.3257}{.3257 + .0833} * \frac{.3257}{.3257 + .0046} = .7852 \qquad (4.6)$$

where r = 1/MTTR$_{\text{System}}$ and $\lambda_{\text{System – upgrade}}$ = 1/MTBF$_{\text{System – upgrade}}$ (1/12 hours) and $\lambda_{\text{Subsystem upgrade}}$ = 1/MTBF$_{\text{Subsystem upgrade}}$ (1/220 hours).

Availability at industry recommended objective values would be;

$$A_M = \frac{.3257}{.3257 + .0833} * \frac{.3257}{.3257 + .0030} = .7890 \qquad (4.7)$$

where .0030 = 1/333 hours.

The subsystems to upgraded baseline system MTBF value was established as 111 hours. The values of 220 hours and 333 hours represent an increase of 98 percent and 200 percent. As seen from the calculated availability values, the increase in availability for these proposed reliability improvements equate to only a small amount. The impact of the 10 percent incremental increases above the recommended objective value is represented in figure 9.

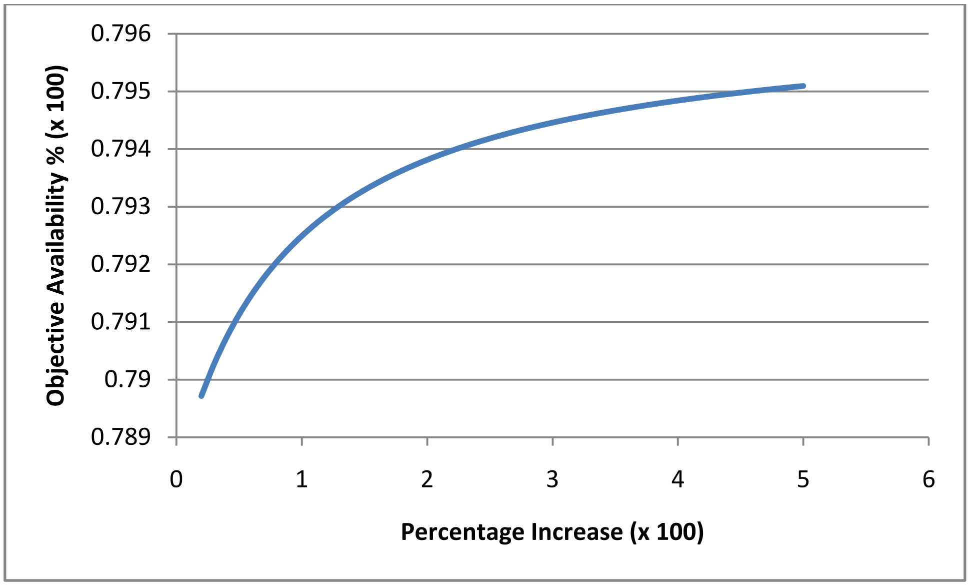

Figure 9– Objective Availability vs Upgrade MTBF Increase

Repair Time Sensitivity Analysis

Finally, there may be limits to what may be achieved through reliability improvements. Another area to consider when examining ways to reduce Life Cycle Costs is to explore the maintainability of the system. This process begins by defining maintainability goals. The determination of these goals coincides with the reliability specifications. Trade-offs between reliability and maintainability can be examined (Ebeling, 2005). The COTS based component replacements considered for this modification contract consist of black box type LRUs that require shorter replacement time and provide ease of access. For this reason, Headquarters AMC with the consultation of industry experts have set a goal of a repair time reduction to not more than 30 minutes on average for modifications related repairs compared to the historical value of 3 hours from equation 4.3.

Threshold Availability at the 30 minute recommended repair time would be:

$$A_M = \frac{.3257}{.3257 + .0833} * \frac{2}{2 + .0046} = .7944 \tag{4.8}$$

where 2 = 1/.5 hours.

Objective Availability at the 30 minute recommended repair time would be:

$$A_M = \frac{.3257}{.3257 + .0833} * \frac{2}{2 + .0030} = .7951 \tag{4.9}$$

As seen from these calculations, maintainability design goals present even further availability improvements beyond the reliability improvements of 78.52% and 78.90% experienced from calculations presented in equation 4.6 and 4.7. The visibility of the availability gains achieved from this modification program would be valuable for any developer tasked with setting readiness requirements that are realistic and achievable.

Table 7– Aircraft Availability Improvement Values

	3.07 Hr MTTR	0.5 Hr MTTR
Baseline Availability	.7791	N/A
Threshold Availability	.7852	.7941
Objective Availability	.7890	.7951

Resulting Minimum Number of Spares Require

$$A_M = percentage\ of\ aircraft\ operational = \frac{40arcft}{X} = 0.7944 \tag{4.10}$$

Solving for X:

$$X = \left\lceil \frac{40arcft}{0.7791} \right\rceil = 51\ after\ rounding\ up$$

The number of spares = 51 – 40. To keep 40 aircraft operational on average for 1 year, 11 spares are required at both threshold and objective availability values.

The key purpose for this research was not to show whether these increases would provide sizeable gains, or optimize reliability to cost trade-offs, but to develop an objective, standard, repeatable method for quantifying the Materiel Availability KPP and the associated Materiel Reliability KSA value for defense weapon system requirements documents.

V. Recommendations

Answering the Research Question

Air Mobility Command (AMC) lacks a standardized method to establish these mandatory threshold and objective values for the Materiel Availability KPP and Materiel Reliability KSA for modifications to existing weapons systems. A draft guide is proposed by the Joint Staff with the purpose of assisting program decision makers, but it's applicability to the AMC problem is unclear.

Is the draft Reliability, Availability, Maintainability and Cost Guide (RAM-C) that the Office of the Secretary of Defense in Collaboration with the Joint Staff prepared applicable for use on modification program?

Yes this draft guide is applicable for modification programs. We feel that better results can be achieved when utilizing this draft guide if recommendations to the 5 investigative questions are implemented.

Investigative Questions

Question 1: What portions of the guide are applicable to this study and what portions do not apply?

The primary purpose of this study was to determine if the principles and processes contained within a draft RAM-C guide would provide assistance in helping the combat developer in establishing reasonable, balanced mandatory sustainment requirements. The concepts and principles were applied to an ongoing major aircraft modification program for planners at Headquarters AMC.

Unlike new weapons systems acquisitions, most modifications are undertaken to improve on existing capabilities without changing the basic theory of employment of the upgraded system. The processes outlining the development of the CONOPS, OMS/MP, and FD/SC do not seem applicable to this study mainly because these areas would remain unchanged from the legacy system. Also, the information pertaining to maintenance concepts and product support were of little use for this modification, considering the maintenance and support framework would be unchanged from the legacy system.

The concepts in this document that was most useful was the information pertaining to the calculation of the baseline reliability and availability metrics. Also the spares requirements calculation was very helpful and insightful.

Question 2: What modification program would be a viable candidate for the use in this study?

For this study we considered two in-progress aircraft modification programs for Headquarters AMC, the C- 5 RERP and the KC-135 CNS/ATM. Both programs were modifications to aircraft that have been in the Air Force inventory for decades. This provided us access to a wealth knowledge and historical trend data that is required to assess what information that is pertinent in establishing sustainment requirements.

In choosing our aircraft for this study we examined issues such as size of modification, accessibility to performance data and phase of contract acquisition. Each program presented a different level of complexity based on the number of subsystems to be upgraded. Both programs involved some form of COTS systems components and access to industry's estimated performance data was available. The main deciding factor between the two modification programs was the size of the system upgrade. For this reason the KC-135 CNS/ATM program was chosen as the program for study. But overall, based on the results achieved from this research, it is highly conceivable that a modification as complicated as the C-5 RERP could be accomplished utilizing the same principles contained within this study given an ample amount of time to do so.

Question 3: If the guide is deemed applicable for use in modification or upgrade programs what areas within the guide requires changes and what changes are recommended?

The concepts presented in the draft guide are mainly focused on acquisition of an entirely new weapon system. To get the best results from this document as a tool for modification programs some changes should be made. One area that did not receive much attention was historical data examination and sensitivity analysis. A critical insight gained during this research was how examination of different factors such as characteristic life values and the impact such evaluation has on achieving predicted measures. More emphasis should be placed on reliability sensitivity analysis and availability sensitivity analysis. The document as it stands now only examines a comparative evaluation of competing systems without evaluating the variables of each system to determine how this analysis affects feasibility and overall availability.

Because the document does not address the historical performance of weapons system, the creators only evaluate sustainment requirements based on a constant failure time distribution. This document should address time dependent failure distributions based on actual failure data.

Question 4: How should historical reliability and maintenance data information systems be utilized to establish availability and reliability estimates?

The REMIS maintenance and supply data system that was utilized in this research provided a tool to access the historical failure and repair time information needed to establish sustainment requirements. Due to limitations with current operating time reporting, REMIS should be utilized with the direct assistance of subject knowledge experts such as Headquarters AMC, the Tanker program office, and operational KC-135 units to assist in the validation of any assumptions made to data collection and analysis. Also, given that each historical data system present tools not share between systems, time should be allotted to cross reference each system for accuracy and to fill in holes that can give a better picture of the entire program to include logistics areas.

Question 5: Does the current body of literature concerning Performance Based Logistics support our efforts to establish sustainment performance parameters?

Through a review of a substantial body of literature outlining the theoretical basis for Performance Base Logistics (PBL), we have been able to determine that PBL can be used as a tool to aid in the design of product support strategies for new programs or major modifications, or as we reengineer product support strategies for legacy weapon systems. We have found that it is commonly perceived that performance based logistics is likely to improve product availability, reliability, maintainability and supportability at a lower cost through leveraging commercial best practices. Typically the government does a poor job at optimizing sustainment design for individual weapons system. The costs effective sustainment management principles that commercial industry is force to adhere to under PBL contracts can provide a "best practices" acquisition knowledge road-map. The lessons learned from commercial PBL contract implementations can be utilized to reduced the Total Life Cycle Costs and reduce the logistics footprint requirement under traditional acquisition contracts.

Assumptions

In order to conduct this research some key assumptions were made:

1. All subsystems identified for modification in KC-135 CNS/ATM program are required for flight in-accordance with the Minimum Equipment Safety Listing (MESL) for MDS KC135 as of December 01, 2008. A critical failure reported on any one of these system causing that system to be non-mission capable causes a non-mission capable status for the aircraft system as a whole.
2. Failure and Repair data reported in REMIS regarding equipment status and performance of maintenance actions are considered accurate.
3. Immediately upon a report of component failure repair action will commence.
4. A reported failure results in the failed subsystem's replacement or repair to a level of new condition (renewal process).
5. The reliability measures of mean time between failures (MTBF) will be an equilibrium measure based on the evaluation of actual failures reported over the 12 month reporting period for the aircraft and units of study.
6. The time that an aircraft is available for flight operation is based on the time from completion of a maintenance action to the start of the next maintenance actions based on a 24 period.
7. Information received from Headquarters Air Mobility Command and industry pertaining to Commercial Off-the Shelf Technology (COTS) is accurate.
8. Independence between subsystems exist.

Limitations

One of the main requirements in determining time between successive failures is the operating time of the equipment being evaluated. One of the limitations and a known system abnormality in REMIS is that the system does not output current operating time in reports that contain this field. The method of using a 24 hour operating clock to determine MTBF was validated utilizing data obtained from Headquarters Air Mobility Command. Current operating for each unit under evaluation would give a more precise measurement for each unit being evaluated.

We selected only the Reliability and Maintainability Information System (REMIS) will be the only reliability and maintainability information system used to perform this research. A more thorough evaluation of the capabilities and shortcomings of each data source could provide an improved level of validation of the legacy systems historical performance measurements.

Future Research Opportunities

The key objective of this research was not to achieve optimized materiel readiness requirements for the program under evaluation in this study, but to aid in determining if the draft guide proposed by OSD was applicable as a tool to in establishing mandatory readiness requirements. To truly gauge the effectiveness of this guide as a tool to establish optimal readiness goals, costs should be evaluated in addition to the factors address in this research. The sensitivity analysis performed during this research along with costs data should provide better insight on Total Life Cycle Costs.

Also, an analysis of a program that is much more complex in scope and number of the subsystems or components to be modified could provide better insight on how the processes outlined in this study could impact overall system availability.

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Appendix 1 – PRP-4126 Screenshots

USAF - PRP4126 - On/Off Equipment Maintenance Detail Report

User-Input Select Elements/Options Were As Follows:

Report Subtitle:	
Type Equipment:	A - AIRCRAFT / DRONES
Equipment Designator:	KC135R
Standard Reporting Designator:	
Command:	
Geographic Location:	NLZL
Organization	
TCTO Data Code:	
Job Control Number:	
Data Filtering:	SPECIFIC CRITERIA ONLY
On Equipment Actions:	Y
Off Equipment Actions:	Y
Unlinked Off Equipment Actions:	N
Date Range:	From FEB 2008 Thru FEB 2009
	On Equipment Maintenance Detail:
Block Number:	
End Item Serial Number:	
Performing Geographic Location:	
Work Center Code:	
How Malfunction Code:	
Action Taken Code:	
When Discovered Code:	
Type Maintenance Code:	
Work Unit Code:	51A%
Part Number:	
Component Serial Number:	
Discrepancy Narrative Key Word:	
WCE Narrative Key Word:	
Corrective Narrative Key Word:	

For: joe.m.blackman
REMIS Report Is For Official Use Only

- 1 -

Prepared: 10 Feb 2009 2300Z
By REMIS: PCN SG099-PRP4126

Figure 10- PRP-4126 On/Off Equipment Maintenance Detail Report

USAF - PRP4126 - On/Off Equipment Maintenance Detail Report

Off Equipment Detail:

Part Number:
Component Serial Number:
Performing Geographic Location:
Work Center Code:
How Malfunction Code:
Action Taken Code:
When Discovered Code:
Type Maintenance Code:
Work Unit Code:
Discrepancy Narrative Key Word:
WCE Narrative Key Word:
Corrective Narrative Key Word:

Sort Order	Element
1	End Item Equipment Designator
2	End Item Serial Number
3	Standard Reporting Designator
4	Block Number
5	Command
6	Geographic Location
7	Performing Geographic Location
8	Organization
9	Off Equipment Part Number
10	Off Equipment Component Serial Number
11	Work Unit Code
12	Work Center Code
13	Stop Date And Time
14	Job Control Number
15	Action Take Code
16	How Malfunction Code

Display Optional Column Data
Block Number,Standard Reporting Designator,End Item Serial Number,Job Control Number,Command,Geographic Location1,Organization,TCTO Data Code,Work Unit Code,Type Maintenance Code,Action Taken Code,When Discovered Code,How Malfunction Code,Performing Geographic Location,Work Center Code,Discrepancy Narrative,Corrective Action Narrative,

For: joe.m.blackman
REMIS Report Is For Official Use Only

- 2 -

Prepared: 10 Feb 2009 2300Z
By REMIS: PCN SG099-PRP4126

Figure 11- On/Off Equipment Maintenance Detail Report

USAF - PRP4126 - On/Off Equipment Maintenance Detail Report

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Equipment Designator	Type Equipment	Block Number	Standard Reporting Designator	Serial Number	Current Operating Time	Job Control Number	Command	Geographic Location	Organization	TCTO Data Code
KC135R	A	142	AGF	5700001462	0.0	08247L005	ANG	NLZL	0121 ARF WG	

Discrepancy Narrative: (-) - PERFORM VISUAL INSP & OPS CK OF FD-109 FLIGHT DIRECTOR: RGA IAW 1C-135-11-30-4

***** On Equipment Actions *****

Work Unit Code	Component Position Number	Type Maintenance Code	Action Taken Code	When Discovered Code	How Malfunction Code	How Malfunction Class Ind	AFTO Form 350 Tag Number	Work Center Event Identifier	Sequence Number	Transaction Date	Start Time	Stop Time	Performing Geographic Location	Work Center Code	Crew Size	Units	Labor Manhours
51A00	0	B	X	M	799	6		292	912	SEP 05, 2008	1200	1330	NLZL	1E120	2	1	3.0

Corrective Action Narrative: FD/RGA VISUAL INSP & OPS CHECK C/W.

****

Equipment Designator	Type Equipment	Block Number	Standard Reporting Designator	Serial Number	Current Operating Time	Job Control Number	Command	Geographic Location	Organization	TCTO Data Code
KC135R	A	142	AGF	5700001462	0.0	093668050	ANG	NLZL	0121 ARF WG	

Discrepancy Narrative: (/) WIRE #'S 1TN18178A16B $ TN18174A20B HAS DAMAGED INSULATION ON GND WIRES. SEE MCARTHUR IN ELEN FOR MORE INFO

***** On Equipment Actions *****

Work Unit Code	Component Position Number	Type Maintenance Code	Action Taken Code	When Discovered Code	How Malfunction Code	How Malfunction Class Ind	AFTO Form 350 Tag Number	Work Center Event Identifier	Sequence Number	Transaction Date	Start Time	Stop Time	Performing Geographic Location	Work Center Code	Crew Size	Units	Labor Manhours
51AAA	0	B	G	F	105	2		75	509	JAN 06, 2009	1200	1600	NLZL	1E120	1	1	4.0

Corrective Action Narrative: REPAIRED DAMAGED WIRING

****

Equipment Designator	Type Equipment	Block Number	Standard Reporting Designator	Serial Number	Current Operating Time	Job Control Number	Command	Geographic Location	Organization	TCTO Data Code
KC135R	A	142	AGF	5700001462	0.0	081938050	ANG	NLZL	0121 ARF WG	

Discrepancy Narrative: (/) PILOTS HDG CIRCUIT BREAKER TRIPPED TWICE IN FLIGHT

***** On Equipment Actions *****

Work Unit Code	Component Position Number	Type Maintenance Code	Action Taken Code	When Discovered Code	How Malfunction Code	How Malfunction Class Ind	AFTO Form 350 Tag Number	Work Center Event Identifier	Sequence Number	Transaction Date	Start Time	Stop Time	Performing Geographic Location	Work Center Code	Crew Size	Units	Labor Manhours
51AC0	0	B	R	D	901	1		492	650	JUL 12, 2008	1700	1930	NLZL	1E120	2	1	5.0

Corrective Action Narrative: REMOVED AND REPLACED FD-109 ROLL COMPUTER; OPS CHECK GOOD

***** Linked Off Equipment Actions *****

End Item Equipment Designator	Standard Reporting Designator	Federal Supply Classification	Equipment Designator	Serial Number	Current Operating Time	Job Control Number	Command	Geographic Location	Organization	TCTO Data Code
KC135R	AGF	5826	522-4428-018	57001462	0.0	081938050	ANG	NLZL	0121 ARF WG	

Discrepancy Narrative: PILOTS HDG CIRCUIT BREAKER TRIPPED TWICE IN FLIGHT

Work Unit Code	Component Position Number	Type Maintenance Code	Action Taken Code	When Discovered Code	How Malfunction Code	How Malfunction Class Ind	AFTO Form 350 Tag	Work Center Event	Sequence Number	Transaction Date	Start Time	Stop Time	Performing Geographic Location	Work Center Code	Crew Size	Units	Labor Manhours	On Base Turn In Doc Number	On Work Center	On Equip Sequence Number

For: joe m blackman - 3 - Prepared: 10 Feb 2009 2300Z

Figure 12- On/Off Equipment Maintenance Detail Report

Appendix 2 - PRP-4126 Excel Screenshots

Equipmen	Block Number	Serial Numbe	Current Opera	Job Control	Command	Geograph	Organization	Work Unit Code	Transaction Da	Start Time	Stop Time	Perform
KC135R	120	5700001440	0.00E+00	81772851	ANG	NLZL	0121 ARF WG	4199	15-Jul-08	1630	1800	NLZL
KC135R	120	5700001440	0.00E+00	81772850	ANG	NLZL	0121 ARF WG	4199	9-Jul-08	1200	1300	NLZL
KC135R	120	5700001440	0.00E+00	81772852	ANG	NLZL	0121 ARF WG	4210	17-Jul-08	1500	1800	NLZL
KC135R	120	5700001440	0.00E+00	81912855	ANG	NLZL	0121 ARF WG	14AAE	10-Jul-08	1200	1400	NLZL
KC135R	120	5700001440	0.00E+00	81912856	ANG	NLZL	0121 ARF WG	14BD0	11-Jul-08	1800	2200	NLZL
KC135R	120	5700001440	0.00E+00	81772853	ANG	NLZL	0121 ARF WG	14BEG	3-Jul-08	1400	1800	NLZL
KC135R	120	5700001440	0.00E+00	81912850	ANG	NLZL	0121 ARF WG	14CBA	9-Jul-08	1200	1300	NLZL
KC135R	120	5700001440	0.00E+00	81902850	ANG	NLZL	0121 ARF WG	14DCA	9-Jul-08	1100	1200	NLZL
KC135R	120	5700001440	0.00E+00	81842850	ANG	NLZL	0121 ARF WG	51399	10-Jul-08	1200	1430	NLZL
KC135R	134	5700001454	0.00E+00	83066116	AFE	QFQE	0100 ARF WG	46425	2-Nov-08	1000	1100	QFQE
KC135R	134	5700001454	0.00E+00	82295151	AFE	QFQE	0100 ARF WG	61BA0	16-Aug-08	1305	1530	QFQE
KC135R	142	5700001462	0.00E+00	80537507	AFE	QFQE	0100 ARF WG	3200	29-Feb-08	725	730	QFQE
KC135R	142	5700001462	0.00E+00	80537502	AFE	QFQE	0100 ARF WG	4199	29-Feb-08	700	705	QFQE
KC135R	142	5700001462	0.00E+00	80537503	AFE	QFQE	0100 ARF WG	4199	29-Feb-08	705	710	QFQE
KC135R	142	5700001462	0.00E+00	80537504	AFE	QFQE	0100 ARF WG	4199	29-Feb-08	710	715	QFQE
KC135R	142	5700001462	0.00E+00	80537505	AFE	QFQE	0100 ARF WG	4199	29-Feb-08	720	725	QFQE
KC135R	142	5700001462	0.00E+00	80189992	ANG	NLZL	0121 ARF WG		5-Feb-08	1300	1400	
KC135R	142	5700001462	0.00E+00	81939685	ANG	NLZL	0121 ARF WG		18-Jul-08	1200	1230	
KC135R	142	5700001462	0.00E+00	81939685	ANG	NLZL	0121 ARF WG		23-Jul-08	1700	1730	
KC135R	142	5700001462	0.00E+00	83099874	ANG	NLZL	0121 ARF WG		12-Nov-08	1200	1400	
KC135R	142	5700001462	0.00E+00	83099874	ANG	NLZL	0121 ARF WG		5-Nov-08	1900	1940	
KC135R	142	5700001462	0.00E+00	83099874	ANG	NLZL	0121 ARF WG		8-Nov-08	1700	1900	
KC135R	142	5700001462	0.00E+00	81309624	ANG	NLZL	0121 ARF WG		5-Jun-08	1330	1400	
KC135R	142	5700001462	0.00E+00	82059821	ANG	NLZL	0121 ARF WG		25-Jul-08	1420	1430	

Figure 13– PRP-4126 On/Off Equipment Maintenance Detail Report (Excel)

Appendix 3 – Arena® Input Analyzer Failure Time Distribution Histograms

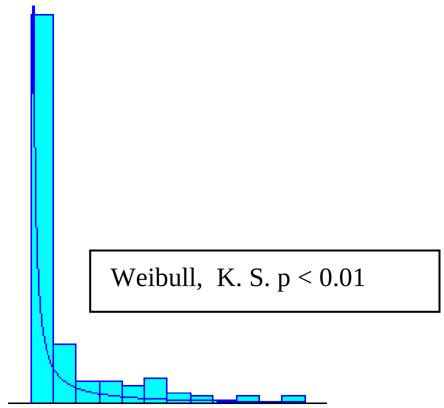

Figure 14– DFD Failure Time Distribution

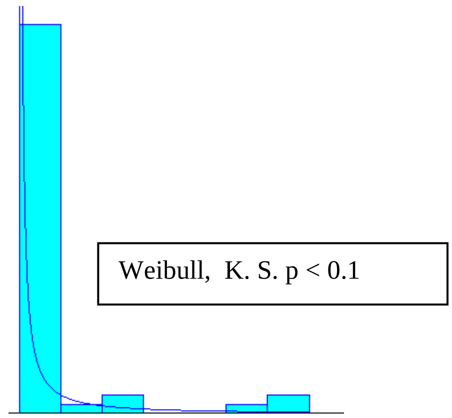

Figure 15– AOA Failure Time Distribution

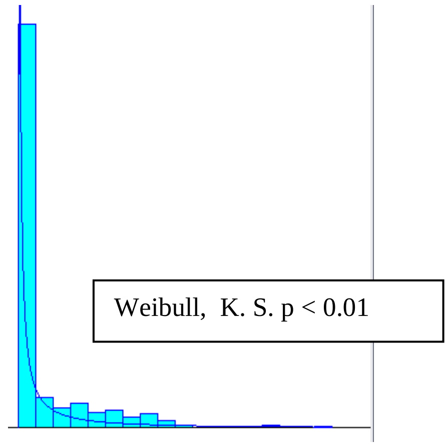

Figure 16– AP Failure Time Distribution

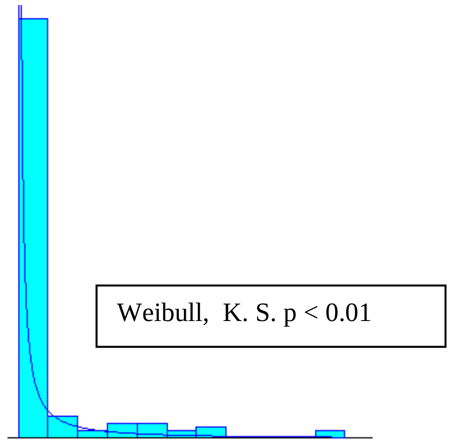

Figure 17– RA Failure Time Distribution

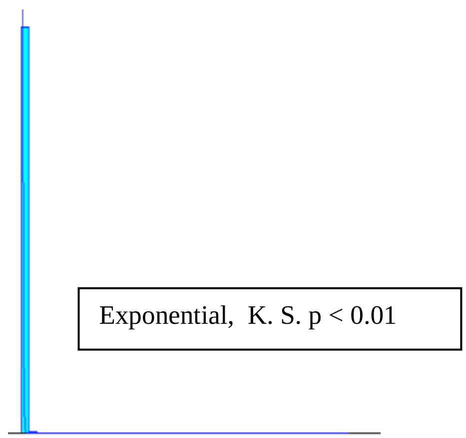

Figure 18– Aircraft minus Upgrades Failure Time Distribution

Appendix 4 – Arena® Input Analyzer Repair Time Distribution Histograms

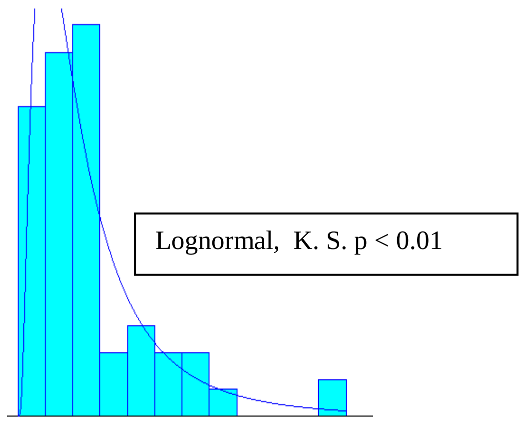

Figure 19– DFD Repair Time Distribution

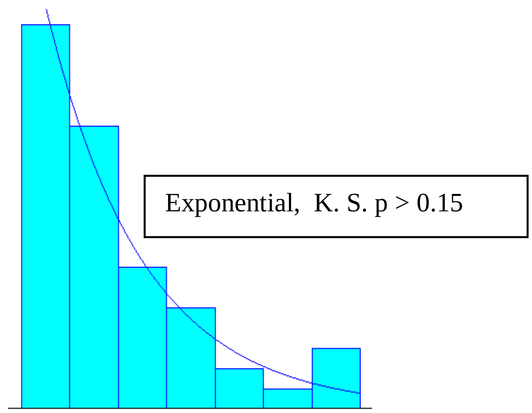

Figure 20– AOA Repair Time Distribution

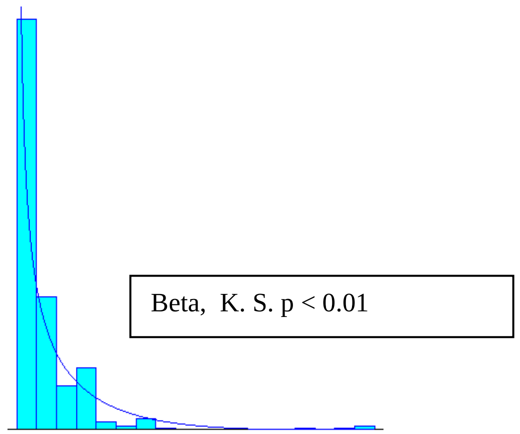

Figure 21– AP Repair Time Distribution

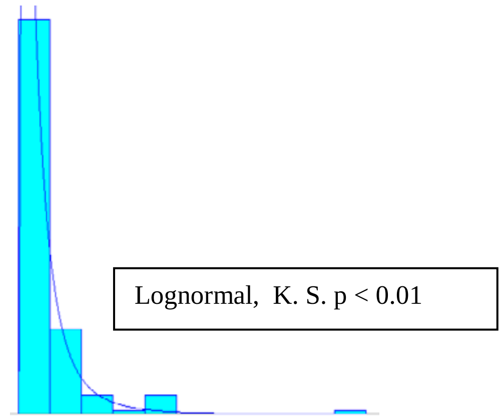

Figure 22– RA Repair Time Distribution

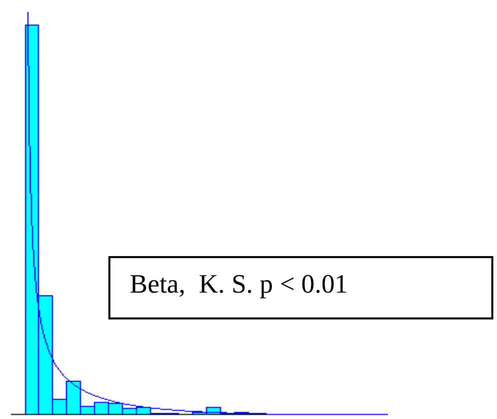

Figure 23– Aircraft minus Upgrade Repair Time Distribution

Appendix 5 – Blue Dart

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Word Count: 731

Quantification of Mandatory Sustainment Requirement

To emphasize the importance of sustainment, the DoD Joint Requirements Oversight Council addressed sustained Materiel readiness and established a mandatory Key Performance Parameter (KPP) for Materiel Availability; it also established supporting Key System Attributes (KSAs) for Materiel Reliability and Ownership Cost (Chairman of the Joint Chiefs of Staff Manual (CJCSM) 3170.01C, 2007). KPPs are those system attributes considered most critical or essential for an effective military capability. KSAs are those system attributes considered most critical or essential for an effective military capability but not selected as a KPP. KSAs provide decision makers with an additional level of capability prioritization below the KPP but with senior sponsor leadership control (generally 4-star level, Defense agency commander, or Principal Staff Assistant) (Chairman of the Joint Chiefs of Staff Manual (CJCSM) 3170.01C, 2007).

The values used to describe each KPP and KSA are defined by a threshold value and an objective value. The threshold value for an attribute is the minimum acceptable value considered achievable within the available cost, schedule, and technology at low-to-moderate risk. Performance below the threshold value is not operationally effective or suitable. The objective value for an attribute is the desired operational goal achievable but at higher risk in cost, schedule, and technology. Performance above the objective does not justify additional expense.

No distinction is made between the approaches in establishing these values for major system acquisitions, versus smaller, modification-focused efforts for existing systems. In some cases a range of stated values may be appropriate, but in other cases the best approach may be to specify the value as a percentage change or as a function of other variables. The Joint Staff proposed guidance, "Reliability, Availability, Maintainability and Cost (RAM-C) Guide," to assist in determining these values for major acquisition programs, but the guidance has yet to be tested on modification contracts. To assess its applicability, we performed a case study of a recent acquisition program under consideration by Air Mobility Command. We sought to apply the principles put forth in this draft guide prepared by the Office of the Secretary of Defense (OSD) in Collaboration with the Joint Staff.

Air Mobility Command (AMC) lacks a standardized method to establish these mandatory threshold and objective values for the Materiel Availability KPP and Materiel Reliability KSA for modifications to existing weapons systems. In order to address this issue the draft guide proposed by the Joint Staff was applied to a modification effort under consideration by AMC.

The Air Force Air Mobility Command's Directorate of Plans and Programs approached us with a request for help in quantifying their KPPs for several ongoing major aircraft modifications, and will support our research. Therefore, we initially focused our research on recommending a standardized method for quantifying Materiel readiness sustainment metrics for Air Force Air Mobility Command's modification efforts but we designed our approach and methods to be applicable to all major system modifications and upgrades.

To achieve this objective, we used an ongoing AMC major aircraft modification as a case study. We also engaged in bi-lateral discussions with program and subject matter experts, and conducted a review of applicable literature to develop a model that incorporates multiple factors impacting each sustainment metrics. This model was based on the concepts and principles put forth in the RAM-C draft guide. The decision model included components of predictive modeling and sensitivity analysis of the subsystem components that are incorporated within the projected upgrade to determine the overall affect on Materiel readiness values. The sensitivity analysis performed demonstrates the ability of the procedures utilized in the study to provide decision makers with additional tools that provide visibility of the trade-offs that may be capitalized upon. The concepts in this guide would allow developers to meet the warfighters requirements in a realistic manner while simultaneously minimizing costs.

The processes utilized in this research were able to prove that the draft RAM-C guide developed by the Joint Staff is a valuable tool to help combat developers think through the top-level sustainment requirements for RAM-C early in the requirements generation and refinement phases of a program. With the addition of information that addresses sensitivity analysis required and the historical performance of the legacy weapon system included in this guide we feel that this document could prove to be an even better tool when applied to the modification of existing weapons systems.

REPORT DOCUMENTATION PAGE		*Form Approved* *OMB No. 074-0188*
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1. REPORT DATE *(DD-MM-YYYY)* 26-03-2009	**2. REPORT TYPE** **Master's Thesis**	**3. DATES COVERED** *(From – To)* Sept 2007 – Mar 2009
4. TITLE AND SUBTITLE Quantification of Mandatory Sustainment Requirements		**5a. CONTRACT NUMBER**
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Blackman, Joe, M, Master Sergeant, USAF		**5d. PROJECT NUMBER**
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(S) Air Force Institute of Technology Graduate School of Engineering and Management (AFIT/EN) 2950 Hobson Street, Building 642 WPAFB OH 45433-7765		**8. PERFORMING ORGANIZATION REPORT NUMBER** AFIT/GLM/ENS/09M-01
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Headquarters Air Mobility Command Logistics Branch, Requirements Division, AMC?A5QL Scott AFB, Ill 62225 NO POC		**10. SPONSOR/MONITOR'S ACRONYM(S)**
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.		
13. SUPPLEMENTARY NOTES		

14. ABSTRACT: To emphasize the importance of sustainment, the DoD Joint Requirements Oversight Council addressed sustained Materiel readiness and established a mandatory Key Performance Parameter (KPP) for Materiel Availability; it also established supporting Key System Attributes (KSAs) for Materiel Reliability and Ownership Cost (Chairman of the Joint Chiefs of Staff Manual (CJCSM) 3170.01C, 2007).

Current guidance requires two numbers: a threshold value and an objective value (Chairman of the Joint Chiefs of Staff Manual (CJCSM) 3170.01C, 2007). No distinction is made between the approaches in establishing these values for major system acquisitions, versus smaller, modification-focused efforts for existing systems. The Joint Staff proposed guidance to assist in determining these values for major acquisition programs, but the guidance has yet to be tested on modification contracts. To assess its applicability, we performed a case study of a recent acquisition program under consideration by Air Mobility Command. We sought to apply the principles put forth in this draft guide prepared by the Office of the Secretary of Defense in Collaboration with the Joint Staff

This research seeks to assist the combat developer and program manager to develop an objective, standard, repeatable method for quantifying the mandatory Materiel Availability KPP and the associated Materiel Reliability KSA values established by the Joint Requirements Oversight Council.

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15. SUBJECT TERMS
Key Performance Parameters, Key System Attributes, Materiel Availability, Materiel Reliability

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** Dr Alan Johnson
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			**19b. TELEPHONE NUMBER** *(Include area code)* e-mail: alan.johnson@afit.edu
U	U	U	UU	87	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39-18