ADVANCING FORWARD-LOOKING METRICS: A LINEAR PROGRAM OPTIMIZATION AND ROBUST VARIABLE SELECTION FOR CHANGE IN STOCK LEVELS AS A RESULT OF RECURRING MICAP PARTS

GRADUATE RESEARCH PAPER

Lisa B. Ryan, Major, USAF

AFIT-ENS-GRP-13-J-9

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

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GRADUATE RESEARCH PAPER

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

Lisa B. Ryan

Major, USAF

June 2013

AFIT-ENS-GRP-13-J-9

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Approved:

________//SIGNED//__________ Darryl Ahner, Ph.D. (Advisor)

___11 June 2013__ Date

Abstract

The intent of this research is to introduce forward-looking metrics and take the first steps in developing a forward-looking metric for Air Force sustainment operations. Specifically, this research seeks to answer four research questions addressing what the Air Force is currently using for sustainment metrics, what are forwarding looking metrics, how can a forward-looking metrics be developed to mitigate current sustainment operations shortfalls, and how can they be used to optimize stock levels, within a given set of constraints, based upon a changing MICAP-hour requirement. These questions are answered through a comprehensive literature review, interviews with subject matter experts and the development of an integer linear program. The research identified a need to sub-divide the MICAP hours metric into three categories, using a robust data selection process: recurring, non-recurring and in-inventory MICAP hours. From this, four primary models are developed, which culminated in an integer linear program to determine the optimal stock level increases to improve (decrease) monthly recurring MICAP hours, subject to the lowest cost with the highest effectiveness. The C-5 Galaxy aircraft fleet sustainment data is used to develop this forward-looking metric.

This research proves forward-looking metrics are a viable tool for the future of sustainment operations and should be leveraged in combination with technology to be the most effective and efficient Air Force in the world.

Dedicated to my loving husband.

Acknowledgments

I sincerely appreciate the multitude of support received from across the Air Force for this research endeavor. Thank you to the staff of the Air Force Sustainment Center, who provided the vast array of data to conduct this research. Thank you to the members within the 635th Supply Chain Operations Wing, who allowed me to participate in the Cascading Metrics IPT and provided vital, firsthand accounts of issues within their units and the current initiatives they are spearheading to improve sustainment metrics within the Air Force. I give a special thanks to my advisor, Dr. Ahner, the mastermind behind this topic, who diligently guided my education in linear programming and facilitated the development of this research. I truly would not have been able to do this research without your tutelage. Lastly, my biggest thank you goes to Mr. Mark Fryman at AFIT. Thank you, Mark, for being my sounding board during the development of this modeling. For always knowing who to call when I couldn't find the data. And for ALWAYS having a can-do attitude!

Maj Lisa B. Ryan

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I. Introduction

General Issue and Problem Statement

The United States is proud to own the largest air force in the world, with 5,484 aircraft, 450 ICBMs and 63 satellites (Almanac, 2012), but sustaining this fleet has many challenges. Specifically, the Air Force supply system is fraught with outdated technology, complex processes and a myriad of metrics that are difficult to interpret.

Current Air Force metrics used to assess aircraft fleet sustainment health are complex, do not provide actionable decision options and are primarily "historical" metrics. Air Force metrics primarily show what happened after the fact for post-operation trend analysis, including: issue effectiveness, stockage effectiveness, cannibalization rates, average repair cycle days, etc. Conversely, forward-looking metrics are measures that identify deviations from a desired state before it occurs or enable a desired state to be reached through an understanding of what controllable system inputs map into the metric function. The Air Force is not currently using forward-looking metrics, but has taken initial steps in developing "scorecards" and "dashboards," which enable a smooth transition into forward-looking metrics. Forward-looking metrics could greatly support the Air Force by providing a real-time assessment and identify areas of improvement; they will help manage problems before they become serious.

As the Air Force's budget continues to shrink, Air Force leadership needs to pinpoint their money and efforts on areas to improve aircraft fleet health the most. A forward looking metric is needed to enable this capability for aircraft sustainment.

Research Questions

The objective of this research is to begin to answer the question posed by the Air Force Sustainment Center, "Can forward-looking metrics be used in Air Force sustainment operations and if so, how?" Since the question is extremely broad, this research will focus on developing a forward-looking metric for Air Force stock levels, as related to a changing Mission Capability (MICAP) hours. The intent of this research is to introduce forward-looking metrics into Air Force sustainment operations and take the first steps necessary in developing a forward-looking metric. The following investigative questions will be analyzed:

1. What metrics are currently used for sustainment operations in the Air Force?
2. What are forward-looking metrics?
3. Can forward-looking metrics be developed to mitigate current sustainment operation shortfalls?
4. How can forward-looking metrics be used to optimize stock levels, within a given set of constraints, based upon a changing MICAP-hour requirement?

Methodology Overview

This research leveraged multiple research practices to answer these research questions, including current and historical literature review, interviews with sustainment operations experts and linear programming. Ultimately, analysis of resource allocation using linear programming was used to gain insight into how to effectively influence future sustainment decision making for aircraft parts. The C-5 Galaxy fleet's supply and maintainability data was be used to build the optimization program using Excel Solver.

Assumptions/Limitations

The researcher assumes the data obtained from the Air Force Supply and Maintenance systems was valid and accurate data. Data was obtained from the Requirements Management System (D200).

To simplify the data sets into readily useable data, an assumption was made that all MICAPs were satisfied within the same month they went MICAP. If a part was MICAP and counted in two or more sequential months, it appears as separate MICAPs.

Limitations to this research arose from availability of data; therefore the methodology was shaped around what data was available. Additionally, there was limited information available on sustainment metrics used in the civilian aviation industry. This is likely due to proprietary information not being publically available.

II. Literature Review

Chapter Overview

This chapter provides an overview of recent literature and research on forward-looking metrics, sustainment metrics and Air Force sustainment initiatives. This is not intended to be an exhaustive review, but to provide an introduction to forward-looking metrics and an overview of metrics as they pertain to sustainment operations within the Air Force.

Metrics

Metrics can be classified into one of three categories: Historical Metrics, Real-Time (Scorecard or Dashboard) Metrics and Forward-Looking Metrics. For the intent of this research, the following definitions apply to these categories of metrics.

Historical, or rear-looking metrics, are measures that give data on what happened after it occurred (Adler, 2003). Examples in civilian industry include: sales, profits, return on investment, number of customers, costs, etc. Within the Air Force, most of the metrics are historical; examples include: issue and stockage effectiveness, aircraft availability, mission capable rate, etc.

Real-time metrics are usually referred to as a scorecard or dashboard metrics. The Scorecard (known as a Dashboard within the Air Force community) framework for Performance Measures (PMs) was introduced by Kaplan and Norton in 1996, which they called the "Balanced Scorecard (BSC)." The BSC framework is built around four perspectives: 1) financial, 2) customers, 3) internal processes, and 4) learning and growth (Kaplan & Norton, 1996). The BSC incorporates traditional financial performance measures (historical metrics) with non-financial strategic goals to give a more "balanced" view of operational performance (BSC Resources, 2013). This concept has evolved to redefine PMs and metrics into more realistic plans to achieve strategic targets (Gunasekaran & Kobu, 2007).

Forward-looking metrics are measures that identify deviations from a desired state before it occurs or enable a desired state to be reached through an understanding of what controllable system inputs map into the metric function. They describe what will occur before it happens. Although it can be referred to as a predictive measure, the intent of a forward-looking metric is more than that; it is one that incorporates predictive indicators into a useable data set for analysis. For example, a three phased-approach of (1) using trend analysis on historical data, (2) incorporating a known future requirement and then (3) determining the gap between the two is a good path in building a forward-looking metric (Adler, 2003). This will be discussed further in a following section.

Forward-Looking Metrics

> Development of forward-looking metrics is a long standing quest within the Department and remains in the forefront of Congressional interest… The key elements of a [forward-looking metric] are a clean input signal, a short term predictive feedback loop and a long term feedback loop to continually improve the predictive metric. (Sadauskas, 2009)

Although forward-looking metrics have only recently come onto the military's horizon of research within the past few years, civilian industry has been researching forward-looking metrics extensively in business marketing, sales forecasting and customer loyalty. Since neither of these subject areas applies directly to sustainment operations, only one study will be discussed, which highlights the majority of the research performed. In 2006, a team of six researchers studied forward looking metrics, which they termed Adaptive Foresight. Although their research was on customer metrics, the foundation of their research on forward-looking metrics can be translated for use with the Air Force's sustainment of its aircraft.

Zeithaml et al (2006) studied customer metrics to develop adaptive foresight for anticipating changes in the marketplace to influence (or increase) a company's customer base. The researchers found the metrics being used were primarily historical metrics, and by the time the data was received and processed, it merely represented what happened in the past.

Some companies determined these metrics were insufficient in assessing their customers and transitioned to Dashboard metrics. The most common dashboard for customer metrics is called the Customer Relationship Management (CRM) metric. Data for the CRM metric are housed in large databases and have evolved to provide a near-real time assessment. But even these fall short of the adaptive foresight (forward-looking metric) being sought (Zeithaml, Bolton, Deighton, Keiningham, Lemon, & Petersen, 2006).

Zeithaml et al (2006) propose forward-looking metrics, which they term "headlights," are more desirable than what is currently available, as headlights "project where customers are going rather than where they have been." The rear-looking (historical) customer metrics focus on perceptions, attitudes, behavior and financial measures. The forward-looking customer metrics, such as the Customer Lifetime Value (CLV) metric, incorporates additional factors, such as the customer's characteristics, company's planned marketing strategy and environmental factors.

The study continues by providing a four-step approach to Adaptive Foresight, as shown in Figure 1.

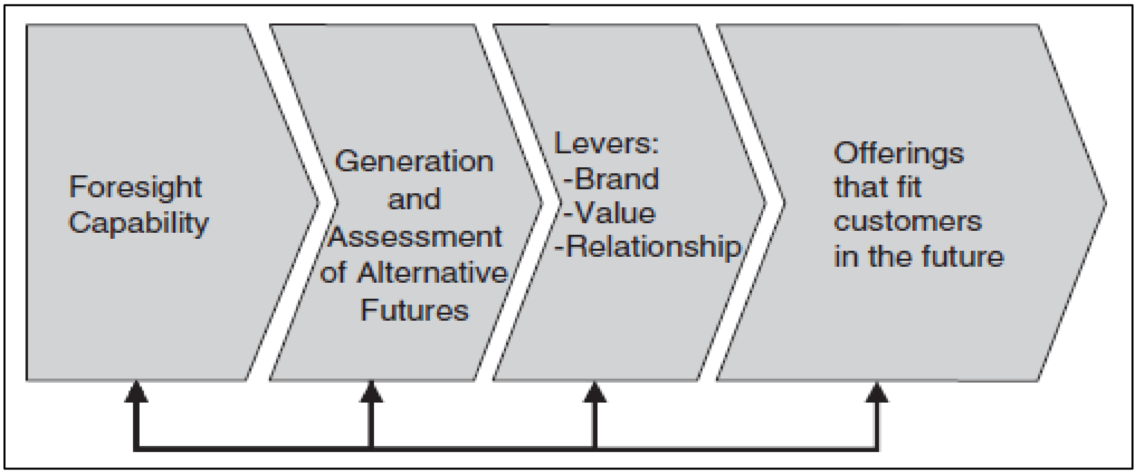


Figure 1: Adaptive Foresight: The Process (Zeithaml, Bolton, Deighton, Keiningham, Lemon, & Petersen, 2006)

Step 1: Developing foresight capability: This step requires the company be able to behold the possibility of different futures occurring.

Step 2: Generating alternative futures: Develop future strategies/scenarios for both external factors (customer or market changes) and internal factors (resources).

Step 3: Identifying key levers to influence customers: Identify how the company can influence customers within those given scenarios from Step 2.

Step 4: Developing offerings that fit customers' "futures": Developing the services or products identified in Step 3 that will influence the customer within the given scenarios. The exact future is unknown, so companies should determine which potential futures identified in Step 2 are more likely to occur and focus their energy on developing the key levers from those scenarios.

Sadauskas (2009) presents a more concise model, as shown in Figure 6, in an effort to "achieve a desired effect under specified standards and conditions through a combination of means and ways across the [doctrine, organization, training, materiel, leadership and education, personnel and facilities] DOTMLPF to perform a set of tasks to execute a specific course of action."

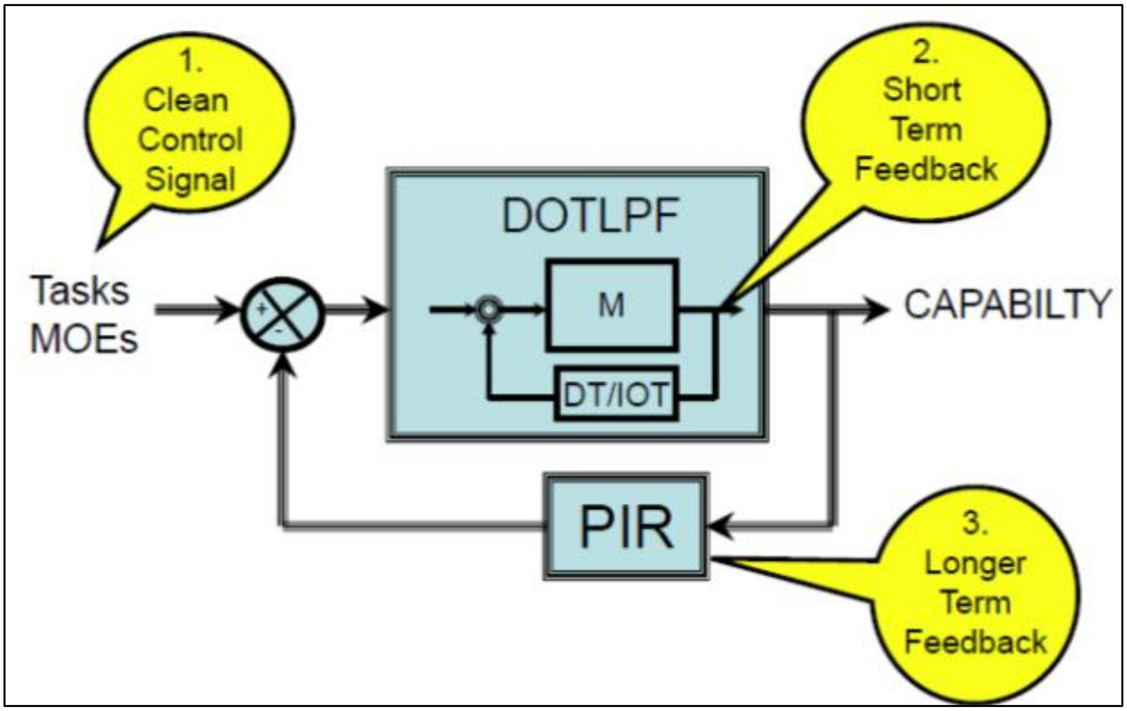


Figure 2: Notional model for Enhancing Forward-Looking Schedule and Performance Predictors (Sadauskas, 2009)

Using Sadauskas (2009) research on forward-looking capability and combining with research from civilian industry, one path to developing forward-looking metrics can be defined as:

Step 1: Determine the current tasks and associated metrics currently in use and how they influence the system (Control Signals).

Step 2: Determine the forward-looking capability required and what influences it.

Step 3: Establish a framework for the forward-looking metric.

Step 4: Develop a feedback loop for continual adaptive forecast.

Sustainment Metrics

> The Weapon Systems Acquisition Reform Act of 2009 includes a Performance Assessment requirement to evaluate the extent to which current metrics are likely to predict a timely delivery of a level of capability to the warfighter that is consistent with the level of resources to be expended and provides superior value to alternative approaches that may be available to meet the same military requirement. (Sadauskas, 2009)

Civilian Industry Sustainment Metrics

There are limited articles on supply chain management PMs and metrics within the civilian industry, making it difficult to compare the civilian aviation industry sustainment metrics to those the military uses. In a survey of literature and reported case studies between 1995 and 2004, Gunasekaran and Kobu (2007) studied the importance of PMs and metrics to identify the key indicators used in the supply chain (SC) and logistics environments. Twenty-six metrics were identified, as listed in Table 1.

Table 1: Metrics used to measure performance in SCM systems and their relations to categories and factors suggested by researchers (Gunasekaran & Kobu, 2007)

Table 3. Metrics used to measure performance in SCM systems and their relations to categories and factors suggested by researchers.

	A				B				C					D			E		F		G			
Metrics	1	2	3	4	1	2	3	4	1	2	3	4	5	1	2	3	1	2	1	2	1	2	Total	Percentage
01 Accuracy of scheduling		X			X				X							X		X	X		X		7	32
05 Bid management cycle time		X			X				X					X				X	X		X		7	32
06 Capacity utilization		X	X			X					X				X	X		X	X		X		9	41
07 Compliance to regulations		X	X				X		X	X				X				X	X	X		X	10	45
08 Conformance to specifications		X		X			X			X	X					X		X	X			X	9	41
18 Delivery reliability		X		X	X		X						X			X		X	X			X	9	41
24 Forecasting accuracy				X	X		X		X						X	X		X	X			X	9	41
29 Inventory costs	X	X				X		X	X	X	X	X	X			X	X		X		X	X	14	63
33 Labor efficiency			X			X					X				X	X		X	X		X		8	36
35 Lead time for procurement				X	X					X					X			X	X		X		7	32
36 Lead time manufacturing		X		X	X						X				X	X		X	X		X		9	41
39 Obsolescence cost	X			X	X		X		X								X		X			X	8	32
44 Overhead cost	X	X			X	X			X		X					X	X		X			X	10	42
46 Perceived quality				X			X	X					X					X		X		X	7	32
47 Perceived value of product				X			X						X					X		X		X	6	27
50 Process cycle time		X			X			X	X		X	X			X	X		X	X		X		11	50
51 Product development time		X	X		X				X					X				X	X		X		8	36
54 Product/service variety	X		X	X			X	X	X					X				X		X		X	10	45
55 Production flexibility		X	X		X	X	X	X			X					X		X		X	X		11	50
62 Return on investment	X					X			X					X			X		X			X	7	32
63 Selling price	X			X		X	X						X	X			X		X			X	9	41
68 Stock out cost	X			X			X	X					X				X		X			X	8	32
71 Supply chain response time		X	X		X			X	X					X	X	X		X	X		X		11	50
76 Transportation cost	X					X						X			X	X	X		X			X	8	32
77 Value added	X			X		X					X		X		X	X	X		X			X	10	45
81 Warranty cost	X			X			X		X								X		X			X	7	32
Total	10	13	7	13	12	9	12	7	13	4	9	3	7	7	9	14	9	17	22	5	11	16		
Percentage	38	50	27	50	46	35	46	27	50	15	35	12	27	27	35	54	35	65	85	19	42	61		

A. Balance score perspectives: 1. Financial, 2. Internal process, 3. Innovation and improvement, 4. Customers. **B**. Components of performance measures: 1. Time, 2. Resource utilization, 3. Output, 4. Flexibility. **C**. Location of measures in supply chain links: 1. Planning and product design, 2. Supplier, 3. Production, 4. Delivery, 5. Customer. **D**. Decision level: 1. Strategic, 2. Tactical, 3. Operational. **E**. Financial base: 1. Financial, 2. Nonfinancial. **F**. Measurement base: 1. Quantitative, 2. Nonquantitative. **G**. Traditional vs. Modern: 1. Function based, 2. Value based.

Gunasekaran and Kobu also presented six observations as they relate to these key performance indicators (KPI), as follows:

1. Internal business process (50% of the KPI) and customers (50% of the KPI) play a significant role in SC environments. This implies that internal business process PMs have significant impact on the operational performance.

2. The most widely used PM is financial performance (38% of the KPI). This indicates that we cannot ignore the fact that still cost plays a major role in a SC environment. However, nonfinancial performance measures are important for measuring the operational performance.

3. Innovation and process improvement constitutes 27% of the KPI which is defined as one of the performance measures for SC systems. This may be an indication that most companies either do not measure or researchers have ignored these areas for measuring the performance. However, they may have significant impact on the overall performance.

4. From the perspective of components of PMs: time and productivity (46% and 40% respectively of the KPIs) have significant weight in measuring the performance.

5. Resource utilization and flexibility (35% and 27%, respectively of the KPIs) have not been measured considering the fact that they are intangibles and difficult to measure. However, they play a major role in effective management of SC systems.

6. In the location of PMs along the supply chain; the performance of planning and product design, supplier, production and delivery constitutes 50%, 15%, 35% and 12% respectively of the KPIs. It is to be noted that measuring the performance related customer satisfaction (27% of the KPIs) has not been given due consideration in measuring the performance of SC. (Gunasekaran & Kobu, 2007)

The quip "what gets measured, gets done" has validity, especially within supply chain management. But the Air Force's sustainment process does not use many of the KPIs observations (above) from civilian industry.

Air Force Sustainment Metrics

Air Force sustainment metrics include both historical and scorecard (dashboard) metrics. This section reviews these metrics and discusses the evolution of the scorecard metrics.

Historical Metrics

Similar to what Gunasekaran and Kobu presented as their first observation from their research, the military also understands the importance of internal business processes and the customer play a significant role in sustainment operations. Therefore, identifying the customer is imperative to what the Air Force should use for KPI. Although the Air Force Supply function serves a variety of functions at a tactical level, including Transportation, Civil Engineer and Services organizations, the main customer is the

Maintenance organization. Following the importance of this customer, the Air Force Logistics Management Agency (AFLMA) has identified four supply-related metrics for supporting maintenance (AFLMA, 2001):

1. Issue Effectiveness (IE) Rate: This metric is most representative of the customer's view of the support received from the supply function. It provides the percentage of customer requirements filled with assets in stock. It is calculated using the following equation:

$$\textit{Issue Effectiveness} = \frac{\textit{Issues}}{\textit{Issues + All Backorders}} \times 100 \tag{1}$$

2. Stockage Effectiveness (SE) Rate: This is similar to issue effectiveness; it measures the percentage of customer requirements filled by base-level stock, but only accounts for items with an authorized stock level at that location.

$$\textit{Stockage Effectiveness} = \frac{\textit{Issues}}{\textit{Issues + All Backorders – 4W Backorders}} \times 100 \tag{2}$$

3. Repair Cycle Time: Used primarily as a local management indicator, this metric accounts for the number of days an unserviceable part spends in the repair cycle. The intent is to minimize this time to get unserviceable parts back into the Air Force supply system for use. It is comprised of four components, as follows:

$$\textit{Repair Cycle Time} = \begin{array}{l}\textit{Pre-maintenance Days + Repair Days +Post-maintenance}\\ \textit{Days – Awaiting Parts (AWP) Days Number of Items}\\ \textit{Turned In}\end{array} \tag{3}$$

4. Average Repair Cycle Time by Segments: This metric breaks down the total repair cycle time metric into its individual components to analyze how efficient each step is in the process. It is represented as follows:

$$\textit{Total Repair Cycle Time} = \begin{array}{l}\textit{Pre-Maintenance Days +Repair days + Post-}\\ \textit{Maintenance Days}\end{array} \tag{4}$$

AFLMA also identifies two supply-focused metrics listed as Maintenance-Related metrics, due to maintenance's ability to influence these metrics. They are:

1. Total Not-Mission-Capable for Supply (TNMC-S): This metric identifies the rate possessed aircraft are unavailable due to parts. Although this metric is primarily influenced by spare parts availability, Maintenance can affect it by consolidating the supply requirements to as few aircraft as possible.

$$\textit{TNMCS Rate} = \frac{\textit{NMCS Hours + NMCB Hours}}{\textit{Possessed Hours}} \times 100 \tag{5}$$

2. Cannibalization (Cann) Rate: This metric shows the number of cannibalization actions taken by Maintenance for every 100 hours the aircraft has flown. Cann rate are typically linked to the supply issue effectiveness rate, since canns are

normally performed when the supply system is unable to issue a part. The metric includes both aircraft and engine canns, as shown in the following equation:

$$\textit{CANN Rate} = \frac{\textit{\# of Acft-to-Acft CANNs + \# of Engine-to-Acft CANNs}}{\textit{Total Sorties Flown}} \times 100 \qquad (6)$$

These 6 metrics are highlighted as a sampling of many supply chain indicators, including the 33 metrics listed in the AFLMA Maintenance Metrics Handbook (AFLMA, 2001). All of these metrics are historical metrics.

Scorecard and Dashboard Metrics

As previously discussed, the concept of the scorecard and dashboard metrics is to combine traditional, rear-looking metrics with strategic goals to define a real-time operational performance. The Air Force uses the scorecard concept in sustainment operations and is discussed by Harper (2012) in recent research on supply chain risk management. Although Harper's research presents a simulation model for introducing and assessing risk on inventory within the supply chain, she proposes two new metrics, reviews existing metrics and discusses aggregation or disaggregation of metrics. Providing a solid foundation of the current metrics structure, Harper presents a BSC framework, shown in Figure 3, replacing the four perspectives from Kaplan and Norton with Air Force-specific perspectives of: 1) Warfighter, 2) Logistics Process, 3) Resource Planning, and 4) Workforce and Innovation.

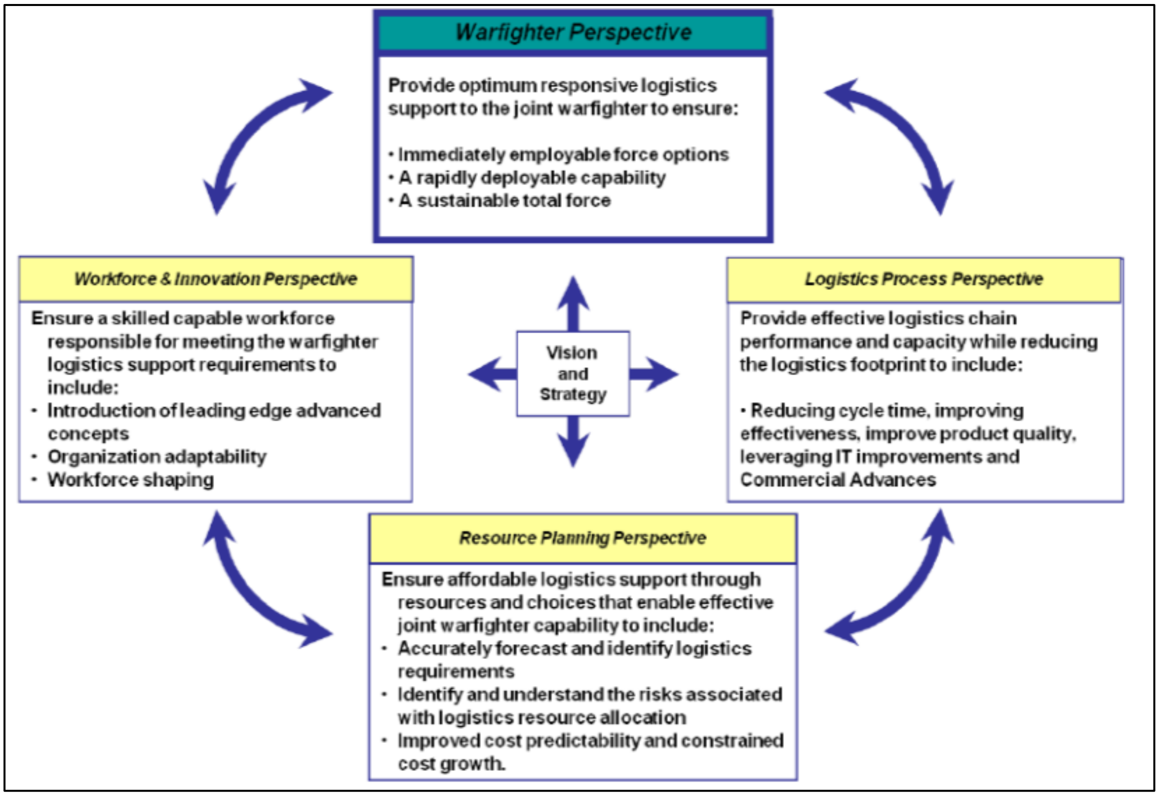


Figure 3: Balanced Scorecard (Harper, 2012)

Harper further assigns 10 sustainment metrics across four Air Force perspectives, as shown in Table 2; metrics include two of the customer-focused metrics identified by AFLMA, IE and SE.

Table 2: Balanced Scorecard Framework (Harper, 2012)

Warfighter Perspective	Resource Planning Perspective	Logistics Process Perspective	Workforce & Innovation Perspective
MICAP Hours	NOR	AA	AA
CWT	IE	MICAP Hours	TRV
Perfect Order Fulfillment	SE	MICAP Incidents	
	TRV	Backorders	

Although the balanced scorecard provides real-time metrics that are useful to the Air Force, they do have major challenges. Five main criticisms of the scorecard are presented by the DeGroote School of Business (2008):

> 1. **Linkage to strategy:** Only 5% of the workforce understands their company strategy. Only 25% of managers have incentives linked to strategy. 60% of organizations don't link budgets to strategy. 86% of executive teams spend less than one hour per month discussing strategy.
>
> 2. **Choice of Information:** The choice of what measures to use is often based on the information that is most easily obtainable, rather than the most useful.
>
> 3. **Scorecard Revision:** Questioning the assumptions held about the organization's strategy, and of the linkages and measures of the Balanced Scorecard, particularly when the actual results differ from the expected results is essential. If the strategy is found to be lacking the organization will need to refine it and may consequently revise some or all of the measures on the balanced scorecard.
>
> 4. **Lagging Metrics:** The measurements are referred to as lagging indicators and they dominate most performance measurement systems. About 70% of all measurements tend to fall into this category. One of the major challenges in building your balanced scorecard is to keep the number of measurements to a manageable few.
>
> 5. **Apples and Oranges:** Benchmarking works well when the process being benchmarked is essentially the same at the multiple units (either internal or external) participating in the exercise. Benchmarking is not informative when it is used to compare fundamentally different processes or products. Furthermore, it is not effective when the companies being compared work from significantly different strategies. (DeGroote School of Business, 2008)

Requirements Management System (D200)

The Requirements Management System (RMS), commonly called D200, computes worldwide spare parts requirements for Air Force managed assets. The system was originally designed with nine subsystems to cover the breadth of the supply processes, but one was never deployed and two have since been deactivated. There primary subsystem is the D200A and three supporting subsystems that feed into D200A. These four main subsystems are:

- D200A: Secondary Item Requirements System (SIRS): computers buy, repair, termination and excess quantities for consumable and recoverable supply items.
- D200E: Requirements Item Identification (RIID): receives weekly feeds from the D043 Cataloguing System. Provides stock list changes, stock numbers, substitutability structures, lead time and cost data from the acquisition system.
- D200F: Application, Programs, Indenture (API): provides D200A with past and future data on operations and maintenance activities which create a demand for repair parts. Information includes flying hours, inventory, ammunition, sorties flown, programmed depot maintenance and engine overhaul.
- D200N: Central Secondary Item Stratification (CSIS): stratifies D200A data into anticipated fiscal year expenditures.

Additionally the Logistics Management Data Bank (D043) is an extension of D200N. Once the budget is pushed from D200N into D043, it makes final adjustments to the supply budget prior to submission to Congress. The Requirements Determination System is mapped out below in Figure 2.

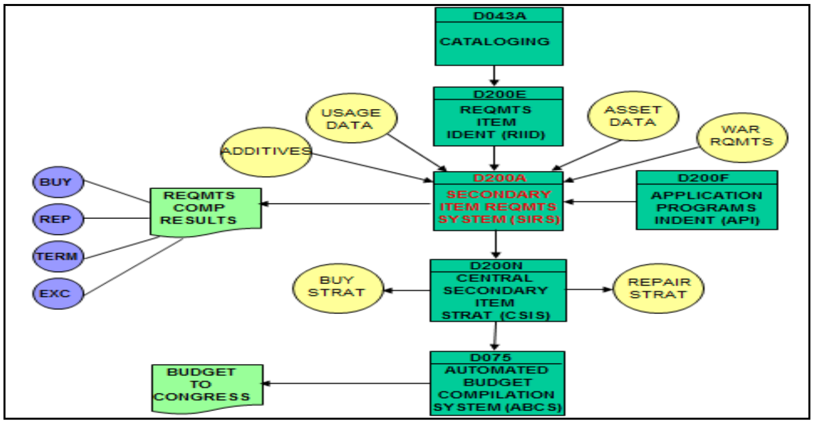


Figure 4: Requirements Determination System Process (401 SCMS/GUMD, 2011)

Most users are familiar with the D200A subsystem of RMS, as data feeds into this system and provides a variety of analytical results. The plethora of input and output are below in Figure 5, and illustrate the complexity of data mining and analysis required.

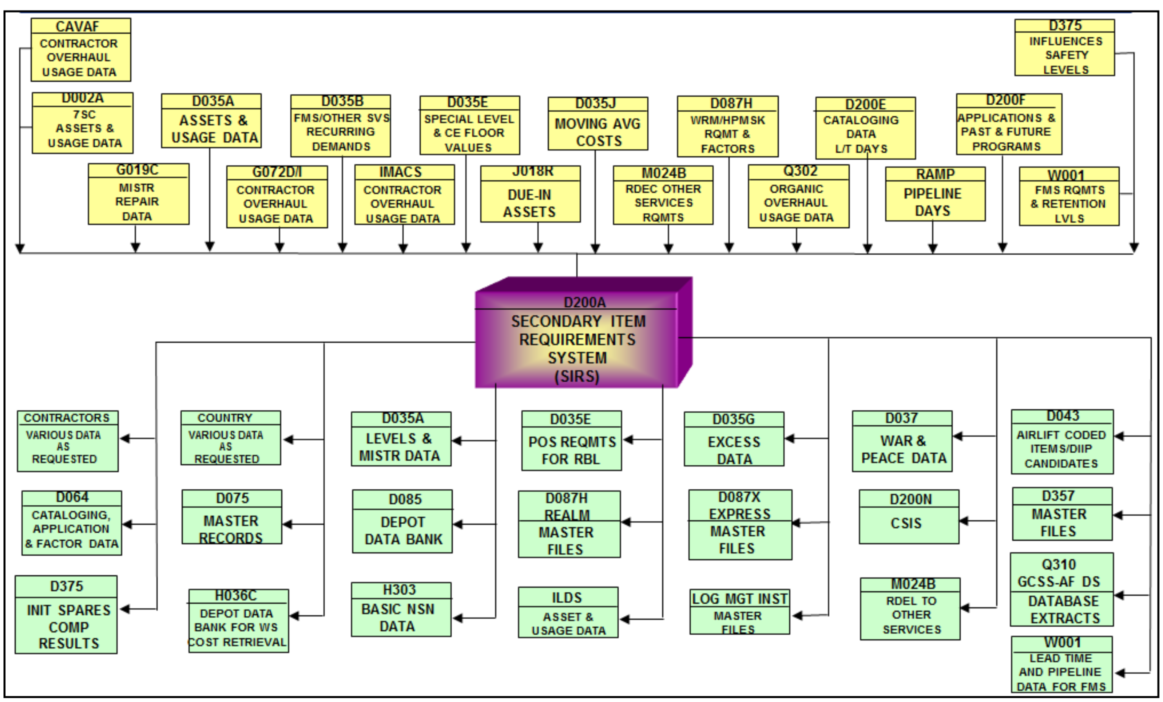


Figure 5: D200A Inputs and Outputs (401 SCMS/GUMD, 2011)

The Aircraft Availability Model (AAM) is an optimization program embedded with D200A and is used to compute safety levels of stock. For aircraft items, AAM optimizes inventory (stock) level requirements, subject to aircraft performance goals and cost thresholds. For non-aircraft items, AAM optimizes inventory (stock) level requirements, subject to expected backorders (i.e., Customer Wait Time) and fill-rate and cost thresholds. AAM provides two main output for safety levels for base-level stock and depot-level stock, as shown in the following two equations:

$$\textit{Base Safety Level} = \textit{Base Stock Level} - \textit{Base Pipeline} \tag{7}$$

$$\textit{Depot Safety Level} = \textit{Depot Stock Level} - \textit{Depot Pipeline} \tag{8}$$

The RMS, using D200A and the Aircraft Availability Model, has a forward-looking capability, which in turn provides recommendations for optimal levels of safety stock. But currently, the system isn't being used at its fullest capability. At the tactical and operational levels, it is used for real-time decision making, and for acquisition at the strategic level. When asked why this program wasn't used in a forward-looking capacity, multiple leaders within the supply chain stated a variation of "garbage in, garbage out."

Air Force Sustainment Metrics Initiatives

In 2007, the Government Accountability Office (GAO) published their report "DoD's High Risk Areas: Progress Made Implementing Supply Chain Management Recommendations, but Full Extent of Improvement Unknown." It was a follow-up report from 2001 to assess how well the DoD had implemented previous recommendations on improving the supply chain. The main recommendation from the 2007 report was that “DOD complete its logistics strategy and develop and implement outcome focused performance metrics and cost metrics for supply chain management” (GAO, 2007)

The Air Force Sustainment Center is responsible for implementing this recommendation within the Air Force, as their mission is Sustain Weapon System Readiness to generate Airpower for America. The center provides expeditionary capabilities to the warfighter through depot maintenance, supply chain management and installation support (AFSC, 2012). This section covers the current research and initiatives ongoing in the Air Force logistics community applicable to this research.

Cascading Air Force Sustainment Metrics

(635 SCOW, 2012)

In December 2012, personnel from the Supply Chain Operations Wings (SCOW) from both the Mobility and Combat Air Forces met for an Integrated Process Team (IPT) to map out the current Air Force Supply Metrics to show how they affect overall Fleet Availability (FA). FA, also known as aircraft availability (AA), is the overall indicator used by the Air Force to determine the health of the fleet (AFLMA, 2001). The SCOWs were tasked by the Air Force Sustainment Center (AFSC with an intended interim operational capability (IOC) of January 2013, and full operational capability (FOC) in April 2013. Although the IPT members did not feel they could attain the prescribed IOC/FOC timeline, they were successful in mapping out a hierarchy of metrics, as shown in Appendix A.

As can be seen in the figure in Appendix A, the main supply metrics the Air Force uses affect AA through different pipelines and often affect each other. The legend also depicts which metrics are automated, readily available, manually collected, etc. The Cascading Metrics team also has recommended two new metrics, Expected Delivery Day Accuracy and Alternate Resolution options when for stock outs. Unfortunately, it accurately depicts the complexity in gathering data within the Air Force Supply System, leaving much to be desired. As of the conclusion of this research, this initiative is still ongoing.

Enterprise Supply Chain Analysis, Planning and Execution (ESCAPE)
(HQ AFMC/A4N, 7 Dec 12)

> There is not a single, authoritative source for (AF) supply chain planning data, forcing a heavy reliance on multiple automated systems, providing conflicting data. These disparate systems are found throughout the supply chain and may be unique to their functional stovepipe or part of a legacy suite of applications. They provide data dissimilarities, lack data integrity and lack of discipline in providing supply chain data. Current IT systems were originally designed in the 1960s-1970s, and upgraded to newer technology when possible; many of the processes remain the same as originally designed. (HQ AFMC/A4N, 7 Dec 12)

The Air Force Materiel Command (AFMC) Directorate of Logistics (A4) is working toward a supply chain capability called the Enterprise Supply Chain Analysis, Planning and Execution (ESCAPE) system. The system is a derivative of the Expeditionary Combat Support System (ECSS), an integrated technology system that was being built for the Air Force, but was recently terminated. ESCAPE is being developed to provide a "comprehensive, integrated, accurate and timely supply chain planning" system. This will be accomplished via five modules: Demand Planning, Inventory Management, Supply Planning, Exception Management and Analytics. The Analytics section, of note, will enable a capability in data stratifications and metrics dash-boarding not currently available. As noted by AFMC/A4N:

> The Air Force supply chain planning functions currently lack the ability to optimize resources across the enterprise and have no standard management processes to integrate…(or) optimize weapon system availability...which leads to inaccurate, inconsistent and un-timely information required for effective decision making. (2012)

The result, as the report goes on to say, is “un-supportable plans that cause increased MICAPs and longer maintenance flow days.” (2012). Among the many business capabilities ESCAPE intends to provide, it aims to develop Enterprise Metrics that are transparent, standardized, timely and cost-effective. Similar to the work being done on Cascading Metrics by the SCOW, the ESCAPE team has identified a need for a hierarchy of interrelated metrics. The intended outcome is to develop a supply chain planning capability to better optimize and align scarce resources.

ESCAPE is being implemented using the six-step Service Development and Deliverable Process (SDDP). SDDP was designed by the Air Force in 2010 to define how the Air Force will use business process reengineering to shape and implement new solutions (USAF, 2011). As of the conclusion of this research, the ESCAPE system completed the first step of the SDDP, Identification of Capability Requirements, and will soon be entering into the next stages (Burnworth, 2013).

National Stock Number (NSN) Management Initiative
(Baird, 2012)

Sustainment operations in the Air Force have undergone many changes over the past decade. Prior to 2000, sustainment operations were managed by the base-level Supply Squadrons. Each base had their own supply personnel to manage inventory, MICAP, stock control, equipment levels, etc., for their primary assigned aircraft at their base. Although most aircraft fleets were spread across multiple bases and usually more than one Major Command (MAJCOM), sustaining the fleet was not primarily managed at a strategic level.

In 2000, the Air Force stood up Regional Supply Squadrons (RSS) at five MAJCOMs to centralize sustainment operations within the MAJCOM. The five MAJCOM RSSs became responsible for specific functions formally owned by their base-level supply squadrons, to include stock control, MICAP and customer service. The personnel and processes were relocated from the base-level to the centralized RSS, but there was no process change in how to manage the inventory for each base. Early iterations of a need for the NSN Management Initiative emerged as the RSSs became fully operational and began “stepping on each other’s toes,” as some bases had multiple MAJCOM’s aircraft assigned.

Further realignments have occurred since then. The five RSSs merged into two RSSs, one for the Mobility Air Forces (MAF) and one for the Combat Air Forces (CAF) aircraft, but had still not worked out some of the emerging issues due to how the process was managed. Then the Air Force Global Logistics Support Center was established, but only remained active for a few years. The latest change of structure came in June 2010, when the 635th Supply Chain Operations Wing (SCOW) was established at Scott AFB (Robertson, 2010).

Under the SCOW structure, there are two groups (SCOG) and four squadrons (SCOS). The SCOGs are located at Scott AFB (managing MAF aircraft) and Langley AFB (managing CAF aircraft). Although there is a new structure, the same problems still remain. For example, Kadena AB Japan has five weapon systems which are managed across all four of the squadrons. Therefore, supply actions that arise for common stock number's originating from Kadena AB will potentially be worked by multiple squadrons.

The intent of the NSN Management Initiative is to have one owner of a NSN at retail level to work all processes associated with that NSN, such as requirements, cancellations, backorders, etc. Of the more than 3.5 million NSNs supporting Air Force aircraft, only approximately 678,000 are unique NSNs (meaning only used on one aircraft). This causes significant overlap; since almost 3 million NSNs are used on more than one aircraft, managing by aircraft type means you have multiple owners of those NSN, causing duplication, additional work and often rework.

This program hopes to extend the retail-level NSN management beyond just the Air Force managed supply items and include contract-managed NSNs as well. Recently, a supply part managed by Lockheed Martin was due for contract renewal, which is outside of the purview of the weapon system managers (WSM). This particular contract was having issues and there was going to be a gap in supply support during this delay. Fortunately, a Lockheed Martin representative contacted the retail level WSM to notify of the issues and the SCOS was able to plot a course of action during the 60 to 90-day gap in support. Leaning forward, the SCOS increased their stock level to accommodate demand during the gap until support was brought back online. But this raised the question, who should be monitoring these contracts within the supply chain? (Gehrich, 2013)

In July 2012, the NSN Management Initiative began its testing phase and identified constraints related to the reports it would be using. According to Mr. Gerry Baird, 436 SCOS Analyst, the project is currently halted to remedy these problems and will resume testing in late spring 2013.

Summary

This literature review presented background information on the three types of metrics: historical metrics, dashboard/scorecard metrics and forward-looking metrics. The Air Force is primarily using historical and scorecard metrics for sustainment operations. A recent interest in developing a new way to use our metrics has arisen in the Air Force over the past few years and has introduced many initiatives, including the Cascading Metrics, ESCAPE and NSN Management Initiatives. But none of these initiatives have been able to produce a forward-looking metric.

Therefore, this literature review has answered the first two investigative questions: 1) What metrics are currently used for sustainment operations in the Air Force? and 2) What are forward-looking metrics? The remaining two investigative questions will be answered in the following methodology and analysis portions of this research.

III. Methodology

Chapter Overview

The intent of this research is to develop a forward-looking metric that can be used to determine how to change stock levels to reduce MICAP hours within the Air Force supply system. An example is provided using C-5 fleet data.

Scope and Data Description

A data pull was conducted from the RMS, D-200A module, providing data on all C-5 MICAPs from October 2009 to Sep 2012. The data set included 79 different fields, with over 30,500 lines of data, which will further be referred to as the main data set. As of the June 2012 D200A Summary Computation, there were 2,862 primary component NSNs associated with the C005A/B/C/M aircraft. However, there were 7,851 total NSNs that had a MICAP action associated with it over the given timeframe. Only three of the fields from this main data set were used: date, NSN, and MTD MICAP Hrs. The variables and NSNs used in each of the optimization models are listed in Appendices B through F.

Model Development

To minimize the scope for the first model (further known as Model 1), only the primary C-5 Structural Component NSNs were used, which included 134 NSNs. This did not include Interchangeable & Substitution Group (I&SG) parts. Narrowing down the main data set to just the structural NSNs reduced the MICAP data to 2,075 lines, with only 123 NSNs having a MICAP action during the given timeframe. Each of these 123

NSNs were labeled with an X variable (X001, X002, X003 … X123) for simplification. A pivot table was built for a cursory analysis of the data and two spreadsheets were built from the pivot table. One spreadsheet shows the number of MICAPs in the system each month, by NSN. The second spreadsheet shows the total amount of MICAP hours each NSN accrued each month. To simplify the set into readily useable data, an assumption was made that all MICAPs were satisfied within the same month they went MICAP. If a part was MICAP and counted in two or more sequential months, it appears as separate MICAPs.

The two spreadsheets were further divided into individual fiscal year (FY) sheets, FY10, FY11 and FY12. All subsequent analysis for Model 1 was performed on FY10 data. NSNs with no MICAP Hours listed were deleted from the sample. Reasons some of the NSNs had zero MICAP hours is likely due to either the NSN did not have any MICAPs during FY10, but had MICAPs in the out years, or the MICAP action was satisfied before it could accrue one hour of time. This reduced the FY10 set to 92 NSNs. Next, the mean of MICAP hours (hr) and number of MICAPs (#) for each NSN were obtained using the following equations:

$$\mu(hr) = \frac{Annual\ MICAP\ Hours}{Annual\ Number\ of\ MICAPs} = h \tag{9}$$

$$\mu(\#) = \frac{Annual\ Number\ of\ MICAPs}{12} = d \tag{10}$$

An optimization linear program was developed using Excel Solver, with the following formulation:

$$\text{Min } c^T(x)$$

$$\text{Subject to:} \quad h^T(x) >= m \qquad (11)$$
$$I(x) <= d$$

Variables represented: c is the “cost” of each NSN, which is represented as 1 in this model; T is the transpose of a matrix; x is the dependent variable NSN; h is the mean hours for each MICAP NSN, as shown in Equation 7; m is the number of MICAP hours that should decrease each month; I is an identity matrix for each NSN; and d is the mean monthly MICAP requirement (demand) for each NSN, as shown in Equation 8. The objective function in Model 1 is insignificant, as the objective is to define which variables should be put into stock to decrease the monthly MICAP hours.

Based on the data set for Model 1, the mean of the monthly MICAP hours was 14,000.5 hours. Therefore, “m” cannot be any larger than 14,000.5, as you cannot decrease the hours more than are available to decrease. Next, it was determined by how much to reduce the MICAP hours (m); Model 1 used a 10% decrease of the maximum MICAP hours, thus decreasing it by 1,400.05 hours. Model 1 provided two variables with applicable amounts by which to decrease the overall MICAP hours, as shown in Table 4.

Table 3: Model 1 Output (FY10)

Variable	NSN	Amount (per month)
X044	1560012611313	0.41667
X048	1560014372544	2.34381

Robust Variable Selection for Determining Candidate Forward Looking Metrics

Unfortunately, variable X044 is less than a whole number, meaning there is not a stable MICAP requirement throughout the year for the NSN to evoke at least one additional asset on hand. This contradicts the desired result of determining which NSNs should be increased by at least one to reduce MICAP hours. Therefore, a second model (Model 2) with business rules is required to provide a robust data set to determine candidate variables. This robust variable selection for Model 2 includes the following business rules:

1. Variable Median MICAP Demand (d) ≥ 1
2. Mean MICAP Hours per MICAP action (h) ≥ 24 hours

The first business rule divides the MICAP hours into two categories: Recurring MICAP hours and Non-recurring MICAP hours. Recurring MICAP hours have a median demand greater than or equal to one, which indicates a stable MICAP requirement throughout the fiscal year. Non-recurring MICAP hours had a median MICAP requirement less than one, indicating an unstable requirement or random occurrence throughout the fiscal year. This business rule changes “d” from the mean found in equation 8 to the median.

The second business rule eliminates the recurring MICAPs that were satisfied in less than 24 hours, as determined by equation 7. MICAPs delivered on average less than 24 hours are not useful to this model since it assesses AF-wide MICAP requirements and not specific placement of parts. These NSNs are likely already in the supply system and able to be satisfied via lateral support or cannibalization action. These NSNs are further referred to as “In-Inventory” MICAPs.

Applying the robust data selection business rules to the FY10 data set reduced the variables from 92 variables in Model 1 to 17 variables for Model 2. An optimization linear program was developed using the same parameters from equation 9 used in Model 1, with the robust data set.

Final Model Development

Based on the data set for Model 2, the median of the monthly MICAP hours was 9351.79 hours. Therefore, “m” in the constraints of our model formulation cannot be any larger than 9351.79. Following the same methodology in Model 1, Model 2 used a 10% decrease of the maximum MICAP hours, thus decreasing it by 935.179 hours. Model 2 provided one variable with applicable amount that will enable the desired MICAP hour decrease (m), as shown in Table 5.

Table 4: Model 2 Output (FY10)

Variable	NSN	Amount (per month)
X048	1560014372544	1.879211173

This variable was also present in the Model 1 output set, but since the population size of the data set was so small (only 17 variables), it was unclear if the new robust data set had provided the intended solution. Therefore, Model 2.1 was developed using the same program as Model 2, but with all C-5 NSNs (Models 1 and 2 had limited the data set to only structural NSNs).

Model 2.1 (FY10) had 78 NSN variables in the model and optimized five variables, as shown below:

Table 5: Model 2.1 Output (FY10)

Variable	NSN	Amount (per month)
X1058	1560008718185	1
X1429	1560014372544	3.75
X1432	1560014372548	4.29769
X1441	1560014536213	1.58333
X2859	4510004101062	6.25

Model 2.1 (FY11) had 52 NSN variables in the model and optimized four variables, as shown below:

Table 6: Model 2.1 Output (FY11)

Variable	NSN	Amount (per month)
X1211	1560011160447	1
X1432	1560014372548	2
X2001	1680001033526	1
X5294	5330015771850	0.748162256

Model 2.1 (FY12) had 40 NSN variables in the model and optimized five variables, as shown below:

Table 7: Model 2.1 Output (FY11)

Variable	NSN	Amount (per month)

X1250	1560011795638	1
X1429	1560014372544	1.789481719
X1432	1560014372548	1.5
X1520	1560016030195	1
X2230	1680011775069	1.5

Summary

In summary, the Forward-Looking Metric development process is illustrated in Figure 6.

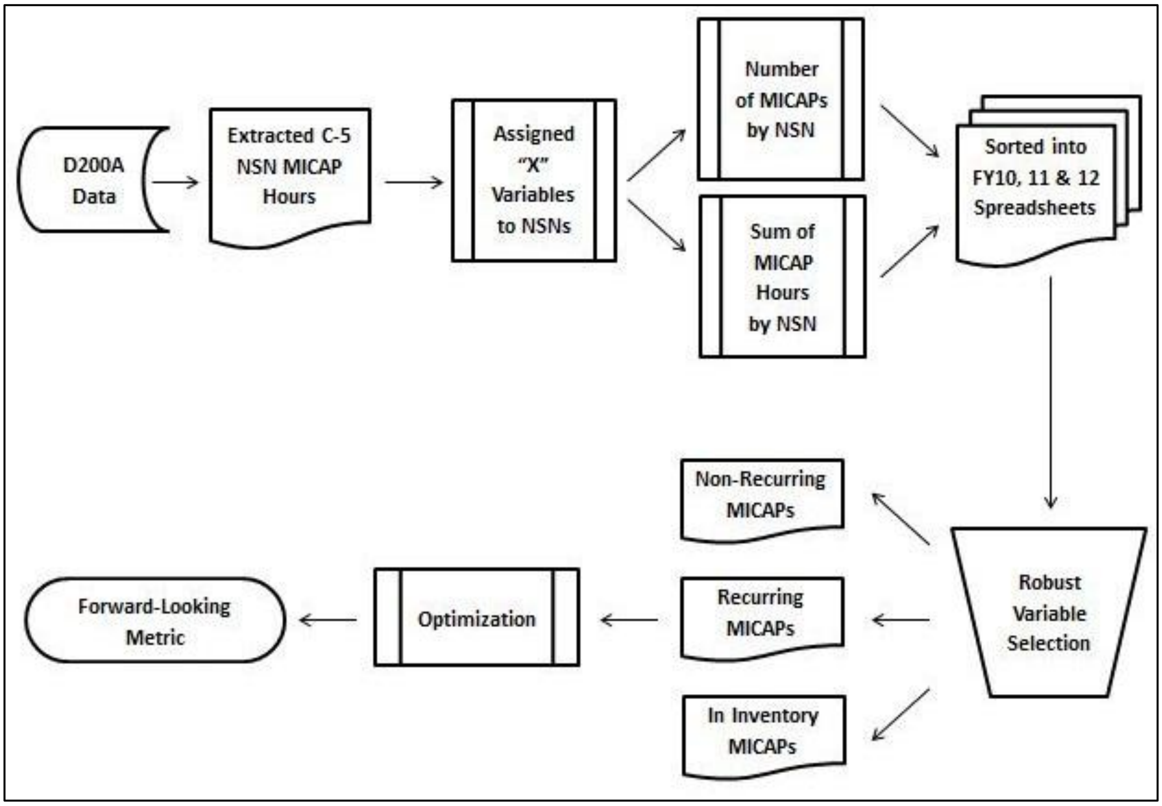


Figure 6: Development of Forward-Looking Metric

Utilizing D200A data, the Monthly MICAP Hours data for all C-5 NSNs from October 2009 to September 2012 was extracted into an Excel spreadsheet. Each of the

7,851 NSNs with MICAP actions during that timeframe were assigned an "X" variable (X0001, X0002 … X7851). Using the Pivot Table function of Excel, two queries were performed to 1) count the number of MICAPs that occurred, by month, for each NSN and 2) sum the MICAP Hours accrued, by month, for each NSN. This data was further separated into individual spreadsheets for FY10, 11 and 12. Each year's worth of data then underwent the Robust Variable Selection Process, summarized in Table 8.

Table 8: Robust Variable Selection: Business Rules

MICAP Category	Rule 1: Monthly Median MICAP Demand	Rule 2: Monthly Mean Hours per MICAP Action
Non-Recurring	< 1	N/A
Recurring	> = 1	> = 24 hours
In-Inventory	N/A	< 24 hours

The Robust Variable Selection process subdivided the data sets into three categories of MICAPs: Non-Recurring MICAPs, Recurring MICAPs and In-Inventory MICAPs. With only the Recurring MICAP data set, an optimization linear program was developed to provide the forward-looking metric for change in stock levels as a result of Recurring MICAP parts.

Model 2.1, with the robust data selection business rules, provided a sound optimization program to developing a forward looking metric for changing stock levels to reduce MICAP hours. Further analysis is done in the next section, which illustrates a refinement of Model 2.1 via Models 3 and 4.

IV. Analysis and Results

Chapter Overview

This section presents the results from Models 2.1 for FY 10, 11 and 12 and analyzes the data into useable information. Further, two additional models are proposed for real-world application. Model 3 presents an integer format of Model 2.1 for whole number stock level changes. Model 4 incorporates unit price to gain not only effectiveness but also efficiency within the forward looking metric. Ultimately, Model 4 presents the best results for a forward-looking metric and can be utilized across the other AF weapon systems for sustainment operations.

Analysis of Model 2.1

Model 2.1 provides a sound optimization program for a forward-looking metric; three linear programs were run using FY10, FY11 and FY12 data individually. Using a 25% reduction of Recurring MICAP hours based on the average Recurring MICAP hours per month, the following results were produced from Model 2.1:

Table 9: Model 2.1 Results

FY	Variables	Mean MICAP Hrs	25%MICAP Hr Reduction	Number of NSNs Optimized
FY10	78	34,212.3	8553.075	5
FY11	52	10,056.1	2514.025	4
FY12	40	13,491.4	3372.85	5

The number of variables decreased in each successive fiscal year of Model 2.1. This represents that different NSNs were recurring MICAPs over the three-year period, likely due to an increase in stock levels for the recurring MICAP NSNs to prevent MICAPs in the out-years. There were 140 different NSNs used across the three FY models; seven NSNs were used in all three models and 16 NSNs were in two models. Further, there was only one NSN (X1432) optimized in all three models and one NSN (X1429) optimized in two of the three models. Since the variables changed significantly from year to year, it was decided to not combine the three FYs into one program, but to look across the three FYs for the most consistent Recurring MICAP Hours data throughout the year. The Recurring MICAP Hours data was plotted in the following three figures, using the cumulative MICAP hours for each month in the FY.

The cumulative MICAP hours for FY10 ranged from 60,722 hours in October 2009 to 16,632 hours in September 2010. The delta was 44,090 hours, which is almost triple the total hours at the end of the FY. MICAP hours had a substantial downward trend throughout the year.

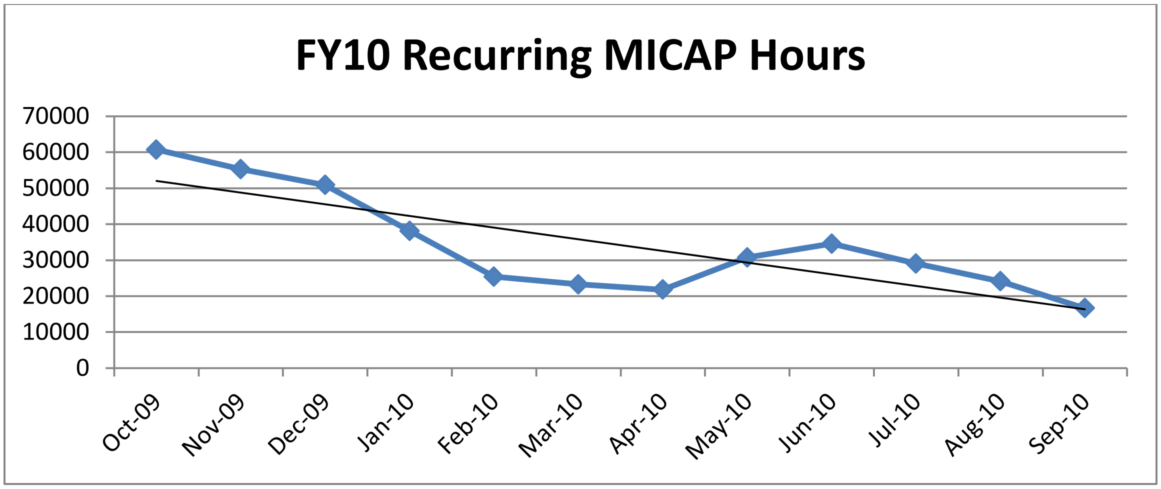


Figure 7: FY10 Recurring MICAP Hours

The cumulative MICAP hours for FY11 ranged from 17,672 hours in January 2011 to 5,528 hours in September 2011. The delta was 12,144 hours. MICAP hours had a downward trend for a majority of the year.

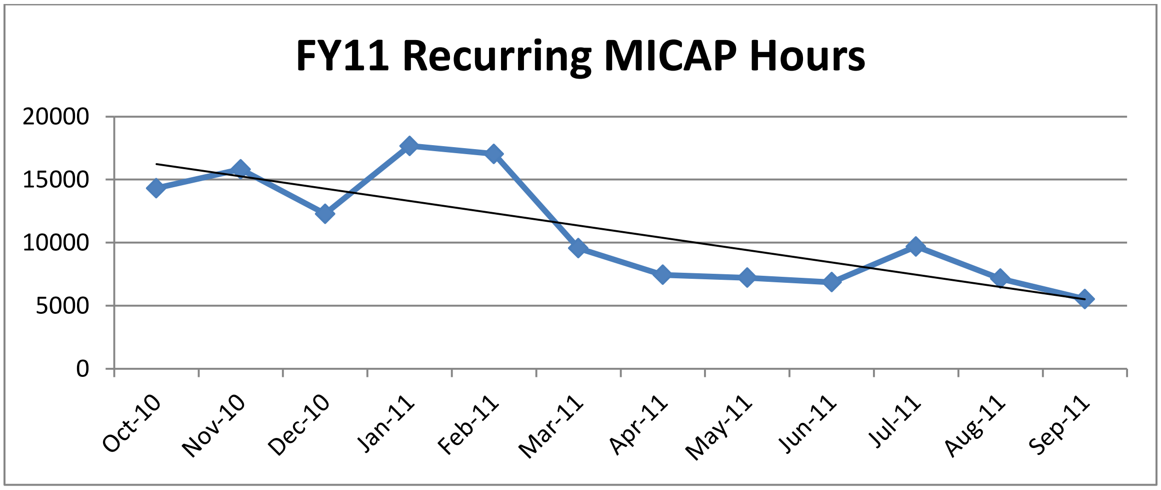


Figure 8: FY11 Recurring MICAP Hours

The cumulative MICAP hours for FY12 ranged from 6,241 hours to 22,719 hours, with a delta of 16,478 hours. Unlike the previous two FYs, FY12 had a slight upward trend throughout the year, and the beginning and ending values were 7,261 and 8,624, respectively. Although FY11 had the smallest range in hours, FY12 had the most consistent data.

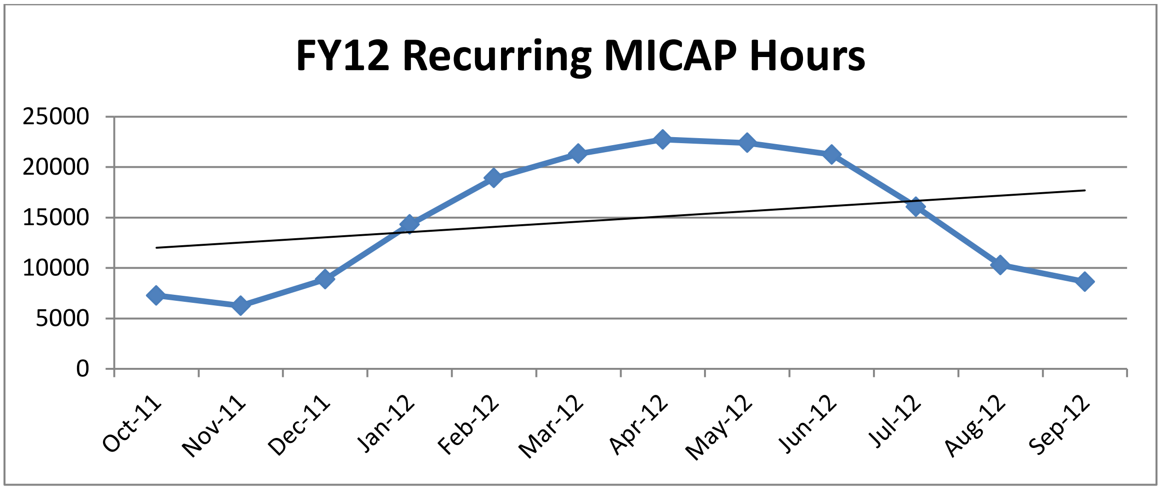


Figure 9: FY12 Recurring MICAP Hours

Charting out the FY12 Non-Recurring MICAP hours and In-Inventory MICAP hours showed similar trend consistency throughout the year, as shown in the following two figures. As budgetary constraints become more prominent, use of this forward looking metric approach will become critical in more efficiently managing which NSNs to impact improved performance of the supply chain.

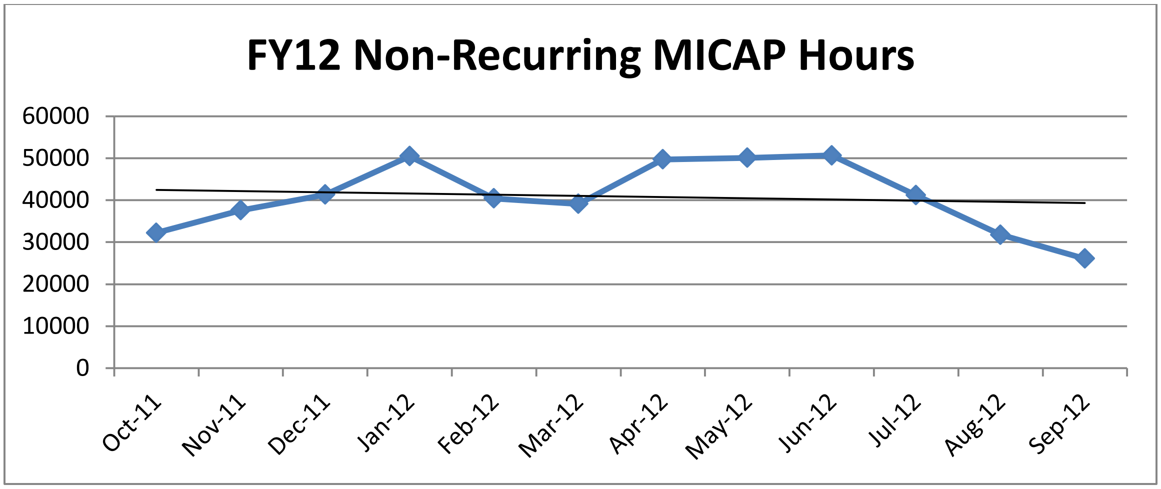


Figure 10: FY12 Non-Recurring MICAP Hours

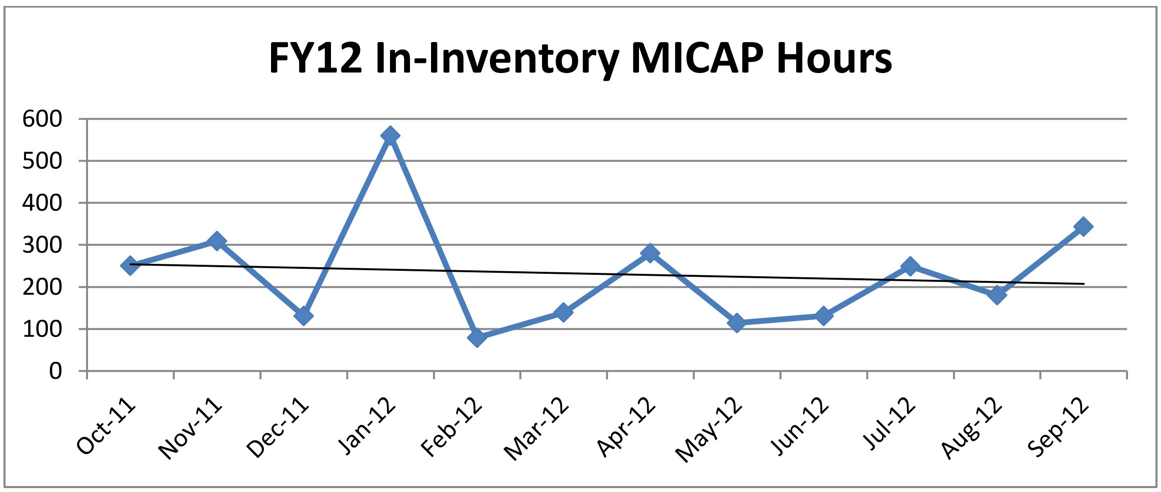


Figure 11: FY12 In-Inventory MICAP Hours

Since the FY12 data was the most consistent across the entire FY for Recurring MICAP Hours, and exhibited similar consistency in the Non-Recurring and In-Inventory Hours, it was determined to use only FY12 data for further analysis. This data is probably more consistent with the current operations of the AF supply chain since contingency funding is diminishing.

Development and Analysis of Model 3

The most productive model is the FY12 Model 2.1 because of low variability in difference across the FY for a monthly median. A monthly median will allow the data to be normalized for a consistent output. However, a downfall in Model 2.1 still exists in that it provides portions of a NSN for optimization. Since portions of a NSN can not be obtained in the real world, but only whole parts, Model 3 was developed as an Integer Linear Program of Model 2.1. Running Model 3 provided the following results, as shown in Table 10.

Table 10: Model 3 Output (FY12)

Variable	NSN	Amount (per month)
X1250	1560011795638	1
X1429	1560014372544	3
X1432	1560014372548	1
X1520	1560016030195	1
X2230	1680011775069	1
	TOTAL	**7**

Comparing the output of Model 3 with Model 2.1 (FY12) shown in Table 8 reveals that the output variables did not change, but the amount does reallocate the distribution to obtain a whole number, which is useable in the real world. Therefore, although Model 2.1 (FY12) provides the optimal solution to reduce the MICAP hours, Model 3 provides the optimal real-world solution since partial NSNs cannot be obtained. Model 3 is a more useable version of Model 2.1

Development and Analysis of Model 4

The final model developed for optimizing MICAP hours was to introduce cost into the program. Models 1 through 3 had used a cost of "1" for all NSNs to demonstrate an equal relationship between all NSNs within the program. This was done to identify the most effective means of optimizing MICAP hours by removing cost from the equation. In the absence of cost being the determining factor, the program defaulted to optimizing based on need, or highest MICAP hours. It is logically followed that the NSNs with highest MICAP hours (longest time to satisfy the requirement) means the aircraft is down for parts a greater amount of time, likely leading to an increased TNMC-S and AA rates. (Note: since TNMC-S and AA rates are determined by the number of aircraft available, and one aircraft could have multiple MICAPs against it, there is not a direct correlation between MICAP hours and TNMC-S or AA rates; hence, there is only a likely probability it would lead to an increased rate. However, researching the link between these metrics would be productive follow-on research.) Therefore, Model 3 provides the most effective optimal solution for a forward-looking metric to implement reduced MICAP hours. However, it is imperative to also look at the efficiency of the program and not just the effectiveness.

Model 4 introduces cost data into Model 3 by setting the actual replacement cost of the NSN as the variable coefficient. Using the same business rules from Model 3, the Model 4 output contained only one variable from the Model 3 output, X1520, and an additional seven variables, in values ranging from 1 to 4 each, as shown in Table 11.

Table 11: Model 4 Output (FY12)

Variable	NSN	Amount (per month)
X1301	1560012075267	1
X1520	1560016030195	1
X2366	2840010753644	1
X2769	3130008092769	4
X3338	4730011940163	2
X5052	5330002211231	1
X6084	5930007229740	1
X6711	6130014612915	1
	TOTAL	**12**

By inserting cost into Model 4, the objective function of the linear program now produces more useable information, as it introduces efficiency into the model to complement the effectiveness from Model 3. This provides an alternate intent of minimizing actual cost for efficiency. Fortunately, Model 4 successfully optimizes based on the constraint of reducing MICAP hours by the prescribed amount (25% reduction), making Model 4 effective. So, although the output from Model 4 increases the total amount of items to place into stock from 7 to 12 (as shown in Tables 9 and 10), it reached the optimal solution for both effectiveness and efficiency, based on the given constraints. (Note: no correlation is being made on the effect of Model 4 on TNMC-S or AA rates.)

Forward-Looking Metric: Cost to Decrease Recurring MICAP Hours

To further develop a forward-looking metric, the Model 4 optimization linear program was run a series of times to plot how to decrease recurring MICAP hours. This was done through the following steps, resulting in the plot at Figure 10.

Step 1: The median of the FY12 data was found for recurring, non-recurring and in-inventory MICAP hours, as follows:

Table 12: FY12 Median MICAP Hours

	Median MICAP Hours
Recurring MICAP Hours	13,491.4
Non-Recurring MICAP Hours	40,780.5
In-Inventory MICAP Hours	214.5

Step 2: Using the median Recurring MICAP hours (13,491.4 hours) as the maximum amount the MICAP hours can be reduced, Model 4 was run and the cost obtained from the objective function.

Step 3: The Recurring MICAP hour constraint was incrementally reduced by 1000 hours and cost data obtained, until the output was zero.

Step 4: The stable medians for non-recurring and in-inventory MICAP hours and the decreasing recurring MICAP hours were plotted with the applicable cost for Recurring MICAP hours, as shown in Figure 10 (cost shown in millions of dollars).

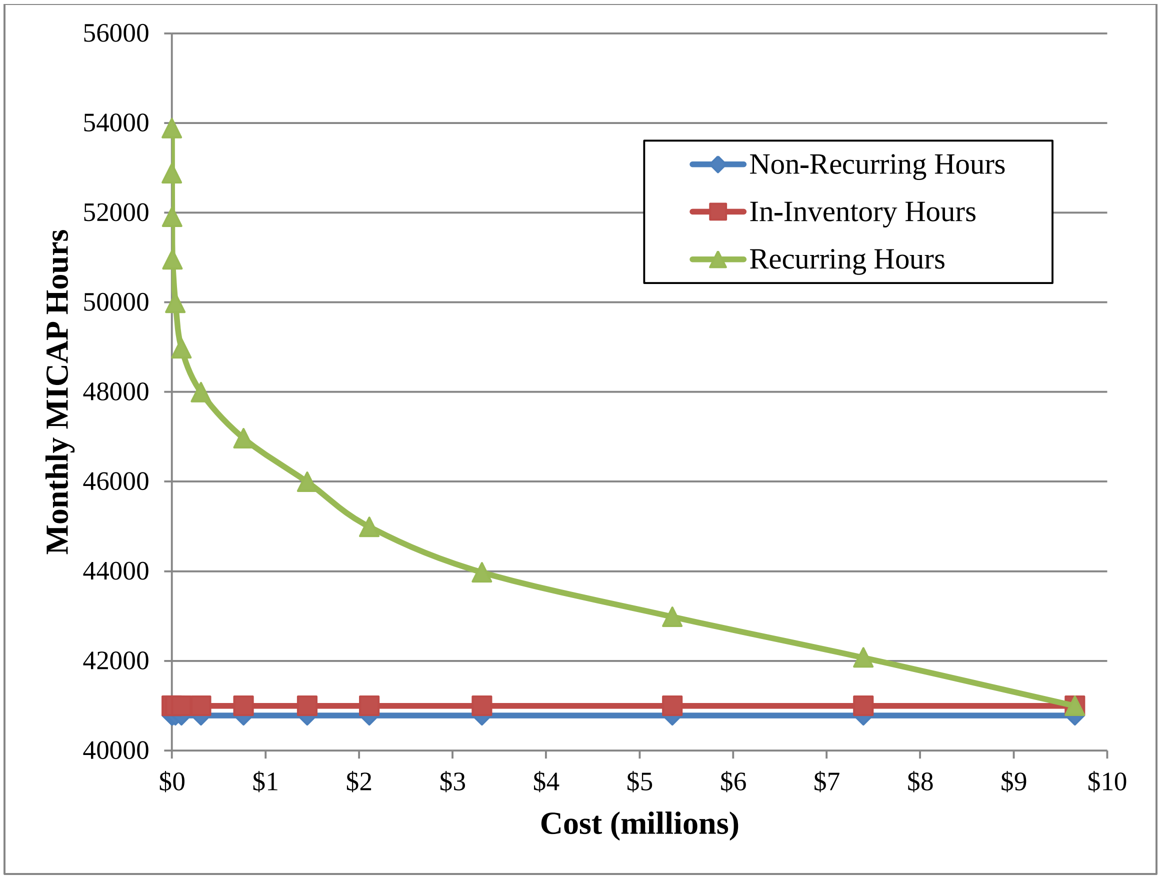


Figure 12: Cost ($M) to Decrease Recurring MICAP Hours

Summary

Building onto Model 2.1, Models 3 and 4 were developed to introduce the most effective and efficient way to minimize cost will improving MICAP hours. The outcome, as shown in Figure 10, shows the cost associated with decreasing Recurring MICAP hours based on Model 4, using an integer linear program and optimizing for actual cost. This forward-looking metric can be used to effectively plan to decrease MICAP hours in the most efficient manner.

V. Conclusions and Recommendations

Chapter Overview

This research began to answer the question "Can forward-looking metrics be used in Air Force sustainment operations and if so, how?" Specifically, this research focused on developing a forward-looking metric for Air Force sustainment operations by examining recurring MICAP hours and optimizing stock levels via linear programming. The following investigative questions were analyzed:

1. What metrics are currently used for sustainment operations in the Air Force?
2. What are forward-looking metrics?
3. Can forward-looking metrics be developed to mitigate current sustainment operation shortfalls?
4. How can forward-looking metrics be used to optimize stock levels, within a given set of constraints, based upon a changing MICAP-hour requirement?

Conclusions and Significance of Research

The intent of this research was to develop a forward-looking metric that can be used to determine how to change stock levels to reduce MICAP hours within the Air Force supply system. A forward-looking metric was developed via an integer linear program using C-5 fleet data. Figure 11 depicts the mathematical model's optimal solutions of reducing recurring MICAP hours at the associated costs. It identifies the most effective means (recurring MICAPs) and provides actual NSNs and associated quantities to buy. This research has successfully answered the question, that Yes, forward-looking metrics CAN be developed for Air Force sustainment operations.

Although this is only one area of sustainment operations, this same methodology could be applied across multiple areas and weapon systems within the Air Force's control.

This research is significant for three reasons. First, "forward-looking metric" until this point has merely been used as a buzz-word. Although the AFSC posed the question, no extensive research has been done and it is not currently in use in the Air Force. The preponderance of the current initiatives, some of which were highlighted in this research, only look at the current metrics framework and try to enhance their capability. For example, the Cascading Metrics team has identified a need for two new metrics, but both are historical metrics and do not encapsulate any forward-looking capability. As technology enables the Air Force to data mine metrics more efficiently and effectively, the Air Force's supply chain managers must begin to incorporate new ways of analyzing itself; forward-looking metrics provide that capability.

Second, this research was able to provide an actual forward-looking metric program for decreasing recurring MICAP hours. Further, this program can be easily used for any of the Air Force's weapon systems and potentially extrapolated into other sustainment operations. From this, a decision maker can determine a future optimal level of capability for sustainment operation. In action, a decision maker can use knowledge of future increased operations, determine the appropriate level of support (as defined within this research as the allowable monthly MICAP hours for an aircraft fleet), and increase specific stock levels (NSNs) to meet that needed requirement. This research provided an actionable metric and tool.

Lastly, this research posed a new way to look at MICAP hours by sub-diving the hours among three categories: recurring, non-recurring and in-inventory MICAP hours.

Typically, the Air Force looks as MICAP hours as one entity, which makes it difficult to determine which assets can enhance capability the most. For example, if only the highest MICAP hours are looked at, then the Air Force might mistakenly focus on a non-recurring MICAP that potentially grounded the entire fleet. The MICAP hours would be extremely high, but there is no value-added in increasing stock levels for these assets as there isn't a recurring requirement. This would also be a great area of additional research, to determine how to incorporate the different categories into additional metrics,

Recommendations for Action

It is recommended that AFSC further develop this forward-looking capability into software that can be used across the enterprise. Potentially, the optimization program developed in this research could be used as ESCAPE begins software development for its metrics capability. Access into the current Air Force data warehouses and programs need to be directly and electronically accessed to feed into the program for ease of use and continual updating. Additionally, this research be applied across all the weapon systems for use, as it can function across any platform that captures and stores the same data.

Recommendations for Future Research

Due to the wide breadth of the initial problem, this research was significantly narrowed down to look at only one aspect of sustainment operations, stock levels. Further, only basic criteria for optimizing stock levels based on recurring MICAP hours were used to keep the scope of the research attainable. Therefore, there are significant opportunities for follow-on research, as follows:

- Using the current research as a basis, include Demand (parts ordered) for the NSNs and how Stock Levels were changed over time. If demand remains constant and a NSN has a steady MICAP rate (hence a recurring MICAP), the stock levels were likely increased to meet that requirement. This will be able to provide a more accurate trend of the requirement, vice using only the MICAP hours.

- Using the current research as a basis, incorporate TNMC-S and AA rates into the optimization program. Since AA is the overall indicator for sustainment operations success, this may highlight other NSNs that drive effectiveness higher.

- Find new ways to incorporate the different categories of MICAPs (recurring, non-recurring and in-inventory) into sustainment operations and metrics.

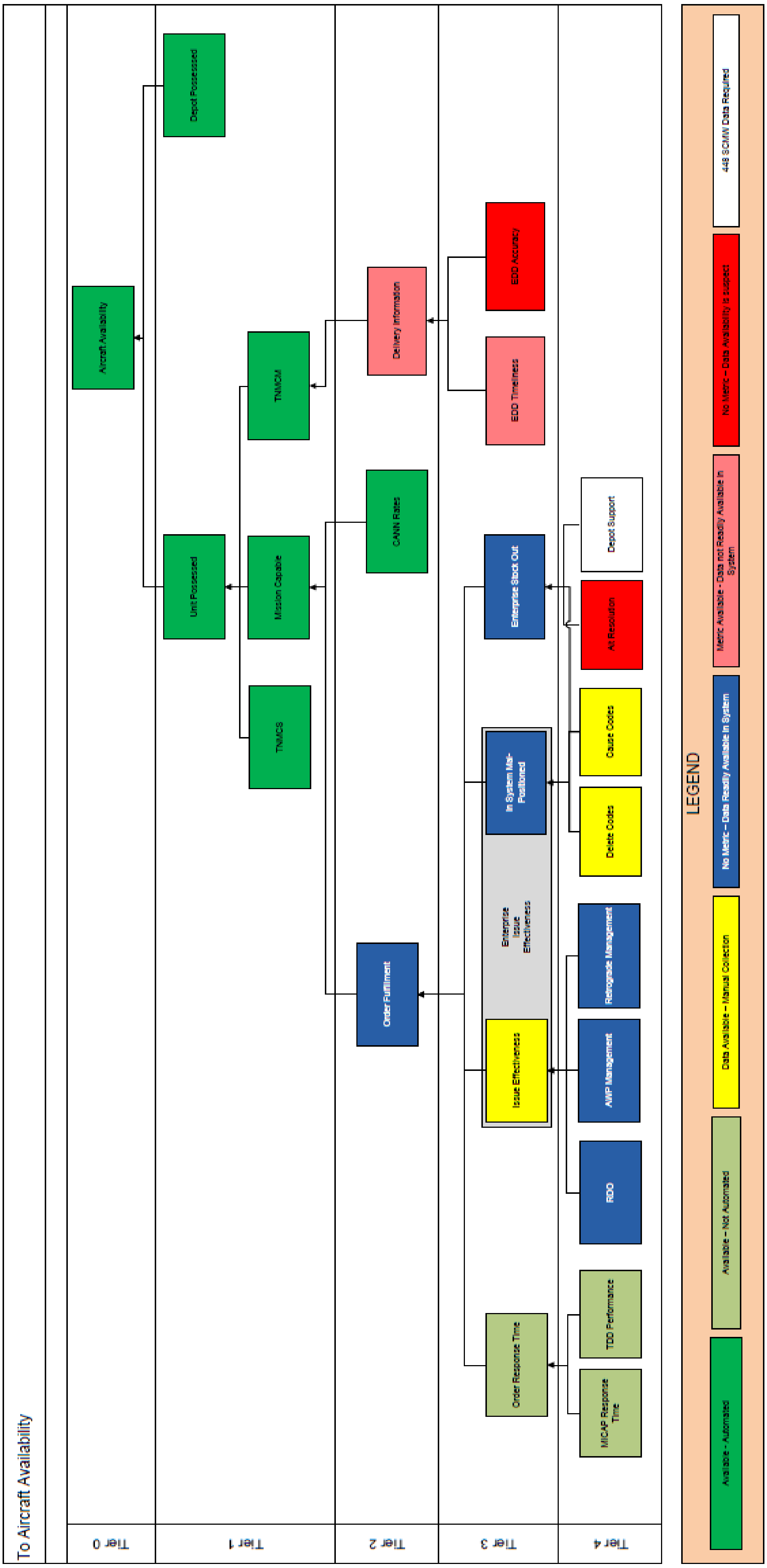
- Determine the correlation between AA and the Cascading Metrics hierarchy, as presented by the 635 SCOW. This research topic was presented by the participants in the December 2012 IPT and would be a useful addition to the hierarchy as it evolves.

- Using the current research as a basis, develop data to address the minimum MICAP hour increase due to decreased funding to this mission area.

Summary

Can Forward-Looking Metrics be used within the Air Force's sustainment operations? Yes, they can, and this research has developed an initial methodology and linear program for a forward-looking metric. The metric developed can determine the optimal stock level increases to improve (decrease) monthly MICAP hours, subject to the lowest cost with the highest effectiveness. Using the C-5 Galaxy aircraft fleet's sustainment data, an integer linear program can be manipulated to determine which parts (by NSN) should be attained to decrease the MICAP hours and at which levels. This research proves forward-looking metrics are a viable tool for the future of sustainment operations and should be leveraged in combination with technology to be the most effective and efficient Air Force in the world.

Appendix A: Cascading Metrics (635 SCOW, 2012)



Appendix B: Table of Variables and NSNs used in Model 1

Variable	NSN
X001	1560000817000
X002	1560000855872
X003	1560001758108
X004	1560001957356
X005	1560001957357
X006	1560002251772
X007	1560003175310
X008	1560004048394
X010	1560004114743
X011	1560004114744
X012	1560004228335
X013	1560004228553
X014	1560004502244
X016	1560004553200
X017	1560004553201
X020	1560004814504
X021	1560004851725
X022	1560004981148
X025	1560007634932
X026	1560007742114
X028	1560010052521
X029	1560010052522
X030	1560011492746
X031	1560011694763
X032	1560011694764
X033	1560012575349
X035	1560012611304
X036	1560012611305
X037	1560012611306
X038	1560012611307
X039	1560012611308
X040	1560012611309
X041	1560012611310
X042	1560012611311
X043	1560012611312
X044	1560012611313
X045	1560012611314
X046	1560012611315
X047	1560013131802
X048	1560014372544

X049	1560014372548
X050	1560014372557
X051	1560014375212
X058	1650002388623
X059	1650002411858
X060	1650002418858
X062	1650004169660
X063	1650004176300
X066	1650004312559
X067	1650004312578
X068	1650004866297
X069	1650004877678
X070	1650004884600
X073	1650005350668
X074	1650008318134
X075	1650008335289
X076	1650008889805
X077	1650008900210
X079	1650010751690
X080	1650012115433
X081	1650012461515
X082	1650012481754
X083	1650012488592
X084	1650013271355
X085	1650014434863
X087	1660001647347
X089	1680001140352
X090	1680001851139
X092	1680002487639
X095	1680003437650
X097	1680004024827
X098	1680004029812
X099	1680004122737
X101	1680007580025
X102	1680007607881
X103	1680011627371
X104	1680011640384
X105	1680011664022
X106	1680011775069
X107	1680011798080
X108	1680011815672
X109	1680011815673
X110	1680012133841
X111	1680012133842

X112	1680012164525
X114	1680994832212
X116	3120011899293
X117	4210004973144
X119	4310012534928
X120	4810001452615
X121	4810001506089
X122	4810002399239

Appendix C: Table of Variables and NSNs used in Model 2

Variable	NSN
X014	1560004502244
X021	1560004851725
X028	1560010052521
X029	1560010052522
X031	1560011694763
X032	1560011694764
X035	1560012611304
X042	1560012611311
X047	1560013131802
X048	1560014372544
X049	1560014372548
X050	1560014372557
X068	1650004866297
X082	1650012481754
X098	1680004029812
X119	4310012534928
X122	4810002399239

Appendix D: Table of Variables and NSNs used in Model 2.1 (FY10)

Variable	NSN
X0186	1560001363085
X0213	1560001441040
X0244	1560001705154
X0348	1560002410999
X0479	1560004097064
X0563	1560004502244
X0675	1560004851725
X0846	1560007253356
X0851	1560007254566
X1043	1560008646976
X1058	1560008718185
X1059	1560008718186
X1126	1560010052521
X1127	1560010052522
X1143	1560010144483
X1234	1560011694763
X1235	1560011694764
X1240	1560011744032
X1351	1560012611304
X1358	1560012611311
X1397	1560013131802
X1429	1560014372544
X1432	1560014372548
X1433	1560014372557
X1441	1560014536213
X1483	1560015543005
X1484	1560015543006
X1485	1560015543063
X1486	1560015543064
X1613	1620010805925
X1631	1620012056281
X1640	1620014621373
X1650	1630011826267
X1729	1650002307141
X1747	1650003238292
X1822	1650008563281
X1858	1650012481754
X1861	1650012599382
X2045	1680002417901
X2084	1680004024827

X2085	1680004029812
X2171	1680008333945
X2283	1680013465943
X2333	2620007022972
X2343	2835013429919
X2406	2915004899215
X2416	2915011896019
X2418	2915012147308
X2811	4140001060997
X2859	4510004101062
X2880	4510015732420
X3121	4730000950949
X3404	4810000099505
X3408	4810001162144
X3413	4810001360476
X3431	4810004103629
X3443	4810004866293
X3469	4810012603664
X3549	4820011916897
X3562	4820013181730
X3580	4920014688951
X4502	5315001922153
X5131	5330005861070
X5499	5340002021511
X5889	5821014563702
X5906	5826014120738
X5938	5841015204271
X5962	5895011925440
X5974	5895014904756
X6681	6105012293758
X6689	6110011614873
X6710	6130014223698
X6714	6130015357275
X6860	6220007088861
X6994	6610010261701
X7136	6685005267864
X7144	6685008037705
X7149	6685008908410

Appendix E: Table of Variables and NSNs used in Model 2.1 (FY11)

Variable	NSN
X0186	1560001363085
X0213	1560001441040
X0869	1560007322771
X1211	1560011160447
X1234	1560011694763
X1235	1560011694764
X1429	1560014372544
X1432	1560014372548
X1582	1620003175535
X1613	1620010805925
X1650	1630011826267
X1710	1650001336104
X1729	1650002307141
X1758	1650004169660
X1833	1650010751690
X1879	1650014434863
X1932	1660004568546
X2001	1680001033526
X2085	1680004029812
X2230	1680011775069
X2333	2620007022972
X2367	2840010753645
X2406	2915004899215
X2416	2915011896019
X2503	3040008190108
X2808	4110011560198
X3407	4810001025411
X3420	4810001791284
X3438	4810004538951
X3464	4810012110166
X3581	4920015064328
X3920	5306001877313
X5146	5330007819468
X5294	5330015771850
X5636	5340015609257
X5889	5821014563702
X5911	5826014651630
X5938	5841015204271
X5978	5895015072148
X6134	5930015394078

X6569	5985010890737
X6682	6105012755704
X6714	6130015357275
X6951	6350002996203
X6958	6605010182181
X7009	6610015004464
X7014	6610995938834
X7016	6610998171137
X7045	6615014934075
X7140	6685006898672
X7175	7010015063625
X7176	7010015407428

Appendix F: Table of Variables and NSNs used in Models 2.1 (FY12), 3 and 4

Variable	NSN
X0362	1560002489209
X0563	1560004502244
X0894	1560007634932
X0906	1560007742114
X1234	1560011694763
X1250	1560011795638
X1301	1560012075267
X1429	1560014372544
X1432	1560014372548
X1520	1560016030195
X1729	1650002307141
X1799	1650004954535
X1858	1650012481754
X1879	1650014434863
X1932	1660004568546
X1983	1680000210334
X2045	1680002417901
X2161	1680007580025
X2230	1680011775069
X2343	2835013429919
X2366	2840010753644
X2416	2915011896019
X2438	2995001153522
X2515	3040013021166
X2769	3130008092769
X2841	4310012534928
X3338	4730011940163
X3484	4820001322002
X5052	5330002211231
X5889	5821014563702
X5938	5841015204271
X5978	5895015072148
X6084	5930007229740
X6711	6130014612915
X6966	6605015705261
X7007	6610014932400
X7014	6610995938834
X7082	6680004367623
X7089	6680011016433
X7175	7010015063625

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AFIT-ENS-GRP-13-J-9

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 074-0188*

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From – To)*
14-06-2013	GRP	May 2012 – June 2013

4. TITLE AND SUBTITLE Advancing Forward-Looking Metrics: A Linear Program Optimization and Robust Variable Selection for Change in Stock Levels as a Result of Recurring MICAP Parts	**5a. CONTRACT NUMBER** **5b. GRANT NUMBER** **5c. PROGRAM ELEMENT NUMBER**
6. AUTHOR(S) Ryan, Lisa B., Major, 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 Way Wright-Patterson AFB OH 45433-7765	**8. PERFORMING ORGANIZATION REPORT NUMBER** AFIT-ENS-GRP-13-J-9
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Air Force Sustainment Center, Director of Logistics Attn: Col Jeffrey Sick 3001 Staff Drive, Suite 1AG75A Tinker, AFB OK 73145-3033 405 739-2218 (DSN: 339-2218) Jeffrey.sick@tinker.af.mil	**10. SPONSOR/MONITOR'S ACRONYM(S)** AFSC/LG **11. SPONSOR/MONITOR'S REPORT NUMBER(S)**

12. DISTRIBUTION/AVAILABILITY STATEMENT
DISTRIBUTION STATEMENT A
APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The intent of this research is to introduce forward-looking metrics and take the first steps in developing a forward-looking metric for Air Force sustainment operations. Specifically, this research seeks to answer four research questions addressing what the Air Force is currently using for sustainment metrics, what are forwarding looking metrics, how can a forward-looking metrics be developed to mitigate current sustainment operations shortfalls, and how can they be used to optimize stock levels, within a given set of constraints, based upon a changing MICAP-hour requirement. These questions are answered through a comprehensive literature review, interviews with subject matter experts and the development of an integer linear program. The research identified a need to sub-divide the MICAP hours metric into three categories, using a robust data selection process: recurring, non-recurring and in-inventory MICAP hours. From this, four primary models are developed, which culminated in an integer linear program to determine the optimal stock level increases to improve (decrease) monthly recurring MICAP hours, subject to the lowest cost with the highest effectiveness. The C-5 Galaxy aircraft fleet sustainment data is used to develop this forward-looking metric. This research proves forward-looking metrics are a viable tool for the future of sustainment operations and should be leveraged in combination with technology to be the most effective and efficient Air Force in the world.

15. SUBJECT TERMS: Forward Looking Metrics; Recurring MICAP; Supply Metric; Linear Programming

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			Darryl Ahner, PhD (AFIT/ENS)
U	U	U	UU	72	**19b. TELEPHONE NUMBER** *(Include area code)* (937) 255-3636; Darryl.Ahner@afit.edu

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