3-2004

Mitigating Growth Cost for Mobility Readiness Spares Packages

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THESIS

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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 2004

AFIT/GLM/ENS/04-04

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Abstract

A Mobility Readiness Spares Package (MRSP) is an air-transportable package of spare parts configured for rapid deployment in support of conflict or war. Each package is tailored to support a specific scenario, for a specific type and number of aircraft without re-supply for the first 30 days of deployment. Inventory is limited to mission-critical spares. The high cost of airlift and spares drive a necessity to keep MRSPs as small as possible, yet robust enough to meet wartime goals.

Historical MRSP inventories exhibit significant volatility and the subsequent growth of their inventory creates significant cost to the Air Force. Annual MRSP growth budget estimates over FY03 – FY05 ranged from $700M to $1.2 billion.

This research proposes methods to reduce unnecessary growth, stabilize inventory, and still maintain a viable MRSP. Causes of inventory growth are identified by examining historical data. Controlled experiments are conducted against volatile data to evaluate the effectiveness of exponential smoothing and moving averages in stabilizing inventory. Asset-based MRSP computations are used to give greater consideration to the sunk cost of inventory. This research provides the Air Force a set of business rules that stabilize inventory, reduce spares budgets, and maintain a viable MRSP that meets wartime goals.

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Acknowledgements

I am truly blessed to have great family, friends, colleagues, and mentors who have all played a role in supporting me as I completed my research at AFIT. I owe all of them a debt of gratitude. I would like to thank the following people for their support:

My family, who have been patient and supportive over the many nights I had to dedicate to research and studies; who always support me as I serve in the Air Force, and who make each day worth living. I love you and appreciate all you do.

My friends and classmates at AFIT in GLM04M, who exemplify military spirit and professionalism. You are truly generous and selfless. I am proud to know you and have worked with you. You are always welcome in my home.

My Advisor, Major Bradley Anderson, and reader Lt Col Stephen Swartz, who provided guidance, wisdom, humor, and encouragement.

Mr. Mike Niklas, who provided expertise and guidance on many of the analysis that supported this research.

Stephen Gray

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I. Introduction

Background

A Mobility Readiness Spares Package (MRSP) is an air-transportable package of spare parts (reparable and/or consumable). These packages are configured to be rapidly deployed in case of emergency, conflict, or war. Each package is tailored to support a specific *scenario*, type of *aircraft* deployed and a specific *number* of aircraft without re-supply for the first 30 days of deployment. In addition, MRSPs are developed to achieve a specific *target availability* level know as the Direct Support Objective (DSO). The DSO sets the minimum acceptable number of aircraft that should be mission capable at the end of the first 30 days of war (Department of the Air Force, 1999).

Normally, the only items included in an MRSP are those that generate a non-mission capable (NMC) condition (e.g. a grounded aircraft) and are identified in subsystems listed on the Minimum Essential Subsystem List (MESL) (Department of the Air Force, 2003: 14-7). The inventory contained in an MRSP is critical to achieving the DSO and ensuring the Air Force can meet its wartime objectives. Concerns, such as cost of airlift and cost of reparable spares, drive a necessity to keep MRSPs as small as possible, yet robust enough to meet the DSO. Therefore, MRSPs are developed with the goal of assembling the best mix of spares at the least cost—*the optimal mix of spares*. Annually, MRSPs are reviewed and calculated; then fielded the following year.

As weapon systems mature, the characteristics of spare parts change (i.e. prices, failure rates, item characteristics, etc); the mix of spares in an MRSP adjusts with its environment. In fact, the responsiveness of the process is one of its key benefits. However, MRSP inventories exhibit a large amount of variability from year-to-year and that variability drives a significant cost to the Air Force. The Venn diagram shown in Figure 1 provides evidence of this variability.

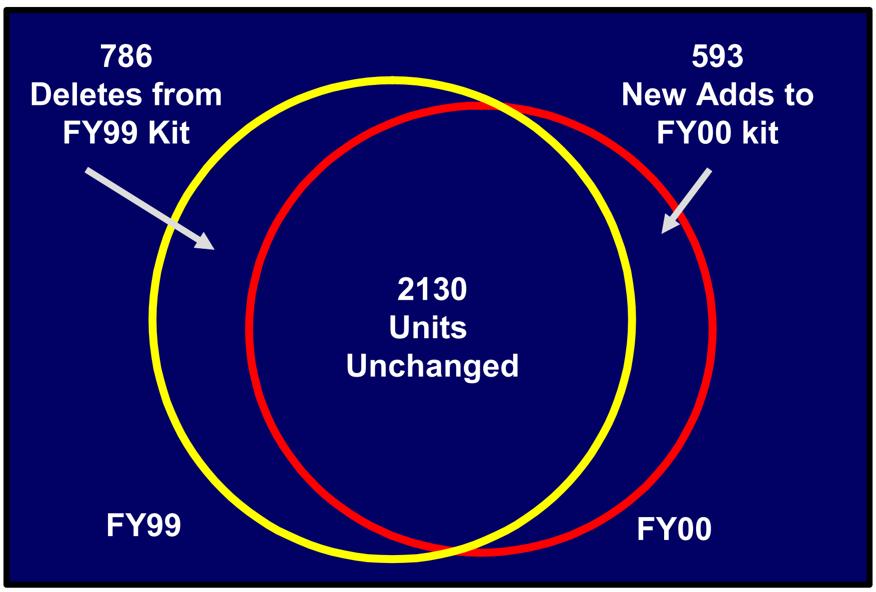


Figure 1. Comparing FY99 B-52 MRSP Authorizations to the FY00 MRSP

The totals shown in Figure 1 are an aggregate of all B-52 spares in all ACC B-52 MRSPs, not just one kit. The growth in inventory is easy to see. In FY00, 593 assets were added to the kits and 793 assets were deleted. The 593 units of growth drove an estimated repair/procurement cost of $24.1M. Other weapon systems exhibited the same characteristics, albeit a varying degrees of change and cost. A sample of their cost estimates, based on ACC analysis, is shown in Table 1 (Air Combat Command, 2001).

	Units			Cost		
W/S	FY00-99	FY01-00	FY02-01	FY00-99	FY01-00	FY02-01
B-1	133	148	351	$ 5.3	$ 16.3	$ 43.3
B-52	593	263	588	$ 24.1	$ 3.3	$ 57.3
F-15	2554	1635	2631	$ 77.2	$ 73.0	$ 128.5
E-3	614	542	910	$ 18.1	$ 31.9	$ 32.1
E-8	101	103	355	$ 11.6	$ 13.0	$ 80.3
C-130	305	792	214	$ 6.2	$ 10.8	$ 3.0

Table 1. Historical ACC MRSP Growth

The growth listed in Table 1 excludes programmed changes to the MRSP. Modifications to aircraft, time compliance technical orders (TCTOs), and planned force structure changes (e.g. taking a 6-ship deployment package to a 10-ship package) are excluded from these growth estimates. These spares (modifications and TCTOs) are funded through another budget program as *initial spares*. The growth represented above could be the results of changes in input data, scenarios, software changes, etc. This research seeks to pinpoint the causes of inventory growth and find ways to mitigate their impact.

Problem Statement

Mobility Readiness Spares Packages inventories exhibit significant volatility year-to-year and subsequent growth of their inventory mix creates significant cost to the Air Force. Annual MRSP growth budget estimates range from $700M to $1.2 billion over the period FY03 – FY05, across fiscal year defense program (Air Force Material Command, 2003).

Research Question

This research will be centered on the question "what methods can be used to eliminate unnecessary MRSP inventory growth?" By identifying methods to reduce MRSP growth, the cost associated with annual MRSP updates will be reduced. Reduced inventory cost frees scarce dollars for use on other requirements. This research seeks to identify methods to reduce unnecessary growth and still maintain a viable MRSP.

Investigative Questions: To answer the research question, the following areas will be researched:

1. What are the primary causes of MRSP growth (e.g. do changes in demand rates, unit prices, scenario data, and indicative data cause growth in MRSPs)?
2. Does the MRSP computation process recognize the sunk cost of inventory?
3. Does the use of prior-year assets in MRSP computations add stability to the resultant authorizations?
4. Can widely-accepted techniques reduce the amount of growth and subsequent cost from year to year?

Proposed Methodology

Literature review, historical data analysis, and controlled experiments will be the primary methods for conducting this research. First, an extensive literature review will be conducted to identify related studies on inventory growth and understand the logic behind MRSP computations. Next, a four-phase approach will be used to conduct analysis and experiments (see Figure 2).

In phase I, a review of historical ACC MRSP data will identify those key data elements that changed from year-to-year (e.g. that exhibited some form of variability). The output of that analysis will identify "root cause" data elements that will be subsequently studied in phase II. Phase II is comprised of controlled experiments, actual MRSP computations, where all input data is held constant except for the root cause elements. Using these experiments, the affect of variability will be measured and studied. Phase III takes the output of phase II and examines the results using multiple linear regression. The regression analysis measures the strength of the relationship between a change in input data and a subsequent change in MRSP authorized quantities.

Once root cause data has been identified and verified, the final phase of the analysis attempts to apply exponential smoothing and moving average costs to stabilize the data. Asset-based computations will be conducted to account for the sunk cost of prior year inventory. The output of these computations, using all three treatments, will be measured and studied to see if they add stability to the MRSP authorizations and reduce growth.

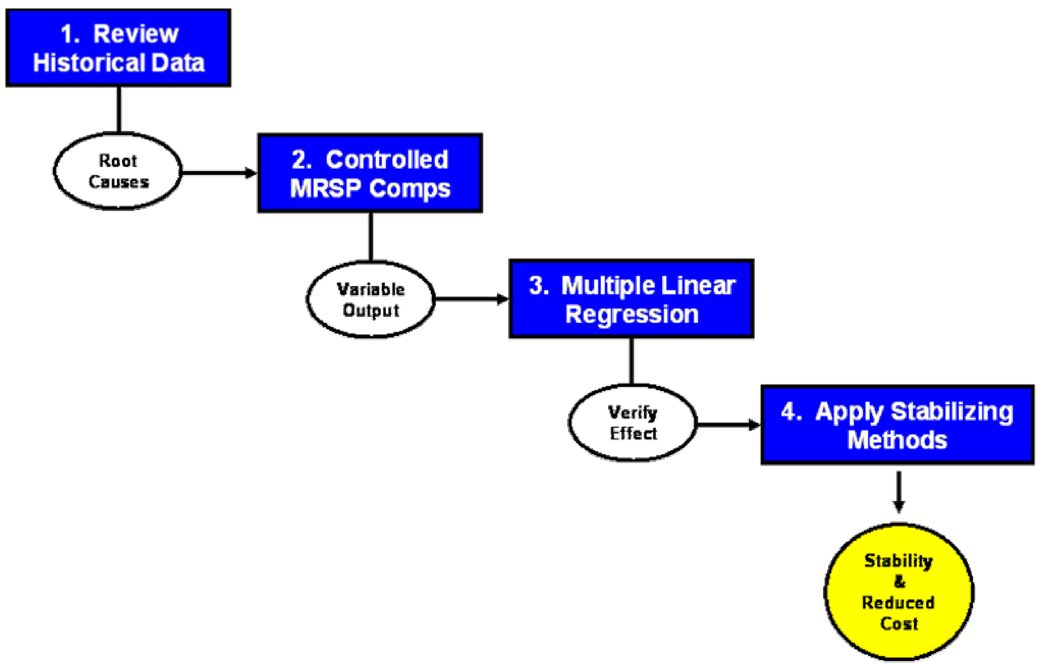


Figure 2. Four-phase Approach

Scope and Limitations

Although the results of this thesis are based on controlled experiments, the results should be easily transferable to actual Air Force processes. The experiments will be conducted using the same software used to develop MRSPs in the field, the Aircraft Sustainability Model (ASM). Also, historical ACC data will be used that was drawn from the FY99-FY03 B-52 MRSPs. A limitation to this dataset is that the stock numbers examined will only be those stock numbers present in each MRSP from FY99 to FY03.

In a typical B-52 MRSP, one might find roughly 350 line items. A comparison of ACC data revealed that 112 line items were common between all years. Therefore, analysis and experiments in this thesis were limited to that population. Although this a smaller set of stock numbers than that contained in a typical B-52 MRSP, it is still sufficient to experiment with and understand MRSP processes.

The Logistics Management Institute provided an unclassified steady-state scenario to base the experimental MRSPs against. No changes to this scenario were made during the analysis. Therefore, analysis was limited to the effects of changes experienced in input data alone.

Conclusion

The objective of this research is to find ways to stabilize the MRSP, mitigate MRSP growth, and reduce its associated cost. There are two significant benefits to be gained. First, if growth is reduced, inventory cost is reduced and scarce dollars are freed up to pay for other compelling Air Force needs. Second, stabilizing the MRSP will reduce the amount of labor-intensive work at the major command (MAJCOM) and base-level. At MAJCOM level, MRSP Managers are bound to a lengthy review process that painstakingly examines the range of items in authorized MRSPs and the complete set of data used to compute quantities for those items (Department of the Air Force, 2003: 14-14). At base-level, MRSP technicians annually reconcile MRSPs, adding and removing spares as the authorizations change. Stabilizing the MRSP should reduce the amount of unnecessary additions and deletions to the MRSP.

II. Literature Review

Introduction

This literature review is divided into two distinct parts. The first part provides a description of MRSPs and their purpose followed by a general overview of the MRSP computation. The computation review is not intended to be all-inclusive. Rather, it will provide a generalized example of how certain data inputs affect computation outputs, particularly as they relate to this thesis. The second part of the literature review focuses on selected reports and analysis that discuss inventory growth, similar to the growth historically seen in MRSPs.

Two of the investigative questions identified in Chapter #1 will be addressed through this review. First, knowledge of how data elements (e.g. demand rates, prices, scenario data, and other data) affect computation results will help identify root causes of inventory growth, particularly with regard to variability in input data. Also, by reviewing related inventory analysis and reports, knowledge will be gained about the causes of inventory growth through the research of others. The second investigative question addressed in this review deals with the question of sunk cost. Current software functionality will be examined and logistics analysts will be consulted to determine if current practices (e.g. computations) account for the sunk cost of MRSP spares.

Background on MRSPs

An MRSP is an air-transportable package of spare parts, typically related to an end-item, like an aircraft or piece of communications equipment. These packages are configured to be rapidly deployed in case of emergency, conflict, or war. In the case of aircraft MRSPs, each package is tailored to support a specific *scenario*, type of *aircraft*, and a specific *number* of aircraft without re-supply for the first 30 days of deployment. In addition, MRSPs are developed to achieve a specific target availability level known as the DSO. The DSO sets the minimum acceptable number of aircraft that should be mission capable at the end of the first 30 days of war. Most contingency scenarios are divided into two portions (e.g. surge and sustainment) where the first 10 days of a conflict represent the *surge* portion of the deployment and the latter 20 days representing the *sustainment* portion of the deployment. The current MRSP concept is designed to support both portions of a deployment. Packages built to support non-airborne end-items (e.g. communications, RED HORSE, and other equipment) are designed to include all spares necessary to support all end-items based on the deploying unit's unit type code (Department of the Air Force, 2003: 14-30).

The inventory contained in an MRSP is critical to meeting the DSO and ensuring the Air Force can meet its wartime objectives. Given the importance of military operations in achieving national objectives, it would seem compelling to make MRSPs as large as possible, with a plethora of spare parts that would satisfy any possible need. However, there are other compelling concerns, such as constrained airlift and the cost of aircraft spares that drive the necessity to keep MRSPs as small as possible, yet robust enough to meet the DSO. Overall, MRSPs are developed with the goal of getting the best mix of spares at the least cost—the optimal mix of spares, rather than over-estimating inventory "just-in-case."

New MRSP authorizations are calculated and fielded once a year. An MRSP review cycle has been established in harmony with the budget cycle so that the review process feeds the overall Air Force spares budget submission. Specifically, the Air Force objective is to authorize, acquire on time, preposition, pre-stock, and maintain in a serviceable condition ready for use, all MRSPs needed to support the wartime activities specified in the War and Mobilization Plan. Although MRSPs are considered “reserves,” they are used and consumed as needed to support peacetime operations. Given the existing logistical constraints (e.g. constrained depot repair, limited funding, and variability in demand), it is not economical or feasible for the Air Force to hold MRSPs inviolate. The demands of “boiling peace” drive the necessity to use wartime spares to support peacetime missions. Once an MRSP asset is used, the supply chain is set in motion to replace wartime spares as soon as possible. The MRSP is prepositioned at or near the base of intended use and/or airlifted to the employment bases prior to, concurrently with, or following the deploying forces (Department of the Air Force, 2003: 14-6).

Normally, the only items that may be included in an MRSP are those that generate a non-mission capable (NMC) condition (e.g. a grounded aircraft) and are included in subsystems listed on the Minimum Essential Subsystem List (MESL) for the supported weapon system (Department of the Air Force, 2003: 14-7). The inventories in an MRSP are additive to the world-wide requirement for spares. Mobility readiness spares packages are considered additive because they support a requirement over and above normal peacetime spares requirements. Figure 3 shows the development of the world-wide requirement and how MRSPs fit into the total Air Force spares requirement.

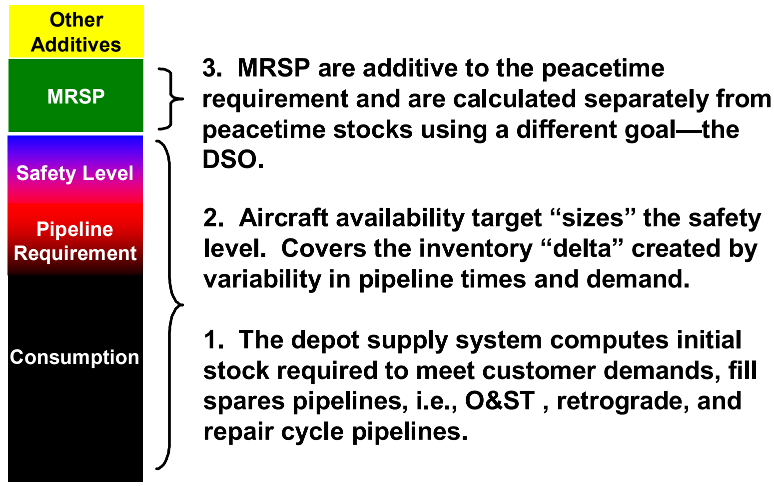


Figure 3. MRSPs in the World-Wide Requirement

Mobility readiness spares packages are developed through a user/depot manager review cycle. Spares needed for MRSPs are identified budget-leadtime away in an effort to ensure spares are available at the time the MRSP is fielded. As with peacetime spares computations, the MRSP process uses historical demand rates and factors as a predictor of future requirements.

MRSP Computations

ASM, developed by the Logistics Management Institute (LMI), is the software package and mathematical model used to compute the optimal mix of spares for MRSPs. ASM uses a marginal analysis technique to select items based on their contribution to weapon system availability per unit cost, thus guaranteeing cost-effective spares mixes (Slay and others, 1996: 1-1).

In order to establish the link between cost and availability, ASM uses many different factors in its calculations. The input files fed into ASM contain 62 unique data elements. However, model results are primarily driven by the scenario data, demand rates, item costs, cannibalization feasibility, quantity per application, item indenture, and pipeline times (Kline and others, 2001: 1-3).

ASM uses a three-step process to compute MRSPs. First, the model characterizes the probability distribution of the number of items in the various segments of the logistics pipeline. Second, the model calculates the expected backorders for all items under consideration. Last, the builds an optimal "shopping list" of those spares that provide the largest reduction in expected backorder per dollar invested (Slay and others, 1996: 1-3). Knowing the likelihood and location of spares in the various segments of the pipeline helps determine the probability of incurring a backorder. Given the probability and number of expected backorders, inventory is selected based on the spares that provide the greatest reduction in expected backorders. This logic directly relates to two driving considerations in the development of MRSPs. First, MRSP spares are expensive and funding is limited, so getting the most cost-effective mix of spares that achieves predetermined support goals is an economically prudent approach to sparing. Second, airlift is scarce and inventory takes up cargo space, so getting the optimal mix in terms of availability ensures the Air Force does not deploy non-essential spares. The next few paragraphs will look at the three-step process and associated calculations to the degree they relate to the objective of this thesis and its investigative questions.

Step#1: Determining the Probability Distribution

When modeling a typical Air Force base flying a steady-state scenario, the occurrence or arrival of demands can be described by a stationary random (stochastic) process. This process is frequently described using a Poisson distribution where the expected number of demands per day is represented by λ and the expected number of demands in a time-period, T, is λT (Slay and others, 1996: 2-3). For MRSP calculations, demand (e.g. λ) is expressed as the total organizational intermediate demand rate (TOIMDR) which incorporates the demand rate, quantity per application, and operating program in lieu if a typical daily demand rate (as shown below):

$$TOIMDR = Recurring\ Demand/(FHP * QPA) \tag{1}$$

where FHP is the flying hour program and QPA is the quantity per application (e.g. the number of a given item installed on an aircraft). For this research, TOIMDR and demand rate are used synonymously. In this example, demand for a single item at a single base is modeled. For a Poisson process, the probability that exactly n demands will occur in T days is given by:

$$p(x) = \frac{e^{-\lambda T}(\lambda T)^n}{n!} \tag{2}$$

In a wartime environment or in the "boiling peacetime" environment that the Air Force now operates in, actual demands can be more erratic than those represented by a Poisson process. Air Force demand rates exhibit a degree of variability that makes the negative binomial distribution a practical choice for modeling wartime or erratic demands. ASM has the capability to use the negative binomial distribution; however, current Air Force practice is to use the Poisson distribution (Slay and others, 1996: 2-10).

Step #2: Calculating Expected Backorders

As mentioned earlier, knowing the likelihood and location of spares in the various segments of the pipeline helps determine the probability of incurring a backorder. In the Air Force supply chain, demand is modeled with respect to a base and item's resupply pipeline. For the purposes of this research, a multi-echelon pipeline (e.g. a pipeline supported through both base and depot repair) is examined. There are four relevant segments of the resupply pipeline: order and ship time (O&ST), depot repair, base repair, and the retrograde segments as shown in Figure 4.

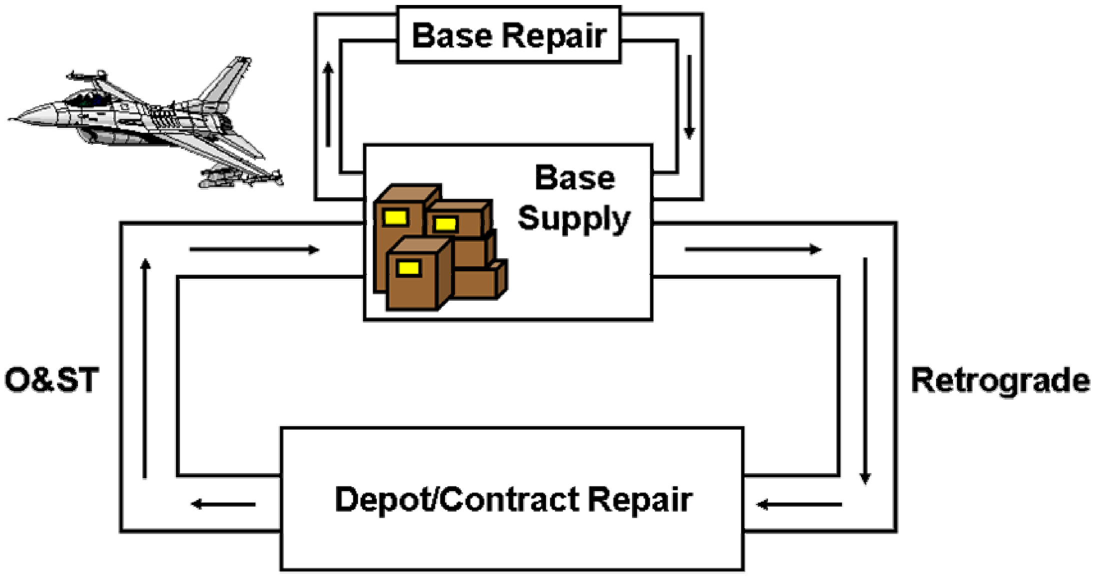


Figure 4. Multi-echelon Pipeline

Of particular importance are the base repair and O&ST segments. Each of these segments, at any point in time, has a number of spares "in motion." The number of spares in the pipeline at any time is independent (e.g. not dependent on or impacted by other items in the pipeline) and can be represented by means (e.g. the average number of spares in the pipeline segment). To determine the average number of spares in the base repair pipeline, the percent of base repair, which is the amount of items repaired at the base, and the repair cycle time are used:

$$\textit{Base Repair Pipeline Quantity (BRPQ)} = \lambda * PBR * BRT \qquad (3)$$

where *PBR* is the percent of base repair and *BRT* represents the base repair time. Likewise, those items not repaired at the base help determine the number of spares in the O&ST pipeline:

$$Order\ \&\ Ship\ Time\ Quantity\ (OSTQ) = \lambda * (1 - PBR) * OST \qquad (4)$$

where the not-repaired-this-station (NRTS) quantity is computed by *1-PBR* and order and ship time is represented by *OST*.

To this point, all pipeline segments have been considered except the depot repair pipeline. Depot repair actions and depot stocks provide spares to many users and help keep assets flowing in the pipeline. However, depot resources are finite and constraints exist that add delays in the pipeline. Therefore, ASM models the depot segment with respect to capabilities (e.g. the portions of demand satisfied through depot repair) and constraints (e.g. the expected backorders at the depot). The portion of demand to be satisfied by depot repair is expressed as:

$$\lambda_0 = \sum_{i=1}^{N} \lambda_b \times NRTS \qquad (5)$$

where λ_o represents depot demand, λ_b represents the base demand, and NRTS represents those items not repaired at base level. Additionally, the depot repair time is expressed as $\lambda_o * DRT$, where λ_o represents depot demand and *DRT* is the depot repair time. Given these two depot rates, depot expected backorders are computed and added into the *OS&T* and *BRPQ* pipeline computations to give the *total resupply pipeline (TRP)*:

$$TRP = OSTQ + BRPQ + \frac{DEBO}{N} \qquad (6)$$

where *DEBO* is the expected depot backorders and *N* represents the number of bases being supported by the depot. Step #2 is complete once the base expected backorders are computed.

At this point, the literature review has provided enough knowledge to draw some relevant conclusions with regard to investigative question #1 *"what are the primary causes of MRSP growth."* The literature points out how demand rates mathematically influence pipeline values, which ultimately influence final MRSP quantities. With that knowledge, certain basic conclusions can be drawn about demand rate characteristics. First, larger demand rates result in larger pipeline quantities and thus drive a larger requirement for inventory. Next, a moderate change in demand rates will cause a subsequent change in pipelines. A caveat to these statements is that all other pipeline factors must remain relatively constant or at least not change in a way that would counteract the increase in demand.

The effects of demand rate changes can be viewed using a notional example. Consider an item with an annual demand rate of 24 units (.0658 per day) and an average base repair time of 0.253 days. The pipeline quantity for this item, assuming 100 percent base repair, would be six (see Table 2). Under these conditions and assuming a stock level of one, the expected backorders would be 5.077. However, if demand decreases by four units annually and all other rates remain the same, the expected backorders decrease by one unit (e.g. down to 4.068).

Avg Dmds/year (λ)	Base Repair Time (t)	λt = Base Pipeline	EBO
24	0.253	6.074	5.077
20	0.253	5.062	4.068

Table 2. Notional Base Data with EBO

Chapter #4 contains analyses that further illustrate the impact of demand rate changes on pipelines and ultimately, MRSP buy quantities. Unit price is another relevant factor that begins to influence computation results in the third step of the ASM's process—*building the optimal spares list.*

Step #3: Building the Optimal Spares List

Unit price becomes a factor in the final stage of the MRSP calculation. A high-level view will be used to illustrate the function of cost in ASM's marginal analysis technique. Although this is a simplified example, the basic process is the same. Again, notional data is used to illustrate the affect a moderate change in unit price will have on the model's buy decisions. Table 3 lists two notional aircraft spares along with their associated base, depot, and pipeline data.

Item	Cost	Dmds Per Year	PBR	RCT	Base Pipeline	OST	Depot RCT	Total Resupply Pipeline	Depot Demands	Depot Pipeline	Depot EBO
Receiver	$500	24	0.2	0.2531	3.44150	0.06	0.05570	0.14340	19.2	1.06944	1.06944
Decoder	$500	24	0.3	0.2355	3.84802	0.06	0.06785	0.16033	16.8	1.13988	1.13988

Table 3. Base, Depot, and Pipeline Data

These two items have identical cost, demands, order & ship times, and relatively identical depot and base repair pipelines. ASM conducts a marginal analysis to determine the biggest reduction in expected backorder per dollar invested. Table 4 shows a simplified marginal analysis.

Item	EBO w/Zero Stock	EBO w/One Stock	Marginal Improvement	Improvement per dollar
Receiver	3.44150	2.47352	0.96798350	0.001936
Decoder	3.84802	2.86934	0.97867800	0.001957

Table 4. Marginal Analysis

ASM compares a number of stock options (e.g. different combinations of stock over each item) and the improvement achieved in expected backorders by looking at the EBO with zero stock and the EBO with one unit of stock. ASM then divides the marginal improvement in EBO by the unit price to determine the improvement per unit cost. The item with the highest improvement per dollar, the Decoder in this example, is selected and allocated one unit of stock (e.g. the model "buys" one Decoder). For this example, both item costs were $500. When a moderate change in unit price is experienced, the model may make a different buy decision. Table 5 shows the affect of reducing the unit cost of the Receiver by $20.

Item	EBO w/Zero Stock	EBO w/One Stock	Marginal Improvement	Improvement per dollar
Receiver	3.44150	2.47352	0.96798350	0.002017
Decoder	3.84802	2.86934	0.97867800	0.001957

Table 5. Re-Computing at Lower Cost

Given a cost reduction of $20 and holding all other data elements constant, the model now chooses to buy the Receiver because it has the highest improvement per dollar. This example is not intended to exclusively mimic the calculations of ASM nor is it intended to detract from the capabilities of ASM. It is, however, useful to see the impact of moderate change in price on a basic marginal analysis technique similar to that employed by ASM. The analysis documented in Chapter #4 of this research delves into the affect of historical price changes on actual MRSP computations.

ASM completes many iterations of marginal analysis, trying all possible combinations of spares in its effort to develop the "best" or optimal spares mix. Each stock decision is accumulated on a shopping list. The resultant availabilities and costs arising from each added spare produces a curve, as shown in Figure 5. Given a desired availability target, ASM accumulates spares until the target is reached (Slay and others, 1996: 2-16). One of the benefits of developing inventory requirements in this manner is that the output spares requirement can also be used for budget development.

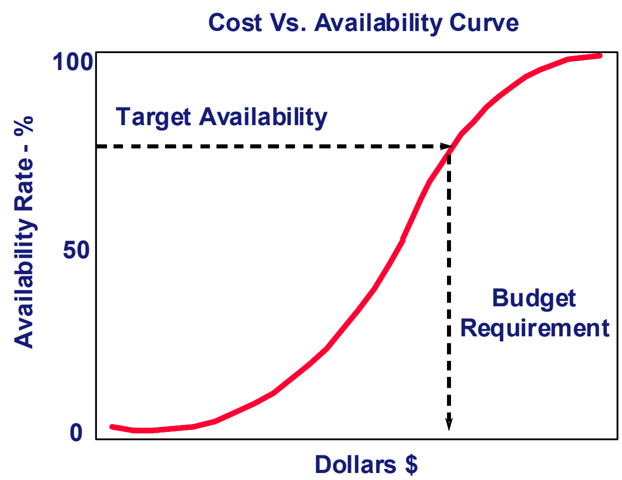


Figure 5. Cost vs. Availability Curve

In fact, the output MRSP quantities or "shopping list" quantities are fed back to the Requirements Management System as additives to the world-wide requirement for spares, which ultimately feeds the AFMC spares budget.

To this point, the three-step process has been described along with its associated data inputs. However, ASM also uses scenario data, which is the information that describes the aircraft flying hour program and logistics support over the deployment timeline, to determine the best spares mix needed to support operations. A short description of ASM scenario data follows, which concludes the first half of the literature review.

Scenario Data

There are three main sets of data associated with modeling a scenario: aircraft packages, flying profile, and logistics support. The aircraft package is defined by the planned aircraft activity (PAA) which specifies the number of aircraft deployed. ASM refers to this as "Fleet Size." ASM has the capability to model single or multiple bases. However, when multiple bases are modeled, ASM assumes an equal number of aircraft across each base.

The flying profile encompasses all information related to the flying activity (steady-state and dynamic environment) to include total flying hours, maximum sorties per day, and hours per sortie. Flying hours represent the combined hours for all systems scheduled to operate on a given day. Next, the maximum sorties per day represent the number of sorties per aircraft per day in a dynamic operating period. The maximum sorties per day are also referred to as the maximum turn rate. Last, the hours per sortie represent the average hours per sortie in a dynamic environment (Kline and others, 2001).

For dynamic environments (e.g. wartime scenarios), ASM allows the user to decelerate flying hours. The concept of deceleration follows the logic that aircraft failures do not change linearly with respect to flying hours. The LMI found that demand is more closely related to sorties flown than operating hours executed (Kline and others, 2001: 17). Using the deceleration logic, ASM estimates that the demand rate generated by a 1-hour fighter sortie increases by 10 percent for each additional hour of sortie duration. For bomber and transport aircraft, the ASM assumes a 20 percent increase in demand (Kline and others, 2001: 8-19). For example, a decelerated 2-hour wartime mission is expected to generate 1.1 times the demand as a 1-hour steady-state mission.

The ASM software allows the users to specify scenario data, basic model parameters, and advanced model parameters through simple, user-friendly screen and tabs. When first preparing an MRSP computation, the user is first shown the parameters page frame (Figure 6). The parameters page contains all the system parameters. Parameters include system name, the days to be analyzed, the system availability target (expressed as NMCS), the budget constraints, repair and resupply assumptions, and the operating hour scenario (Kline and others, 2001: 2-4).

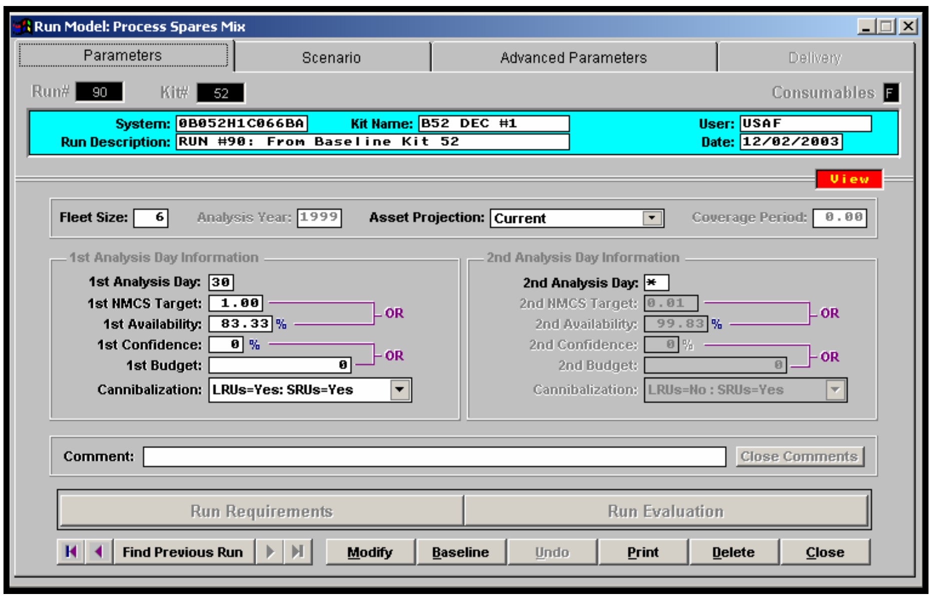


Figure 6. ASM Parameter Screen

Next, the Scenario tab, Model Parameters Page Frame, accesses the scenario page (see Figure 7). Here, the user inputs the flying hours, maximum sortie rates, hours per sortie, and the steady-state flying hour per sortie. Also, the user can choose to decelerate flying hours on this screen. Flying or operating hours are the combined number of hours all the systems are scheduled to operate in a day. The model multiplies that number by the demands per operating hour and the quantity of the item per systems (item data) to obtain the total demands for an item for each day (Kline and other, 2001: 2-13).

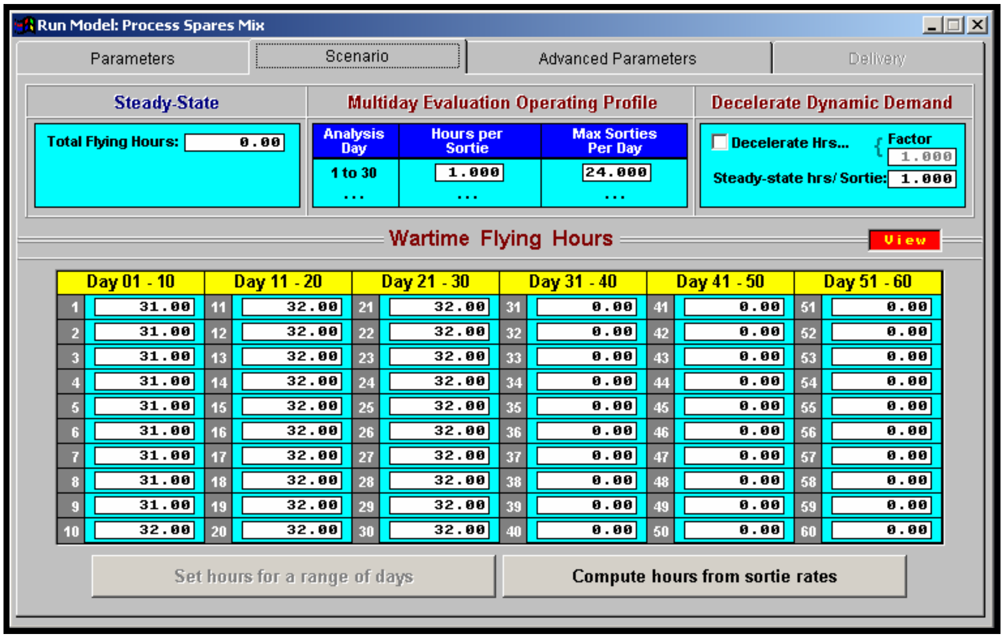


Figure 7. Model Parameters Scenario Tab

Last, the Advanced Model Parameters tab (Figure 8) allows the user to alter the model's optimization routine and incorporate specific stock objectives. These parameter settings can be used to force the model to include previous procurements, previously ordered spares, or specific item-manager's target levels (Kline and others, 2001: 3-1). Of particular interest on this tab is the option to include initial assets. As Kline states, this switch allows the user to force the model to include previous procurements and/or previously ordered spares. Activating this function includes assets on-hand in the MRSP computation, so long as the user includes initial assets in the ASM kit input file. In effect, ASM now computes an *asset-based MRSP*. The asset-based capability in ASM was used extensively in the course of this research.

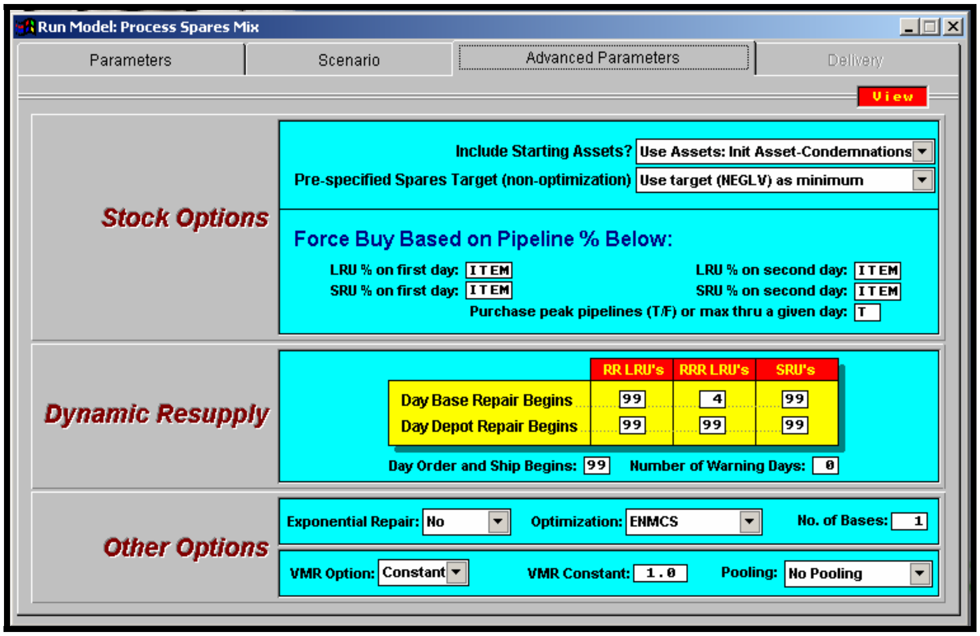


Figure 8. Advanced Model Parameters Tab

This concludes the first part of the literature review. To quickly summarize, this review has covered four main areas: a description of MRSPs, the purpose of MRSPs, a general overview of the MRSP computation process, and a short description of scenario data. The next part of the literature review is dedicated to examining selected reports and analysis that discuss inventory growth, similar to the growth historically seen in MRSPs

Sunk Cost of Inventory as an Input to the MRSP Computation

The sunk cost of inventory is not considered in the calculation for MRSPs (King and Slay: 2001). In fact, the only cost considered is the unit price, which equates to the latest acquisition price of the reparable spare (Slay and others, 1996: 1-2). This directly addresses research question #2 *"Does the MRSP computation process recognize the sunk cost of inventory?"* However, the idea of considering sunk cost is not new. In 1993, Mattern noted that the Air Force had approved the idea of using asset-based computations for war reserve material, considering the value of assets already available, thus making the buy requirement smaller than when the computation acts as if no assets were available. However, Mattern notes that the implementation of such an idea became difficult under the "spare is a spare" concept. Mattern also noted that a "capping" logic would be required to prevent the kits from continually growing as the greedy nature of the computation absorbs the larger pool of available assets (Mattern, 1993, 6-2). The issue of asset-based computations re-emerged in 2000 when ACC advocated implementation of asset-based computations to the Air Force Supply Wartime Policy Working Group (AFSWPWG) (Almeida, 2000). In turn, the AFSWPWG tasked LMI to investigate the potential of asset-based computations. In their analysis, King and Slay noted a technical problem "that asset-based computations minimize new requirements, but also keeps excess spares which allows the kit to expand year after year." King and Slay made three other points: (1) overall volatility is significantly reduced, (2) new requirements are only slightly reduced, and (3) a capping logic is needed to prevent the model from taking on too much excess. This research seeks to validate and address these issues and others generated by the subsequent thesis analysis.

Despite the lack of action or policy change, ASM has the capability to compute asset-based computations and can accept user-specified initial asset levels in several different ways. The default setting for ASM software is set to use a zero asset case (e.g. ASM determines spares mixes from scratch). Other capability exists for the user to include those decisions in the model's solution. The user's initial levels may be items procured previously or items needed but not yet procured. Using initial assets does not increase the MRSP growth cost as the assets have already been paid for (Slay and others, 2002: 5-5).

Research and reports of Demand Variability and Inventory Growth

In September 1986, Christopher Hanks of LMI identified “churn” as a primary cause of change in Air Force budget calculations and Program Objective Memorandum (POM) submissions. According to Hanks, “churn refers to the tendency of item characteristics to change overtime.” The Air Force recognizes that its inventory processes are stochastic or variable, which can only be described in terms of averages or other statistical parameters. In these terms, the idea of churn is that many of the parameters (e.g. demand rates, re-supply times, prices) are not stable overtime (Hanks, 1986: 3-7).

As weapon systems mature, the characteristics of spare parts change (i.e. prices, failure rates, item characteristics, etc). As asset characteristics change, the mix of spares maintained in an MRSP change. In fact, the responsiveness of the process is one of its key benefits. However, MRSP inventories exhibit a large amount of variability from year-to-year, which creates an immense cost to the Air Force (Almeida, 2000). These costs are driven by the need to procure new spares to fill MRSP authorizations or the cost of repairing existing spares for the same purpose. A key question to the management and funding of MRSPs is “how much variability or “churn” is acceptable in year-to-year updates to MRSPs?”

Annual MAJCOM-prepared MRSP growth budget estimates ranged from $700M to $1.2 billion across FY03 to FY05 as shown in Table 6 (Walton, 2003).

FY03	FY02	FY03	FY04	FY05	FY06	FY07	Total
APOM	$ 127.09	$ 136.18	$ 128.62	$ 118.54	$ 118.99	$ 122.34	$ 751.76
FY04	FY04	FY05	FY06	FY07	FY08	FY09	TOTAL
POM	$ 111.49	$ 117.25	$ 119.97	$ 125.89	$ 129.80	$ 135.43	$ 739.82
FY05	FY05	FY06	FY07	FY08	FY09	FY10	TOTAL
APOM	$ 163.95	$ 177.84	$ 193.46	$ 213.79	$ 238.64	$ 271.76	$ 1,259.44

Table 6. SRRB Budget Estimate for MRSP

The growth estimates shown above are limited to un-programmed growth within the context of MRSP. Any increase in MRSP cost related to aircraft modification or TCTOs have been excluded. It is reasonable to conclude that variability in key input data (i.e. demand rates scenario data, unit prices, etc) are the primary causes of inventory growth outside of programmed changes. Past studies have identified variability in rates and factors as a primary cause of inventory churn. This part of the literature review will focus on cases where existing literature identifies the existence of and effects of churn.

In his 1986 study, Hanks analyzed spares calculations for the F-16A/B over the period 1982 to 1984. An increase in requirements over the period 1982 to 1983, valued at $110.4 million was attributed to changes in various item characteristics from one database to the next. In a breakdown of the $110.4 million, roughly a third was due to changes in item parameters such as failure rates per flying hour, repair times, and NRTS rates (e.g. churn). Another third resulted from items with first-time, non-zero demands. The remainder is attributed to completely new items, those not existing in the prior year's database (Hanks, 1986: 3-8).

Hanks noted a series of other causes for the volatility of gross requirements. Mission-related factors such as force-structure change, modifications to aircraft and/or weapon systems, and planned changes in the flying hour program all contribute to the volatility of spares requirements. Likewise, funding decisions (e.g. the decision to under-fund spares) make the gap between budget submissions and the POM larger because the POM submission were calculated based on the assumption that all spares from the previous estimate were bought and placed in the inventory. Finally, Hanks notes that changes in item prices are another potentially significant reason why requirements estimates may change from budget to last look (ibid, 3-1 and 3-14).

In March 1988, RAND Corporation published a study on the benefit of improving the reliability of aircraft systems. Although database churn was not one of the areas RAND intended to study, they discovered that data churn affected spares inventories. With regard inventories, Abell noted that the yearly change in the database used to calculate the numbers of spare parts needed and the associated cost of those spares induced an increase in annual expenditures on spare parts equal to 16 and 21 percent of the total cost of all the spares in the system (Abell and others, 1988: vi).

In 1985, Randall King and Virginia Mattern of the LMI were tasked by Air Staff to investigate the dynamics of the requirements determination process for reparable peacetime operating spares. Using the D041 databases from September 1983 and 1984 and exclusively focusing on F-16 data, King and Mattern attributed database churn to two factors. First, there were significant differences in the actual stock numbers applicable to the F-16 from database to database. These stock numbers either did not exist in the previous database or they existed but had never been in demand. Second, King and Mattern found significant changes in database factors like demand rates, item prices, condemnation rates, and resupply times from one database to the other. These changes were found in a relatively small percent of the components in the database, yet these components drove the bulk of the churn cost (e.g. four percent of the components generated 64 percent of the churn costs) (King and Mattern, 1985: 2-1).

As evident in the above stated research and demonstrated in this thesis, changes in demand rates, item prices, condemnation rates, resupply times, and other factors have a significant effect in causing Air Force MRSP authorizations to change over time and promote churn across Air Force inventories. However, data changes are not the only activity that cause inventory churn. Both changes in Air Force inventory policy, specifically those policy changes that apply to MRSPs, and planned changes to weapon systems (e.g. TCTOs and modifications) drive changes in inventory.

The impact of policy change has been well documented. Mattern noted in her report titled *"Changes to the Air Force's Policy for Calculating Wartime Spares Requirements"* that five policy changes returned a net cost reduction of $5.8M and a net improvement in available aircraft at the end of the surge portion of a simulated conflict (Mattern, 1993: 2-14). Those five policy changes were:

1. Use an expected availability goal in lieu of confidence levels
2. Optimize on expected availability instead of confidence levels
3. Use multiple DSOs for surge and sustainment
4. Drop the pipeline floor policy
5. Use more specific buy kits

Improvements were not consistent across all weapon systems, however, change in the breadth and depth of spares in the MRSP was consistent once the policy changes were implemented.

In an earlier report, King and Mattern advocated changes to three MRSP policies: eliminate the pipeline floor, implement a target cannibalization constraint separate from the DSO, and cap buy actions when the expected non-mission capable rate equals the

DSO. Once again, the recommended change in policies drove a significant cost reduction, 19 percent or $7.3M, across a single F-15C MRSP (King and Mattern, 1989: 47).

Slay identified the impact of change to the War Mobilization Plan-5 (WMP-5) in his 1995 report on demand forecasting. In 1993, an updated WMP-5 was published reflecting the two major theater war concept. The new WMP-5 dictated dramatic increases in F-15C and A-10A flying hours resulting in an MRSP cost increase of $99.2M. Seeing results like this drove the Deputy Chief of Staff for Logistics to put a moratorium on using the new WMP-5 for MRSP computations (Slay, 1995: 11). Slay also noted the primary cause for the increase in cost was the widely recognized flaw that demands increase linearly as flying hours increase. In fact, the process of decelerating flying hours was developed to overcome disproportionate increases in demands as flying hours increase.

Summary

Literature supports the assertion that changes in demand rates, item prices, and other item-specific factors are a primary cause of inventory churn. Additionally, the notional examples provided in this review illustrate, at a very high level, the impact of a rate or price change on inventory decisions. A review of ASM logic provided the framework for understanding the interaction of demand rates and prices with the mathematics behind the model.

Two investigative questions have been addressed through this literature review. As mentioned above, literature shows that changes in demand rates, item prices, and other item-specific factors are a primary cause of inventory churn. Second, literature has established that the sunk cost of inventory is not considered in MRSP computations. In the next chapter, methodology is discussed which will explore the impact of variable rates and factors on actual MRSP computations and the impact of using asset-based computations.

III. Methodology

Introduction

This chapter provides the methodology used to conduct analyses needed to answer specific investigative questions. At the onset, this chapter sets the stage for all analyses by identifying data sources and describing data treatments (e.g. data sorting, screening, and compiling actions). All data preparation actions are discussed as a precursor to articulating the thesis methodology.

The methodology presented directly addresses those investigative questions not answered by the literature review. Recall, investigative questions #1 and #2 were directly addressed through the literature review. A portion of the analysis described in this chapter will also address question #1. All of the investigative questions are provided here for review:

1. What are the primary causes of MRSP growth (e.g. do changes in demand rates, unit prices, scenario data, and indicative data cause growth in MRSPs)?
2. Does the MRSP computation process recognize the sunk cost of inventory?
3. Does the use of prior-year assets in MRSP computations add stability to the resultant authorizations?
4. Can widely-accepted techniques reduce the amount of growth and subsequent cost from year to year?

The analysis of MRSPs will take a four-phase approach as depicted in Figure 9. This analysis is designed to answer the remaining investigative questions. In phase I, a review of historical ACC MRSP data will identify those key data elements that changed from year-to-year (e.g. that exhibited some form of variability). The output of that analysis will identify "root cause" data elements that will be subsequently studied in phase II. Phase II is comprised of controlled experiments, actual MRSP computations, where all input data is held constant except for the root cause elements. Using these experiments, the affect of variability will be measured and studied. Phase III takes the output of phase II and examines the results using multiple linear regression. The regression analysis measures the strength of the relationship between a change in input data and a subsequent change in MRSP authorized quantities.

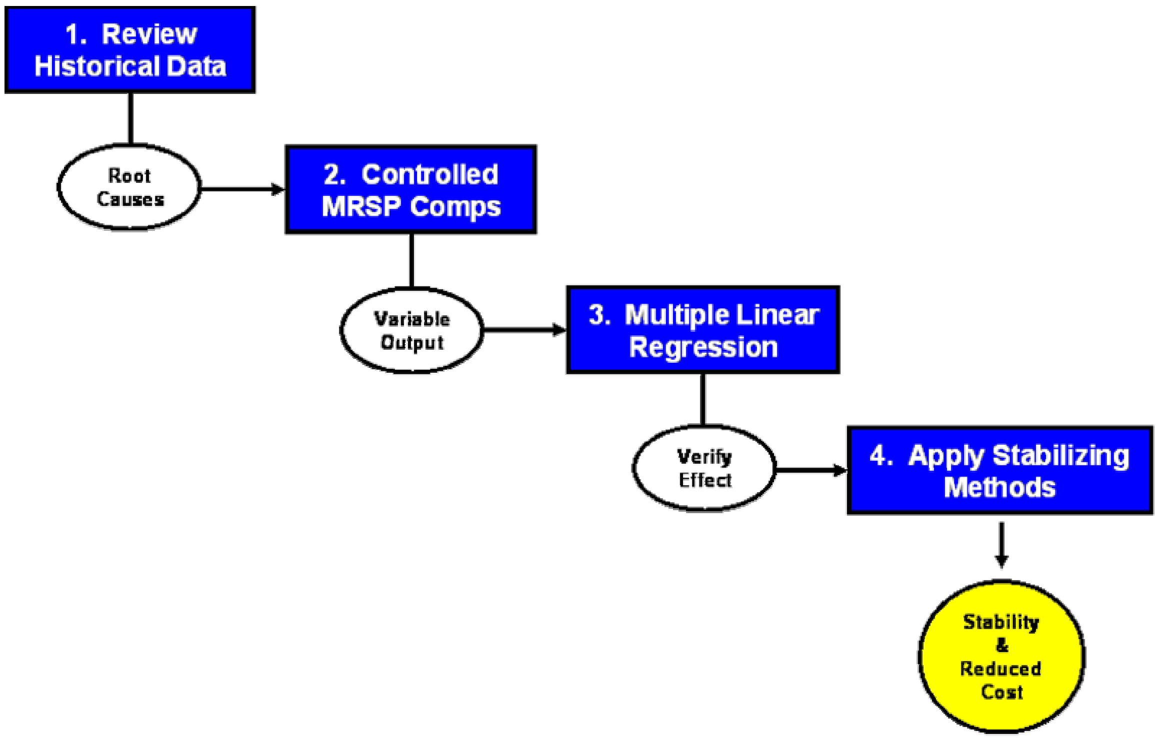


Figure 9. Four-phase Approach

Once root cause data has been identified and verified, the final phase of the analysis attempts to apply widely-accepted techniques (e.g. exponential smoothing and moving averages) to stabilize the data. Question #3 will be answered by computing actual asset-based MRSPs. The output of these computations, using all three treatments, will be measured and studied to see if they add stability to the MRSP authorizations and reduce growth or see if there is no improvement in terms of stability and growth. Question #4, which deals with policy, procedure, or logic changes will be addressed in this chapter and in chapter #5, based on the results of the controlled experiments and asset-based computations

It is important to remember that these analyses are conducted using actual B-52 MRSP data and using ASM software, which has the same basic logic that is embedded in current legacy systems. This chapter begins with a short description of data sources and the basic scenario used for all experimental MRSP computations. Once completed, the remainder of this chapter is dedicated to outlining the methodology.

Data Sources and Data Retrieval

Data needed for thesis analysis was obtained from two sources: LMI and ACC. LMI provided a desktop version of ASM that enabled the computation and assessment of "experimental" MRSPs. Additionally, LMI provided a B-52 MRSP data input file populated with FY03 data. The FY03 B-52 MRSP served as the baseline for all comparison and analysis. Additionally, LMI provided supporting documentation and technical manuals that described the process embedded in ASM software and gave instructions on software use.

Air Combat Command was the source for historical MRSP asset and demand data ranging from FY99 through FY02. Air Combat Command provided electronic Weapon System Management Information Systems (WSMIS) - Requirements Execution/Availability Logistics Module (REALM) inquiries that contained historical MRSP rates, factors, and other indicative data. A subset of the WSMIS/REALM output is shown in Table 7. These data files provide information that is critical to this thesis. The output quantities from *then*-year MRSPs, item prices, cannibalization indicators, maintenance concepts, item type indicators (e.g. LRU or SRU), and demand rates for each period are provided in each file. When combined with the FY03 data obtained through LMI, experiments can be conducted on a concurrent five-year set of data. All source data used to support this thesis was obtained electronically over email, file transfer protocol, or was copied and provided on CD-ROM.

KSN	NSN	TOIMDR	DDR	BRR	TYPE	WUC	COMP EXP CD	CANN	U/P	WBRCT	WOST	QPA	Min QPA	Maint Concept	NOTE CODE	ADJ FACTOR	NOUN
0B052H1C060BR	1095004752436	0	0	0	LRU	75EAG	Y	Y	1503	0	30	9	1	RR	2	1	RELEASE,BOMB EJECTI
0B052H1C060BR	1095004752437	0	0	0	LRU	75EAG	Y	Y	1400	0	30	18	1	RR	2	1	RELEASE,BOMB EJECTI
0B052H1C060BR	1095004882075	0	0	0	LRU	75ACB	Y	Y	484	0	30	2	1	RR	2	1	CONTROL BOX,ELECTRI
0B052H1C060BR	1240013353300	0	0	0	LRU	11RAB	C	N	31065	0	29	1	1	RR	2	1	CELL,OPTICAL ELEMEN
0B052H1C060BR	1280001596180	0	0	0	LRU	77JF0	C	Y	54420	0	30	1	1	RR	2	1	GENERATOR,SYMBOL SI
0B052H1C060BR	1280001596185	0	0	0	LRU	77JE0	C	Y	64896	0	30	1	1	RR	2	1	SERVO CONTROL UNIT
0B052H1C060BR	1280002501236	0	0	0	LRU	77JD0	C	Y	38526	0	30	1	1	RR	2	1	VIDEO DISTRIBUTION
0B052H1C060BR	1280004050630	0	0	0	LRU	77JG0	C	Y	22038	0	30	2	1	RR	2	1	PANEL,CONTROL
0B052H1C060BR	1280008983679	0	0	0	LRU	73GBA	C	Y	10875	0	2	1	1	RR	2	1	PRESSURIZATION UNIT
0B052H1C060BR	1280010730473	0	0	0	LRU	77JJA	C	Y	14585	0	30	2	1	RR	2	1	UNIT ASSEMBLY,GIMBA
0B052H1C060BR	1280011163832	0	0	0	LRU	73KE0	C	Y	38051	0	30	2	1	RR	2	1	CONTROL,TRANSMITTER
0B052H1C060BR	1280011207216	0	0	0	LRU	73LK0	C	Y	31395	0	30	1	1	RR	2	1	CONTROL,RADAR SET
0B052H1C060BR	1280011207217	0	0	0	LRU	73LH0	C	Y	24584	0	30	1	1	RR	2	1	CONTROL,COMPUTER
0B052H1C060BR	1280011226908	0	0	0	LRU	73LB0	C	Y	17463	0	30	3	1	RR	2	1	INDICATOR,MULTIFUNC
0B052H1C060BR	1280011509022	0	0	0	LRU	73KA0	C	Y	186615	0	30	3	1	RR	2	1	COMPUTER,FIRE CONTR
0B052H1C060BR	1280011512272	0	0	0	LRU	73LD0	C	Y	46221	0	30	1	1	RR	2	1	CONVERTER,SIGNAL DA
0B052H1C060BR	1280011513174	0	0	0	LRU	73QB0	C	Y	48282	0	30	1	1	RR	2	1	CONVERTER,SIGNAL DA

Table 7. WSMIS/REALM Output

Information regarding war planning is maintained in classified documentation and is accessible through AFMC or ACC. This information was not included in any form in this thesis. A notional scenario was used for all experiments conducted. While the notional scenario is not identical to an actual war plan, it is sufficient to complete thesis experiments. Since the effect of scenario changes were not studied, only one scenario was needed to conduct experiments.

The bulk of data treatment was done outside of ASM using Microsoft Access. ASM input files were manipulated to match the objective of each analysis. For example, when an analysis was conducted to compare the impact of demand changes on MRSP computations, an MRSP was first computed using the baseline MRSP (FY03) file. Next, FY02 demand rates were over-laid into the baseline file and the MRSP was re-computed.

All other data elements, including scenario data, were held constant in an effort to isolate the impact of demand rate variability. The overlay of data is the *treatment* done via Microsoft Access. All treatments were done at the stock number level, which ensured changes in one data element were consistent across year-groups.

Comparative Analysis

Phase I of the thesis analysis will compare historical MRSP data to identify potential growth-causing data elements. The analysis focused on finding changes (e.g. volatility) in data across historical MRSP data sets. Once identified, variable data became the focus of further analysis in phase II.

The analysis specifically considers those data elements critical to computations of MRSPs. All data elements were arrayed by year, by type and the values for each data element were compared from year-to-year. If there was no change in the data element, then the data were eliminated as a potential cause of growth. For example, if the B-52 MRSP maintenance concept remained constant across all stock numbers and all years, then it could be eliminated as a potential cause of growth. However, if the maintenance concept changed from year-to-year, then it was identified as a potential contributor.

Aside from input data, the other relevant factor influencing MRSP computations is the wartime scenario. For the purposes of this thesis, the default scenario was used for all experiments which eliminated scenario changes as a cause of growth. Therefore, attention was focused on the effect of changes in input data, rates, and factors. Table 8 summarizes the notional B-52 scenario.

WEAPON SYSTEM	B52
SCENARIO	Steady-State
PAA	6
DSO	83.33
SORTIE RATE	1
NMCS TARGET	1
HOURS/SORTIE	1
MAX SORTIES	24
DEPOT RESUPPLY	N/A
INITIAL ASSETS	0
ASSET PROJECTION	Current

Table 8. B-52 Scenario Data.

Using ASM for MRSP Computations

Using ASM, MRSPs can be computed with a stand-alone laptop computer. This capability allows for multiple computations under controlled conditions where particular data elements can be held constant while others are allowed to vary. The impact of variability in such areas as price, demand rates, and depth/range of spares can be evaluated using these types of experiments.

Experimental MRSPs need to be computed in a number of ways to answer the investigative questions. First, the formerly identified "root cause" data elements will be tested for impact on MRSP authorizations. For example, suppose demand rate was identified as a root cause data element. The baseline MRSP is first computed using FY03 baseline rates and factors. Next, FY02 demand rates are over-laid to the FY03 file and the MRSP is re-computed. This process is continued until all year-groups have been updated and computed using different demand rates. Under this example, the growth in each year represents the demand-related change in MRSP authorized quantities. Phase I will provide various combinations of root cause data that will be fed into the model.

Output results will be evaluated and studied. This process is graphically shown in Figure 10.

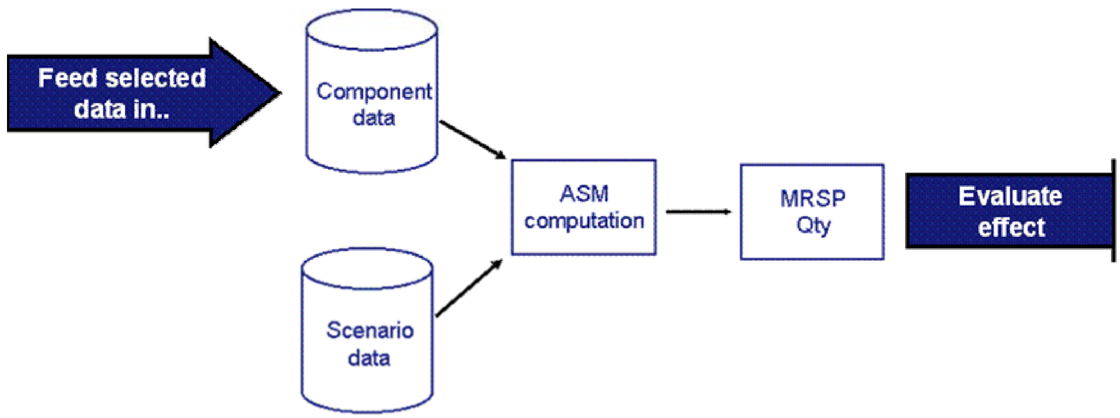


Figure 10. Design of Experiment – MRSP Computations

The impact of variability can and will be seen by computing MRSPs using "root cause" data elements. Outputs experiments in phase II form the basis of further analysis and multiple linear regression in phase III.

Multiple Linear Regression

Linear Regression is a form of analysis that allows the use of sample data to estimate the relationship between the mean value(s) of one variable as it relates to another variable. Since there are many variables used in the computation of an MRSP, a one-to-one relationship between two variables cannot be explicitly assumed. Therefore, multiple linear regression, a probabilistic model that seeks to determine the effect of more than one variable, is appropriate to measure the *effect* of root cause data elements on MRSP quantities (McClave and others, 2001: 534). A software package called JMP, version 5.01, was used extensively to calculate regression statistics and build leverage plots for visual representation.

Root cause data elements will be tested to determine if their *effect* is significant toward determining the MRSP buy and authorized quantities. The relationship between variable data and MRSP quantities will be depicted using leverage plots. These leverage plots are shown with confidence curves, which indicate whether the test is significant at the 5% level by showing a confidence region for the line of fit. If the confidence region between the curves contains the horizontal dashed line, then the effect is not significant. If the curves cross the horizontal dashed line, the effect is significant. Figure 11 shows these descriptions graphically (SAS Institute, 2002: 131).

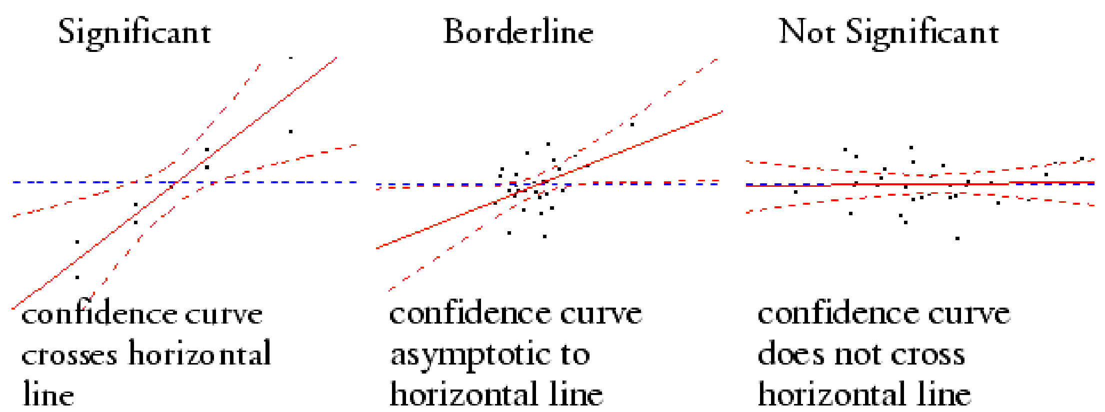


Figure 11. Comparison of Significance Shown in Leverage Plots

Besides the visual representation, JMP software provides a series of important statistical measures used in phase III of the MRSP analysis. First, the coefficient of determination (r^2) is measured, which gives the contribution of the dependent variables in predicting the independent variable. Note that r^2 is always between zero and one. The r^2 value describes the proportion of variation in the response around the mean attributed to variables in the model rather than to random error (McClave and others, 2001: 494-495). An r^2 of *one* occurs when there is perfect fit (e.g., random error equals zero); however, an

r^2 of *zero* indicates a high-level of random error. Next, the effect of variables will be evaluated based on the *F-statistic*. The *F-statistic* is the ratio of explained variability divided by the model degrees of freedom to the unexplained variability divided by the error degrees of freedom. The larger the proportion of the total variability accounted for by the regression model, the larger the *F-statistic* (McClave and others, 2001: 557). Therefore, it can be implied that root cause data elements with a high *F-statistic* make a stronger contribution to the MRSP authorized quantities.

The Analysis of Variance F-Test will be used to test the global usefulness of the regression model using the following format (McClave and Others, 2001: 558 & 635):

Null and Alternate Hypothesis:

H_o: $\beta_1 = \beta_2 = \ldots\ldots = \beta_k = 0$ (all model terms are unimportant for predicting y)
H_a: At least one $\beta_k \neq 0$ (At least one term is useful for predicting y)

Test Statistic:

$$F = \frac{R^2 / k}{(1 - R^2)/[n - (k+1)]} = \frac{MeanSquare(Model)}{MeanSqaure(Error)}$$

where n = sample size and k = the number of terms in the model

Reject Region:
$F > F_\alpha$, with k numerator degrees of freedom and $n - (k + 1)$ denominator degrees of freedom

Assumptions:

- The mean of the probability distribution of ε is 0.
- The variance of the probability distribution of ε is constant for all settings of the independent variable x
- The probability distribution of ε is normal
- The values of ε associated with any two observed values of y are independent

Verification of Assumptions:

- The mean of the residuals (e.g. the difference between an observed value and a predicted value) equal zero

- The standard deviation of the residuals is equal to the standard deviation of the fitted model

The regression analysis simply serves to compare and determine the effect the change in variables has on MRSP buy quantities and authorizations. As each MRSP is calculated, the resultant buy quantities are arrayed for each year along with the particular data elements in question (i.e. demand rates, prices, etc). Two periods are selected and compared. For example, suppose the FY99 and FY00 MRSP demand rates and prices are used to compute two separate MRSPs. The FY99 buy quantities, demand rates, and prices would be subtracted from the FY00 rates, prices, and quantities to obtain the difference in each variable. These values, (e.g. the difference in demand and authorized quantity) were arrayed and imported to JMP software for statistical analysis.

Through comparative analysis, multiple linear regression, and actual MRSP computations, this research hopes to establish causality between changes in data and changes in MRSP quantity. Once causality is determined, the research shifts to phase IV and focuses on finding methods to reduce data volatility and ultimately, reduce the growth and cost of growth in MRSPs.

In phase IV of the analysis, three methods (e.g. exponential smoothing, moving averages, and asset-based MRSP computations) will be evaluated to see if they stabilize MRSP data and reduce MRSP growth. Exponential smoothing and moving averages are widely-accepted methods of forecasting, which are appropriate for reducing volatility in forecasts. This research used exponential smoothing to reduce variability in demand rates and moving averages to stabilize unit price because there is precedence for these practices in current Air Force inventory models. In fact, three of the four techniques coded into D200, the Requirements Management System, employ two or four quarter moving averages and/or exponential smoothing (Clark, 2002: 13). To understand the capability and applicability of these methods, a short discussion of moving averages and exponential smoothing is appropriate.

A *moving average* is the average value of a set of data over a particular observation "window." The average is calculated by summing the observed values and dividing that sum by the number of observations. The user defines the size of the window (e.g. number of observations) to use in the calculation. This technique is often referred to as the *N-period moving average* (Fitzsimmons, 2004: 502) where *N* represents the user-specified number of periods. As time passes, the most recent observation is added into the calculation and the oldest observation is dropped out.

Simple exponential smoothing is a more sophisticated method of forecasting. Simple exponential smoothing also "smoothes out" blips in data and provides three advantages over *N*-period moving averages: (1) old data are never dropped or lost, (2) older data are given progressively less weight, and (3) the calculation is simple and only requires the most recent data (Fitzsimmons, 2004: 502). The accuracy of an exponentially smoothed forecast can be determined by the *mean absolute deviation*, which is the average difference between the forecasted quantity and the actual quantity for the forecast period.

Exponential smoothing employs a smoothing parameter (usually denoted by the Greek letter α and takes a value between zero and one). The higher the value of the smoothing parameter, the faster the weight placed on older data declines. Generally, only the observed value in the current time period (A_t), the forecasted value for the current time period (S_t), and a value for the smoothing parameter α are needed to generate a forecast for one time period into the future (F_t). Specifically, the most influence or weight is assigned to the most recent data and the weight assigned to progressively older data tapers off exponentially according to a pre-set smoothing parameter (Clark, 2002: 13). The general equation for exponential smoothing is given by:

$$S_t = \alpha(A_t) + (1-\alpha)S_{t-1} \tag{7}$$

The benefit of exponential smoothing can be seen with a notional example. Consider a reparable spare with a normal and smoothed demand rate as shown in Table 9.

	Normal	Smoothed
FY99	0.0662	N/A
FY00	0.0360	0.0511
FY01	0.0734	0.0547
FY02	0.0457	0.0596
FY03	0.0811	0.0634

Table 9. Demand Data (Normal vs. Smoothed)

The normal demand rates show a large degree of variability. However, the same data, exponentially smoothed with an alpha value of 0.5, mitigates the peaks and valleys in demand and stabilizes the rate over the period. Graphically, Figure 12 shows just how different the smoothed values progress over the period as compared to the normal demand pattern.

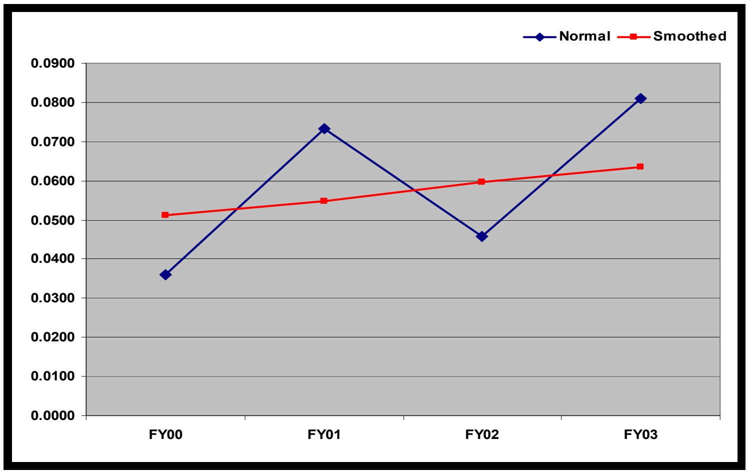


Figure 12. Affect of Exponential Smoothing

Applying the *N-period moving average* to MRSP unit price reaps similar benefits. While less sophisticated than exponential smoothing, it can be used to mitigate the swings in unit price. Again, there is precedence for the application of moving averages within AFMC. In 2002, the Studies and Analysis Office (AFMC/XPS) conducted an analysis on the applicability of a moving average cost (MAC) for inventory valuation. A DoD policy change drove the need to value inventory at historical cost. Historically, AFMC valued inventory at the latest acquisition cost (LAC), which is the same cost used for MRSP computations. The moving average cost (MAC) is a cost valuation that is more representative of the prices actually paid for items in AFMC (Stafford and others, 2002: 64). Applying the MAC to MRSPs is appropriate for two reasons. First, the unit price is equal to the LAC and is typically not the actual cost of placing an asset in the MRSP. In most cases, new MRSP spares are identified two years prior in the buy kit and are budgeted for two years before a kit is fielded. For existing spares (e.g. not a new procurement), an excess spare may be taken off the shelf or the repair of an existing carcass may be sufficient to fill a new MRSP authorization. Using excess spares comes at zero cost; repairing an existing carcass only results in a cost at the *repair cost* of the spare. Second, the LAC is the most current acquisition cost. For that cost to be applicable to an MRSP increase, the asset would have had to be procured and delivered within the last year. Given standard procurement leadtimes in excess of one year, it is likely that the new MRSP authorization will be filled with a spare that was procured beyond the previous year.

The effect of MAC can be shown using the same notional stock number shown in the exponential smoothing example above. Calculating a MAC for this item reveals:

	U/P	MAC
FY99	$ 20,771.07	N/A
FY00	$ 23,102.77	$ 21,936.92
FY01	$ 22,549.34	$ 22,826.06
FY02	$ 24,584.19	$ 23,566.77
FY03	$ 22,058.04	$ 23,321.12

Table 10. Unit Price & 2-Year Moving Average Cost

Graphically, the effect of MAC is shown in Figure 13. The MAC diminishes the effect of sharp spikes or drops in unit price.

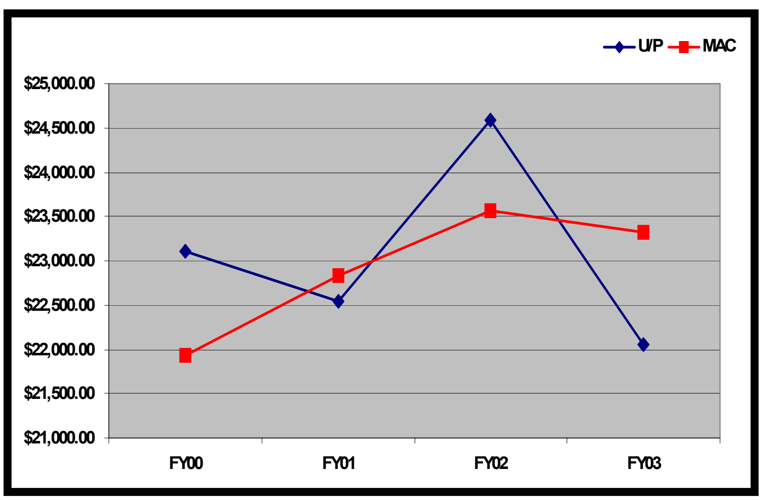


Figure 13. Effect of Moving Average Cost

Both methods, MAC and exponential smoothing, reduce the variability seen in demand and unit price. On a large scale, they could reduce volatility in MRSP computations over the course of different years. Both of these methods were tested as part of the final MRSP computation analysis to this thesis, as well as the applicability of asset-based computations.

An asset-based computation is identical to a standard MRSP computation except prior-year assets are included with the input data. For this research, a portion of the prior year MRSP authorization is used as a surrogate for actual spares data. Since MRSPs are additive to the world-wide requirement and the B-52 MRSP is not a new weapon system, it is reasonable to presume a large percentage of the prior year's MRSP is available. However, a separate, preparatory treatment is needed to limit the amount of spares made available to the model.

Initial assets will be capped at the price-neutral, optimal quantity. First, a baseline MRSP is computed with unit price set equal to one dollar in order to obtain the "optimal" mix of spares, at least in terms of availability. This optimal mix serves as the upper bound of initial assets for the remaining asset-based computations. Second, a percent of the prior-year's initial assets are applied in increments of 20 percent ranging from zero percent to 100 percent. Six runs (e.g. computations) will be processed for each year-group of data (e.g. FY00, FY01, FY02, and FY03) omitting FY99 since there was no FY98 data available to calculate against. Overall, 24 runs are needed to evaluate asset-based effects. The results of these computations will provide a dataset to measure the impact of initial assets on the total MRSP authorization and the total buy quantities.

Capping the MRSP quantities prevents an over-estimation of available assets. Using the cost-neutral optimal mix narrows the potential set of initial assets to the most important in terms of aircraft availability.

Summary

In addition to the knowledge gained through the Literature Review, the analysis of MRSPs will answer the remaining investigative questions. This analysis will take a four-phase approach. Phase I provides a review of historical data in order to identify any variability within the ACC dataset. Phase II uses controlled experiments to measure the affect of variability on actual MRSP computation results. Phase III takes the output of phase II and examines the results using multiple linear regression in order to measure the strength of the relationship between a change in input data and a subsequent change in MRSP authorized quantities. Phase IV applies widely-accepted techniques (e.g. exponential smoothing and moving averages) and asset-based computations in an attempt to stabilize the data and reduce MRSP growth. The output of these computations, using all three treatments, will be measured and studied to see if they add stability to the MRSP authorizations and reduce growth. The results of all of these efforts will aid in developing recommendations to the Air Force for policy, procedure, and process change in the context of MRSPs.

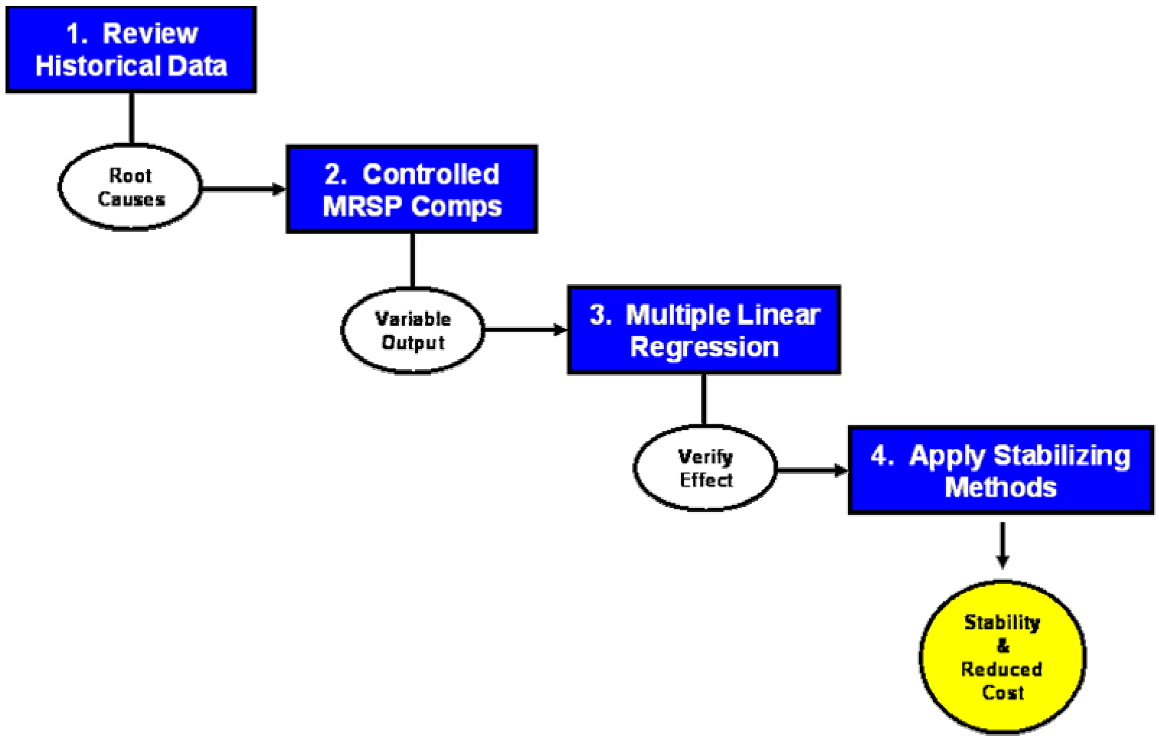


Figure 14. Four-phase Approach

IV. Results and Analysis

Introduction

This chapter summarizes the results of analyses described in Chapter #3. The knowledge gained by examining these results helped answer the research questions presented in Chapter #1. Those research questions are provided here for review:

1. What are the primary causes of MRSP growth (e.g. do changes in demand rates, unit prices, scenario data, and indicative data cause growth in MRSPs)?
2. Does the MRSP computation process recognize the sunk cost of inventory?
3. Does the use of prior-year assets in MRSP computations add stability to the resultant authorizations?
4. Can widely-accepted techniques reduce the amount of growth and subsequent cost from year to year?

Questions #1, #3, and #4 will be answered in this chapter through the various analysis and comparisons. Question #2 was answered in the literature review. Analyses were conducted in four phases:

1. A historical data review to identify root causes of inventory variability
2. Controlled experiments (e.g. actual MRSP computations) , using root cause data elements to measure the impact of variability on MRSP authorizations
3. Multiple linear regression, which tests the significance of the effect of variable root cause data
4. The application of commonly-accepted methods in order to stabilizing MRSP data and the resultant inventories

Evaluation of Historical Data

For the purposes of this research, it is important to remember that growth is evident when a spare part that was not contained in the prior year's MRSP is added, or an existing authorization is increased over the prior year's quantity. A example from ACC's budget estimate over FY99 through FY02 reveals a significant amount of growth in terms of MRSP quantity and cost (see Table 11) (Air Combat Command, 2001).

	Units			Cost		
W/S	FY00-99	FY01-00	FY02-01	FY00-99	FY01-00	FY02-01
B-1	133	148	351	$ 5.3	$ 16.3	$ 43.3
B-52	593	263	588	$ 24.1	$ 3.3	$ 57.3
F-15	2554	1635	2631	$ 77.2	$ 73.0	$ 128.5
E-3	614	542	910	$ 18.1	$ 31.9	$ 32.1
E-8	101	103	355	$ 11.6	$ 13.0	$ 80.3
C-130	305	792	214	$ 6.2	$ 10.8	$ 3.0

Table 11. Historical ACC MRSP Growth

In Chapter #3, the mathematical review and the EBO example showed how demand rate and price variability influenced ASM calculations and resultant MRSP authorizations. A review of historical ACC MRSP data is needed to answer investigative question #1 *"what are the primary causes of MRSP growth."* In this evaluation, data elements that exhibited variability were flagged for further study.

To start this evaluation, selected data elements were arrayed by stock number, by year. Next, the values for each data element were compared from year-to-year. If there was no change in the data element across all year groups, the data was eliminated as a potential cause of variability. For example, if the B-52 MRSP maintenance concept remained constant across all years and all stock numbers, then it was eliminated as a potential cause of growth. However, if the maintenance concept changed from year-to-year, it was identified as a potential contributor and flagged for further research.

Of the 62 input data elements used by ASM, 6 out 10 relevant data elements were common between the historical ACC MRSP files and the LMI-provided ASM input files. These six formed the basis for historical analysis. Table 12 summarizes the results from the evaluation of these six data elements. Appendix #I contains details on each data element analysis along with a data element definition.

Data Element	Contributor (Y/N)	Significant?
Maintenance Concept	N	N
Item Type Flag (LRU/SRU)	N	N
Cannibalization Flag	Y	N
Quantity Per Application	Y	N
Demand Rate	Y	Y
Unit Price	Y	Y

Table 12. Data Element Summary

The "contributor" column in Table 12 simply specifies that the historical data did or did not exhibit some form of variability. It is reasonable to eliminate maintenance concept and LRU/SRU flag as a cause of variability, at least from a historical perspective with the B-52, because these elements did not change over any of the year-groups. However, QPA, CANN flag, unit price, and demand rate did exhibit some form of variability and required further study.

Each "contributor" exhibited differing degrees of variability. For example, there were only three instances of a CANN flag changing in the period FY99 to FY03 (e.g. a change from "yes" to "no" in one year affecting one stock number). Likewise, the QPA only changed five times on five stock numbers over the entire period. In contrast, demand rates and prices almost always changed in each year for each stock number. Since there was only minor change in QPA and CANN flags, they were eliminated as significant causes of variability. Therefore, the remaining analysis focused on demand rates and prices. Keep in mind that there are other relevant data elements present in the ASM input file; however, these elements were not present in the historical ACC files and could not be studied for effect. For example, the ACC historical data files do not have non-optimized (NOP) quantities, so there is no way to evaluate the impact of historical changes in NOP field values. Despite the lack of matching data, there is sufficient information to proceed to phase II of the analysis.

Controlled Experiments Computing MRSPs with ASM

The objective of this analysis is to measure the impact of price and demand rate changes on final MRSP authorized quantities. To do so, prior-year rates/prices were used in place of current-year rates/prices in a series of controlled MRSP computations. All other data was held constant. Since this is the first instance in which ASM is used, it is useful to review the scenario used in the analysis (see Table 13).

WEAPON SYSTEM	B52
SCENARIO	Steady-State
PAA	6
DSO	83.33
SORTIE RATE	1
NMCS TARGET	1
HOURS/SORTIE	1
MAX SORTIES	24
DEPOT RESUPPLY	N/A
INITIAL ASSETS	0
ASSET PROJECTION	Current

Table 13. B-52 Scenario Data.

Five MRSPs were computed starting with the baseline MRSP, which was followed by four consecutive computations using FY99, FY00, FY01, and FY02 demand rates and/or prices. Table 14 shows the results of the first computation and comparison allowing for variation in the demand rates.

Data Set	Buy Qty	Total Buy Cost
FY99 Demand Rates	631	$ 22,619,868.66
FY00 Demand Rates	505	$ 17,357,810.40
FY01 Demand Rates	466	$ 17,600,069.40
FY02 Demand Rates	419	$ 15,394,805.69
FY03 Demand Rates (Baseline)	413	$ 13,806,264.49

Table 14. Baseline MRSP with FY99-FY02 Demand Rates.

The results of this comparison reveal two relevant points. First, allowing demand rates to vary while holding all other data elements constant does drive variability in the MRSP gross authorized quantities. The authorized quantities changed each year as demand rate values changed. Second, although the aggregate quantity and cost trend decreases over time, with the notable exception of FY00, there is still growth associated with each year-to-year computation. In fact, a closer look at the resultant buy quantities at the stock number level show a growth of 181 units between FY99-00, 11 units between FY00-01, 10 units between FY01-02, and 47 units between FY02-03. These growth quantities are derived by isolating and summing the stock numbers with a buy quantity increase. Note that a reduction in one stock number is not allowed to offset the quantity and cost of another part.

In practice, AFMC's budget assumes some small credit for excess MRSP assets, but only in the case that AFMC can be assured of a future sale (e.g. a maintenance customer demand). For the purposes of this research, the lack of sales data prevented including any such credit decisions.

Variability, like that shown in Table 14, illustrates the sensitivity of the model with regard to individual stock numbers and their associated rates and factors. In addition, it illustrates that growth is still a by-product of the marginal analysis, despite an overall reduction in MRSP quantity and cost. Next, the same kits were computed in the same manner, except demand rates were held constant at the FY03 value, and price was allowed to vary.

Data Set	Buy Qty	Total Buy Cost
FY99 Prices	402	$ 10,548,104.77
FY00 Prices	405	$ 11,536,773.86
FY01 Prices	405	$ 11,533,420.25
FY02 Prices	400	$ 12,028,917.76
FY03 Prices (Baseline)	416	$ 12,792,730.09

Table 15. Baseline MRSP with FY99-FY02 Prices

The effect of variable prices was not as dramatic as variable demand. This is primarily caused by the fact that prices did not exhibit near the degree of variability that was seen in demand rates, although there were changes in each data set. One data anomaly stands out when comparing prices from years to year. Only one stock number in the test dataset had a price change over the period FY00 to FY01 (e.g. 6620011873320). All other stock numbers remained at the prior year's price. Further research revealed that the prices were in fact used for the fielded FY00 and FY01 MRSPs, therefore, the dataset was not discarded. However, it is acknowledged that using relatively the same prices for two years diminished the impact of that data element on the overall growth in the test MRSPs.

To complete phase II, MRSPs were computed with variable demand rates and prices. The results of these computations are listed in Table 16.

Data Set	Buy Qty	Total Buy Cost
FY99 Rates & Prices	633	$ 17,298,310.99
FY00 Rates & Prices	501	$ 14,929,156.31
FY01 Rates & Prices	463	$ 15,211,022.88
FY02 Rates & Prices	417	$ 13,695,176.72
FY03 Demand Rates (Baseline)	416	$ 12,792,730.09

Table 16. Baseline MRSP with FY99-FY02 Demand Rates and Prices

Once again, the effect of variable demand and price is evident in that the buy quantities and total buy cost change each time demand rates and prices are allowed to vary. This is variability at the gross MRSP level (e.g. variability in the total size of the kit). Looking at the outputs of phase II reveals evidence of net growth as well. Table 17 shows the output inventory growth (in units) from phase II experiments.

Growth	FY00-99	FY01-00	FY02-01	FY03-02
Price	5	0	0	62
Demand Rate	181	11	10	47
Both	52	50	10	71

Table 17. Inventory Growth from Phase II Experiments

Both the controlled MRSP computations and the literature review provide evidence that variability in rates and prices drive growth in inventories. Multiple linear regression was used in phase III to test the significance of the effects of demand and price variability on MRSP quantity.

MRSP Multiple Linear Regression

The objective of phase III is to statistically evaluate the effect of demand rate and price changes on MRSP authorized quantities. Test results (e.g. the R^2) will be summarized and relationships will be depicted using leverage plots. The R^2, which estimates the proportion of the variation in the response around the mean that can be attributed to terms in the model rather than to random error, is evaluated in the following manner. An R^2 of one occurs when there is a perfect fit (the errors are all zero). An R^2 of zero means that the fit predicts the response no better than the overall response mean (SAS Institute, 2004:131). For the sake of brevity, only the FY03-02 MRSP leverage plot and associated data is shown in this chapter. The remaining leverage plots are given in Appendix #II.

The effect of change in demand, price, and authorized quantity was first tested when the baseline MRSP was re-computed using FY02 demand data (holding all other data constant). The results of the regression are shown in Figure 15. For a review, the regression model is setup as follows:

Null and Alternate Hypothesis:

H_o: $\beta_1 = \beta_2 = \ldots\ldots = \beta_k = 0$ (all model terms are unimportant for predicting y)
H_a: At least one $\beta_k \neq 0$ (At least one term is useful for predicting y)

Test Statistic:

$$F = \frac{R^2 / k}{(1 - R^2)/[n - (k+1)]} = \frac{MeanSquare(Model)}{MeanSqaure(Error)}$$

where n = sample size and k = the number of terms in the model

Reject Region:
$F > F_\alpha$, with k numerator degrees of freedom and $n - (k + 1)$ denominator degrees of freedom

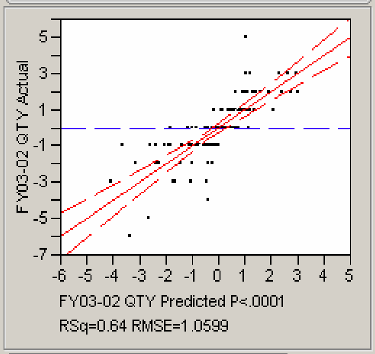
Visually, the effect of demand, price, and the interaction between price and demand are statistically significant (e.g. a steep angle to the horizontal dashed line). The leverage plot in Figure 15 shows the actual quantity delta on the y-axis and the predicted quantity delta on the x-axis.

The R^2 value is .63784, which implies that 63% of the variance about the mean is explainable by the change in demand data and/or price. This value is sufficient to affirm the relationship between a change in demand/price and a change in MRSP authorized/buy quantities. Therefore, we reject the null hypothesis and accept that at least one variable, price or demand rate, significantly effect MRSP quantities.

Response FY03-02 QTY

Whole Model

Actual by Predicted Plot



Summary of Fit

RSquare	0.63784
RSquare Adj	0.62778
Root Mean Square Error	1.059876
Mean of Response	-0.00893
Observations (or Sum Wgts)	112

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	213.67065	71.2235	63.4035
Error	108	121.32042	1.1233	Prob > F
C. Total	111	334.99107		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.1433649	0.102569	1.40	0.1651
FY03-02 COST	-0.000015	0.000001	-11.15	<.0001
FY03-02 DMD	3309.3989	332.5856	9.95	<.0001
(FY03-02 COST-5743.15)*(FY03-02 DMD+0.00004)	0.0063404	0.002663	2.38	0.0190

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
FY03-02 COST	1	1	139.67595	124.3402	<.0001
FY03-02 DMD	1	1	111.22479	99.0128	<.0001
FY03-02 COST*FY03-02 DMD	1	1	6.36727	5.6682	0.0190

Figure 15. Whole Model Results and Effects Tests for FY03-02

Intuitively, this analysis verifies the effect of demand and price change on MRSP quantities. To validate this regression model; two assumptions need to be checked by means of residual analysis. First, the mean of the residuals (e.g. the difference between an observed value and a predicted value) should equal zero (McClave et al, 2001: 636).

Also, a plot of the residuals should show equal variance across the residuals. The results of these tests check sufficiently and are graphically provided in Figure 16.

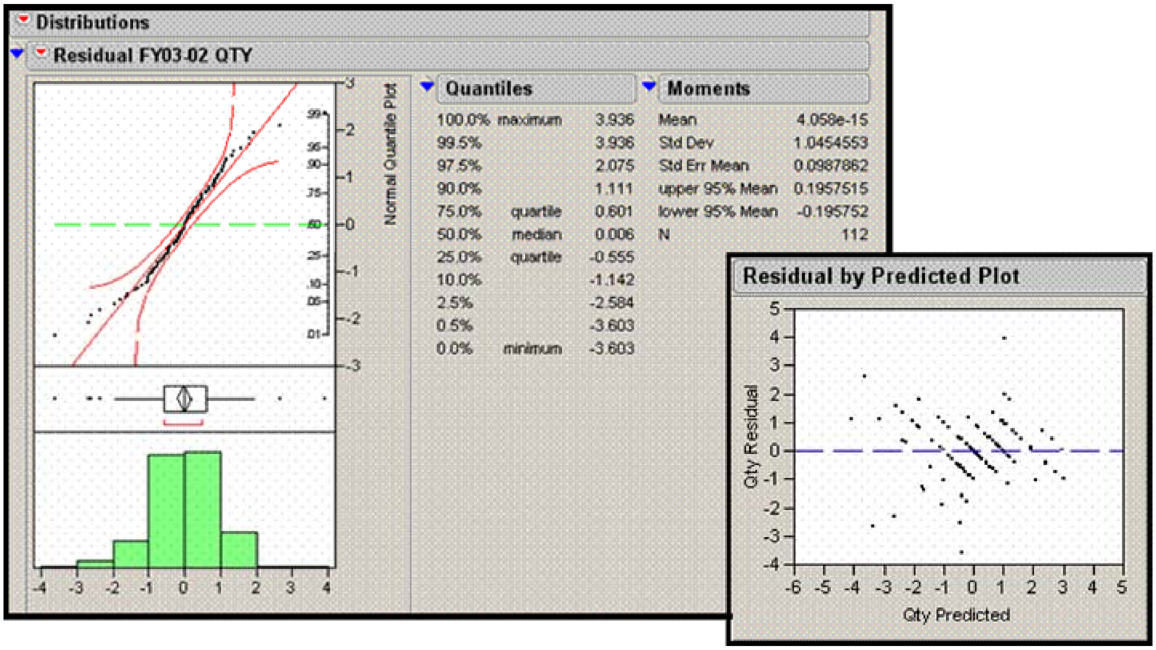


Figure 16. Normal and Residual Plot

The comparisons for other years revealed similar results, with the change in demand rate and price explaining the majority of the variance seen in MRSP quantity. The results of the regression analysis support the premise that a change in demand rates/prices drives a subsequent change in authorized quantities. Also, the literature review and phase II experiments provide evidence of this relationship. Given this evidence, it seems logical that if volatility in demand and prices could be controlled, then the growth in MRSP should be reduced. Phase IV of the analysis tests that premise.

Phase IV is focused on applying treatments to stabilize variability in MRSP authorizations and reduce the cost of MRSP growth. In phase IV, two widely accepted forms of forecasting were applied: moving averages and exponential smoothing.

Additionally, asset-based computations were conducted to determine if using prior year assets would stabilize the kit and reduce growth costs.

Analysis of Final Computations

ASM software has the capability to compute asset-based MRSPs. To do so, ASM accepts user-specified initial asset levels in several different ways. In the common case (e.g. zero initial assets), ASM determines spares mixes "from scratch." Using this method, ASM ignores available inventory and assumes all spares must be procured at the LAC. At the other extreme, ASM can evaluate the performance and cost of a specified spares mix (Slay and others, 1996: 5-5). Although the asset-based capability is available, it is not used in practice. Rather, all Air Force MRSPs are computed from scratch (King and Slay: 2001). As noted earlier, this directly addresses research question #2 *"Does the MRSP computation process recognize the sunk cost of inventory?"* However, the third research question "*Does the use of prior-year assets in MRSP computations add stability to the resultant MRSP authorizations?"* was examined through the asset-based analysis that follows.

Asset-based computations were conducted using all of the same assumptions and scenario data as used in earlier analysis. All data elements were held constant, only demand and prices were allowed to vary and the "use initial assets" switch in ASM was activated. Like former analysis, the population of stock numbers used was limited to the 112 numbers present in all five year-groups. Initial assets were estimated based on the prior year's MRSP authorized quantities. Four different computations were made for each year (e.g. FY00, FY01, FY02, and FY03) using varying percentages of initial assets.

The rationale for feeding the model different sizes of inventory is to see how authorized quantities and cost behave in response to different values of inventory.

Three separate asset-based computations were processed using three separate approaches.

1. Asset-based computations with excess initial assets (e.g. more than 100% of the prior year's authorized quantities
2. Asset-based computations capped at the optimal quantity and limited to 100 percent of the prior year's authorized quantities
3. Asset-based computations capped at the optimal quantity, limited to 100 percent of the prior year's authorizations, with exponentially smoothed demand rates and moving average costs

For the sake of brevity, only the final analysis is shown here in chapter #4. However, the other results are presented in Appendix #III. The initial set of asset-based computations with excess assets unleashed the greediness of the model. Given the opportunity to achieve reductions in EBO at no cost, the model absorbs almost all initial assets. Capping initial assets contained the model's greediness, but did not stabilize the gross inventory. However, applying all treatments helped stabilize growth and reduce cost as shown over the next few paragraphs.

Before computing any asset-based computations, a preparatory treatment was used to prepare the data. First, all MRSPs (e.g. FY99, FY00, FY01, FY02, and FY03) were computed with all unit costs set equal to $1. The output was an "optimal" mix of spares based on contribution to availability (e.g. the DSO) and constrained the cost-related marginal analysis function in ASM. The output authorizations from these cost-neutral computations served as the upper bound (e.g. cap) for initial assets. Last, percentages of the prior year's authorized quantities were applied ranging from zero to 100 percent, which prevents excess assets to enter the experiment.

The final analysis also applied widely-accepted forecasting techniques along with initial assets in order to stabilize the growth and associated cost. All MRSPs in this analysis were computed using a moving average cost, exponentially smoothed demand, and 100% of the previous year's MRSP quantity. As shown in Table 18, using all treatments dramatically reduced growth over the kit computed from scratch and all other asset-based combinations.

Growth	FY01-00	FY02-01	FY03-02
Standard	50	10	71
Asset-base, 120% Prior Year Spares (No Cap)	100	57	26
Asset-Based - Capped at Optimal MRSP Qty	11	10	47
Asset-Based - Capped, Smoothed & Averaged	0	19	6

Table 18. Growth Comparison – All Analysis

Applying all three treatments provides the largest reduction in growth and the most benefit in terms of stability and cost. When compared to current practices (e.g. computing MRSPs from scratch), these results represent a 96 percent reduction in growth cost over the period FY00-FY03 (see Table 19).

Growth	Standard	All Treatments	Standard	All Treatments
	Quantity		Cost	
FY01-00	50	0	$ 1,859,254.18	$ -
FY02-01	10	19	$ 245,603.65	$ 121,044.50
FY03-02	71	6	$ 4,331,315.26	$ 130,751.10
Sum	**131**	**25**	**$ 6,436,173.09**	**$ 251,795.60**

Table 19. Results of MRSP Computations with all three treatments

Applying all three treatments achieves the objective of stabilizing the MRSP inventory and reducing growth cost. These treatments achieved a $6.2M growth cost difference, yet the provided an MRSP equal in capability as that of the standard computation.

Since these experiments were conducted using actual MRSP data and computation processes identical to those used in practice, the Air Force should reap similar benefits if these methods (e.g. treatments) were implemented. However, applying cost savings generically to all weapon system and MRSPs would be erroneous. The true cost savings across weapon systems is dependent on the availability of inventory, the variability of demand, and the cost of specific weapon system spares. In the case of a weapon system with stable demand, the benefit is expected to be less significant. However, where erratic demand and prices exist, these treatments, if implemented, should help reduce inventory volatility and reduce cost.

Summary

The analysis discussed in this chapter answered three distinct investigative questions. First, a review of historical MRSP data and basic controlled experiments showed that demand rates and prices were the primary causes of variability and growth in historical and test MRSPs. Second, using asset-based computations does not in itself add stability to gross MRSP inventories. However, the application of exponential smoothing, moving average costs, and asset-based computations does reduce growth and add stability to the MRSP. Conclusions and recommendations based on these analyses results follow in Chapter #5.

V. Conclusions

Introduction

This thesis sought to identify the causes of MRSP growth and find methods to stabilize MRSP inventory and associated cost. Air Force Materiel Command is required to budget for MRSP inventories as an additive part of the worldwide requirement for spares. These inventories drive significant costs and consume a large part of the Air Force sustainment budget. Any improvement, in terms of reducing unnecessary cost, frees up scare dollars for other priority requirements. The thesis was guided by four distinct investigative questions:

1. What are the primary causes of MRSP growth?
2. Does the MRSP computation process recognize the sunk cost of inventory?
3. Does the use of prior-year assets in MRSP computations add stability to the resultant authorizations?
4. Can widely-accepted techniques reduce the amount of growth and subsequent cost from year to year?

The remainder of this thesis will be dedicated to answering these questions and presenting any conclusions and recommendations drawn from the results of the research.

What are the primary causes of MRSP growth?

Variability in demand rates and prices are the primary causes of MRSP inventory growth. Both the results of the literature review and controlled experiments/analysis support this conclusion. It is reasonable to assume that other data elements, if allowed to vary from year-to-year, would have an effect on growth. This effect may be positive or negative, depending on the nature of the data and how the data is used in the MRSP computation. However, historical review of ACC B-52 test data shows that demand rates and prices exhibit the vast majority of variability among the plethora of data elements used to compute test MRSPs.

Given that demand rate and prices vary from year-to-year, it is important for Air Force managers to understand the causes of variability and attempt to control it. A certain level of variability is expected in any stochastic process. However, self-induced variability should be minimized and avoided. Air Force managers can help reduce unnecessary variability by standardizing processes, procedures, and training. Further, when variability exists, applying commonly-accepted control methods can stabilize the variability and keep inventory growth under control.

Does the MRSP computation process recognize the sunk cost of inventory?

Unfortunately, current MRSP computations do not consider the sunk cost of inventory or prior-year assets. This practice is wasteful as standard *scratch*-based computations yield unnecessary growth, which ultimately drives a cost to the Air Force. Computing from scratch ignores the fact that inventory needed to fill MRSPs is purchased ahead of need through the computation and management of "buy" kits. Further, computing from scratch at LAC ignores the fact that it may be more cost-effective to keep a spare in the MRSP than to replace it with a different spare.

Ignoring prior-year spares adds volatility to the peacetime requirement and may generate excesses in total Air Force inventories. In contrast to standard MRSP computations, the peacetime requirement is computed using an asset-based approach via D200 – the Requirements Management System. Given there is precedence for asset-based computations and benefit in terms of cost/budget reduction as defined by this research, it seems reasonable to make wartime spares computation procedures consistent with peacetime business practices. Based on the potential benefit demonstrated in this thesis, the Air Force should use asset-based computations for MRSPs.

Does the use of prior-year assets in MRSP computations add stability to the resultant authorizations?

In short, there was no evidence found through this research that supports the idea that asset-based computations exclusively add stability to MRSP authorizations. Asset-based computations do reduce the cost associated with procurement by properly accounting for the sunk cost of inventory. However, this research showed that using other commonly-accepted methods does add stability to the process and result in less growth and lower cost.

Can widely-accepted techniques reduce the amount of growth and subsequent cost from year to year?

This research found that using exponential smoothing and moving average costs helped mitigate growth by stabilizing the MRSP inventory. There is precedence for the use of both of these methods. Both methods are consistent with methods used in the computation of peacetime spares. Three of the four techniques coded into D200 employ two or four quarter moving averages and/or exponential smoothing (Clark, 2002: 13). Additionally, AFMC/FM is implementing moving average costs as the preferred method for inventory valuation (Stafford and others, 2002: 64). Applying the MAC to MRSPs is appropriate in that the unit price is not the cost of placing an asset in the MRSP nor is the current LAC the price paid at the point an MRSP asset was procured. Typically, the actual price paid is the price of the spare at least two years ago.

Applying exponential smoothing, moving average cost, and asset-based computations to the test dataset reduced both the dollar value of the gross MRSP and reduces the growth exhibited from year-to-year. Additionally, applying all three treatments provided the largest reduction in growth and the most benefit in terms of stability and cost as compared to other individual treatments. When test results are compared to current practices (e.g. a standard MRSP computation), a 96 percent reduction in growth cost over the period FY00-FY03 is achieved (see

Table **20**).

Growth	Standard	All Treatments	Standard	All Treatments
	Quantity		Cost	
FY01-00	50	0	$ 1,859,254.18	$ -
FY02-01	10	19	$ 245,603.65	$ 121,044.50
FY03-02	71	6	$ 4,331,315.26	$ 130,751.10
Sum	**131**	**25**	**$ 6,436,173.09**	**$ 251,795.60**

Table 20. Standard vs. Treated MRSP Computations

Applying all three treatments achieves the objective of stabilizing the MRSP inventory and reducing growth cost. These treatments achieved a $6.2M growth cost difference, yet provided an MRSP with the same capability as the standard approach. This represents the potential cost reduction in one MRSP, for one weapon system at one base. Currently the Air Force maintains 45 airborne weapon systems and 267 MRSPs worldwide.

Managerial Implications

In terms of feasibility, implementing an asset-based approach is feasible in that the capability exists. ASM has the functionality; however, a system change would be required to implement asset-based computations in WSMIS/REALM, the legacy system used to compute MRSPs. Further, feasibility is dependent on two issues. First, available assets must be quantifiable and attributable to the MRSP. Segregating MRSP from peacetime spares for accountability purposes is appropriate and does not violate the spirit and intent of the "a spare is a spare" concept. Second, available assets must be capped no higher than 100% of last year's MRSP. Providing more than the previous year's MRSP authorizations, though done for a portion of this thesis, would be impractical since it would imply reaching into peacetime spares. Further, the greedy nature of the ASM, left unconstrained, would generally absorb any inventory it was given to a point that even exceeds the inventory needed to achieve the DSO.

Although feasible, there is one other consideration worth noting and addressing: *at what point is it appropriate to take a stock number out of the MRSP?* Under current practice, changes in rates, factors, and prices drive assets in and out of the MRSP. Under an asset-based approach, the greedy nature of the model might hold an item despite a large increase in price. To remedy these cases, it may be appropriate to use a demand floor or lower control limit that essentially eliminates an item from the MRSP when there is not enough demand to warrant continued presence in the MRSP. Also, it is important to remember that MRSP breadth is influenced and shaped by asset modifications and TCTOs. In some cases, stock numbers that are no longer useful will be removed as new modifications are brought into the weapon system.

It is clear that the experiments reveal significant reductions in inventory growth and cost. Since these experiments were conducted using actual MRSP data and identical computation processes, the Air Force should expect to reap similar benefits in practice. However, applying cost savings generically to all weapon system and MRSPs would be erroneous. The true saving as across weapon systems is dependent on the availability of inventory, the variability of demand, and the cost of specific weapon system spares. In the case of a weapon system with stable demand, the benefit is expected to be less significant. However, where erratic demand and prices exist, these treatments, if implemented, should help reduce inventory volatility and reduce cost.

Recommendations for Future Research

This research found the Air Force could achieve significant budget reductions and long-term inventory savings by controlling variable data. Three areas of further study would compliment this effort and improve our understanding of MRSPs and the processes used to develop them.

First, research needs to be done to determine at what point it is appropriate to take a stock number out of the MRSP. Under current practice, changes in rates, factors, and prices drive assets in and out of the MRSP. Under an asset-based approach, the greedy nature of the model might hold an item despite a large increase in price. A method needs to be developed to establish a demand floor or lower control limit that essentially eliminates an item from the MRSP when a certain criteria is breeched (i.e.. there is not enough demand to warrant continued presence in the MRSP or contribution to the DSO reaches an extremely low level, etc).

Next, at a time where the United States faces a new war, the War on Terrorism, and the Air Force is striving to be expeditionary, it is fair to examine the adequacy of the current 2-MTW plan used to develop MRSPs. The intent here would not be to re-write the WMP-5. However, logisticians should develop ideas and a basic understanding of how MRSPs should be developed to support the changes in deployment characteristics. One of the first questions to examine is "What is a wartime demand rate?" Current practice is to use peacetime rates to model wartime demands. Given the demands of boiling peace and the fact that training requirement are often more rigorous than war, is it fair to estimate wartime using peacetime rates?

Last, the 12-month MRSP Review Cycle is a process ripe for reengineering. Most duties associated with the management of MRSPs could be done as additional duties for a typical MAJCOM staff NCO. The Air Force continues to suffer from dirty data issues in the collection of demand rates (e.g. the R-54 process) and disagreement over rates, factors, and item characteristics lead to inappropriate human intervention. There are significant efficiencies to be gained by reengineering the MRSP review process.

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Appendix #I – Historical Analysis

Maintenance Concept

Maintenance concept identifies if an asset is a two or three level maintenance item. By two-level, we say the assets is *removed and replaced* on the aircraft at the point of failure. In these cases, no base-level repair is authorized. By three-level, we say the item is *removed, repaired, and replaced* at base-level, meaning there is some base-level capability and the repair is authorized at base-level. The ASM Users Manual defines maintenance concept in the following manner:

> Maintenance—Definition: This field determines the point at which (if ever) wartime base and depot repair of failed LRUs and SRUs begins. The maintenance concept is used to group spares to establish when repair begins for each group in wartime. Specifically, Maintenance can be used to determine when base and depot repair begin during war for RR (remove and replace) LRUs, RRR (remove, repair, and replace) LRUs, and SRUs. The standard use of those categories assumes that the RRR items have repair start early in the war and that the RR items have no repair until later in the war. However, you may designate LRUs as either RR or RRR on the basis of your own categorization separating them into any two groups differentiated by having their repair start on different days of the war (Kline and others, 1999: A-27)

Comparison of B-52 maintenance concept data across the period FY99 – FY03 revealed no change for any stock number over the five-year period.

Item Type Flag (LRU/SRU)

Item type flags designate an item as a line replacement unit (LRU) or a shop replacement unit (SRU). Typically, LRU is used to refer to end-items or "black boxes." An SRU typically refers to a circuit card or other subcomponent of an LRU. Although the item flag itself will not drive a change in quantity, a change from strictly LRUs to a mix of LRUs and SRUs implies a change maintenance concept (e.g. moving from two to three levels of maintenance at the deployed site). A comparison of B-52 item type codes reveals no change in any stock number over the five-year period.

Cannibalization Flags

A Cannibalization Flag (CANN flag) denotes if it is feasible to remove a spare from one aircraft (donor) and install it on another (gaining). Ideally, this decision is made because no other spares are available and an aircraft is needed to fly a wartime mission for which there are no other mission capable aircraft. Cannibalization actions are modeled because they (1) will happen, and (2) accounting for CANN actions ultimately reduces the total inventory needed to support deployed forces.

The CANN flag itself is not a complicated number, rather, it is a simple data element (e.g. "Y" for feasible; "N" for infeasible). In the view of ASM, cannibalization raises aircraft availability for a given cost; therefore to reach the availability target, fewer spares are required. But it is also true that, for a given availability, as the degree of cannibalization increases, so does the number of expected backorders (Slay and others, 1996: 5-10).

In terms of computation, two model inputs, quantity per application and the non-mission capable supply (NMCS) target, have a significant impact on the number of potential CANN actions. Larger NMCS targets permit more cannibalization; since cannibalization is free (from a procurement perspective), the model uses it to reduce NMCS aircraft (Slay and others, 1996: 5-10). Supporting a QPA quantity larger than one requires more assets in the MRSP, but also provides a larger amount of spares to cannibalize.

With regard to this analysis, when the CANN flags change, the resulting MRSP quantities are expected to be different from year-to-year. Once again, if the flags are stable (e.g. remain constant from year-to-year), they can be eliminated as a possible cause of historical MRSP volatility. Likewise, if there is a large amount of variation from year-to-year, CANN flags will be added to the population of "root cause" data elements.

A quick comparison of CANN flags for B-52 MRSPs (FY99 – FY03) revealed only three stock numbers that experienced a change in the CANN Flag (see Table 21. B-52 MRSP CANN Flags, Units Prices, Demands Rates and Quantities). Consequently, analysis reveals that other data elements (e.g. prices and demands) were also variable across the same time-period.

	CANN Flag				Unit Price				Demand Rate				MRSP Quantity			
NSN	FY99	FY00	FY01	FY02	FY99	FY00	FY01	FY02	FY99	FY00	FY01	FY02	FY99	FY00	FY01	FY02
1680006327844	N	Y	Y	Y	$ 2,057.94	$ 1,784.79	$ 1,784.79	$ 1,916.67	0.0917	0.0565	0.0109	0.0095	5	4	4	4
5930002294052HS	N	Y	Y		$ 624.05	$ 1,325.67	$ 1,325.67	-	0.0816	0.0417	0.0023	-	6	4	2	-
5996013849562FG	N	Y	Y	Y	$ 21,210.05	$ 21,273.46	$ 21,273.46	$ 29,314.11	0.0623	0.0556	0.0476	0.0266	3	3	2	2

Table 21. B-52 MRSP CANN Flags, Units Prices, Demands Rates and Quantities

For the sake of brevity, the CANN flags are shown in Table 21. B-52 MRSP CANN Flags, Units Prices, Demands Rates and Quantities along with unit price, demand rate, and the resultant MRSP quantity. The MRSP quantity changed from FY99 to FY00 as did the CANN flag, but it cannot be concluded that the cause of the change was due to the change in CANN flag alone. In all cases, the demand rates and unit prices changed, which could also have driven the change in MRSP quantity. In fact, analysis of demand rates and unit prices across all stock numbers in all year-groups shows that change in rates and prices is the norm rather than the exception. Unlike maintenance concept and item type codes, CANN flags cannot be eliminated as a contributor of MRSP variability.

Quantity per Application

The QPA shows how many of an item is on an end-item or aircraft. For example, A B-52 has eight main landing gear wheels, so the QPA for this wheel is eight. A relationship exists between QPA and next higher assemblies (NHAs). Quantity per application is assigned under the assumption that the NHA is one. In the B-52 example, the NHA for the main landing gear wheel is one – the *aircraft*.

The QPA follows the same logic with respect to variability and expected impact. All things remaining equal, a change in QPA is expected to drive a change in the final MRSP authorization. A comparison of historical B-52 QPAs revealed that the QPA did change by at least one for five stock numbers. The QPAs and MRSP quantities for these five stock numbers is shown in Table 22.

	QPA					QTY				
MRSP NSN	FY99	FY00	FY01	FY02	FY03	FY99	FY00	FY01	FY02	FY03
1280010730473	1	2	2	2	2	4	4	2	3	3
1280012270719	1	2	2	2	2	5	4	4	4	4
1630013154062	1	8	8	8	8	3	3	10	9	10
4320004743550HS	6	4	4	4	4	6	6	4	5	3
4810008095147RV	16	16	8	8	8	12	6	6	6	5

Table 22. B-52 QPA Changes

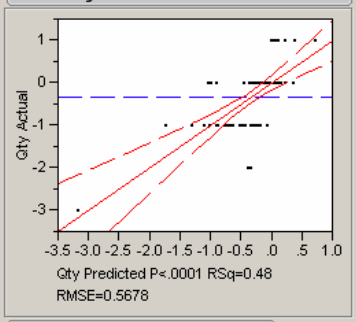
Unfortunately, the comparison of historical QPA data did not yield consistent results. For example, when the QPA for stock number 1280010730473 changed from one to two, the final MRSP quantity stayed the same. Likewise, when the QPA for stock number 4810008095147RV went from 16 to eight, there was no change in the MRSP quantity. This implies that, in this case, another factor drove the change, or lack of change in MRSP quantity. However, in the bigger picture, it also implies that QPA cannot be eliminated as a contributor of MRSP variability.

Appendix #II – Statistics Summary

Response Qty

Whole Model

Actual by Predicted Plot



Summary of Fit

RSquare	0.481588
RSquare Adj	0.459987
Root Mean Square Error	0.5678
Mean of Response	-0.32895
Observations (or Sum Wgts)	76

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	21.563732	7.18791	22.2952
Error	72	23.212584	0.32240	Prob > F
C. Total	75	44.776316		<.0001

Parameter Estimates

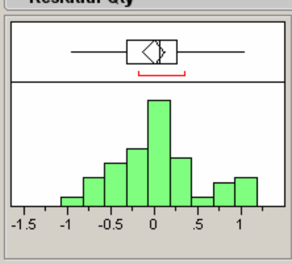
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-0.119477	0.080168	-1.49	0.1405
Cost	0.0000279	0.000026	1.06	0.2933
DmD	2279.0661	362.7973	6.28	<.0001
(Cost-1341.01)*(DmD+0.00012)	-0.059133	0.041565	-1.42	0.1592

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Cost	1	1	0.361262	1.1206	0.2933
DmD	1	1	12.722628	39.4626	<.0001
Cost*DmD	1	1	0.652512	2.0239	0.1592

Distributions

Residual Qty



Quantiles

100.0%	maximum	1.030
99.5%		1.030
97.5%		0.993
90.0%		0.900
75.0%	quartile	0.265
50.0%	median	0.073
25.0%	quartile	-0.316
10.0%		-0.734
2.5%		-1.631
0.5%		-1.665
0.0%	minimum	-1.665

Moments

Mean	1.012e-15
Std Dev	0.5563282
Std Err Mean	0.0638152
upper 95% Mean	0.1271265
lower 95% Mean	-0.127126
N	76

Residual by Predicted Plot

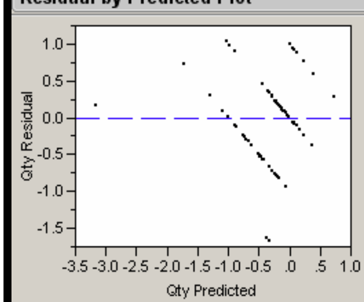


Figure 17. FY02-FY01 Multiple Linear Regression Results

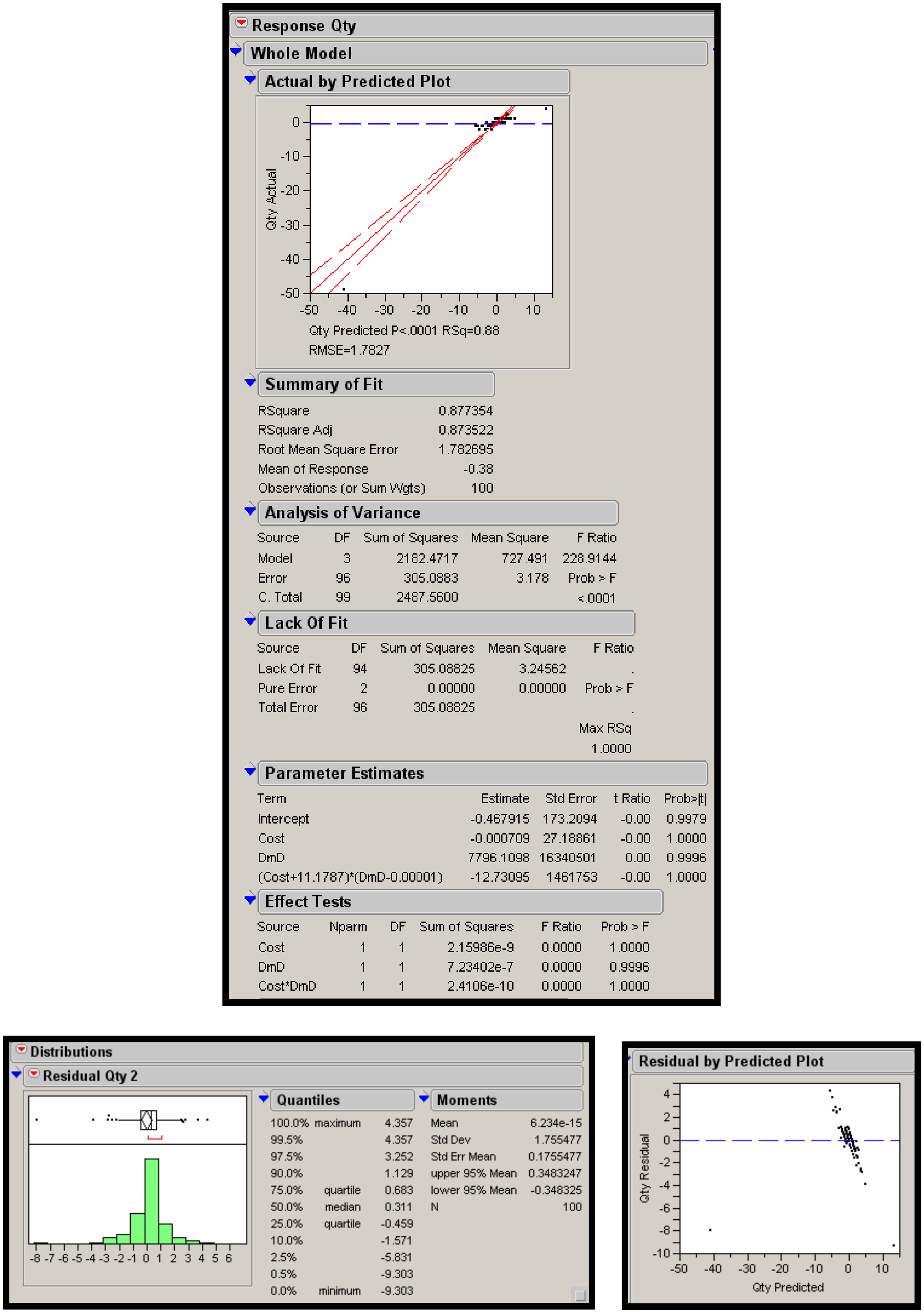
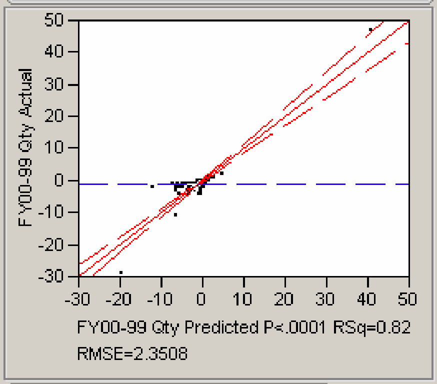


Figure 18. FY01-FY00 Multiple Linear Regression Results

Response FY00-99 Qty

Whole Model

Actual by Predicted Plot



Summary of Fit

RSquare	0.820678
RSquare Adj	0.815697
Root Mean Square Error	2.350848
Mean of Response	-1.17857
Observations (or Sum Wgts)	112

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	2731.5683	910.523	164.7562
Error	108	596.8603	5.526	Prob > F
C. Total	111	3328.4286		<.0001

Parameter Estimates

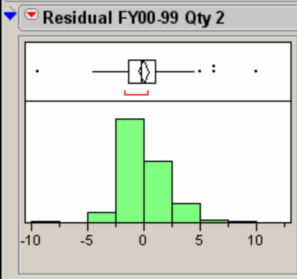
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	1.026475	0.257969	3.98	0.0001
FY00-99 Cost	-0.000039	0.000033	-1.21	0.2305
FY00-99 Dmd	7691.3336	349.3505	22.02	<.0001
(FY00-99 Cost-2670.21)*(FY00-99 Dmd+0.00026)	-0.229196	0.067236	-3.41	0.0009

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
FY00-99 Cost	1	1	8.0370	1.4543	0.2305
FY00-99 Dmd	1	1	2678.7336	484.7085	<.0001
FY00-99 Cost*FY00-99 Dmd	1	1	64.2189	11.6202	0.0009

Distributions

Residual FY00-99 Qty 2



Quantiles

100.0%	maximum	9.971
99.5%		9.971
97.5%		6.205
90.0%		2.997
75.0%	quartile	1.010
50.0%	median	-0.264
25.0%	quartile	-1.314
10.0%		-1.974
2.5%		-3.635
0.5%		-9.393
0.0%	minimum	-9.393

Moments

Mean	4.556e-14
Std Dev	2.3188617
Std Err Mean	0.2191118
upper 95% Mean	0.4341847
lower 95% Mean	-0.434185
N	112

Residual by Predicted Plot

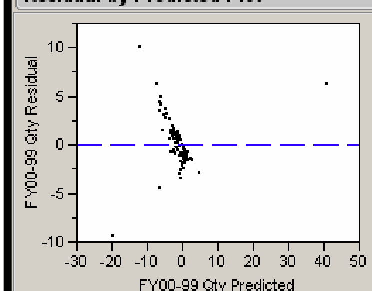


Figure 19. FY00-FY99 Multiple Linear Regression Results

Appendix #III. Asset-based Computations with Excess Spares

The first set of asset-based computations were conducted using excess assets. The percent of available assets ranged from zero to two hundred percent. Reviewing the analyses reveals three results. First, there was no consistent behavior in the output gross authorized quantities when assets are applied. In two cases, authorized quantities remained relatively stable, at least when up to 100% of the prior-year assets were applied. In two other cases, the output authorizations gradually increased. Second, given more than 100 percent of the prior-year's kit unleashes the greediness of the ASM model. This is to be expected as model logic would surely recognize and consume an improvement in EBO at no additional cost. Third, when given a portion of last year's kit, only a small amount of new buys are required to cover the DSO in the new kit. For example, supplying 60 percent of the prior-year's assets reduces, on average, the cost of new buys to about a third of the cost of the full kit. Again, this is to be expected as any asset provided up front should be expected to reduce the overall buy cost of the new MRSP. The numerical results for the first set of asset-based computations is provided in Table 23. Using excess assets (e.g. 120 and 200 percent of the prior year's authorizations) drove instability as much as or greater than the instability induced by variability in rates and prices. Since the objective of this research is to find ways to mitigate instability, a second approach was used to further evaluate the usefulness of asset-based computations.

Asset-based - Prior year Spares (No Cap)					
FY00	**Initial Assets**	**Buy Total**	**Total Auth**	**Buy Cost**	**Kit Cost**
0 Percent	0	631	631	$ 22,619,686.66	$ 22,619,686.66
60 Percent	302	353	640	$ 12,251,269.22	$ 22,729,016.86
80 Percent	404	261	638	$ 8,680,843.66	$ 22,681,970.13
100 Percent	505	179	645	$ 6,086,889.06	$ 22,970,935.26
120 Percent	606	107	662	$ 3,989,308.49	$ 23,756,274.42
200 Percent	1010	16	913	$ 172,744.82	$ 32,472,656.57
FY01	**Initial Assets**	**Buy Total**	**Total Auth**	**Buy Cost**	**Kit Cost**
0 Percent	0	466	466	$ 17,600,069.40	$ 17,600,069.40
60 Percent	380	110	478	$ 4,211,125.18	$ 17,797,496.23
80 Percent	500	32	512	$ 1,423,994.86	$ 19,153,505.17
100 Percent	631	0	601	$ -	$ 22,281,379.59
120 Percent	762	0	716	$ -	$ 26,760,414.98
200 Percent	1262	0	965	$ -	$ 40,687,035.23
FY02	**Initial Assets**	**Buy Total**	**Total Auth**	**Buy Cost**	**Kit Cost**
0 Percent	0	419	419	$ 15,394,805.69	$ 15,394,805.69
60 Percent	276	160	436	$ 4,695,361.61	$ 16,287,456.94
80 Percent	367	99	462	$ 2,787,836.33	$ 17,983,717.05
100 Percent	466	64	516	$ 1,598,890.51	$ 20,239,332.80
120 Percent	565	43	582	$ 983,147.02	$ 22,830,311.86
200 Percent	932	0	756	$ -	$ 30,641,199.53
FY03	**Initial Assets**	**Buy Total**	**Total Auth**	**Buy Cost**	**Kit Cost**
0 Percent	0	413	413	$ 13,806,264.49	$ 13,806,264.49
60 Percent	245	176	421	$ 4,512,452.75	$ 15,010,617.19
80 Percent	336	105	440	$ 2,531,885.04	$ 16,310,038.26
100 Percent	419	24	443	$ 313,529.04	$ 15,708,334.73
120 Percent	502	48	534	$ 614,700.33	$ 20,193,579.56
200 Percent	838	0	704	$ -	$ 27,999,942.71

Table 23. Asset-based Comps with Prior Year's Spares (No Cap)

In the second analysis, prices and demand rates were allowed to vary from year-to-year. Before computing these asset-based kits, a preparatory treatment was used to prepare the data. First, all MRSPs (e.g. FY99, FY00, FY01, FY02, and FY03) were computed with all unit costs set equal to $1. The output was an "optimal" mix of spares based on contribution to the DSO and constrained the cost-related marginal analysis function in ASM. The output authorizations from these cost-neutral computations served as the upper bound (e.g. cap) for initial assets.

A standard kit (zero assets) was computed at the onset and then a percent of the prior-year's assets was applied in increments of 20 percent, stopping at 100 percent, which prevents excess assets to enter the experiment. In all, six runs (or computations) were completed for each year; FY00, FY01, FY02, and FY03 (e.g. 24 runs in all).

Asset-Based - Capped at Optimal MRSP Qty					
FY00	**Initial Assets**	**Buy Total**	**Total Auth**	**Buy Cost**	**Kit Cost**
0 Percent	0	635	635	$ 19,053,917.07	$ 19,053,917.07
20 Percent	37	598	635	$ 17,542,538.40	$ 19,053,917.07
40 Percent	86	549	635	$ 15,775,354.33	$ 19,053,917.07
60 Percent	143	492	635	$ 13,678,816.75	$ 19,053,917.07
80 Percent	192	443	635	$ 11,911,632.68	$ 19,053,917.07
100 Percent	229	407	636	$ 10,501,010.01	$ 19,154,673.07
FY01	**Initial Assets**	**Buy Total**	**Total Auth**	**Buy Cost**	**Kit Cost**
0 Percent	0	463	463	$ 15,211,022.88	$ 15,211,022.88
20 Percent	37	426	463	$ 13,706,613.60	$ 15,211,022.88
40 Percent	83	380	463	$ 12,260,779.67	$ 15,211,022.88
60 Percent	142	321	463	$ 9,708,251.15	$ 15,211,022.88
80 Percent	188	275	463	$ 8,262,417.22	$ 15,211,022.88
100 Percent	225	238	463	$ 6,758,007.94	$ 15,211,022.88
FY02	**Initial Assets**	**Buy Total**	**Total Auth**	**Buy Cost**	**Kit Cost**
0 Percent	0	417	417	$ 13,695,176.72	$ 13,695,176.72
20 Percent	28	389	417	$ 12,830,220.23	$ 13,695,176.72
40 Percent	68	349	417	$ 11,445,687.80	$ 13,695,176.72
60 Percent	123	297	420	$ 9,713,830.29	$ 13,822,857.54
80 Percent	191	229	420	$ 7,464,341.37	$ 13,822,857.54
100 Percent	163	257	420	$ 8,329,297.86	$ 13,822,857.54
FY03	**Initial Assets**	**Buy Total**	**Total Auth**	**Buy Cost**	**Kit Cost**
0 Percent	0	413	413	$ 13,806,264.49	$ 13,806,264.49
20 Percent	28	385	413	$ 13,170,139.06	$ 13,806,264.49
40 Percent	70	343	413	$ 11,909,294.97	$ 13,806,264.49
60 Percent	118	293	411	$ 10,544,504.09	$ 13,892,152.93
80 Percent	160	251	411	$ 9,283,660.00	$ 13,892,152.93
100 Percent	188	224	412	$ 8,708,293.62	$ 13,952,911.98

Table 24. Asset-based Computations – Capped at the Optimal MRSP Quantity

The results of the cost-neutral, asset-based analysis reveal three important findings. First, eliminating the presence of excess assets limits of keeps the greedy nature of the model in check. Growth at the *gross* MRSP level assets was minimal amounting to three extra units of stock at the highest point. Net growth was also reduced once prior year spares were capped (see Table 25). Next, limiting initial assets to the availability-based optimal kit quantity instilled stability in total units authorized and total kit cost. Last, it is rational to conclude from the results of this experiment that asset-based computations can diminish variability in MRSP authorizations at the gross level. Table 24 summarizes the results of this experiment.

Growth	FY01-00	FY02-01	FY03-02
Standard	50	10	71
Asset-base, 120% Prior Year Spares (No Cap)	100	57	26
Asset-Based - Capped at Optimal MRSP Qty	11	10	47

Table 25. Growth Comparison

The final analysis also applied widely-accepted forecasting techniques along with initial assets in order to stabilize the growth and associated cost. All MRSPs in this analysis were computed using a moving average cost, exponentially smoothed demand, and 100% of the previous year's MRSP quantity. As shown in Table 26, using all treatments dramatically reduced growth over the kit computed from scratch and all other asset-based combinations. Applying all three treatments provides the largest reduction in growth and the most benefit in terms of stability and cost. The detailed results of this analysis are provided in Table 27.

Growth	FY01-00	FY02-01	FY03-02
Standard	50	10	71
Asset-base, 120% Prior Year Spares (No Cap)	100	57	26
Asset-Based - Capped at Optimal MRSP Qty	11	10	47
Asset-Based - Capped, Smoothed & Averaged	0	19	6

Table 26. Growth Comparison – All Analysis

Asset-Based - Capped, Smoothed & Averaged					
FY00	Initial Assets	Buy Total	Total Auth	Buy Cost	Kit Cost
0 Percent	0	573	573	$ 16,308,650.17	$ 16,308,650.17
20 Percent	101	472	573	$ 13,737,740.30	$ 16,308,650.17
40 Percent	203	370	573	$ 10,622,100.61	$ 16,308,650.17
60 Percent	301	272	573	$ 7,387,159.19	$ 16,308,650.17
80 Percent	380	203	583	$ 4,481,225.94	$ 16,413,394.34
100 Percent	420	169	588	$ 2,715,983.64	$ 16,734,529.50
FY01	Initial Assets	Buy Total	Total Auth	Buy Cost	Kit Cost
0 Percent	0	491	491	$ 15,265,553.51	$ 15,265,553.51
20 Percent	116	374	490	$ 11,710,156.69	$ 15,229,348.70
40 Percent	230	265	495	$ 8,659,951.76	$ 15,302,382.62
60 Percent	324	176	499	$ 5,116,973.57	$ 15,305,429.29
80 Percent	426	83	503	$ 2,223,156.64	$ 15,422,705.19
100 Percent	490	18	496	$ 211,930.38	$ 16,548,554.30
FY02	Initial Assets	Buy Total	Total Auth	Buy Cost	Kit Cost
0 Percent	0	443	443	$ 14,727,331.84	$ 14,727,331.84
20 Percent	105	338	443	$ 11,571,626.90	$ 14,727,331.84
40 Percent	194	249	443	$ 8,659,922.48	$ 14,727,331.84
60 Percent	272	175	447	$ 5,227,611.76	$ 14,468,883.45
80 Percent	337	111	448	$ 2,507,182.36	$ 14,624,954.45
100 Percent	378	51	429	$ 294,073.03	$ 15,517,172.15
FY03	Initial Assets	Buy Total	Total Auth	Buy Cost	Kit Cost
0 Percent	0	421	421	$ 13,870,074.89	$ 13,870,074.81
20 Percent	92	329	421	$ 10,741,418.82	$ 13,870,074.81
40 Percent	181	243	424	$ 7,269,365.21	$ 13,845,915.08
60 Percent	253	170	423	$ 4,797,118.36	$ 13,866,093.43
80 Percent	316	99	415	$ 1,352,335.48	$ 13,886,028.88
100 Percent	348	40	388	$ 333,676.85	$ 15,700,115.47

Table 27. Asset-based – Capped, Smoothed, & Averaged

Vita

Captain Stephen D. Gray graduated from Miramar High School in Miramar, Florida. He enlisted in the Air Force in 1983 and attended Louisiana Tech University and Southern Illinois University, completing undergraduate studies and graduating with a Bachelor of Science degree in Industrial Technology in May 1992. He was commissioned through Officer Training School in 1994.

His first assignment was at Headquarters Air Force Materiel Command at Wright-Patterson AFB as a staff officer in the Supply Division and the Lean Logistics Office where he teamed with others in the development of Lean Logistics and the Depot Repair Enhancement Program (DREP). In 1996, he was assigned to the Depot Reengineering Office, Warner-Robins Air Logistics Center, Robins AFB, GA and managed the implementation of DREP across 86 repair centers and 12 Product Directorates. In 1998, Captain Gray was assigned to Headquarters Air Combat Command, as the Chief, Command RSP Section, Weapon System Support Branch. In Aug 2002, he entered the Graduate School of Engineering and Management, Air Force Institute of Technology. Upon graduation, he will be assigned to Headquarters Air Force Materiel Command.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 074-0188

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From – To)*
02-26-2004	**Master's Thesis**	Sep 2003 - Mar 2004

4. TITLE AND SUBTITLE
MITIGATING GROWTH COST FOR MOBILITY READINESS SPARES PACKAGES

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Gray, Stephen D., Captain, USAF

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(S)
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8. PERFORMING ORGANIZATION REPORT NUMBER
AFIT/GLM/ENS/04-04

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
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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 A Mobility Readiness Spares Package (MRSP) is an air-transportable package of spare parts configured for rapid deployment in support of conflict or war. Each package is tailored to support a specific scenario, for a specific type and number of aircraft without re-supply for the first 30 days of deployment. Inventory is limited to mission-critical spares. The high cost of airlift and spares drive a necessity to keep MRSPs as small as possible, yet robust enough to meet wartime goals.

Historical MRSP inventories exhibit significant volatility and the subsequent growth of their inventory creates significant cost to the Air Force. Annual MRSP growth budget estimates over FY03 – FY05 ranged from $700M to $1.2 billion.
This research proposes methods to reduce unnecessary growth, stabilize inventory, and still maintain a viable MRSP. Causes of inventory growth are identified by examining historical data. Controlled experiments are conducted against volatile data to evaluate the effectiveness of exponential smoothing and moving averages in stabilizing inventory. Asset-based MRSP computations are used to give greater consideration to the sunk cost of inventory. This research provides the Air Force a set of business rules that stabilize inventory, reduce spares budgets, and maintain a viable MRSP that meets wartime goals.

15. SUBJECT TERMS
Mobility Readiness Spares Package, MRSP, contingency spares, deployable spares, inventory growth, inventory variability, inventory cost, asset-based computations, MRSP computations, aircraft sustainability model

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			Bradley E. Anderson, Major, USAF (ENS)
					19b. TELEPHONE NUMBER *(Include area code)*
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Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39-18