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Improving Minuteman III Maintenance Concepts

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IMPROVING MINUTEMAN III MAINTENANCE CONCEPTS

THESIS

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Abstract

Since the end of the Cold War, the Air Force has sought out efficiencies across multiple processes to transform into a cost-effective force. However, processes applicable to the Minuteman III (MM III) weapon system have only recently seen efforts to increase effectiveness. The purpose of this research is to investigate whether the use of third generation maintenance concepts could benefit the sustainment of the MM III through its planned retirement around 2030. Primary and secondary sources outlining the history of the strategic missile force and its current state were collected. Themes from each era were analyzed using Prospect Theory as a means to understand the past and interpret the current state. The resulting interpretation led to propositions on how third generation maintenance concepts could be applied to the sustainment of the MM III as well as benefit its planned replacement, the Ground Based Strategic Deterrent (GBDS) program.

Acknowledgments

I would like to express the utmost gratitude and respect towards two groups. The first being a group of great leaders: Generals Henry “Hap” Arnold, Curtis LeMay and Daniel “Chappie” James, Jr., Lieutenant General James “Jimmy” Doolittle, and Brigadier Generals William “Billy” Mitchell and Robin Olds Jr. These leaders displayed tenacity and fortitude throughout their life of service to this great nation. It is my hope that the lessons learned from their exploits are never forgotten. The second appreciation goes towards the powerful enlisted community of the Air Force, past, present, and future. Their incredible dedication day in and day out to ‘get the job done’ is a testament to the strong work ethic and morals this country was founded upon. I am humbled to be able to serve alongside such great men and women to support and defend the Constitution of the United States and all the values we hold dear.

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I. Introduction

Background

The Minuteman III (MM III) Intercontinental Ballistic Missile (ICBM) system has been existence since the 1970s and, in some cases, the infrastructure buried below ground has been retrofitted from old Minuteman I facilities which date back to the 1960s. As a system with strategic importance to the deterrence policy of the United States, the reliability of each weapon and its associated infrastructure is critical (Phillips, Rehmert, Waller, Bergdolt, & Walston, 2011). Additionally, the MM III is expected to provide strategic deterrence through at least 2030 when its replacement, the GBSD (Ground Based Strategic Deterrence), is projected to become operational (Woolf, 2015). With the increasing age of the MM III and the GBSD's expected lifespan of at least 50 years, the ability for maintenance personnel to adequately sustain this deterrence force has strategic implications for the United States foreign policy.

However, since the end of the Cold War, the nuclear enterprise as a whole has degraded due to lack of oversight, funding, and modernization. The Honorable Frank Kendall, Under Secretary of Defense for Acquisition, Technology, and Logistics, stated in a 2014 speech to the Air Force Association Conference and Exposition that:

> …it has become clear to Secretary Hagel and DOD's senior leadership that a consistent lack of investment and support for our nuclear forces for far too many years has left us with little margin to cope with mounting stresses…For too long, our leaders have not [done] enough to support the missileers and the others involved in this enterprise - overlooking career paths, compensation, decaying infrastructure, and small unit leadership that are mission-critical (Kendall, 2014).

Because of this lack of investment in infrastructure and modernization throughout the nuclear triad, many systems, including the MM III, have outlived their original service life and are in need of an updated replacement (Woolf, 2015). Though the United States made a commitment in the 2010 Nuclear Posture Review to work towards a world without nuclear weapons and to deemphasize their use in the national security strategy, the focus must be on maintain a safe, secure, and effective force until such weapons are removed from the arsenal (Department of Defense, 2010). Admiral Cecil D. Haney, the former Commander of United States Strategic Command (USSTRATCOM), reiterated this sentiment in testimony before the Senate Committed on Armed Services on 19 March 2015, stating that:

> The likelihood of major conflict with other nuclear powers is remote today, and the ultimate U.S. goal remains the achievement of a world without nuclear weapons. Until that day comes, the U.S. requires a safe, secure, and effective nuclear deterrent force, even as it continues to reduce its nuclear stockpile and the number of deployed nuclear warheads. (Haney, 2015)

Admiral Haney continued by stating:

> We must commit to investments that will allow us to maintain this infrastructure in a safe and secure way for as long as nuclear weapons exist, or risk degrading the deterrent and stabilizing effect of a credible and capable nuclear force. Today we spend less than 3 percent of the DOD budget on nuclear capabilities. As stated by the Congressional Budget Office, recapitalization investments that are necessary to ensure safety and security will increase this number to "roughly 5 to 6 percent." (Haney, 2015)

Significant nuclear weapon system modernization is already underway to produce a new ballistic missile submarine, a stealth bomber force, and a replacement ICBM. Additionally, there are significant acquisition efforts within the Air Force for other weapon systems such as the F-35, the KC-46, and the T-X. With these high-cost acquisition programs, the fight for dollars to fulfill all requirements is strained (Mehta, 2016a). Additionally, the maintenance costs of legacy weapon systems (such as the F-16) until their modernized counterparts (e.g. the F-35) are operational has been shown to be increasing, thus increasing the stress on the DOD's budget (Versprille, 2016). This statement is also true for the MM III, as depicted in Figure 1, which indicates that Operations and Maintenance (O&M) costs have nearly doubled between 1996 and 2016 (AFTOC, 2017).

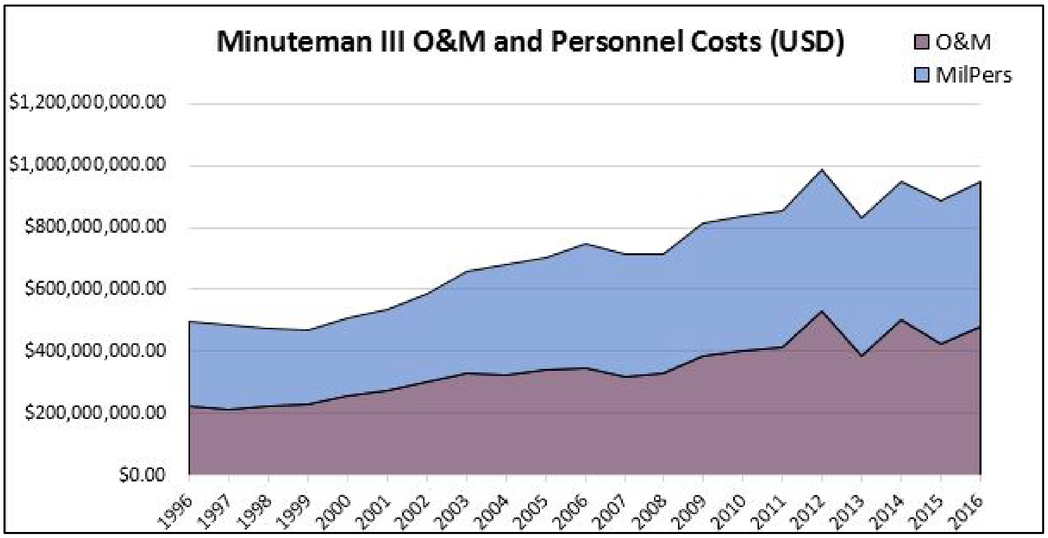

Figure 1. MM III O&M and Personnel Costs

The maintenance policy governing ICBM sustainment has highly favored a run-to-failure model where the performed maintenance is in reaction to a system breaking. Because of the lack of modernization coupled with aging infrastructure, the maintenance and sustainment communities have experienced increased difficulty in ensuring the high levels of reliability demanded by the strategic posture of the United States under such a policy. Thus, this research will explore a modernized maintenance policy utilizing Reliability-Centered Maintenance (RCM), and Condition-Based Maintenance (CBM) as an option to aid in extending the life of the MM III. Additionally, by incorporating these techniques prior to the deployment of the GBSD, lessons learned and best practices can be applied to the future system.

Problem Statement

The problem facing the ICBM sustainment community is that the maintenance policy currently utilized in support of the MM III is reactive in nature and does not leverage technology to detect/predict failure. Thus, RCM and CBM concepts are applied to the ICBM construct in order to answer the question of how these principles may be implemented to develop a preventative maintenance policy rather than a reactive policy.

Research Questions

1. Can MM III sustainment managers leverage RCM methods to provide the required level of readiness at an appropriate cost?
2. Can existing CBM technologies can be applied to the MM III and GBSD in order to effectively sustain the weapon systems?

Research Focus

The scope of this research concentrates on a holistic view of the weapon system due to the complexity and magnitude of components that make up the entire MM III system. Additionally, this research is not intended to determine specific reliability levels nor to surmise what technologies should be leveraged. Instead, the focus of this research will center around whether or not RCM and CBM are viable solutions to pursue in order to improve MM III sustainment.

The GBSD is not considered to be a primary focus of this research. This is because the components that will make up this new weapon system are still in the conceptual phase of development. However, because the GBSD acquisition program is considered to be a recapitalization of the existing infrastructure, the GBSD must be included in this research.

Methodology

This research utilizes the case study method as a means to investigate the situation surrounding ICBM sustainment to answer the research questions listed above. To answer the research questions listed earlier, a comprehensive history of policies and actions regarding the ICBM community is compiled using sources such as policy documents, senior leader statements, and cost data. Such a compilation attempts to incorporate policies, procedures, personnel and systems information into a balanced historical view from the beginning of the nuclear enterprise through 1992. Doing so allows the researchers to analyze that information through a theoretical lens in order to reduce bias within the research.

After doing so, the same nature of information is gathered for the current state of the ICBM community from 1992 through the present day. This compiled information concerning the current state is also viewed through an appropriate theoretical lens to develop a group of expectations for the current and future state of the ICBM community. From this, the researchers utilize these expectations, as projected through theory, to determine if there is support for the research questions and to develop any recommendations based on that determination.

Assumptions/Limitations

Discussion regarding the nuclear enterprise and the future of defense spending for a nuclear deterrent force is currently abundant. As such, the current state of policies and funding regarding the nuclear enterprise in general and the MM III weapon system specifically is a constantly changing target. Therefore, a limitation of this research is that while it attempts to obtain a comprehensive view of the current state, recent events may not be entirely captured. As such, swift changes in the political landscape could result in differing outcomes when a theoretical perspective is applied.

The ability for maintenance tasks to be performed on a weapon system depends heavily on the ability of the supply chain network to be able to provide the required components at the correct time. Additionally, trained and qualified maintenance personnel are needed to perform the task required. While inherently linked, the research did not investigate the ability for the supply chain to adapt to a change in maintenance policy nor other resource requirements such as personnel.

Lastly, much of this research requires secondary sources that interpret the nuclear enterprise, ICBM sustainment, and other topics related to this thesis. Though primary sources such as technical orders, Air Force Instructions, and policy documents were preferred, secondary sources were used to fill in gaps in the research. As such, the assumption is made that these secondary sources were accurate and limited in their potential bias.

Implications

The MM III sustainment community is a vast and complex system of personnel, policies, and procedures. Additionally, it involves a diverse group of roles and responsibilities that touch multiple functional areas of a bureaucratic system intended to allow for progress but limit organizational agitation produced by frequent radical changes. This research intends to determine if a shift in the fundamental maintenance policies governing MM III sustainment could benefit the nuclear enterprise and nuclear deterrence. Implications of such a determination would span the entire sustainment community and could even affect the operational community and deterrence policies. However, even rejection of the research questions would be able to provide the ICBM community with beneficial information as they progress through the acquisition of the GBSD and the retirement of the MM III.

Summary

This chapter emphasizes the issue of aging infrastructure and the costs associated with sustaining legacy systems as well as modernization within the nuclear enterprise. It also outlines the scope of the research and the associated research questions while stating the assumptions, limitations, and possible implications. Chapter II explores the historical nature of the nuclear enterprise, the decline in focus on nuclear matters and the subsequent re-emphasis on nuclear policy. Additionally, it presents the relevant literature on RCM, CBM, and current MM III maintenance policies. Lastly, it investigates Prospect Theory as a tool to interpret the relevant literature. Chapter III discusses the specific methodology performed during this research. Chapter IV presents the results and findings while Chapter V summarizes the research and provides additional areas for research.

II. Literature Review

Chapter Overview

This chapter reviews literature relevant to the research questions with respect to the ICBM community as well as RCM and CBM. First, a description of the MM III weapon system is portrayed in order for the reader to gain a basic technical understanding. Next, a historical review of the ICBM force will explore the decline and subsequent revival of focus on the nuclear enterprise. By doing so, one can attempt to better understand the current state of the ICBM sustainment community and its associated maintenance practices. Additional research will focus on recent studies that were intended to increase the efficiency of operations within the ICBM force. This chapter also reviews the principles of RCM and CBM and their effect on maintenance policies. This framework is essential to understanding the principles explored later in this research. Lastly, this chapter explores Prospect Theory as a tool to be used throughout this research.

MM III Physical Description

The silo-launched ICBM has been a mainstay of the United States' strategic deterrence policy since the early 1960s when the first Minuteman I missiles were placed on alert. The current system employed by the Air Force, the MM III, is comprised of two main facilities that house the majority of systems and components that make up the weapon system. The first is the Launch Facility (LF) which is an unmanned silo and associated equipment that is used to house and launch the LGM-30 missile and its payload. A vertical launch tube, a Launcher Support Building (LSB), and Launcher

Equipment Room (LER) are the three main areas that comprise the LF and are all buried underground. The LSB and LER contain power, environmental control, and communication systems critical to the operation and launch of the missile within the launch tube.

The second facility is the Missile Alert Facility (MAF) which is a manned building housing missileers who monitor weapon system status and, if directed by the president, can execute a missile launch. Depending on the design, some MAFs house both the building containing the missileers (known as the Launch Control Capsule (LCC)) and the associated support and launch equipment (known as the Launch Control Equipment Building (LCEB)), underground. However, older designs have much of the equipment found in the LCEB above ground in what is known as the Launch Control Support Building (LCSB).

Conceptually, these facilities and the equipment contained within them are very similar to most any other facility found throughout the Air Force. Each facility contains structural aspects such as walls and support columns, power systems that ensure the ability to operate, HVAC systems which ensure the proper environmental controls for both the missileers and the missile itself, and there are redundant communication systems that ensure connectivity for launch orders. Additionally, there are overlaid security systems to monitor and detect threats due to the sensitive nature of the weapon system. However, because much of the facilities and their associated equipment are underground, there are unique issues facing the sustainment and maintainability of the weapon system outside of the normal wear out facing similar systems. Colonel Jeff Frankhouser, a former ICBM maintenance group commander, stated "Take a 40-year-old home, now bury it in the ground. Then figure out what your challenges are. We'll have those" (Pappalardo, 2011).

Another challenge facing the maintenance personnel supporting the MM III is that the MAFs and LFs are geographically separated from their main support base (MSB). Though some locations are less than a 30-minute drive, the furthest locations can be in excess of a three-hour drive in ideal conditions and even more with impaired driving conditions from the poor weather that is common at such sites, especially in the winter. This geographic separation introduces a multitude of considerations unique to ICBM maintenance that other Air Force maintenance units do not have.

History of the Nuclear Enterprise

Though the development and wartime use of nuclear weapons during World War II are well known, the path from development to today is not. From Strategic Air Command (SAC) through the Cold War and into the 21st Century, the overall focus on nuclear weapons and the policies of each presidential administration have varied over the years.

Post-World War II

In the early aftermath of World War II, the U.S. Army Air Forces established the Strategic Air Command whose focus was to be able to execute long range offensive operations using atomic weapons. Though early demonstrations to execute this mission were lackluster at best, under the guidance of General Curtis LeMay, the accuracy of nuclear bombing exercises went from missing the target by over two miles in 1947 to coming within 2,000 feet of the target by 1949 (Keeney, 2012). Under General LeMay, SAC developed into a premier organization with the strictest of standards. The leadership demanded a standard of perfection and deviations from that standard were dealt with quickly (Meilinger, 2014).

The Cold War

SIOP-62 was the war plan developed under the Eisenhower administration which detailed the targeting and execution of a massive strike against Russian and Chinese forces. Under the Kennedy administration, Secretary of Defense Robert McNamara pushed for the war plan to become more flexible and include a second-strike capability built around ICBMs as well as submarine-launched ballistic missiles (SLBMs) (Burns & Siracusa, 2013). This new war plan, known as SIOP-63, increased SAC's responsibility and saw the development and integration of silo-based ICBMs into SAC. This missile force, being tasked with a second-strike, retaliatory mission, received the same scrutiny of perfection from SAC as the bomber force under General LeMay.

This nuclear triad formed the basis for American nuclear deterrence policy throughout the rest of the Cold War and still exists today. Each leg on its own has strengths and weaknesses as shown in Table 1. However, when organized together, they form a strong cohesion that provides stable deterrence pressure to rational international actors.

The following presidential administrations saw tensions with Russia ebb and flow based on increased stockpile levels, increased weapon yields, and enhanced defensive capabilities, such as anti-ballistic missile systems designed to defeat ICBM strikes. In 1974, President Nixon published NSDM-242 which stated that "The fundamental mission of the U.S. nuclear force is to deter nuclear war…" and that the strategic posture needed a survivable ICBM force for "…protection and coercion during and after major nuclear conflict" (Nixon, 1974). As such, the strictest adherence to technical guidance in operations, maintenance, and security was required within the ICBM community to ensure the highest level of readiness. The SAC Munitions Officer Handbook offers insight into the mindset expected within SAC and the ICBM community. Statements such as 'be prepared for war,' 'be tough,' and 'don't tolerate incompetence' are extensive throughout the handbook (Belisle & Hickman, n.d.).

Table 1. Strengths and Weaknesses of the Nuclear Triad

	Strengths	Weaknesses
Bomber	• Only recallable nuclear force • Ability to forward deploy as a show of force • Able to be dispersed prior to attack	• Requires the most time to bring on alert • Least survivable • Easiest to counter once launched
SLBM	• Considered the most survivable/assured retaliation • Prompt launch capability	• Few subs on alert at any given time • Limited number of warheads
ICBM	• Large geographic dispersion able to absorb a nuclear attack • Fastest launch capability • High warhead count	• Immobile and easily targetable • No ability to show escalation

The Post-Cold War Environment

In the early 1990s, there began a shift away from the strict adherence to standards that was the bedrock of SAC. With the dissolution of SAC in 1992, the Air Force's nuclear entities were split primarily between two Major Commands, with the bomber force falling under Air Combat Command (ACC) and the ICBM force falling under Air Force Space Command (AFSPC). Additionally, the closure of San Antonio Air Logistics Center in 1995 disbanded the focal point of nuclear logistics and decentralized control among six separate organizations (Defense Science Board Permanent Task Force on Nuclear Weapons Surety, 2011).

With the swift and overwhelming victory of the Gulf War led by new precision strike capabilities, the purview of leadership over the nuclear forces began to waiver. Early in the post-Gulf War environment, some within the Air Force identified a sense of false security and called for caution to not allow the deterioration of nuclear capabilities (Paulsen, 1994). It became common thought among civilian and military organizations that future wars would be quick endeavors won by the increasingly technological precision strike forces and that nuclear deterrence was a relic of the past. This became evident in 2001 when the Nuclear Posture Review under President George W. Bush called for a fundamental shift in thinking to a New Triad which incorporated nuclear forces, non-nuclear forces, and defense infrastructure as the three areas that would provide strategic deterrence in a rapidly changing international security environment (Department of Defense, 2002).

The 2000s Through Present Day

Towards the end of the 2000s, two events transpired which highlighted the degradation within the nuclear enterprise. In 2006, four MM III critical components were mistakenly sent to Taiwan instead of UH-1 helicopter batteries and were not discovered missing until 18 months after the shipment occurred. Additionally, in 2007 six nuclear warheads were flown from Minot AFB to Barksdale AFB within cruise missiles loaded on a B-52. In subsequent reviews, lack of attention to detail, failure to follow prescribed technical procedures, and an overall lack of leadership and oversight in the nuclear enterprise were found to be common among Air Force operations, maintenance, and logistics organizations tasked with nuclear missions (Defense Science Board Permanent Task Force on Nuclear Weapons Surety, 2011). Additionally, shifting priorities had left the nuclear enterprise and policy makers facing $100 billion worth of modernization decisions without first-hand experience in such matters (Office of the Under Secretary for Acquisition Technology and Logistics, 2008).

Many reports from this timeframe had a common theme, that the Air Force and USSTRATCOM "…should restore the rigor and focus necessary to reestablish and sustain the demanding proficiency necessary for nuclear operations" (Office of the Under Secretary for Acquisition Technology and Logistics, 2008). From this, the Air Force decided to partially return to a SAC-like structure where most organizations with a nuclear or non-nuclear, long-range strike mission and those logistics organizations that directly supported that mission would fall under one MAJCOM known as Air Force Global Strike Command (AFGSC).

According to the literature, there are still issues within the nuclear enterprise related to morale, discipline, and attention to detail. One recent example of this is the cheating that occurred at an ICBM base where missile operators were found to be distributing answers to monthly proficiency checks (Holmes, 2014). Efforts from AFGSC and the Air Force to improve these personnel issues (such as the Force Improvement Program) have seen success in bringing about change to the culture of the nuclear enterprise (Raatz, 2015).

Currently, the focus has shifted away from personnel issues to infrastructure and modernization issues. Underinvestment over the past two decades has left the nuclear forces in need of modernization to sustain strategic nuclear deterrence. An open letter signed by eight former commanders of SAC and USSTRATCOM declares that based on the actions of Russia, China, and North Korea, the need for a modernized nuclear triad is clear and that a lack of modernization or an outright removal of one leg would be inherently detrimental to US security (Kehler et al., 2017). However, as mentioned earlier in Chapter I, the costs associated with such acquisition efforts may employ up to 6% of the DOD budget in coming years.

MM III Divergence from Air Force Sustainment Best Practices

As stated earlier, the MM III utilizes technology from the 1960s in order to remain on alert and ready as a viable nuclear deterrence force. Throughout its life cycle, there have been programs to modernize or replace many components of the system and associated test equipment. For example, the Environmental Control System (ECS) within both the MAF and LF was designed with a 10-year service life and only saw one modification in the mid-80s (Systems Engineering and Technical Analysis Staff, 2004). A replacement ECS system was fielded in the early 2010s due to a lack of replacement parts and increasing failure rates. Similar programs have been performed on missile components and C2 systems to ensure a viable launch function in a nuclear war environment.

While it is common among aging Air Force weapon systems, such as the B-52 which was fielded in the 1960s, to receive updates and modifications throughout its operational phase, the ICBM community did not integrate the best practices of the Air Force with respect to life cycle management. Mr. Lawrence Kingsley stated in a 2014 interview that “The entire Air Force is aging, but while the rest of the Air Force moved on with sustainment, ICBMs did not…" (Rowell, 2014). One such example of the ICBM community failing to modernize is the cost per flying hour concept.

Cost per flying hour is a common metric used by life cycle managers of aircraft to forecast sustainment requirements (Sperry & Burns, 2003). As parts fail and require replacement, costs per flying hour increase. This increase in costs can, in turn, be tied directly to the flying hour program that is common among airframes. Each fiscal year the Air Force determines how many flying hours on each airframe are required to keep pilots proficient and ready for operational tasking. By knowing the cost per flying hour, the Air Force can budget sustainment costs. Coupled with failure rate data, the Air Force can also predict how many spare parts will be required to maintain the aircraft. Variability plays a major role in preventing accurate models, but basic forecasting can be done to get a general idea of what sustainment levels will be required to support each weapon system.

Though this model was developed in the 1960s, it became prevalent throughout the Air Force in the post-Cold War environment of the mid-90s (Rose Jr., 1997). This was directly after the ICBM community transitioned under AFSPC which had limited resources devoted to aircraft sustainment, unlike ACC which contained the nuclear bomber force. It was not until nearly 20 years later that research considered developing a cost per flying hour model for the MM III (Miller, 2012).

Another area where the Air Force modernized and ICBMs did not was within the realm of maintenance data management. The Integrated Maintenance Data System (IMDS), formerly known as the Core Automated Maintenance System (CAMS), is a maintenance data collection tool that can aggregate maintenance data inputs at the technician level to provide sustainment managers the information they needed to perform life cycle management functions. Not only are serial numbered assets able to be tracked, but failure rates and maintenance task data are stored and compiled in order to help forecast future sustainment requirements. One intended use of IMDS is to link maintenance and supply data in an effort to bolster the supply chain (Office of the Secretary of the Air Force, 2007). IMDS also links to other sustainment and supply chain management systems used by the Air Force. The 15 April 2007 version of Technical Order 00-20-2 gives a description given to IMDS that is over two pages long detailing the functionalities and capabilities that it provides aircraft maintenance and sustainment personnel. Until the early 2010s, this was not the system used for documenting MM III maintenance. Instead, the Improved Maintenance Management Programs (IMMP) was the preferred tool for MM III maintenance data collection. Less than half a page is used to describe the purpose, and intended use of IMMP and the description does not mention integration with the supply chain other than allowing sustainment managers access to the maintenance data.

In addition to a data management system that is not as robust as the Air Force's standard operating platform, the measurement of maintenance performance is lacking within the ICBM sustainment community. The Air Force Maintenance Management Handbook, first published in 2001, lays out the basis for the metrics deemed important to unit-level maintenance leaders within an aircraft maintenance organization. Through this handbook, sustainment managers seek to understand and describe the health of the fleet using measurements and standards to gauge performance. The handbook also gives front line supervisors a list of things to look for if the metrics begin to move in an undesirable direction. However, nearly ten years after the aircraft maintenance community adopted a robust metrics system, the sustainment community published the ICBM Maintenance Metrics Handbook.

Additional review of the literature showed that since the 1990s researchers have conducted substantial amounts of work towards how the reduction in strategic weapon systems affects the concept of nuclear deterrence (Nyland, 1998) (Pedersen, 2009) (Woolf, 2015). However, there is minimal literature on effective support operations (e.g., maintenance, supply chain operations, security) for the MM III. One example of a research study to increase the effectiveness of maintenance resources investigated the feasibility of an innovative inventory management technique to locate spare parts in the missile field, thus potentially reducing the need to return to the main base if additional spare parts are required during a maintenance task (Hughes, 2015).

Another area of research focused on effective security forces placements in order to support maintenance operations (Dawson, Bell, & Weir, 2007) (Overholts II, Bell, & Arostegui, 2009) in an attempt to optimize personnel utilization and increase maintenance efficiency. Additional research sought to define the impact that a reduced alert rate would have on maintenance personnel utilization rates (Kravitsky, 2007). Though these areas of research are important, they pale in comparison to research done to support maintenance and sustainment efforts throughout the aircraft community in the Air Force.

Reliability-Centered Maintenance

Reliability-Centered Maintenance (RCM) is a maintenance policy that relies on probability to make informed decisions on when to perform maintenance. The goal of any maintenance action is to ensure that mechanical equipment can operate appropriately when required (Moubray, 1997). This is defined by the user as the operating context of the equipment. Whenever the equipment is no longer performing within that operating context, the system experiences degraded capabilities, and thus maintenance actions are required. However, with redundancy built into a system, degraded capabilities may not cause system failure. Thus, the entire system may still be able to function appropriately even though a subcomponent may have failed.

The goal of RCM is to create a maintenance policy based on system functionality and operating context based on the design of the entire system. Over the past 60 years, sustainment communities have changed their views on how components fail. Initial failure models were based solely on an increasing failure rate as assets aged as indicated by the pattern 'B' shown in Figure 2. With the increase in the mechanization of processes, more attention has been given to industrial engineering which has identified five additional failure curves. These additional failure curves more accurately model the life cycle of mechanical systems and can be utilized to more accurately predict failure of individual components.

Pattern 'A' is a bathtub curve which indicates components with a high rate of failure early in its life cycle and after a certain amount of time begins wearing out at an increased rate. Pattern 'C' indicates a steadily increasing rate of failure with no significant increase due to wear out. Pattern 'D' is indicative of components that are produced with a high level of robustness and thus do not have a high early failure rate whereas pattern 'E' indicates a constant failure rate over the entire life cycle. Finally, the curve indicated by pattern ‘F’ is known as an infant mortality curve which models items that have high early failure rates that reduce to a constant failure rate with time.

Figure 2. Six Failure Probability Curves (Moubray, 1997)

Combining these two concepts of understanding the operating context of the system as well as its failure rates allows for the development of a reliability-based maintenance concept. The basic concept of this is explained using Equations 1 and 2 whereby once the probability density function for failure is determined, the reliability, or the probability that the system has not failed at time *t*, can be calculated. By understanding what constitutes unacceptable performance (e.g. failure) and at what rate that occurs, sustainment managers can then develop a preventative maintenance policy based on their level of risk acceptance of a failure.

$$F(t) = \int_{-\infty}^{t} f(t)dt \quad (1)$$

$$R(t) = 1 - F(t) \quad (2)$$

Where:

$F(t)$ = the probability of failure before time t
$f(t)$ = the probability density function for failure
$R(t)$ = the probability of survival at time t
t = time

Through the understanding of when the risk of failure becomes unacceptable for all critical components within a system allows for sustainment managers to set the overall timeframe for preventative maintenance. As seen in many industrial settings, downtime of a system due to maintenance causes a decrease in performance and prevents the creation of products to sell, thus lowering profitability. In the power generation and distribution industry, excessive downtimes can lead to economic losses which highlights the importance of scheduling downtime to perform comprehensive preventative maintenance rather than perform a run-to-failure maintenance model where downtimes are more frequent even though they may be shorter in duration (Dehghanian, Fotuhi-Firuzabad, Aminifar, & Billinton, 2013). Thus, there is increased emphasis on using RCM as a means to build a maintenance policy based on a determined level of risk acceptance.

One of the earliest successes of developing an RCM policy came in the mid-1970s when United Airlines adopted such a policy for the 20,000-hour inspection of their new Boeing 747 aircraft. Under their old maintenance policy for the DC-8s (considered to be a less technologically complex aircraft than the 747s), the 20,000-hour inspection required over four million man-hours to complete. However, with RCM principles built into the maintenance policy, United Airlines was able to complete the same inspection on their 747s with only 66,000 man-hours (Moubray, 1997).

Many industries have realized reduced costs and increased effectiveness by using RCM since its inception in the 1970s. Within the military, organic research studies have investigated utilizing these concepts on existing weapon systems such as the F-15 (Martin, 1997) and H-60 (Reeder, 2014). Additionally, these concepts are currently being designed into new weapon system acquisitions.

A subset of the RCM model, known as Condition-based Maintenance (CBM), has also been adopted by the military as a modernized maintenance concept. The basis for this model is similar to that of RCM; however, it leverages technology to monitor the performance of a system. Rather than using failure models to predict when failure may occur, CBM uses operating tolerances as a means to determine when the operating context of a component has degraded to a point that is unacceptable. Once the component is outside the acceptable tolerance level, indicators are triggered to inform sustainment managers that the system requires maintenance. A partial list of technologies used in CBM to monitor condition are shown in Table 2 (Levitt, 1997).

Table 2. Examples of Proven CBM Technologies

Technology	Use
Chemical Analysis	Monitor oil contamination
Vibration Analysis	Monitor rotating components
Temperature Measurement	Monitor HVAC/Identify friction
Ultrasonic Inspection	Determine thickness of corrosion
Visual Fiber Optic Monitoring	Inspect hard to reach locations

By knowing when a system is out of tolerance yet still functioning, sustainment managers can schedule maintenance before a failure occurs in a manner that allows for multiple maintenance actions to occur. Additionally, monitoring specific component functions allows for maintenance personnel to know what component is out of tolerance so that they can bring the correct tools and spare parts to repair or replace the component rather than spend time troubleshooting the system.

A 1988 study illustrates some of the benefits of switching to a predictive maintenance policy such as RCM and CBM. A survey of 500 manufacturing companies across multiple countries and industries (i.e., electrical power generation, food processing, textiles) examined the benefits gained through the successful integration of predictive maintenance policies. The findings are summarized in Table 3.

Table 3. Benefits of a Successful Predictive Maintenance Program (Mobley, 1990)

Operations and Maintenance (O&M)	
Maintenance Costs	Reduced 50-80%
Overtime Premiums	Reduced 20-50%
Spare Parts Inventory	Reduced 20-30%
Machine Performance	
Machine Breakdown	Reduced 50-60%
Machine Downtime	Reduced 50-80%
Machine Life	Increased 20-30%

The DoD has outlined its policy pertaining to CBM in DOD Instruction 4151.22, *Condition Based Maintenance Plus (CBM+) for Materiel Maintenance*, which states that CBM+ be adopted by new weapon systems and that existing weapon systems should also begin adopting these practices "…where it is technically feasible and beneficial" (Department of Defense, 2012). It also defines CBM+ as:

> CBM+ is the application and integration of appropriate processes, technologies, and knowledge-based capabilities to achieve the target availability, reliability, and operation and support costs of DoD systems and components across their life cycle. At its core, CBM+ is maintenance performed based on evidence of need, integrating RCM analysis with those enabling processes, technologies, and capabilities that enhance the readiness and maintenance effectiveness of DoD

> systems and components. CBM+ uses a systems engineering approach to collect data, enable analysis, and support the decision-making processes for system acquisition, modernization, sustainment, and operations (Department of Defense, 2012).

The F-35 Joint Strike Fighter's Autonomic Logistics Information System (ALIS) is an example of how CBM can be integrated into a weapon system. Sensors embedded within the aircraft continually monitor weapon system performance to indicate when components and systems are not operating within tolerance. When this occurs, ALIS alerts the supply chain and repair network to indicate a need for replacement parts and manpower to return the airplane to a functional status.

Previous attempts within the DoD to implement a CBM+ maintenance policy demonstrate the ability to produce multiple benefits. For example, an Army initiative to develop a CBM+ strategy for a portion of their aviation branch produced notable benefits in safety as well as weapon system availability. Specifically, a 9-12% reduction in potential mishaps, as well as a 3.7-10.3% increase in readiness, was observed in aircraft that had adopted a CBM+ maintenance strategy (OSD CBM+ Action Group, 2010).

Prospect Theory

Prospect Theory is an economics-based theory that focuses not just on decision making under uncertainty, but also includes a propensity for loss aversion as a different function of a decision maker's level of risk. Unlike Utility Theory which focuses on the expected utility gained from a decision, Prospect Theory expands to include the potential for loss when faced with a decision as shown in Figure 3. In doing so, the theory develops each decision to be framed from a reference point at the current state. As demonstrated by the theory, decision makers tend to favor decisions based on certainty rather than uncertainty, even in a probabilistic environment (Slovic, Fischhoff, & Lichtenstein, 1982). Thus, there is a propensity for individuals to insure themselves against an event that has high probability and a low value of loss rather than insuring against a low probability event with a high value of loss.

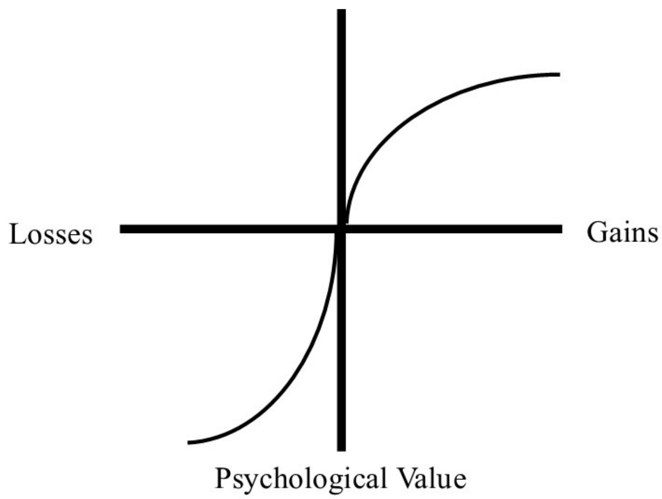

Figure 3. Prospect Theory Value Function (Kahneman, 2011)

Summary

Chapter II outlines the literature review conducted for this research. It explores the nature of the MM III weapon system as well as a history of the nuclear enterprise. A gap in progress between Air Force best practices and practices found in the ICBM community was also explored. Additionally, the literature concerning RCM and CBM concepts is compiled and summarized. Lastly, a summary of Prospect Theory is provided as a means to introduce the theoretical lens used throughout this research.

III. Methodology

Chapter Overview

The purpose of this chapter is to describe and outline the methodology used to answer the research questions that were described in Chapter I. It outlines the case study method for performing exploratory research and how those methods were applied to this research. Lastly, it reviews the theories that were used as potential means to analyze the collected information.

Data Collection

This research utilizes the case study methodology as a means to analyze the data in an attempt to answer the research questions. This method was chosen due to the fact that it is well suited for complex and poorly understood situations (Leedy & Ormrod, 2013). To understand the situation, data collection focused on compiling an extensive collection of both primary and secondary sources. The research established proper bounds so that extraneous data would not apply undue influence on the analysis of the situation. These bounds focused on the people, policies, and procedures related to the nuclear enterprise in general and ICBM sustainment in particular. Data sources pertaining to topics such as organizational culture, nuclear weapon employment policies, and operational effectiveness are considered to understand the climate of ICBM sustainment throughout history for both the macro and micro-level view of the situation. Additionally, data sources pertaining to these topics from multiple points in time are used and grouped together into two timeframes to gain a complete understanding: 1947 through 1992 and 1992 to the present.

Ultimately, the policies surrounding nuclear weapons start with how each presidential administration views the role of nuclear weapons in their geopolitical environment. As such, data sources explaining these views are used as the starting point for each timeframe and explored further using the military's interpretation and implementation of these policies. Data collection also included sources that explained how people, policies, and procedures were organized in order to meet the strategic objectives of the United States. Where research failed to produce primary sources, secondary sources were used as a means to fill in the gaps in research.

Organization of the Data

With a comprehensive collection of data sources, common themes and trends are recognized after a thorough perusal of the sources pertaining to each defined timeframe. This technique, as developed by Creswell's 2014 work, utilizes a systematic approach to analyzing the mass of data that often accompanies qualitative research. To do this, the researcher organizes the data by timeframe and by topic. From there, data sources are used to identify common themes and general descriptions that supported each other so as to triangulate an understanding of the nature of the situation for each timeframe listed above (Creswell, 2014). This triangulation was used as a procedure to ensure the validity of the research method performed.

Developing the Context Using Theory

Next, these themes and trends are interpreted by exposing them to a theoretical lens and determining how well the theory matched the historical context. By viewing the themes through a theoretical lens, the bias is reduced in the research method (Leedy &

Ormrod, 2013). Additionally, by using theory, a robust case for an explanation of why the situations existed is developed. Prospect Theory, as listed in Chapter II, is used to view the themes pertaining to the data sources up until 1992 as a means validate that the theory accurately explained why events occurred in a certain manner.

Exploring the Current State

Because Prospect Theory was determined to accurately represented the past environment of the nuclear enterprise, it is again used to analyze the data pertaining to the current state. This analysis provides a way to synthesize the data into a coherent view and to develop expectations as provided by the theory. These expectations, though not predictive in nature, are used as a means to explore what the future state of the ICBM sustainment community might look like under a reliability-centered policy for maintenance.

From these future expectations, the research follows with a set of propositions on how the ICBM sustainment community can achieve the future state using the Doctrine, Organization, Training, Materiel, Leadership, Personnel, Facilities and Policy (DOTMLPF-P) model used by military planners. These propositions attempt to link the expectations of the current state, as described by Prospect Theory, and the benefits of an RCM and CBM-centric maintenance policy.

Summary

Chapter III explores the methodology used to carry out the case study research including the data collection method and how the data is synthesized into a holistic view of the situation facing the ICBM sustainment community. Additionally, it explores the role of theory, specifically Prospect Theory, in the research and how it applies to create expectations for the future state and propositions on how to achieve those expectations. The results of this analysis are found in Chapter IV.

IV. Analysis and Results

Chapter Overview

This chapter contains the case study analysis and results from this research. It outlines the common themes from primary and secondary sources and analyzes those themes through the theoretical lens described by Prospect Theory. This analysis is then expounded upon through the development of propositions for how to progress using the concepts of RCM and CBM as the basis for the future state.

Tuning the Theoretical Lens

The historical research related to the nuclear enterprise and ICBM sustainment is analyzed to identify overarching themes that are then viewed through a theoretical lens. To start, the directives from the presidents from the 1960s through the 1980s all discuss the importance of having a credible ICBM force that can survive a first strike and be used as an overwhelming retaliatory force. This is considered to be one of the strengths of the MM III as identified in Table 1. The fact that the weapon system is always on alert aides in its usefulness in providing a strategic deterrence (O'Rourke, 2010).

From these the presidential policy documents during the Cold War, the Department of Defense and the targeting community developed a target list structure that was dependent on the number of warheads available rather than having a set target structure which would determine the required number of warheads on alert (Sauer, 2005). This is known as the concept of maximum deterrence, where more on alert weapons equate to a higher level of deterrence. This concept is supported by the SAC Munitions Officer Handbook which states "Munitions functions must ensure maximum availability of trained personnel and [War Reserve Material] munitions to support wartime and contingency operations" (Belisle & Hickman, n.d.). Thus, the clear theme under this concept is that the goal of the nuclear sustainment community up until 1992 was to have the most number of warheads available and set the target requirements to the capability rather than to build a capability that matched the requirements.

Throughout the literature, there are references to 'gaps' in capabilities that fueled the Cold War mindset. These gaps between the perceived Soviet capabilities in bombers, weapon yields, missiles, and anti-ballistic missile systems led to increases in military spending. These increases in military spending helped drive U.S. capabilities higher to close these gaps and ensure high levels of deterrence (Higgs, 1988).

In order to apply a theoretical lens to this historical context, the concept of deterrence as a substitute for value is utilized. Under Prospect Theory, value is considered to be a measure of how an individual attributes the usefulness of the outcome relative to their current position (Kahneman & Tversky, 1979). Thus, when value is replaced with deterrence, the researchers found that Prospect Theory accurately describes events during the Cold War.

The concept of risk aversion under Prospect Theory states that for a positive value, decision makers prefer decisions with high probabilities of success to riskier decisions with lower probabilities of an outcome that may produce higher value (Tversky & Kahneman, 1992). When value is replaced with deterrence, the theory then states that decision makers prefer decisions with a high probability of providing a known level of deterrence to decisions that have a lesser probability to provide unknown levels of deterrence. This is summarized as the concept of 'this is the way we have always done it' where the higher probability of success in providing deterrence outweighs the desire to seek out more effective operations where higher levels of deterrence are uncertain. Through this historical context, the decision to increase warhead levels is the risk-adverse method to provide maximum deterrence.

Applying Prospect Theory to the post-Cold War Environment

The literature concerning the post-Cold War exposes two common themes related to the nuclear enterprise. The first theme concerns a fundamental shift in mindset to valuing the cost of defense and deterrence over the absolute amount of defense and deterrence provided where the second focuses on innovation to produce more effective and efficient results. Before the end of the Cold War, the literature describes a situation where the policy favored a level of deterrence which was supported by military expenditures. However, with the end of the Cold War, the new policy focused on fixing military budgets and optimizing the output provided by such levels. This is evident in that military spending was relatively flat between 1993 and 1999 (Durham, 2015). Additionally, in the post-Cold War environment, there were several efforts to reduce the size of the nuclear arsenal. Though the first Strategic Arms Reduction Treaty (START) was drafted prior to the end of the Cold War, Presidents Clinton, Bush, and Obama all oversaw efforts to reduce the number of active warheads within the nuclear arsenal either through treaties with Russia or unilaterally. In reference to one reduction of ICBMs for compliance under START II, it was said that “These missiles may still have a role to play in U.S. national security strategy, but they may not be needed in the numbers that were required when the United States faced the Soviet threat” (Woolf, 2015).

This sentiment is prevalent in the 2010 Nuclear Posture Review (NPR) conducted under the Obama administration. One section of the NPR discusses the importance of the nuclear triad and how it is a cost-effective method for maintaining deterrence. However, with the aging infrastructure of the MM III force, the NPR states that a study is required to "…consider a range of possible deployment options, with the objective of defining a cost-effective approach that supports continued reductions in U.S. nuclear weapons while promoting stable deterrence" (Department of Defense, 2010). Under this construct, it can be seen that rather than operating under the concept of maximum deterrence, as referenced above, the operating environment is one of minimum deterrence required.

Throughout the post-Cold War environment, the role of efficiency and effectiveness became prevalent. Starting with the Quality Air Force (QAF) program of the early 1990s and continuing to today through programs such as Air Force Smart Operations for the 21st Century (AFSO21) and Expeditionary Logistics for the 21st Century (eLog21), the Air Force has invested high levels of time and energy in order to encourage innovation to increase efficiency and effectiveness throughout all operations.

As stated in Chapter II, the cost per flying hour model is one of many innovations during the early stages of this push for efficiency (Rose Jr., 1997). Another source of innovation comes from the adoption of Activity-Based Costing methods (ABC) at the depots to more effectively track and understand costs in order to drive down waste (Graves, 2001). The push for increased innovation is highlighted by statements from two former Chiefs of Staff of the Air Force, Generals Schwartz and Welsh, that "Every Airman is an Innovator" which was also the theme of the 2014 CSAF reading list (Power, 2014).

To overlay Prospect Theory on the current climate described above, the concept of cost as the Y-axis is used to replace the concept of value rather than the previous concept of deterrence. Thus, the new goal is to reduce the cost of sustainment. In doing so, the theory describes a state where the Air Force has shifted from a risk-adverse to a risk-seeking mindset. This is because the current state describes a certain level of expenditure to meet the defense requirements. Thus, the cost of defense and deterrence under the current conditions becomes a guaranteed loss. Stated differently, the costs associated with the current state of operations are dollars that cannot be recovered nor spent on other programs. However, Prospect Theory states that in this environment, risk-seeking decision makers choose options that have a potential to reduce this loss rather than stay with the guaranteed loss (Tversky & Kahneman, 1992). When adjusted to the concept of costs, risk seeking decision makers will make decisions that have the potential to reduce costs rather than keep with the status quo and the known costs.

These concepts are illustrated using Figure 4 where the center square represents the current way of operating. Within this area are the procedures and methods that are currently outlined in Air Force Instructions (AFIs), Technical Orders (TOs), and other policies that are approved methods. The second square that encases the central square, representing alternate but unproven ways of operating, incorporates methods that would be considered safe. However, these methods may or may not be more effective towards meeting the end goal. The outer square represents alternative methods that would not be considered even if they met the end goal.

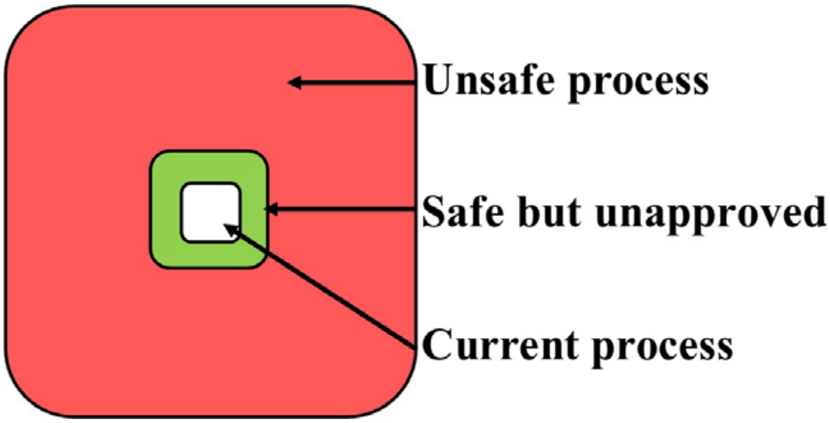

Figure 4. Conceptual Representation of Possible Processes

Under the risk-adverse environment of the Cold War where the goal was maximum deterrence, the benefits of operating within the safe space outweighed the desire to seek out alternative methods. This is because of the uncertainty that alternative methods would lead to higher levels of deterrence and the possibility that they would be considered an unsafe process. However, in the modern environment where the risk-seeking mindset is prevalent, the goal is to be cost-effective. Thus, there is a greater likelihood to seek out those alternative methods that are within the second square in Figure 4 which are considered safe and also provide cost savings. This situation can be described by the push for innovation in the post-Cold War environment as described above. When applied to the nuclear sustainment community, it is seen that, until recently, they have maintained the Cold War mindset of staying within the center square of what is known and safe, (being risk-adverse) and are only now starting to pursue innovative concepts found within the second square (risk-seeking).

Analysis of the Current MM III Maintenance Policy

Because Prospect Theory describes the current state as one that is open to innovation, this research focuses on concepts that could benefit the goal of driving down costs within the MM III sustainment community. Currently, much of the maintenance model for the MM III is under what is known as a run-to-failure policy where items are replaced upon failure. Though there are periodic inspections and environmental sensors to detect failures and abnormal conditions within the MM III system, they are not necessarily predictive in nature. Additionally, because there are many systems and components that make up the MM III, failure of a non-monitored item may not be discovered until a scheduled inspection takes place which could be months or possibly years after failure.

The AFI governing MM III maintenance describes a "find and fix" mentality under the topic of Preventative Maintenance (PM) where maintenance personnel identify discrepancies through periodic inspections and attempt to make repairs on the spot (Department of the Air Force, 2017). Under this maintenance policy, the AFI describes how preventative maintenance is conducted in response to a scheduled inspection where a component is found to be out of tolerance. Because of the geographic separation between the MSB and the LFs or the MAFs, many inspection intervals are aligned to reduce the number of dispatches required.

This maintenance policy described above is considered to be the foundation for the first generation (fix it when it breaks) and the second generation (scheduled overhauls) concept of maintenance policies (Moubray, 1997). The main concern of this first generation, run-to-failure maintenance policy is that it is considered to be the most expensive method to maintain a system due to high costs associated with spare parts and high system downtime (Mobley, 1990). Though it may be appropriate for some components within a system such as low-cost items, a one-size-fits-all maintenance policy that primarily relies on a run-to-failure model has significant opportunities to increase effectiveness.

Moubray's third generation of maintenance policy focuses on utilizing RCM and CBM concepts in order to bring attention to working effectively ('doing the right job') rather than just efficiently ('doing the job right'). This is because under the third generation of maintenance the expectation of maintenance has evolved away from being a 'necessary evil' and instead is seen as a means by which higher availability and reliability can produce greater cost effectiveness (Moubray, 1997). Experts in the field of maintenance management caution against an environment where the focus is solely on efficiency and cutting costs without taking into consideration the effectiveness of the overall maintenance strategy (Levitt, 1997). To combat this, the literature describes a multitude of maintenance strategies and associated tactics used to carry out the strategic goals.

From this analysis, two significant findings are discussed. The first is that the environment within the Air Force as well as the nuclear sustainment community has shifted away from a risk-adverse environment to a risk-seeking environment. Second, though MM III sustainment efforts have realized gains in efficiency, there remains to be found gains in effectiveness, especially within the maintenance policy employed. Because of these two situations existing concurrently, it appears that the environment is acceptable to seek out innovation to increase effectiveness.

This is not to say that new procedures should be adopted without going through the proper vetting process for innovation. The concept of nuclear surety is where the existing policies, procedures, and controls ensure that nuclear weapons are not involved in any accidents, incidents, or unauthorized detonations (Department of the Air Force, 2016). Innovation without verification is dangerous and in direct violation of nuclear surety. However, properly vetted innovation can lead to gains in efficiency as well as effectiveness.

Statement of Propositions

As discussed previously, the prevailing goal in the nuclear enterprise is to provide the proper level of deterrence in a cost-effective manner. Thus, more effective operating methods must be sought out in order to realize additional cost savings. As such, the case has been made that RCM and CBM techniques may be beneficial in achieving this goal and are in line with current DoD policy. However, there are barriers to implementing such a strategy that must be addressed before successful implementation can take place. Therefore, this research develops a list of three propositions to further the discussion with regards to how RCM and CBM maintenance policies may benefit the MM III sustainment community. In doing so, these propositions help answer the research questions listed in Chapter II.

The first proposition is that in order to develop a successful RCM maintenance policy there should be a merger between reliability and readiness. Currently, there are two methods to calculate the alert rate for the MM III weapon system. The first is the Raw Alert Rate which is described by Equation 3 and the second is the Command

Management Standard (CMS) Alert Rate as described by Equation 4 (Phillips et al., 2011).

$$Raw\ Alert\ Rate = \frac{T-S-U}{T} *\ 100\% \tag{3}$$

Where,
T = Total active inventory hours accrued
S = Total scheduled downtime hours accrued
U = Total unscheduled downtime hours accrued

$$CMS\ Alert\ Rate = \frac{T_a-U}{T_a} *\ 100\% \tag{4}$$

Where,
T_a = Total possessed hours accrued
U = Total unscheduled downtime hours accrued

These metrics are both lagging indicators to describe maintenance's performance in keeping the weapon system on alert. The CMS Alert Rate is calculated by removing the weapon systems that are scheduled for maintenance and focusing instead on the ratio of total hours on alert against hours attributed to unscheduled downtime. However, when the variables are examined, it is seen that this metric is not a robust measurement of maintenance performance or fleet health and instead returns an overinflated representation of the facts. By only relying on the hours attributed to unexpected failures as a ratio compared to the total hours attributed to the weapons that are on alert, single failures are unable to reduce the available hours significantly. Compound this with the fact that once the weapon system is scheduled for maintenance, it is no longer accounted under the metric and that there are 150 assets per missile base, multiple failures throughout the measurement timeframe must occur for the alert rate to drop below 99%.

Therefore, actions by maintenance personnel have little impact on the CMS Alert Rate metric and thus does not provide maintenance leaders with a meaningful lagging indicator.

The alternative metric, the Raw Alert Rate, takes into consideration the total number of hours that the entire fleet could be on alert subtracted by all hours that individual weapon systems are not on alert. Taking into consideration the weapon systems that accrue hours under scheduled and unscheduled maintenance, the metric provides a measurement that indicated how proactive maintenance personnel are in returning assets to a serviceable status. Thus, this metric is in line with a reliability-centered focus and can be used as the basis for an RCM policy. As seen in Figure 5, there is a minimum number of LFs that must be alert at any given time to meet the wartime requirements for the MM III fleet. This represents the minimum level of reliability required for the MM III weapon system. However, due to modification programs and other requirements, there is an expected number of LFs that will be off alert at any given time. To ensure that the MM III force never falls below the minimum required number, there is always expected to be a number of weapons on alert above and beyond the minimum required level which is identified as the safety factor.

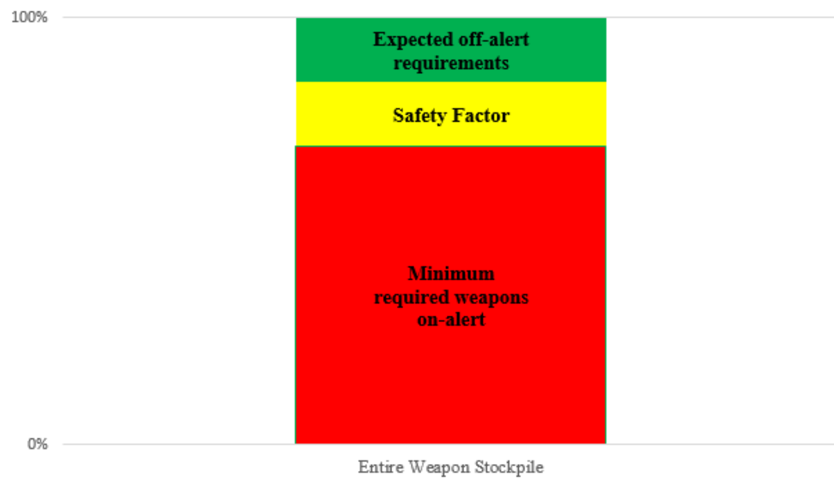

Figure 5. ICBM On Alert Levels

When applied to RCM, sustainment decision makers can use this framework as a method to select an appropriate reliability level which should be within the safety factor. The higher the chosen reliability level is above the minimum required level, the less risk there is in not meeting the wartime required number of weapons on alert. This allows for an expected number of weapon systems to always be off alert and sets the desired reliability level which would form the basis of an RCM strategy. Additionally, the selected reliability level then becomes the goal by which the Raw Alert Rate can be measured against to provide a more accurate view of maintenance performance and its ability to meet required readiness levels.

The second proposition is that in order to properly implement a modernized maintenance strategy, a decision matrix should be used to help identify what subcomponents of the MM III should adopt RCM techniques, CBM technologies, or remain under their current construct. As stated earlier, a one size fits all maintenance strategy does not necessarily equate to the most effective way of maintaining a system.

An example decision matrix from the literature is provided in Figure 6 as a means to begin the identification process of what components may see increased value from adopting an enhanced maintenance policy.

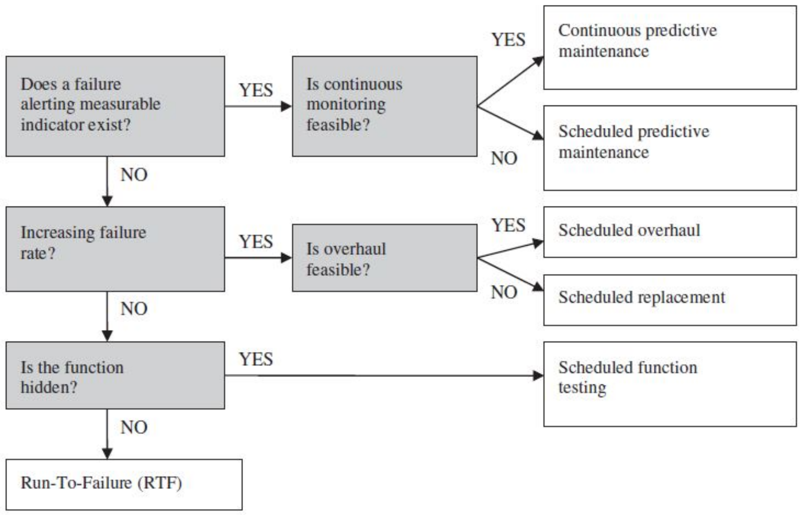

Figure 6. Example RCM Decision Matrix (Carretero et al., 2003)

To adapt this framework to the MM III, the current maintenance priority system can be examined as a method to identify items that would likely not benefit from an enhanced maintenance policy. Under the maintenance priority system discussed in Attachment 2 of AFI 21-202v2, discrepancies that are Priority 5 through Priority 9 are not considered to result in either a non-mission capable (NMC) condition nor a partially mission capable (PMC) condition. Therefore, their criticality to the overall alert status of the weapon must be negligible and thus would likely be cost-efficient to remain under its current maintenance model. Therefore, it would be beneficial to add another logic device at the start of Figure 6 that stated 'Would the failure of the component result in a Priority 5 through Priority 9 discrepancy? If yes, run-to-failure, if no, continue to question 2.'

Additionally, Attachment 3 of AFI 21-202v1 identifies the Mission Essential Subsystem List (MESL) which contains those subsystems that would have an effect on the alert status of the weapon if it became NMC or PMC. This would be a logical starting point for going through this process of identifying what maintenance concept would best fit the most essential subsystems within the MM III weapon system. Once these decisions were made, the next step would be to follow the guidance outlined in DODI 4151.22 to determine if there is a cost benefit to adopting either an RCM or CBM policy for that subsystem. It should again be noted here that the benefits of adopting such technologies before the full development of the GBSD program has economic value and should not be ignored in this analysis.

The third proposition is that in order to sustain a high level of reliability, CBM technologies should be researched for integration into the MM III. This is due in large part to the layout of the MM III infrastructure. As explained in Chapter II, the MM III is a geographically separated weapon system which spans thousands of square miles around each MSB. While there are sensors currently installed within the infrastructure to alert maintenance personnel of operating conditions that are not within approved tolerances, they provide little diagnostic information. This means that maintenance personnel must be dispatched to perform troubleshooting to identify specific components which have failed and may not be equipped with the appropriate tools or replacement parts to return the system to full alert status. By properly incorporating CBM technologies, maintainers can be dispatched with greater knowledge of the condition of the weapon system and potentially even know which component is faulty, thus reducing the amount of time dedicated to troubleshooting.

Another benefit of incorporating CBM technologies into the MM III has to do with the replacement GBSD program. According to studies done on civilian aircraft, almost 70% of items installed followed an infant mortality curve as represented by pattern ‘F’ in Figure 2; whereas only 7% were modeled under pattern ‘D’ which showed little to no early failures (Moubray, 1997). Though this does not directly translate to all industries and components, it identifies a significant concern for newly developed components. Components with high early failure rates increase the demand for maintenance resources which could exceed the planned resource capacity which would, in turn, lead to an increase in weapons off alert.

With the development of a replacement system in works for the MM III, combating excessive infant mortality rates should be a focus. Monitoring these systems using CBM technologies would lead to the ability to predict these early failures with higher accuracy and in a timely manner rather than having an early failure and not be aware of when it occurred. The expected result would be that a high alert rate would be exhibited throughout the early failures due to the predictive nature of CBM technologies.

Additionally, by working towards the integration of CBM technologies and policies before the installation of the GBSD produces two benefits. First, the policies can be implemented and refined over the remaining life cycle of the MM III. This would provide a longer timeline with which to roll out these changes so that the entire ICBM sustainment community can adapt to the new policies in a well-planned manner. Second, Total Life Cycle System Management (TLCSM) principles “…stress the importance of early and strong emphasis on designing systems for supportability to facilitate operational readiness, minimize the logistics footprint, and achieve best value operations and support cost after system deployment" (Cothran, 2008). Current cost estimates put the GBSD acquisition program at $62-$100 billion which, as stated in Chapter I, represents a significant portion of future defense spending which would only increase if the integration of CBM technologies is delayed until after the acquisition program is complete (Mehta, 2016b). In fact, Evolutionary Acquisition (where small modifications are made throughout the production cycle) and poorly defined initial requirements are two of the leading causes of cost overruns identified in major DoD acquisition programs (Porter et al., 2009). Thus, assimilating these technologies into the existing infrastructure enables the GBSD to be designed around these technologies rather than attempt to build them into the new infrastructure post-deployment and risk higher integration costs.

In addition to the two benefits listed above, there is a third potential benefit that the literature suggests may be on the horizon. Current trends focusing on autonomous design (Friedrich, Lechler, & Verl, 2014) and information technology (Manickam, 2012), and potentially topics such as additive manufacturing and data analytics, have led researchers to postulate that the fourth generation of maintenance is on the horizon. Thus, modernizing the MM III maintenance policy to incorporate CBM should result in being in a better position to capture the benefits from the transformation to a fourth-generation concept.

Summary

This chapter describes the analysis performed during this research starting with the selection of Prospect Theory as an appropriate theoretical lens and the application of that lens to the data representing the timeframe up until 1992. An in-depth analysis shows how Prospect Theory describes the current state within the nuclear enterprise and the ICBM sustainment community. Next, a review of the current maintenance construct for the MM III is explored using Prospect Theory as a means to develop three propositions to address the research questions from Chapter I.

V. Conclusions and Recommendations

Chapter Overview

This final chapter summarizes the findings from this research and their applicability to the research questions posed at the beginning of this study. The role this research will play in the future sustainment of the MM III is also explored. Finally, the recommended actions and the potential for future research are summarized to aid those following this path in setting up a starting point from which to further this research.

Conclusions of Research

Throughout this research the goal was to answer the two research questions posed in Chapter I and listed here as a reminder:

1. Can MM III sustainment managers leverage RCM methods to provide the required level of readiness at an appropriate cost?
2. Can existing CBM technologies can be applied to the MM III and GBSD in order to effectively sustain the weapon systems?

From this research, it was found that since the end of the Cold War there has been a shift away from a policy of maximum deterrence to one of minimum required deterrence. Thus, the drive for increased cost-effectiveness combined with a lack of modernization of the MM III maintenance concept has provided an opportunity for innovation to further the goal of reducing sustainment costs while maintaining the required level of weapons on alert.

The current maintenance construct has ensured that a high level of weapons has been continually on alert providing constant strategic deterrence for over half a century.

However, as the weapon system continues to age and O&M costs continue to rise the importance of seeking out cost-effective ways of operating becomes more evident. As such, RCM and CBM methods have been proven in multiple settings, both military and civilian, to be able to reduce support costs while also maintaining and even increasing system availability. From this, a set of three propositions were outlined to explore how to begin the path from the current state to implementing RCM and CBM.

Significance of Research

As noted previously, successful RCM and CBM efforts that have been implemented in a multitude of industries have been shown to provide real cost savings back to the organization while also increasing efficiency and effectiveness in the workplace. If applied appropriately to the MM III, the expectation would be that these savings would also be seen at a significant level. Additionally, because the GBSD program is in the early phases of development, early adoption of RCM and CBM will allow sustainment managers to perfect these concepts prior to fielding the new weapon system. This would also likely result in a cost savings because designing the new GBSD around existing RCM and CBM infrastructure early in the development and planning phases would be easier than attempting to integrate that infrastructure after the GBSD has been fielded.

Recommendations for Action

From this research, there were three propositions that, if explored, would be able to answer the research questions adequately. The first proposition, that there needs to be a merger between reliability and readiness, outlined how taking existing metrics and shifting the goal from maximum deterrence to appropriate readiness would establish the framework required for reliability levels required from the weapon system. The second proposition, that a repeatable and proven decision matrix should be implemented to categorize which enhanced maintenance concept should be pursued, attempted to link the RCM and CBM literature with existing decision models already established for the MM III. The third proposition, that CBM should be investigated in order to sustain high levels of reliability, outlined how pursuing CBM technologies now would be able to ensure the readiness of the MM III throughout the rest of its life cycle as well as have a robust monitoring system in place to identify early failures of newly developed components supporting the GBSD program. Further action in these three areas would provide further support to the two research questions that formed the basis of this study.

Recommendations for Future Research

In addition to the actions outlined by the three propositions listed above, there are areas within the context of this research that would benefit from further research. One area would be to explore the concept of the fourth generation of maintenance and how it applies to military systems in general and the ICBM sustainment community in particular. Being on the leading edge of a transition would provide sustainment managers with a competitive advantage and could be used as a benchmark for the rest of the DoD's sustainment community.

Another area that would benefit from further exploration would be to view the problem of modernizing the ICBM sustainment community from an organizational behavior perspective. Specifically, this would be through the social theories of change management. This research could explore what methods would be able to induce a culture of innovation under the auspices of nuclear surety and the requirement to have a safe, secure, and credible nuclear deterrence force.

Lastly, one of the limitations listed in Chapter I of this research was that the ability for the associated supply chain network to meet a change in maintenance policy would not be a part of this research. However, the link between maintenance and the supply chain is one that is imperative to be functioning properly to support efficient operations. Therefore, there would be significant benefit from further research exploring how such changes in maintenance policy would affect the associated supply chain network.

Summary

This final chapter summarizes the findings from this research. The significance of this research towards sustaining the MM III weapon system through the rest of its life cycle is illustrated as well as the potential benefits towards sustaining the future GBSD program. It also discusses what actions and future research would be beneficial to further build upon the themes explored in this research study.

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14. ABSTRACT
Since the end of the Cold War, the Air Force has sought out efficiencies across multiple processes to transform into a cost-effective force. However, processes applicable to the Minuteman III (MM III) weapon system have only recently seen efforts to increase effectiveness. The purpose of this research is to investigate whether the use of third generation maintenance concepts could benefit the sustainment of the MM III through its planned retirement around 2030. Primary and secondary sources outlining the history of the strategic missile force and its current state were collected. Themes from each era were analyzed using Prospect Theory as a means to understand the past and interpret the current state. The resulting interpretation led to propositions on how third generation maintenance concepts could be applied to the sustainment of the MM III as well as benefit its planned replacement, the Ground Based Strategic Deterrent (GBDS) program.

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