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A Portfolio Decision Analysis Study for Improving Consequence of Facility Failure Indices

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THESIS

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Abstract

The United States Air Force partially integrated the Mission Dependency Index (MDI) into its portfolio project selection model by assigning an MDI value to a facility type or real property category code (CATCODE) in lieu of assigning a unique MDI value to each facility through a structured interview process. This took an initial step to improve the Air Force's asset management practices; however, it failed to accurately capture the consequence of facility failure in some cases. Although a process to adjudicate the MDI value of individual facilities was created, it is still unknown how much the surveyed MDI value deviates from the CATCODE assigned MDI value and how this influences the Air Force's annual project portfolio selection model.

The purpose of this research effort is to measure the deviation in MDI values produced from surveys and the adjudication process with the CATCODE assigned MDI values. It also uses a deterministic approach to portfolio decision analysis to determine the influence these surveyed and adjudicated MDI values have on the Air Force's project portfolio selection model. This research effort serves to provide insight to the Air Force Installation Mission Support Center and the Air Force Civil Engineer Center of the value and utility of surveyed and adjudicated MDI information when compared to their CATCODE assigned counterparts.

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A PORTFOLIO DECISION ANALYSIS STUDY FOR IMPROVING CONSEQUENCE OF FACILITY FAILURE INDICES

I. Introduction

The United States Air Force is an armed service branch of the Department of Defense (DoD). Along with the other sister services, the Air Force has a number of established roles or capabilities known as "core functions" which include Nuclear Deterrence Operations, Air Superiority, Space Superiority, Cyberspace Superiority, Command and Control, Global Integrated Intelligence, Surveillance, and Reconnaissance (ISR), Global Precision Attack, Special Operations, Rapid Global Mobility, Personnel Recovery, Agile Combat Support, and Building Partnerships (United States Air Force, 2003). The ownership and execution of these core functions and geospatial areas are the responsibility of the Air Force's Major Commands (MAJCOMs).

In addition to executing the Air Force's core functions, General David Goldfein, the current Chief of Staff of the United States Air Force, has communicated a number of strategic priorities to commanders and leaders throughout the Air Force. These priorities included the importance of "maintaining" the Air Force's infrastructure and "modernizing and recapitalizing critical infrastructure" to support airpower projection and other core functions with a "network of globally positioned bases" (Goldfein, 2017). As of November 2016, the Air Force has a large infrastructure portfolio valued at $302 billion which is distributed across 183 installations in the United States, Europe, and Asia (Uhlig, 2006). Leaders across the Air Force, DoD, and other federal agencies are challenged with managing large and diverse infrastructure portfolios sustain and support their organization's mission.

Managing aging facilities and infrastructure with limited financial resources has become a challenging issue for the Air Force and other agencies in the federal government. In response to this problem, President George W. Bush signed Executive Order (EO) 13327 in 2004 to ensure that all federal government agencies adopted an "asset management planning process." The adoption of an asset management planning process is intended to "promote the efficient and economical use of Federal real property resources in accordance with their value as national assets and in the best interests of the Nation" (Executive Order No. 13327, 2004). Woodhouse (1997) defined asset management as a "set of processes, tools, performance measures, and shared understanding that glues the individual improvements or activities together." The adoption of asset management practices is even more important for governments and federal agencies because their "large" and "diverse" infrastructure portfolios are often subject to "inadequate funding or inappropriate support technologies" (Vanier, 2001).

The 2011 Budget Control Act and other federal budget cuts have severely limited the amount of financial resources available to the DoD and Air Force's infrastructure, while the DoD estimated in March 2012 to have "20 percent excess infrastructure capacity" (GAO, 2013). Financial resource constraints and excess infrastructure have resulted in the DoD funding only 67 percent of the facility sustainment, restoration, and modernization (FSRM) requirements in fiscal year (FY) 2016 (Serby, 2016). FSRM funds are allocated to conduct maintenance, repair, and modernization of facilities. The FSRM budget was $1.137 million, $1.427 million, and $1.646 million for FY 2015, 2016, and 2017, respectively, or approximately less than one percent of the Air Force's real property replacement value (Uhlig, 2006). This value is well below the industry standard recommendation of an annual maintenance and repair budget valued at 2 to 4 percent of real property replacement value (Federal Facilities Council, 1996). The gap in financial resources allocated to infrastructure illustrates a significant risk to the Air Force's infrastructure assets.

Air Force leadership is aware of the challenge of managing infrastructure requirements with limited resources. Brigadier General Timothy Green, the Air Force Director of Civil Engineers, elaborated on the extent of the risk to the United States Senate Appropriations Committee in March, 2015 by explaining decreased funding to infrastructure would affect "every level of [the] national security strategy" (Roulo, 2015). Brigadier General Christopher Azzano, commander of Eglin Air Force Base, explained "Today, I can handle the emergency requirements to support our day-to-day mission requirements;" however, the significant backlog of deferred maintenance may result in a facility failure rate exceeding the installation's capacity for emergency maintenance and repairs (Serbu, 2016). The risk placed on the Air Force's infrastructure demonstrates the importance of implementing asset management practices to not only comply with EO 13327's requirements, but also to mitigate the impact of depreciated and underfunded infrastructure assets on the Air Force's mission.

Quantifying the Consequence of Facility Failure

The Air Force and many other federal agencies are challenged with prioritizing a large volume of FSRM requirements with limited and constrained financial resources. Gabriel, Kumar, Ordonez, and Nasserian (2016) explain project selection is "inherently multiobjective" and that these different objectives must be satisfied by the project portfolio. These different objectives can be quantified by the use of "valid metrics" to optimize the infrastructure project portfolio (Gabriel et al., 2005). The Air Force has used multiple iterations of project selection models to prioritize the FSRM requirements and develop a project portfolio that best support the Air Force's mission and the National Security Strategy. However, this research effort focused on the current project selection model, as research utilizing this model provided the greatest utility and value to the Air Force. Furthermore, this research effort will examine the metrics used to quantify the consequence of facility failure; specifically, how the values produced by different survey methodologies, with respect to the metric currently utilize by the Air Force, influence the Air Force's annual project portfolio. Although other research efforts have proposed the use of different metrics to quantify the consequence of facility failure, they have not yet produced a data set applicable to the scope of this research effort.

Risk

Mitigating risk is a central and important theme in asset management. Woodhouse (1997) explained the importance of "quantifying risks and building them into the decision process" as it applies to project selection. Kaplan and Garrick (1981) quantified risk as "uncertainty + damage" or rather the probability an event will happen and the resulting consequences of the event. Managing and quantifying the subcomponents of risk is central to the both the military and asset management, especially when additional risk is placed on facilities and infrastructure. Kaplan and Garrick's (1981) damage or consequence of failure is often quantified as financial or monetary values; however, this is not always applicable as some organizations aim to satisfy multiple objectives. Although subject to their own limitations, the use of indices and indirect measurements can provide utility to the decision-making process.

Mission Dependency Index

The Naval Facilities Engineering Command (NAVFAC), National Aeronautical and Space Administration (NASA), and the U.S. Coast Guard of Civil Engineering jointly developed a metric known as MDI in early 2000 to quantify the consequence of facility failure (Uddin, Hudson, & Haas, 2013). The use of the MDI metric helps improve asset management practices and can be used to prioritize project portfolios to better mitigate the risk to the installation's mission. The MDI metric produces a qualitative risk based score between the values of 1 and 100 through a structured interview with different organizational components and agencies. This score can also be separated into five different categories including "critical, significant, relevant, moderate, and low" (Antelman, Dempsey, & Brodt, 2008). Although initially adopted for the previously mentioned organizations, the Air Force also incorporated the MDI metric into its asset management practices.

In 2008, the Air Force recognized that previous project portfolio selection methodologies lacked a "disciple driven asset strategy and metrics that link assets to its missions” which made “prudent, long-term funding decisions” difficult while operating under a “flat and or declining budget environment” (NAVFAC, 2008). In response, the Air Force hired the consulting firm, Booz Allen Hamilton, to evaluate existing metrics used to quantify the consequence of facility failure. Booz Allen Hamilton recommended that the Air Force adopt the use of the Navy’s MDI metric to be used “in conjunction with other data, such as asset condition” to better prioritize project portfolios (NAVFAC, 2008). The next step required for the Air Force to adopt the MDI metric was to prove the concept in practice.

The Air Force and NAVFAC performed a joint MDI survey in 2008 at Langley Air Force Base (AFB) and Fairchild AFB (NAVFAC, 2008). The joint survey proved that the MDI scoring criteria and “structured interview process” was a compatible methodology for the Air Force (Antelman, Dempsey, & Brodt, 2008); however, an initial attempt to perform MDI surveys at each installation at the cost of $5 - 6 million was not funded (Madaus, 2016). These additional surveys would have assigned unique MDI values to each facility. In lieu of the MDI surveys at each installation, the Air Force assigned MDI values based on facilities’ Real Property Category Codes (CATCODE), a way of categorizing different types of facilities based on their function and use. Although the CATCODE approach to assigning MDI values was originally intended to be a temporary methodology, the Air Force has continued to operate under this methodology since its inception 8 years ago.

After implementing the CATCODE MDI methodology, MAJCOMs “identified numerous MDI-to-CATCODE mismatches that were not fulfilling the intent of measuring criticality and replaceability” (Nichols, 2015). The MAJCOMs which had the most frequent mismatches were those whose core functions did not align with aerial warfare. These MAJCOMs included Air Force Global Strike Command and Air Education and Training Command. In response, the Air Force created an adjudication process in which installations could advocate for the reassessment of a facility's MDI value. As of 15 January 2015, this process has identified and successfully approved 1,609 MDI adjudications out of 2,240 adjudication requests. The successful adjudications represent less than 1 percent of the United States Air Force's real property portfolio (Uhlig, 2006). Furthermore, the adjudication process is a lengthy and time consuming process; each adjudication collectively utilizes between 2.5 and 4 personnel hours (Nichols, 2017). Although the adjudication process has provided an opportunity for installations to advocate for changes in their facilities' MDI values, this practice does not currently have the capacity to adjudicate all Air Force facilities. The CATCODE MDI methodology has led to a compounding series of problems which have not been fully corrected by the adjudication process, thus highlighting the need to determine the value and utility of MDI information produced through the CATCODE methodology, NAVFAC structured interview process, and adjudication process to enable the Air Force to adopt the optimal methodology of measuring MDI values.

Problem Statement

The CATCODE methodology partially integrated the MDI metric into the Air Force's asset management practices in lieu of spending additional financial resources to conduct an MDI survey at each installation. Although business practices have allowed installations to advocate for changes or adjudicate MDI values, a better methodology may be needed to better quantify the consequence of facility failure to effectively mitigate risk to the United States Air Force's infrastructure and missions. It is not currently known how much the MDI values produced from these different methodologies deviate or how these deviations influence the Air Force's FSRM requirement prioritization.

Research Objectives and Investigative Questions

The purpose of this research effort is to improve the United States Air Force's methodology to measure and quantify the consequence of facility failure. The following research questions were developed to meet this research objective.

1. How much do the CATCODE assigned MDI values deviate from the MDI values assigned through a NAVFAC structured interview methodology?
2. How does a project portfolio utilizing a CATCODE assigned MDI value compare to a project portfolio utilizing MDI values assigned through a NAVFAC structured interview methodology?
3. How much do the CATCODE assigned MDI values deviate from the adjudicated MDI values?
4. How does a project portfolio utilizing a CATCODE assigned MDI value compare to a project portfolio utilizing adjudicated MDI values?

Methodology

This research effort measured the deviations between MDI values and also used a deterministic approach to portfolio decision analysis. The first and third research question were answered by examining the deviation in MDI values produced by the CATCODE, adjudication, and NAVFAC structured interview process methodologies.

The second research question was answered by examining the difference in project scores and portfolio funding recommendations when CATCODE MDI values and surveyed MDI values were used on the Fairchild and Langley AFB FY 2015, 2016, and 2017 project portfolios or Base Comprehensive Asset Management Plans (BCAMPs). The fourth research question was answered by examining the difference in project scores and portfolio funding recommendations when CATCODE MDI values and adjudicated MDI values were used for the FY 2015, 2016, and 2017 AFCAMP.

Assumptions/Limitations

The primary limitation to this research effort is the problematic nature of calculating the value of surveyed MDI values when compared to CATCODE assigned MDI values. The Air Force's primary objective is not profit driven but rather mutiobjective, including many tangible and intangible attributes. The scope of this research effort does not include calculating the value of surveyed or adjudicated MDI information when compared to CATCODE assigned values; instead, it focuses on the deviation in the MDI values assigned by these methodologies and their respective project portfolios. Therefore, it is assumed that the surveyed and adjudicated MDI values more accurately reflect the consequence of facility failure and thus produce a more optimal project portfolio than the CATCODE assigned MDI values. Additional assumptions and limitations for each research question are thoroughly explained in Chapter III.

Overview

This thesis adheres to a five chapter format. Chapter II summarizes the literature and research relevant to this research effort. Chapter III addresses the deterministic and stochastic portfolio decision analysis methodologies while Chapter IV presents the analysis and results derived from these methodologies. Lastly, Chapter V will summarize this research effort, address each investigative question, and recommend additional research opportunities.

II. Literature Review

This chapter provides background information regarding the existing literature to better understand what has already been researched, further explore the methodologies available to this research effort, and identify relevant research gaps. The chapter examines the advantages of viewing asset management from a system engineering perspective. The next section addresses the United States Air Force's asset management framework and facility sustainment, repair, and modernization (FSRM) project selection criteria. The next section examines the field of decision analysis to lay the framework for the methodology. Lastly, this chapter discusses the history and background information of the MDI metric.

Asset Management

Although the requirement for federal agencies to practice asset management was signed in 2004, the academic theory and formal practice of asset management emerged in the late 1980s and early 1990s (National Asset Management Steering Group, 2006). Many asset management practitioners and scholars are trying to advance and develop the field of asset management. Valencia, Colombi, Thal, and Sitzabee (2011) expand on Woodhouse's (1997) definition of asset management by exploring several themes to create their own definition. Valencia et al. (2011) first explained that asset management is a "holistic, life-cycle view, or systems view" as it offers a variety of "tools and techniques to address infrastructure issues." Next, their definition identifies the importance of "quality data" since good asset management practices are unattainable without it. Lastly, asset management's purpose is to "optimally managing physical assets at least cost to stakeholders", while the term cost not only refers to the financial burden but also to other "intangible costs," including health, public perception and trust, and social costs (Valencia et al., 2011). The field of asset management has progressed from its inception 25 years ago, but the rapid advancement of technology and other factors has created new opportunities and challenges for asset managers.

Robinson, Woodard, and Varnado (1998) characterize our once "fairly independent" infrastructure systems as now being "a complex system of interrelated elements" whose failure has consequences at the regional and possibly even the national level. The reason for this complexity includes "technical, economic, managerial, environmental, political, and social factors" (Godau, 1999). A number of scholars and organizations including the American Society of Civil Engineers (ASCE) and the International Council on Systems Engineering (INCOSE) advocate for the use of Systems Engineering (SE) as a "framework" to address this layer of complexity and interconnectedness (Valencia et al., 2011). The use of applicable practices in SE helps bolster the tools and techniques available to asset managers to better manage interconnected infrastructure assets subject to numerous factors and variables.

<u>Systems Engineering Approach</u>

Systems engineering is an area of study that aims to model the real world as a system. INCOSE (2004) formally defines systems engineering as:

> Systems engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer

> needs and required functionality early in the development cycle, documenting requirements, and then proceeding with design synthesis and system validation while considering the complete problem: operations, cost and schedule, performance, training and support, test, manufacturing, and disposal. SE considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs. (INCOSE, 2004)

The definitions of asset management and SE provided by this research effort demonstrate that both fields are remarkably similar, since they both aim to create a set of the best economical processes for the defined system. An SE perspective yields a critical toolset for organizations adhering to the principles of asset management. Six systems engineering processes, represented in Figure 1, were identified to be compatible and applicable to the field of asset management (Valencia et al., 2011). The six SE processes can bolster and enhance asset management practices; however, the parallels between the decision-making and risk management process are of particular importance to this research effort.

Systems Engineering		Infrastructure Asset Management
Stakeholder Requirements Definition Process	↔	Levels of Service
Decision Management Process	↔	Optimized Decision Making
Risk Management Process	↔	Risk Assessment and Management
Information Management Process	↔	Information Systems and Data Management
Measurement Process	↔	Measure Levels of Service
Life CycleManagement Process	↔	Life Cycle Asset Management

Figure 1. Comparison of SE and Asset Management Processes (Valencia et al., 2011)

Systems engineering and asset management both follow a logical and optimal decision-making process. The preferred way of decision-making cited by Markowitz (1952) is the portfolio that yields anticipated "value of future returns." The National

Asset Management Steering Group (2006) stresses cost or financial resources as the "primary means for quantifying alternatives" (Valencia et al., 2011). The financial investment and return are the preferred metrics when selecting portfolios, but these variables do not account for risk and other intangible aspects. Systems engineering and asset management recognize the two alternate approaches as being "risk-based decision-making and multi-criteria decision-making" (Valencia et al., 2011). Although financial investment and expected returns should be the preferred method of selecting alternatives, this methodology is not always the preferred model for systems engineering and asset management practices.

Asset management and systems engineering have similar approaches to risk management in that their basic risk models are both extrapolated from Kaplan and Garrick's (1981) risk definition of "uncertainty + damage". An example of a risk-based asset management model is the use of Conditional Value at Risk (CVaR) as a way to model maintenance and repair policies on infrastructure (Seyedshohadaie, Damnjanovic, and Butenko, 2010). The CVaR model is based on Neumann and Morgenstern's (1944) expected utility theory which aims to maximize the expected return value, similar to Markowitz's (1954) portfolio selection model. The asset management and SE approaches to risk management are very similar as they both use probability and consequence as the primary variables to model risk; however, a system engineering approach offers additional risk management tools to asset managers.

One example of an applicable SE tool includes risk mapping. Piyatrapooni, Kumar, and Setunge (2004) apply Harrington and Rose's (1999) risk map technique to produce a tool, represented in Figure 2, to help asset management practitioners visualize risk and the decision-making process by "categorizing a risk event into one of three tolerability regions" (Valencia et al., 2011). This technique of risk mapping is currently used by the Air Force. Another benefit of the SE approach to asset management is the identification of additional risk variables. Haimes (2009) explains a "systems-based definition" is able to expand upon the basic risk model by including the variables "vulnerability" and "resilience." Although these additional variables add complexity to the risk model, the systems approach to risk management may more accurately quantify risk and identify previously unknown risk events. SE and asset management have similar approaches to risk management, but there are still tools and techniques available to asset managers through an SE approach.

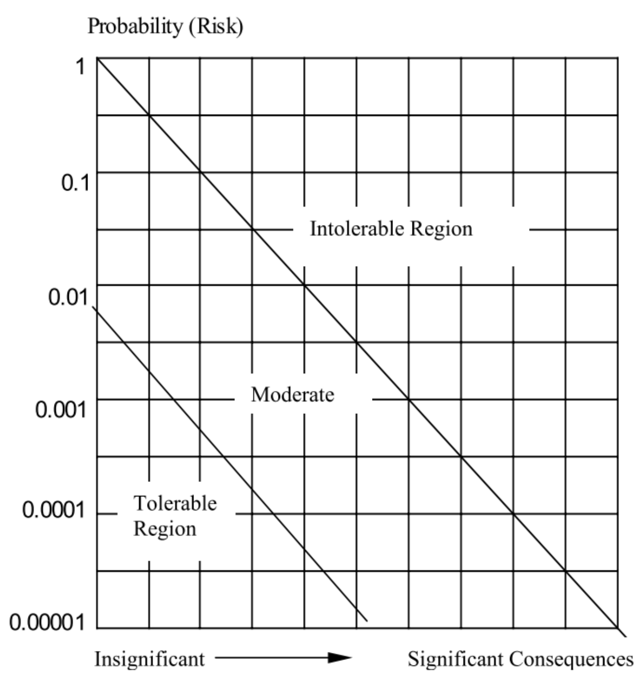

Figure 2. Risk Map (Piyatrapoomi, Kumar, & Setunge., 2004)

The other decision-making model available to asset managers through an SE approach is the multi-criteria decision analysis (MCDA) models. This methodology, represented in Figure 3, involves the creation of an MCDA model in which different objectives are represented through the use of quantified measurements and their respective weights. The objectives and weights are determined through the “stakeholder analysis” in which the viewpoint of those parties affected by the decision are given consideration (Macharis, De Witte, & Ampe, 2009). The different alternatives are then ranked according to the values produced by the multi-criteria model; however, it is important for the decision-maker to understand the assumptions and limitations of the model as they are responsible for the final decision. Macharis et al. (2009) explains the MCDA model is a useful tool for transportation infrastructure as it considers “all effects” from a policy or proposed project. The SE approach to asset management enables decision-makers to make better asset management decisions through the MCDA approach.

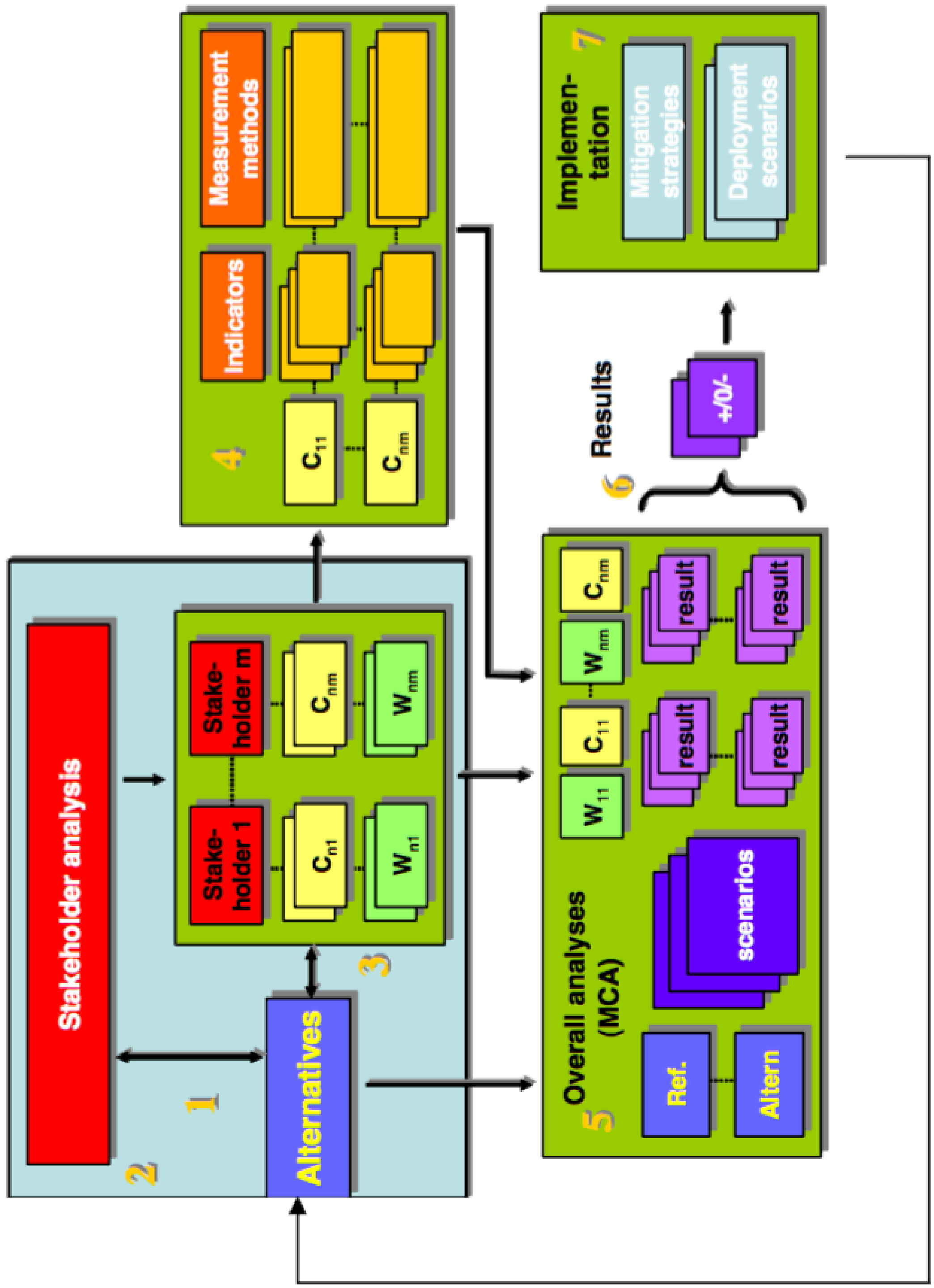

Figure 3. Multi Actor Multi-Criteria Approach (Macharis et al., 2009)

Asset Management Standards

Numerous organizations and scholars have advanced the field of asset management forward, but it is also important for organizations to establish and publish standards to achieve a degree of uniformity across different asset management practicing organizations. The British Standards Institute (BSI) and International Organization for Standardization (ISO) published the ISO 5500 series on Asset Management in an effort to achieve a degree of uniformity between management systems implemented by different organizations. The ISO 5500 series outlines the relationship between key terms and how the asset management system or framework integrates into the organization's management system, as shown in Figure 4 (BSI, 2014). The asset management framework is the organization's approach to asset management through the use of specific policies, objectives, and plans. The framework then shapes how the organization manages its asset portfolio.

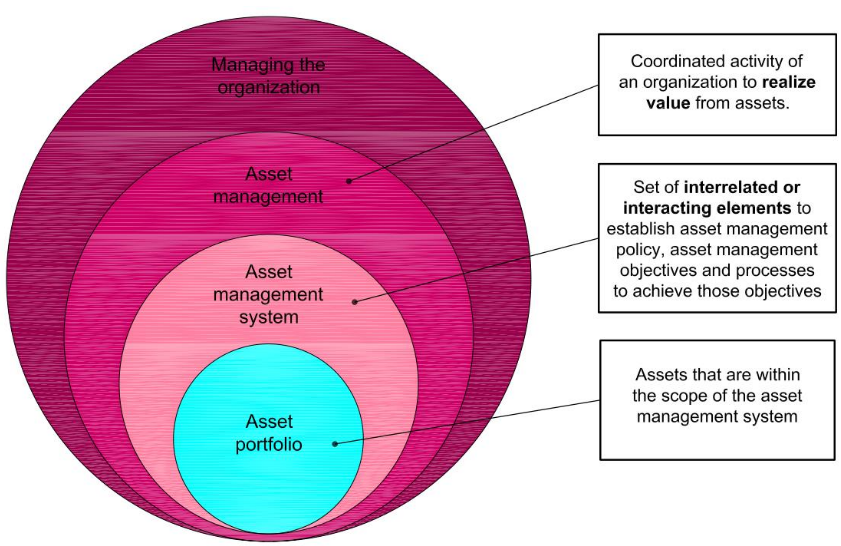

Figure 4. Relationship Between Key Terms (BSI, 2014)

Air Force Asset Management Practices

The Air Force developed an asset management framework to better manage its infrastructure portfolio and meet the requirements specified by EO 13327. The United States Air Force asset management framework, as shown in Figure 5, is an iterative six-step process designed to operate at the strategic or highest organizational level. The first step is "Asset Visibility, Data Maintenance & Accountability;" this is where facility and infrastructure data are recorded and maintained better determine how resources will be allocated to meet the United States Air Force's mission requirements and goals (Bodenheimer, 2016). The next step is to identify the condition of the infrastructure asset and define requirements to enable the infrastructure asset to remain operational. After the requirements are defined, the next step is to "strategize your investment based on priorities and risk" and develop "installation specific plans" (Bodenheimer, 2016). Lastly, the final three steps involve the development, prioritization, and execution of the programs.

Figure 5. United States Air Force Asset Management Framework (Bodenheimer, 2016)

The structure of the Air Force's asset management framework has not drastically changed since the Air Force was formally required to practice asset management in 2003. However, the steps and processes within the framework have evolved as the Air Force has made a continual effort to improve its asset management practices. The program development prioritization step in the Air Force's asset management framework has used several project selection models to prioritize the FSRM project portfolios.

Facility Investment Matrix

The first project selection model used by the Air Force to prioritize FSRM requirements was the Facility Investment Matrix (FIM). This project selection model was implemented in 2003 and took an initial step to better prioritize the Air Force's maintenance and repair project portfolio. The FIM prioritized projects using two categories: facility class and the facility's impact to the installation's mission. The FIM, shown in Figure 6, classified the facility class using its association to a specific mission, to include “Operations and Training”, “Maintenance and Production,” and “Medical,” and also by the functional nature of the infrastructure to include “Utilities and Ground Improvements” and “Dormitories” (AFI 32-1032, 2003). The impact to the installation’s mission was categorized as critical, degraded, or essential using the degree of impact to mission capability, “work-arounds” required to prevent “mission disruption and degradation,” and various fire code and safety violations as selection criteria (AFI 32-1032, 2003).

	IMPACT RATINGS		
Facility Class	**Critical**	**Degraded**	**Essential**
Operations and Training			
Mobility			
Maintenance and Production			
RDT&E			
Supply			
Medical			
Administrative			
Community Support			
MFH			
Dormitories			
Utilities and Ground Improvements			

Figure 6. FIM Requirements Matrix (AFI 32-1032, 2003)

The FIM took the first step to prioritizing the Air Force’s project portfolio, but utilized a lengthy timeline and significant amount of human resources (Nichols, 2013). Additionally, the project selection criteria only considered the impact or consequence, and it is not nearly as robust as other project selection models that considered facility condition and life-cycle cost analysis. Although the FIM had significant limitations, it represented the Air Force's first step to prioritize FSRM requirements and laid the foundation for the next project selection model.

Infrastructure Prioritization Balanced Scorecard

The next project selection model, introduced in 2010, was referred to as the Infrastructure Prioritization Balanced Scorecard. This project selection model, shown in Figure 7, utilized similar selection criteria as the FIM to include the "Health, Safety, and Compliance" and "Local Mission Impact," but it also introduced the use of other additional selection criteria and metrics (HAF, 2010). These included the Facility Condition Index (FCI), "Cost Efficiency," Major Command (MAJCOM) Priority, and MDI. Although the Infrastructure Prioritization Balanced Scorecard was more robust than its predecessor, many of the project selection criteria were redundant and the complexity of the model required significant amount of human resources to prioritize thousands of FSRM requirements. This led, to the implementation of a simpler and less redundant model, the Air Force Comprehensive Asset Management Plan (AFCAMP).

	Wt %	Service Area	Significant 100	Very High 80	High 60	Moderate 40	Small 20	Not Rated 0
Technical Score	15%	**Health, Safety & Compliance*** *Two issues from same category bump a project up to the next risk category (e.g. "high" to "very high")	- RAC 1 - FSDC 1	-QD Arc violation -Nuclear Surety Deviation - Comply w/ fed/state law or regulation	- RAC 2 - FSDC 2 - Airfield Waiver - AT/FP, perimeter defense bldgs		- RAC 3 - FSDC 3 -Comply w/ UFC/DODI/AFI	No Health, Safety & Compliance Issues
		Asset Preservation, Development						
	10%	**Facility Condition (Q-Rating)**	<60 (Q4)	60-79 (Q3)		80-89 (Q2)		>90 (Q1)
	15%	**Mission Dependency Index**	ACTUAL MDI SCORE					N/A
	20%	**Local Mission Impact**	- Significant loss of msn capability & frequent msn interruptions		- Limited loss of msn capability & limited msn interruptions			- Marginal /no adverse impact to msn capability
	15%	**Cost Efficiency***						
		Energy Payback (PB)	PB ≤ 2 yrs		2yr < PB ≤ 5yr		5yr < PB ≤ 10yr	PB > 10yr
		Consolidation/Demo	< $20/SF		$20/SF-$40/SF		$40/SF-$60/SF	> $60/SF
		Companion Project	> $5M	$4M - $5M	$3M - $4M	$2M - $3M	< $2M	No Companion
Priority Score	25%	**Service Quality -- Reliability, Responsiveness & Capacity, Asset Management** (MAJCOM Priority)	Priorities: Each MAJCOM is allocated priorities in the following manor [(One per $1B of RECAP Plant Replacement Value + # of Major Installations) x 2]+3. Example: $21.4 B PRV & 8 bases = 2x(21.5 + 8)+3 = 62 earned priorities for scoring. Points for allocated priorities will be evenly distributed 0-100 across the total number of scored priorities for each MAJCOM.					

Figure 7. Infrastructure Prioritization Balanced Scorecard (HAF, 2010)

Air Force Comprehensive Asset Management Plan.

The Air Force transitioned to a new project selection model in 2015, known as the Air Force Comprehensive Asset Management Plan (AFCAMP), to better measure and mitigate risk to the mission. This process, shown in Figure 8, began after each installation submitted their maintenance and repair requirements for the next 2 years in a product known as the Base Comprehensive Asset Management Plan (BCAMP). The MAJCOM would then consolidate their respective installation's BCAMPs and submit a product to Headquarters Air Force (HAF) and the Air Force Civil Engineer Center (AFCEC) known as the MAJCOM Comprehensive Asset Management Plan (MCAMP). Lastly, HAF and AFCEC would compile the MCAMPs to form the AFCAMP. The project selection model utilized by the AFCAMP process uses different metrics to mitigate risk to the mission.

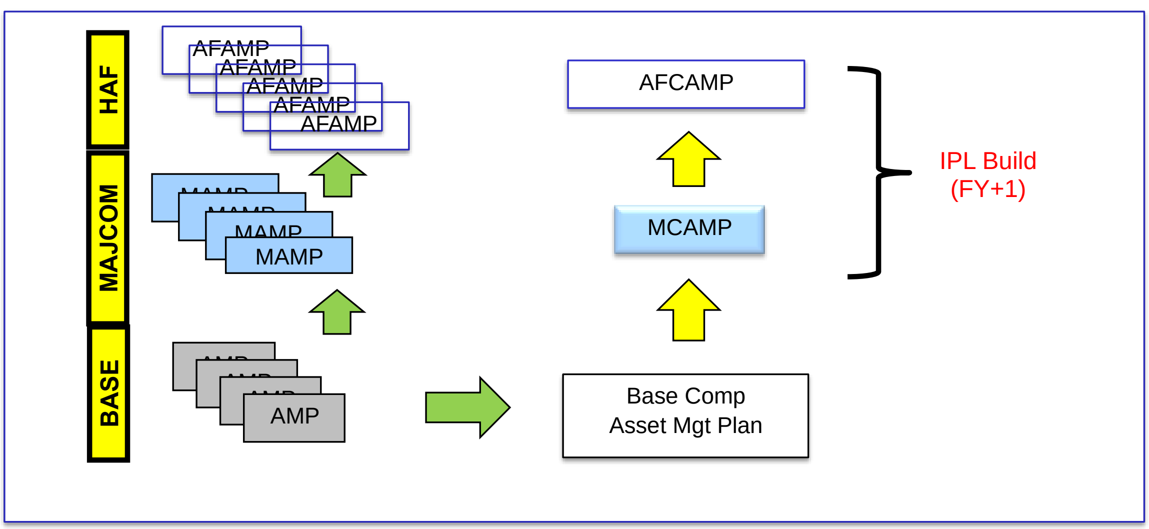

Figure 8. CAMP Process (AFCEC, 2016)

Maintenance and repair projects are selected based on the scoring criteria shown in Equation 1, which includes the probability of failure (POF), consequence of failure (COF), and savings investment ratio (SIR) (AFCEC, 2014). The primary goal of the selection criteria is to mitigate risk to each installation's missions (AFCEC, 2016). As shown in **Error! Reference source not found.**, the POF and COF represent the domains o f risk, with greater risk being represented in areas where the POF and COF are higher. The primary objective of mitigating risk to the mission is reflected in the weights assigned to each scoring criteria as POF and COF are allocated a maximum score of 100 points each while the SIR is allocated a maximum of 10 points. It is not mandatory to calculate the SIR (AFCEC, 2016). The weights assigned to POF, COF, and SIR allow a project to score between 0 and 210 points. The Air Force utilizes several different metrics to measure each criterion.

$$Project\ Score = POF + COF + Project\ Savings \tag{1}$$

The POF, represented in Equation 2, is derived from a condition index (CI) score produced from a sustainment management system known as Builder™, which is an asset management tool and web-based software application developed by the Army. It was designed to help improve DoD asset management practices by conducting "knowledge based" inspections of the infrastructure system's "condition" and "functionality" to determine the "remaining service life" and CI (Builder™, 2013). The CI, an ordinal value between 1 and 100, reflects the asset's probability of failure. The POF can receive a maximum score of 100 points after the asset's CI reaches a value of 50 or below.

$$POF = (2)(100 - \text{CI}) \tag{2}$$

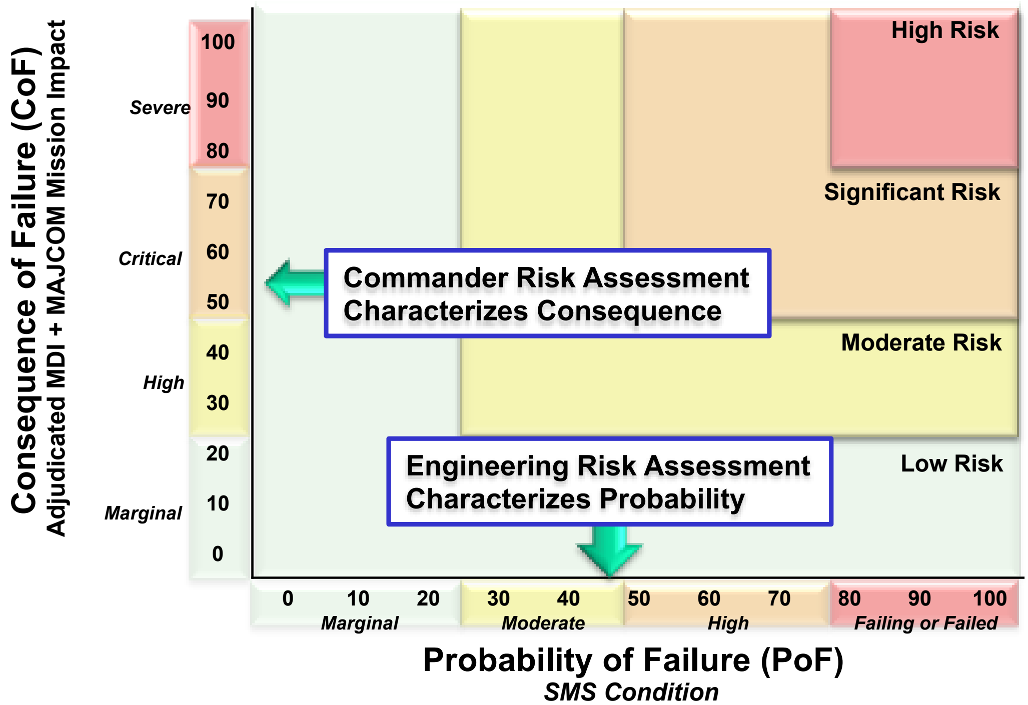

Figure 9. Project Selection Risk Matrix (AFCEC, 2016)

The COF, represented in Equation 3, is derived from two metrics which quantify the consequence of facility failure at the installation and MAJCOM levels. The MDI metric, with a maximum score of 60 points, reflects the consequence of facility failure at the installation level. The projects are also ranked from 1 to *n* by the MAJCOM to measure the consequence of facility failure at their level. This is accomplished during the AFCAMP process when the MAJCOM compiles the BCAMPs and submits the MCAMP to HAF and AFCEC. The highest ranked project receives the maximum value of 40 points, and each additional priority "is decremented equally for each additional priority until the maximum number of priorities for that MAJCOM is reached" (AFCEC, 2016).

$$COF = (0.6)(MDI) + (0.4)(MAJCOM\ Priority) \tag{3}$$

The Project Savings, represented in Equation 4, is derived from the Savings Investment Ratio (SIR). The SIR is derived from the estimated savings expected to be received by executing the project and the estimated cost of the project. These savings include the reduced costs to operate and maintain the infrastructure and reduced energy requirements. The maximum score for SIR is constrained as projects with an SIR of 1.0 or greater can only receive a maximum of 10 points.

$$Project\ Savings = \begin{cases} (SIR)(10) & SIR \leq 1.0 \\ (10) & SIR > 1.0 \end{cases} \tag{4}$$

Decision Analysis

The field of decision analysis also has many similarities to asset management and systems engineering; however, it does offer a set of unique tools and techniques. Parnell, Bresnick, Tani, and Johnson (2013), describe decision analysis as:

> a philosophy and socio-technical process to create value for decision makers and stakeholders facing difficult decisions involving multiple stakeholders, multiple (possibly conflicting) objectives, complex alternatives, important uncertainties, and significant consequences. (Parnell et al., 2013)

Although the Air Force has advanced its asset management practices through the use of multiple MCDA models, examining the MCDA process from a decision analysis perspective could aid the decision makers and stakeholders involved in the project portfolio selection process.

The Air Force has undergone several iterations of the decision analysis cycle as it has utilized several different project scoring models to determine the optimal project portfolio, represented in Figure 10 as the "Dialogue Decision Process" (Parnell et. al, 2013). Despite having undertaken several iterations of the dialogue decision process and decision analysis cycle, these cycles have lacked a structured deterministic and probabilistic analysis to ensure the project scoring models yields the most optimal portfolio. More investigation and research needs to be performed on the quality of the value measures and metrics used in the model.

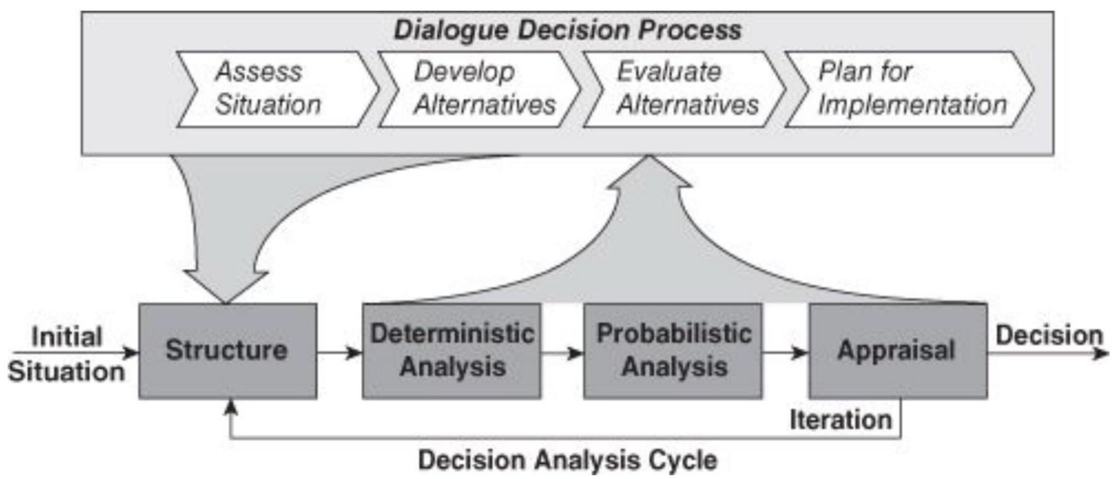

Figure 10. Decision Analysis Cycle (Parnell et al., 2013)

<u>Decision Hierarchy</u>

The decision hierarchy shown in Figure 11 is a tool used to determine the scope of a decision. The types of decisions are classified as policy (top of pyramid), strategic (middle of pyramid), and tactical (bottom of pyramid). Policy decisions are "taken as given" and derived from decisions made by higher organizational authorities (Howard & Abbas, 2015). Tactical-level decisions are decisions "to be decided later." The scope of any decision analysis problem is therefore confined to the strategic level. It is important to obtain the correct scope for any decision analysis problem as it is often considered "the most important aspect of making good decisions" (Howard & Abbas, 2015).

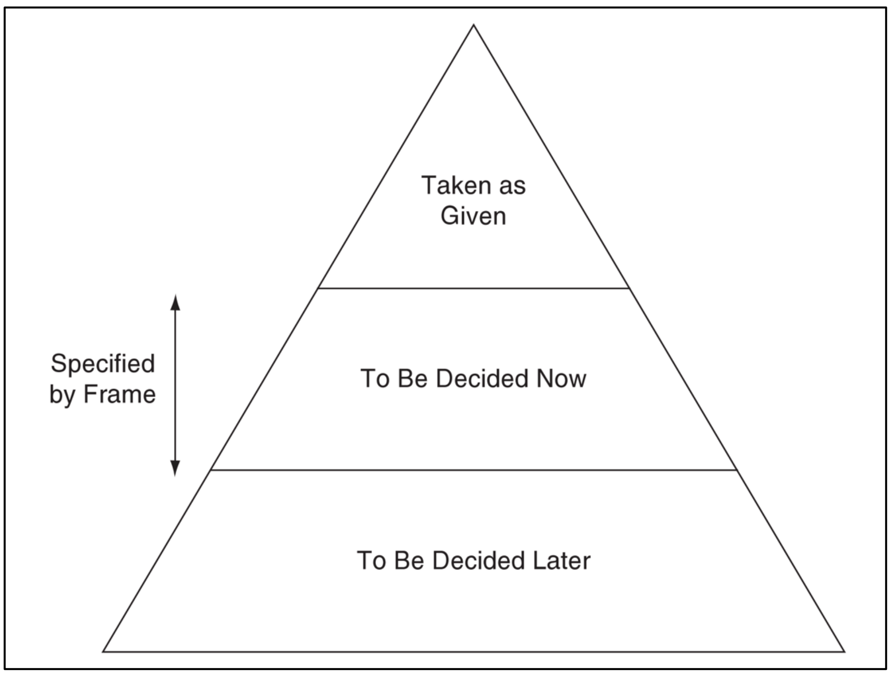

Figure 11. Decision Hierarchy (Howard & Abbas, 2015)

Multiobjective and Linear Additive Portfolio Value Model

The Air Force currently uses a project selection methodology aligned with the linear additive portfolio value model, under which multiple project value measures are "aggregated into an overall project value by using a multi-criteria value/utility function"

(Mild, Liesiö, & Salo, 2010). Similar to the traditional linear additive portfolio value model, which adds "projects one-by-one in descending order of value-to-cost ratios until the budget is depleted" to obtain the maximum portfolio value, the Air Force follows a project model which selects the projects with the highest values generated from project score criteria, regardless of project cost, until the budget is depleted (Mild et al., 2010).

As discussed in Chapter I, it is very difficult for military organizations to quantify risk as a monetary value, as the military does not value a single monetary objective but rather a range of multiple and varying objectives. A multi-criteria value function or MCDA is a better measure of risk for multiobjective organizations and quantifies previously intangible values. The linear additive portfolio model produces a portfolio in which projects with the highest multi-criteria value model scores are funded until the budget is depleted; this model yields a fixed project score cut-line for which all projects scoring above a specified value are funded and all those below the value are unfunded. The purpose of any decision analysis cycle is to provide the decision-maker with clarity of action and valuable information, after which the decision-maker can alter the project portfolio to their preferences.

Robust Portfolio Modeling

Research advancements in the field of operational sciences and decision analysis have yielded a portfolio decision analysis methodology known as robust portfolio modeling (RPM) under which "incomplete information about criterion weights is captured through linear inequalities" (Liesiö, Mild, & Salo, 2008). Adoption of this portfolio decision analysis methodology could allow the Air Force to incorporate the uncertainty in the MDI information when selecting FSRM requirements. Unlike the linear additive portfolio value model, which produces a static project portfolio, RPM produces a "project-specific core index" to identify projects that should be "selected or rejected in the view of incomplete information." RPM also "suggests borderline projects as candidates for the elicitation of additional information" (Liesiö et al. 2008).

In addition to core index values, the RPM approach identifies areas in the portfolio where uncertainty or "incomplete information" influences the MCDA (Mild et al., 2010). Alternatives with a core index value of 1.0, identified in the upper region of Figure 12, stochastically dominate all other alternatives in the portfolio and are therefore not influenced by uncertainty. In contrast, alternatives with a core index value of 0, identified in the bottom region of Figure 12, have no chance of being selected even if additional information was able to reduce the uncertainty. Alternatives with a core index value between 0 and 1.0, identified in the middle region of Figure 12, are influenced by the uncertainty in the MCDA. The RPM approach allows decision makers to think critically about their portfolio and identify regions in the portfolio where the model is most influenced by uncertainty or incomplete information.

Identification		Core	Criteria scores						Parameters		Condition, age, traffic, size, material etc					
ID	Name	Index	C 1	C 2	C 3	C 4	C 5	C 6	Cost	VPS	Facts	Facts	Facts	Facts	Facts	Facts
71	Lupajan silta	1.00	3.80	3.0	1	0	3.00	0.67	158000	428	...	...	...	...	...	...
163	Rödhällsund	1.00	2.89	2.5	2	1	3.00	1.33	75000	325	...	...	...	...	...	...
178	Vähäjoen silt	1.00	2.86	4.0	1	0	3.00	0.00	279000	321	...	...	...	...	...	...
180	Raisionjoen	1.00	2.36	4.0	1	0	3.00	1.33	172000	177	...	...	...	...	...	...
622	Lapinjoen silt	1.00	4.00	3.5	1	0	3.00	1.33	242000	787	...	...	...	...	...	...
643	Lapin silta	1.00	3.02	2.0	4	3	0.00	0.00	80000	340	...	...	...	...	...	...
666	Kappelinsaln	1.00	3.64	2.5	1	1	3.00	1.33	142000	410	...	...	...	...	...	...
700	Loimijoen silt	1.00	4.00	3.5	1	0	3.00	2.00	588000	724	...	...	...	...	...	...
707	Rausenojan	1.00	2.26	3.5	0	0	3.00	0.67	56000	283	...	...	...	...	...	...
762	Friitalan silta	1.00	3.62	3.0	4	3	2.25	2.00	180000	271	...	...	...	...	...	...
821	Harjunpään j	1.00	3.46	3.5	1	0	3.00	1.33	210000	390	...	...	...	...	...	...
2390	Skanssinmä	1.00	3.26	4.0	0	1	4.00	0.00	104000	244	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
651	Raakkuun sil	0.99	4.00	1.0	1	3	0.00	0.67	23000	512	...	...	...	...	...	...
931	Matalaojan si	0.99	1.88	3.5	1	0	3.00	1.33	221000	212	...	...	...	...	...	...
754	Tulkkilan silta	0.98	4.00	0.0	4	3	0.00	1.33	301000	2485	...	...	...	...	...	...
1807	Korven ristey	0.90	1.28	4.0	0	0	4.00	0.67	105000	96	...	...	...	...	...	...
1389	Kilpijoen silta	0.84	2.73	0.0	2	4	0.00	1.33	11000	307	...	...	...	...	...	...
489	Paavolan silt	0.75	1.66	1.0	3	3	0.00	1.33	32000	187	...	...	...	...	...	...
64	Haaron silta	0.62	1.82	0.0	4	3	0.00	0.67	17000	136	...	...	...	...	...	...
31	Piikkiönjoen	0.44	0.26	3.0	4	0	3.00	1.33	67000	19	...	...	...	...	...	...
1591	Lähteenojan	0.44	2.26	0.0	2	2	0.00	0.67	21000	254	...	...	...	...	...	...
528	Savikosken s	0.37	2.55	0.0	2	0	0.00	1.33	88000	287	...	...	...	...	...	...
1497	Mökköisten s	0.27	1.43	0.0	4	2	0.00	0.67	62000	161	...	...	...	...	...	...
487	Kurkelan silta	0.11	1.56	2.0	0	0	3.00	1.33	161000	117	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
54	Muurlanjoen	0.00	1.43	2.0	0	1	0.00	0.67	52000	107	...	...	...	...	...	...
56	Kistolan silta	0.00	0.70	2.5	0	0	3.00	0.67	43000	53	...	...	...	...	...	...
61	Heinäkarin si	0.00	1.02	0.0	0	0	0.00	0.00	36000	76	...	...	...	...	...	...
133	Ketolan silta	0.00	0.36	1.0	2	0	0.00	1.33	12000	27	...	...	...	...	...	...
149	Korvalan silta	0.00	0.51	0.0	0	0	0.00	0.67	26000	38	...	...	...	...	...	...
167	Mövikin silta	0.00	0.90	2.0	0	0	3.00	0.00	31000	67	...	...	...	...	...	...
214	Loukolan silta	0.00	0.61	1.0	2	2	0.00	0.00	40000	46	...	...	...	...	...	...
215	Iso-Hongan s	0.00	0.61	2.0	0	1	3.00	0.00	32000	46	...	...	...	...	...	...
217	Juvan silta	0.00	0.62	0.0	2	2	0.00	0.00	48000	47	...	...	...	...	...	...
228	Vähä-Ollilan	0.00	0.48	0.0	2	1	0.00	0.67	17000	36	...	...	...	...	...	...
229	Rahkion silta	0.00	0.41	1.0	0	1	0.00	0.00	20000	31	...	...	...	...	...	...
230	Karvion silta	0.00	0.71	1.0	0	1	0.00	0.00	15000	53	...	...	...	...	...	...
232	Ojakkaan silt	0.00	0.30	1.0	0	0	0.00	0.67	27000	23	...	...	...	...	...	...

Figure 12. Core Index and Data Table Illustration (Mild et al., 2010)

Mission Dependency Index

Antelman, Dempsey, and Brodt (2008) conceived the MDI concept at the Naval Facilities Engineering Service Center to create a metric that quantifies the consequence or impact of facility failure. The MDI equation was derived using the Navy's categorical expression of probability and severity documented in Office of the Chief of Naval Operations Instruction (ONAVINST) 2500.39C on Operational Risk Management. It is a parametric model comprised of a finite series of variables and produces an ordinal value between 1-100. Additionally, the MDI model identifies categorical ranges, shown in Figure 13, ranging from "critical" and "significant" to "relevant," "moderate," and "low" (Antelman et al., 2008). Although it is not the only way to quantify the consequence of facility failure, the MDI metric is able to quantify previously intangible values as an index.

MDI score	Verbal code	Color code
100 - 85	Critical	Red
84 - 70	Significant	Orange
69 - 55	Relevant	Yellow
54 - 40	Moderate	Green
39 - 1	Low	Blue

Figure 13. MDI Categories (Antelman et al., 2008)

Background

The MDI equation, shown in Equation 5, is expressed using three different input variables to produce an ordinal value between 1 and 100. The first two variables quantify the importance of the missions occurring inside and outside the facility, which represent intradependency (MD_W) and interdependency (MD_B), respectively. These two variables are weighted 85 and 10 percent, respectively (Antelman et al., 2008). The intradependency coefficient measures the relationship between the facility and its hosted mission, while the interdependency coefficient measures the relationship between the facility and all other missions on the installation. These values are determined from responses to the questions listed in Table **1** and the matrices depicted in Figure 14. The first and third questions measure how quickly the missions occurring within and outside the facility would be interrupted in the event of facility failure. The second and fourth questions measure the possibility of relocating the missions to another facility and the prospect of replacing or replicating the services hosted in that facility with another agency, respectively. The answers to these questions are placed in discretized categorical matrices depicted in Figure 14 and translated into dependency scores. Lastly, the third variable represents the number of interdependencies (*n*) between the facility and other agencies and accounts for the other 5 percent of the overall weight.

$$MDI = 26.54\left(MD_W \pm .125\frac{1}{n}\sum_{i=1}^{n} MD_B + 0.1\ln(n)\right) - 25.54 \qquad (5)$$

Table 1. MDI Survey Questions (Antelman et al., 2008)

Question 1	How long could the "functions" supported by your facility (functional element) be stopped without adverse impact to the mission?
Question 2	If your facility were no longer functional, could you continue performing your mission by using another facility, or by setting up temporary facilities?
Question 3	How long could the services provided by (named organizational subcomponent) be interrupted before impacting your mission readiness?
Question 4	How difficult would it be to replace or replicate the services provided by (named organization subcomponent) with another provider?

MISSION INTRA-DEPENDENCY SCORE					
MD_W		Q1: Interruptability			
		Immediate (24/7)	Brief (min/hrs)	Short (<7days)	Prolonged (>7days)
Q2: Relocateability	Impossible	4.0	3.6	3.2	2.8
	Extremely Difficult	3.4	3.0	2.6	2.2
	Difficult	2.8	2.4	2.0	1.6
	Possible	2.2	1.8	1.4	1.0

MD_W = Mission Dependency Within a Command's AoR

MISSION INTER-DEPENDENCY SCORE					
MD_B		Q3: Interruptability			
		Immediate (24/7)	Brief (min/hrs)	Short (<7days)	Prolonged (>7days)
Q4: Replaceability	Impossible	4.0	3.6	3.2	2.8
	Extremely Difficult	3.4	3.0	2.6	2.2
	Difficult	2.8	2.4	2.0	1.6
	Possible	2.2	1.8	1.4	1.0

MD_B = Mission Dependency Between Commands

Figure 14. Intradependency (Left) and Interdependency (Right) Matrix (Antelman et al., 2008)

NAVFAC's MDI assessment methodology included a team performing a survey at each installation every 10 years at an approximated cost of $40,000 to $60,000 per installation to generate and maintain accurate MDI values (Grussing, Gunderson, Canfield, Falconer, Antelman, & Hunter, 2010). Although the Navy initially performed an initial MDI survey of its installations in 2007, it was performed again in 2013 because the survey team had "improved training, staffing, and leadership" in order to better calibrate the team and reduce the subjectivity of the metric (Manning, 2017). The survey team interviewed facility managers and base leadership to acquire the necessary information to calculate an accurate MDI value; however, this methodology required a significant investment of manpower and financial resources.

<u>Limitations of MDI Model</u>

The MDI metric has been widely adopted by the DoD and other government organizations; however, it is still not without its critics. Models are prone to error and limited by the assumptions made developing the model. Kujawski and Miller (2009) argue that the MDI methodology and equation do not accurately measure risk. They list and discuss fallacies to support their central argument. This research sheds light on the errors and limitations of the MDI methodology; however, there are limitations to the claims made in their argument.

The first fallacy Kujawski and Miller (2009) claim is that the "MDI method makes no attempt to quantify probability and includes no discussion of mishap likelihood" per Operational Navy Instruction (OPNAVINST) 3500.39B. As previously discussed, MDI is a component of risk in that it models the consequence of failure and not necessarily a measure of risk itself. The Air Force's project scoring criteria derives the probability of failure value measure from the condition index produced from the sustainment management system known as Builder™. Although fallacies can be extrapolated from the claims made by Antelman et al. (2008), the fallacy of failing to address the probability of failure does not exist with respect to the project scoring criteria used by the Air Force.

The second fallacy listed by Kujawski and Miller (2009) claims "the structured interview process" is subject to inconsistent results and a wide range of responses, as noted by the Department of Energy after conducting its initial study in FY 2016. An explanation of the DOE's inconsistent MDI values may be due to the poor calibration of the DOE's MDI interview team. The interdependency and intradependency values used to compute the MDI metric are subjective and can produce deviated results. This fallacy is apparent when comparing the values obtained during the MDI proof-of-concept survey at Fairchild and Langley AFB as all secondary airfield pavements receive a surveyed

MDI value of 99 while the CATCODE methodology assigns a value of 95 (NAVFAC, 2008).

The third fallacy listed by Kujawski and Miller (2009) argues that the claim by Antelman et al. (2008) that "MDI can be used to prioritize funding for projects having the most positive impact" is without merit. To support their point, they provided an example in which an aircraft control tower in a deployed location has a lower interdependency value than a steam plant in a non-deployed location. They argue the MDI metric fails to account for the consequence of failure outside the purview of the installation; however, Antelman et al. (2008) clearly state that the MDI metric quantifies risk at the "subcomponent's sphere of control" and is therefore confined to the installation level.

Although the MDI model could use additional value measures to quantify the consequence of facility failure at higher organizational levels, additional value measures may make the alternate metric infeasible and too complex. Box's (1976) explanation that "all models are wrong, but some are useful" serves as an important reminder that there are limitations to models as a result of the assumptions made to produce a concise and feasible methodology. Additionally, the Air Force addressed this limitation with the MAJCOM priority metric to account for the consequence of facility failure at higher organizational levels. Furthermore, the air traffic control tower example offered by Kujawski and Miller (2009) is incorrect, as the MDI proof-of-concept survey at Fairchild AFB yielded a MDI value of 99 for the air traffic control tower and 67 for a steam plant (NAVFAC, 2008). Kujawski and Miller (2009) failed to argue the third fallacy, but they were able to address the limitations of the MDI model.

The fourth fallacy listed by Kujawski and Miller (2009) argues that the MDI equation is flawed as it "breaks down" under three circumstances. The first circumstance occurs when the number of nodes (or *n*) is equal to zero as the natural log of zero is undefined for zero; however, they do not suggest a practical scenario where a subcomponent of an organization does not have a network relationship with another subcomponent. The second circumstance they discuss is that "nothing precludes facilities" with interdependencies from equaling zero; however, additional documentation and studies of the MDI metric include scenarios where unoccupied or vacant facilities receive an interdependency value of zero (Grussing, 2010). Lastly, Kujawski and Miller (2009) argue that some critical intradependencies may not be accurately quantified as the MDI equation expresses the average of all intradependencies. For example, a facility with an $MD_w = 4.0$, $MD_b = 4.0$, and $n = 1$ results in a MDI = 93.89; however, the average intradependency score is lower when the same facility has additional nodes with three other facilities with an $MD_b = 1.0$, resulting in an MDI of 91. Kujawski and Miller (2009) do not offer a specific scenario in which this has occurred; however, their arguments into the fallacies of the MDI equation do expose the equation's limitations.

Although widely adopted by the DoD, the MDI metric has limitations and fallacies. It is important to perform an extensive literature review to expand the academic lens through which the MDI methodology is viewed to gain a wider perspective. Kujawski and Miller (2009) are able to address some of the limitations of the MDI methodology, but their argument was weakened by their attempt to discredit MDI methodology altogether.

Summary

This literature review discussed the field of asset management and the additional techniques and tools offered by an SE approach to asset management. The Air Force's approach to asset management was discussed including the framework and the three different iterations of project selection models used to prioritize FSRM requirements. The field of operations science and portfolio decision analysis was examined to formally understand the decision-making process and further explore the methodologies available to examine portfolios when uncertainty is present. Lastly, the history and background of the MDI metric were discussed to better understand how the methodology proposed by Antelman et al. (2008) operates as well as explore the limitations of the MDI model. The next chapter presents the methodology by which the investigative research questions will be answered.

III. Methodology

This chapter introduces the methodologies selected to answer the research effort's investigative questions. The methodologies for each research question are discussed separately since a specific methodology and process was performed to answer each research question. The methodology, justification and reasoning, data, procedures, assumptions, and limitations are discussed.

Measuring Deviation in MDI Values

The correlation between the Category Code (CATCODE) assigned MDI values and the surveyed or adjudicated MDI values was examined by plotting this data on a scatterplot in order to determine the R squared value of the trendline. The R squared values were low; therefore, an analysis of variance (ANOVA) was performed in JMP[R] to determine if the variability between Mission Dependency Index (MDI) could be explained due to the known factors. Although not formally incorporated into this research effort, an ANOVA was performed on the CATCODE assigned MDI values and surveyed MDI values at Langley and Fairchild Air Force Base (AFB) and was determined to be statistically insignificant. This may have been due to poor calibration and training of the joint survey team. The ANOVA is a vital statistical tool and could be used in future research, provided the surveyed MDI values are collected by a proficient and calibrated survey team. An ANOVA was not performed on the CATCODE assigned MDI values and adjudicated MDI values, as it was subject to a selective sample bias.

The MDI values assigned through the CATCODE, adjudication, and NAVFAC structured interview methodologies were logged on a spreadsheet using Microsoft Excel®. This was done to assign each facility both an ordinal value and a categorical level of criticality, as outlined in Antelman's et al. (2008) MDI methodology. The deviation between MDI value methodologies was performed using Equations 6 and 7. The deviations were then plotted on histograms. The MDI categories in ascending order of criticality include low, moderate, relevant, significant, and critical. These categories were assigned a numerical value between 1 and 5, respectively, in order to numerically represent the deviations between surveyed or adjudicated MDI categories and the CATCODE assigned MDI categories. The categorical histogram was assigned bin range of 1. This produced bins ranging from -4 and +4 which numerically represented when the surveyed or adjudicated MDI values were 4 categories lower or higher, respectively, than the CATCODE assigned MDI values. Additionally, the deviations in ordinal values (i.e. 1 - 100) were chosen to have a bin range of 5.

$$Deviation = Surveyed\ MDI\ Value - CATCODE\ MDI\ Value \tag{6}$$

$$Deviation = Adjudicated\ MDI\ Value - CATCODE\ MDI\ Value \tag{7}$$

Data

The data sets used to measure the deviation in MDI values were the applicable CATCODE assigned MDI values, the adjudicated MDI values, and the MDI values obtained during the joint survey at Langley and Fairchild AFB in 2008. The Air Force's second quarter fiscal year (FY) 2016 real property report was used to verify the CATCODEs of the facilities included in the 2008 survey.

Assumptions

It was assumed that facilities missing from the FY2016 real property report included on the 2008 survey were later demolished and were not included in the analysis. Although these facilities represent an important sub-group of the population in which the surveyed MDI value largely deviated from the CATCODE assigned value, these facilities were postured for demolition and would not receive funding for improvements, but rather demolition. It can therefore be assumed the MDI metric has no value in this context and demolished facilities were therefore removed from the population. Additionally, the correct CATCODE was used if the real property CATCODEs assigned in the real property report did not reflect the use of that facility during the 2008 survey. This was either due to errors in the real property reports or due to a real property transaction which changed the use of the facility.

Limitations

The surveyed and adjudicated MDI values are not necessarily a stratified and representative sample of all Air Force MDI values. Although the 2008 joint survey measured the majority of buildings' MDI values, not all facilities, including electrical utilities, water utilities, roads, and fire suppression systems were included in the survey. The MDI survey therefore does not represent the installation's entire real property portfolio. Additionally, Langley and Fairchild AFB represent Air Combat Command

(ACC) and Air Mobility Command (AMC), respectively, and do not necessarily represent the consequence of facility failure of specific facilities at other MAJCOMs. The adjudicated MDI values are subject to a selection bias as installations advocated for the change in MDI values under the belief that these MDI values should be higher, which could potentially place the project in a more competitive position for funding on the AFCAMP.

Portfolio Decision Analysis Model using Surveyed MDI Values

A deterministic approach to portfolio decision analysis was chosen over the robust portfolio modeling approach proposed by Liesiö et al. (2008) due to limitations in the data available to this research effort. The development of probability distributions used to measure and incorporate uncertainty into the portfolio decision analysis model required a larger and more representative sample size of Mission Dependency Index (MDI) information. Alternatively, elements of this methodology were incorporated into the data selection process.

A model was created in Microsoft Excel® to calculate the original project score using the CATCODE derived MDI value and an alternate project score using the surveyed MDI value. The project scores were calculated using the most current project selection model, Air Force Comprehensive Asset Management Plan (AFCAMP), using the existing probability of failure (POF), savings investment ratio (SIR), and Major Command (MAJCOM) priority values. Next, two different project scores were calculated using the CATCODE assigned MDI values and the MDI values obtained via the NAVFAC structured interview process.

The MDI values for projects were calculated using the same methodology as outlined in instructional manuals, known as playbooks, published by the Air Force Civil Engineer Center (AFCEC). The NAVFAC structured interview process yields an MDI value for each mission hosted by the facility, which in some cases, generates multiple MDI values for a single facility. In such case, the mean value of the MDI scores for each mission was used. Additionally, the MDI value for projects with multiple facilities utilizes a facility cost weighted average, as represented in Equation 6. The real property replacement value was used as the facility cost.

$$MDI = \frac{\sum MDI * Facility\ Cost}{\sum Facility\ Cost} \tag{6}$$

<u>Data</u>

The FY 2015, 2016, and 2017 project portfolios, which represent the respective Base Comprehensive Asset Management Plans (BCAMPs) for Langley and Fairchild Air Force Base (AFB) were chosen to be studied because they follow the AFCAMP project selection model. Project portfolios previous to FY 2015 operated under previous project selection models that are no longer utilized by the Air Force. The NAVFAC MDI values used were those collected during the Fairchild and Langley AFB pilot study in 2008. These are the only Air Force installations which have participated in a NAVFAC-style structured interview to measure the installation's MDI values.

Although there is deviation between the MDI values derived from different methodologies, the surveyed MDI scores are considered to have value when the project portfolio recommended a different funding action than the project portfolio using the CATCODE methodology. A subgroup of the Langley and Fairchild AFB BCAMPs was selected to narrow the focus of this methodology. A set of criteria, which incorporated elements of the robust portfolio modeling methodology, was developed to exclude projects from the primary analysis under specific circumstances.

The first criteria excluded must-fund requirements from the primary analyses. The AFCAMP process includes all projects in the project portfolio, including projects that are determined to be must-fund requirements. These projects are given arbitrary project scores. Projects are considered must-fund requirements if they fulfill a policy driven requirement to include, but not limited to, fulfilling a legal or environmental requirement, contractual obligations, and health and safety requirements. Projects determined to be a must-fund requirement are policy-level decisions on Howard and Abbas's (2015) decision hierarchy, whereas all other projects which compete for funding in the portfolio are considered to be strategic-level decisions on Howard and Abbas's (2015) decision hierarchy. Although must-fund requirements are listed in the project portfolio, they are not influenced by the AFCAMP project selection model and therefore would not be influenced by a MDI value derived from the NAVFAC methodology.

The second criteria removed infrastructure not surveyed in the Fairchild and Langley AFB MDI pilot study. The scope of the pilot study did not include all utility infrastructure and therefore the projects that aligned under the Utilities Activity

Management Plan (AMP) were removed from the primary analyses. Additionally, projects for facilities constructed after 2008 were not surveyed and also excluded from primary analyses.

The third criteria identified and removed projects that would not receive funding regardless of the value of the NAVFAC derived MDI score. These projects scored too low to be influenced by a change in the MDI value and were excluded from the primary analyses. Alternatively, projects that scored high enough not to be influenced by the value of the MDI metric were initially considered to be excluded from the primary analyses; however, no such project was identified on any of the Langley and Fairchild BCAMPs.

The subgroup of data from the Langley and Fairchild AFB BCAMPs included projects that were not considered must-fund requirements, aligned under the Facilities and Transportation AMP, and had a project score within a range that made its funding categorization influenceable by a different MDI value. Projects above the cut-line on the portfolio are classified as “Above Presidential Budget (PB)” and were considered projects selected for funding. Alternatively, projects below the cut-line on the portfolio are classified as “Below Construction Task Order (CTO)” and were considered projects not selected for funding. The third classification for projects is “Below PB, In CTO.” These projects did not score high enough to be considered for funding according to the AFCAMP project selection model; however, Headquarters Air Force (HAF), Air Force Installation Mission Support Center (AFIMSC), and AFCEC decided to fund these projects after applying expert judgment.

Assumptions

It was assumed that the project funding cut-line for the respective BCAMPs studied would remain unchanged when conducting analysis for this research question. It would be expected that the project scores would vary if the Air Force used alternate or surveyed MDI values, thereby altering the project score cut-line; however, the use of surveyed MDI information did not change many the fund group of many projects, thereby validating this assumption. Additionally, it was not assumed that the MDI surveys were performed by well calibrated individuals as the surveys were conducted in 2008 when the NAVFAC MDI survey team was not as well trained or calibrated as it had been in the second round of MDI surveyed. Therefore, it cannot necessarily be assumed the surveyed MDI values better reflect the consequence of facility failure. Furthermore, it cannot necessarily be assumed surveyed MDI values recommended a better project portfolio due to the suspected poor calibration of the MDI survey team.

Limitations

The MDI surveys were only performed at Langley and Fairchild AFB, whose missions align under aerial warfare. As previously discussed, the MDI values surveyed at these installations do not necessarily form a stratified and representative sample for installations assigned to other MAJCOMs and Air Force MDI values as a whole. Additionally, the previously stated assumption concerning the calibration and training of the NAVFAC MDI survey team limits the insights that are gained through the analysis.

Portfolios Decision Analysis using Adjudicated MDI Values

A deterministic approach to portfolio decision analysis was selected to examine the effect of the adjudicated MDI values on project portfolios when compared to the Air Force's CATCODE methodology. A model was created in Microsoft Excel® to calculate the original project score using the CATCODE assigned MDI value and an alternate project score using the adjudicated MDI value. The project scores were calculated with the most current project selection model, the AFCAMP, using the existing probability of failure (POF), savings investment ratio (SIR), and Major Command (MAJCOM) priority values. Next, two different project scores were calculated using the CATCODE assigned MDI values and the MDI values obtained through the adjudication process.

The MDI values for projects were calculated using the methodology in the AFCAMP playbook. The adjudication process yields a single MDI value for each facility. The MDI value for projects with multiple facilities utilizes a facility cost weighted average, previously represented in Equation 6.

Data

The FY 2015, 2016, and 2017 AFCAMP project portfolios were chosen to be studied for this investigative question because they follow the Air Force Comprehensive Asset Management Plan (AFCAMP), the Air Force's most current project selection model and process. The adjudicated MDI values used were those approved by AFCEC, as of 15 January 2017, and included facilities from numerous installations.

A similar methodology used to select a smaller subgroup of data for the first investigative question was also applied to the methodology answering the second investigative question. A subgroup of AFCAMP was selected to narrow the focus of this methodology. A set of criteria was developed to exclude projects from the primary analysis under specific circumstances.

Similar criteria were used in this model as the previous to exclude projects from the primary analysis. This includes all must-fund requirements and those projects which scored too high or low to allow the MDI value to influence the linear additive portfolio value model's funding recommendation. Additionally, projects which did not have a corresponding adjudicated value were also excluded from the analysis altogether, similar to how other installation's BCAMPs were excluded from the analysis in the first investigative question.

Unique identifiers were created for each facility to allow those projects with an adjudicated facility to be identified. This was done by combining the four-digit contract code for each installation and the facility number(s). This allowed the project portfolios in the AFCAMP to reference the adjudicated MDI values in a separate spreadsheet.

Assumptions

It was assumed that adjudicated MDI values were the equivalent to those obtained through the structured interview NAVFAC methodology. Additionally, adjudicated MDI values were applied regardless of when the facility's adjudication was approved by AFCEC. In practice, the adjudicated MDI values may have not been used for a project because it was approved after; however, it is assumed that the approved adjudicated MDI value could have been applied for any applicable project on the AFCAMPs or project portfolios examined in this research effort. Additionally, it was assumed changes to the project funding cut-line for the respective AFCAMPs or project portfolios when CATCODE assigned and adjudicated MDI values were used was negligible, because the use of adjudicated MDI values altered the cut line by tenths of a point. Lastly, it was also assumed the MDI adjudication was performed by calibrated individuals, without bias, and accurately reflect the consequence of facility failure.

<u>Limitations</u>

As previously discussed, the selection bias of the adjudicated MDI values applies here as well. The insights gained through the analysis of the changes in the project portfolios are limited to the adjudication process and cannot necessarily be applied to expected changes in project portfolios after surveyed MDI information is obtained.

Summary

This research effort measured the deviation in CATCODE assigned, adjudicated, and surveyed MDI information and used a deterministic approach to portfolio decision analysis to address the investigative questions. The deviation in MDI values were measured ordinally and categorically, as there are multiple ways of measuring the consequence of facility failure with the MDI metric. A deterministic approach to portfolio decision analysis was chosen in lieu of a probabilistic approach due to the limited amount of surveyed and adjudicated MDI information available to this research effort.

IV. Analysis and Results

This chapter discusses the analysis and results produced from the previously discussed methodologies. The purpose of measuring the deviations in surveyed and adjudicated Mission Dependency Index (MDI) values from the real property Category Code (CATCODE) assigned MDI values is to better understand the deviations in MDI values produced by these different methodologies. The insights gained through the first and third investigative questions complement the second and fourth questions as the deviation in MDI values influence the Air Force's linear additive portfolio value model to produce project portfolio recommendations.

Deviations in Surveyed and CATCODE assigned MDI Values

Scatter plots, represented in Figure 15 and Figure 16, were created using the CATCODE assigned MDI values and the surveyed MDI values as the x and y variables, respectively. This was done in order to determine if there was a need to perform additional statistical tests on the data to determine the reasons for MDI value deviation between the two data sets. The R squared value of the trendline for Langley AFB was 0.265 while the R squared value of the trendline for Fairchild Air Force Base (AFB) was 0.0679. Although the R squared values of both Langley and Fairchild AFB were not low, the higher R squared value at Langley AFB suggests the CATCODE MDI model better represents the consequence of facility failure at this installation when compared to the lower R squared at Fairchild AFB. No further statistical tests, including an analysis of variance (ANOVA) were formally incorporated into this research effort to determine why the MDI values deviated from one another. However, the deviations between the MDI values were plotted on histograms in order to further investigate the first research question.

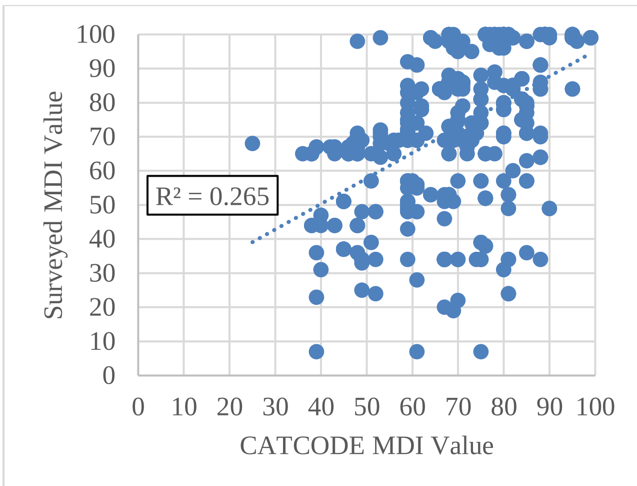

Figure 15. Langley AFB MDI Value Scatterplot

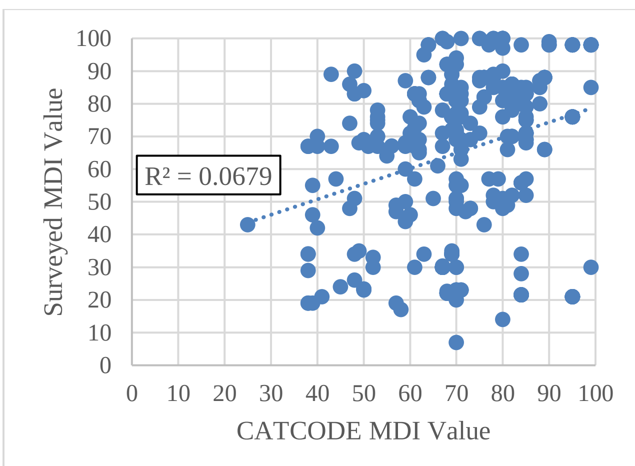

Figure 16. Fairchild AFB MDI Value Scatterplot

The deviation between the surveyed and Category Code (CATCODE) assigned MDI at Fairchild AFB was plotted on a histogram, as seen in Figure 17 and Figure 18, to better understand the MDI value deviation produced by these two methodologies. The positive bins represent scenarios in which the surveyed MDI values were greater than the CATCODE assigned MDI values while the negative bins represent the opposite. The deviation was measured both in the change in MDI categories (i.e. Low, Moderate, Relevant, Significant, and Critical) and the change in ordinal values (i.e. 1 - 100). The x-axis of the histogram in Figure 17 represents the numerical differences in MDI categories. As previously stated in Chapter III, these categories were assigned a numerical value between 1 and 5, respectively, in order to numerically represent the deviations between surveyed MDI categories and the CATCODE assigned MDI categories. The numerical value assigned to each bin represents the number of deviations between the surveyed MDI categories and CATCODE assigned categories. The mean of both the categorical and ordinal histograms are slightly smaller than the median, which indicated the histograms are slightly left skewed. It is important to examine the histogram to better understand how and why the two methodologies deviate from one another.

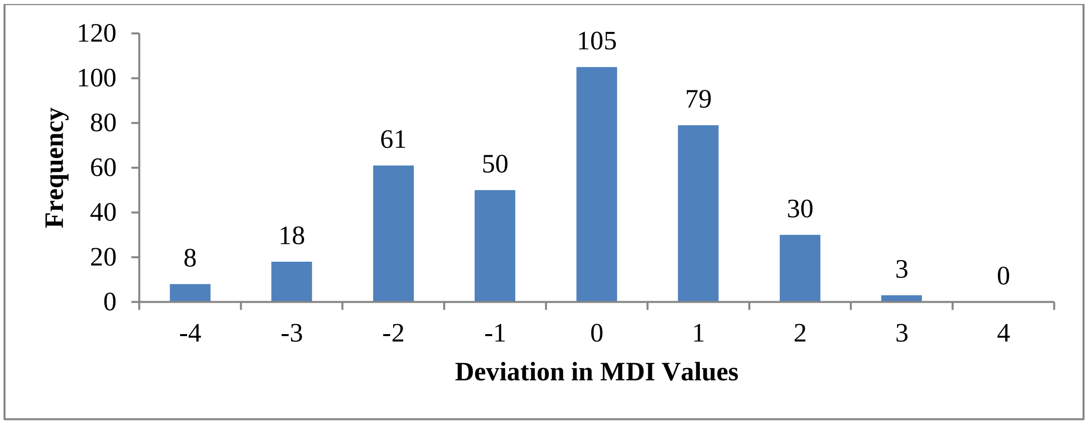

Figure 17. Histogram of Deviation in MDI Categories (Fairchild AFB)

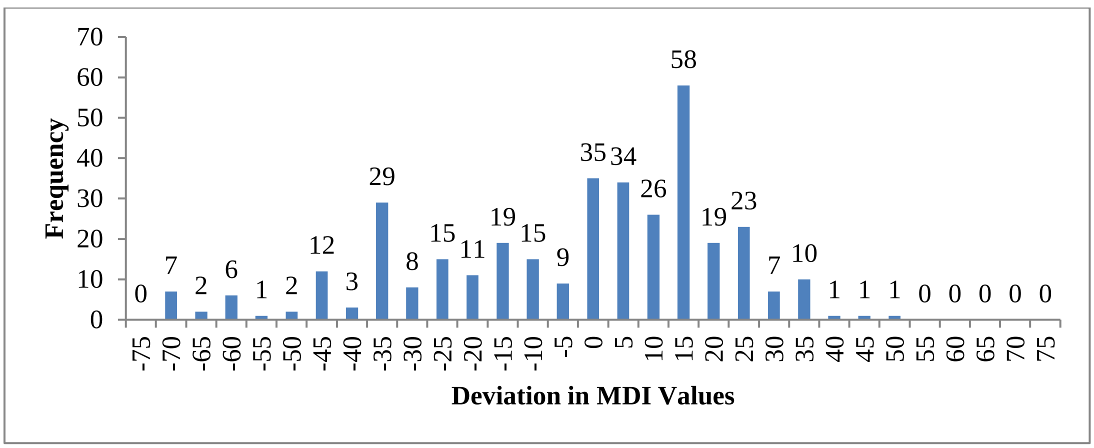

Figure 18. Histogram of Deviations in MDI Values (Fairchild AFB)

The histogram, represented in Figure 17, shows the changes in MDI categories and indicates 249 of 354 facilities, or approximately 70 percent, experienced a change in the MDI category after being surveyed. This indicates there was significant deviation between the surveyed and CATCODE assigned MDI values at Fairchild AFB. Overall, the slight left skew indicates the surveyed MDI values reflected higher consequences of facility failure than the CATCODE assigned values. The spike in deviation in the negative bins reflects a lower surveyed MDI value for other facilities when compared to the CATCODE values. Upon further examination, it was revealed that the majority of the facilities with lower surveyed MDI values were those supporting the 92nd Operations and Maintenance Group's air refueling mission. This indicates the consequence of facility failure is not as high for a mission supporting the Air Force's Rapid Global Mobility core function.

Fairchild AFB also hosts the 336th Training Group whose mission is to train Air Force personnel in survival methods and search and rescue. The surveyed results did not change the majority of the 336th Training Group's facilities' categorical levels of criticality; however, a majority of these facilities' ordinal MDI values did increase. This indicates that, although the CACODE assigned MDI values did not accurately capture the consequence of facility failure, the difference was not significant enough to change the categorical level of criticality assigned to the facilities.

The deviation between the surveyed and the CATCODE assigned MDI at Langley AFB was plotted on a histogram, as seen in Figure 19 and Figure 20, to better understand how these two methodologies result in deviated MDI values. The histogram showing the changes in MDI category indicates 314 of 467 facilities, or approximately 67 percent, experienced a change in the MDI category after being surveyed. This indicates there was significant deviation between the surveyed and CATCODE assigned MDI values at Langley AFB.

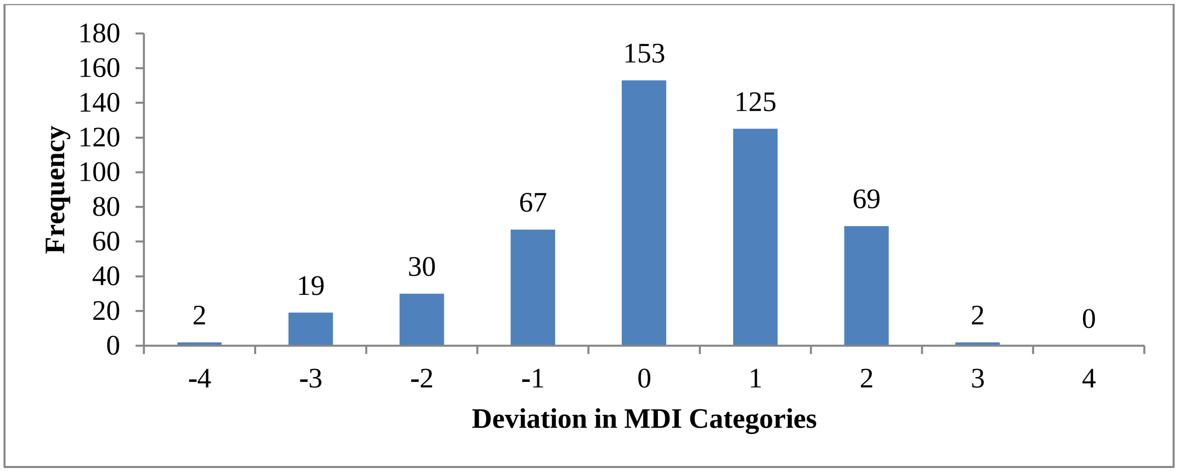

Figure 19. Histogram of Deviation in MDI Categories (Langley AFB)

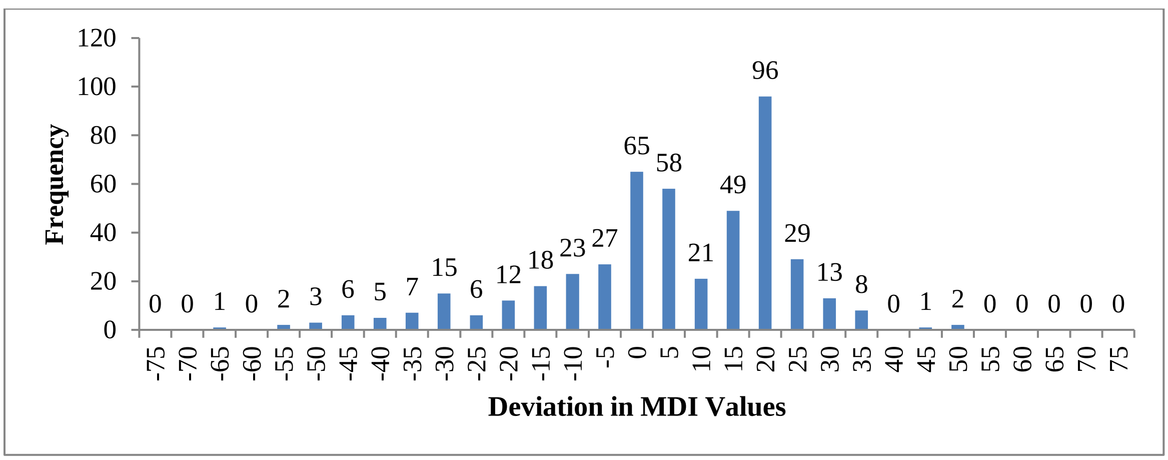

Figure 20. Histogram of Deviation in MDI Values (Langley AFB)

The categorical and ordinal histograms means are slightly smaller than the medians and are therefore slightly left skewed. It is important to examine the histogram to better understand how and why the two methodologies vary from one another. There were no observable trends in the different types of facilities and deviation in MDI values.

The slight left skew indicates the surveyed MDI values reflected higher consequences of facility failure than the CATCODE assigned values.

The deviations between the surveyed and CATCODE assigned MDI values demonstrated the CATCODE methodology did not accurately capture the categorical level of criticality. However, the NAVFAC survey team were not necessarily properly trained and calibrated during the 2008 joint MDI surveys at Langley and Fairchild AFB. Although this may indicate surveyed MDI values capture the consequence of facility failure significantly better than CATCODE assigned MDI values, this research effort is unable to decisively determine how much deviation would occur when performed by a well-trained and calibrated team. The 2008 joint surveyed MDI may be subject to limitations; however, it is still important to understand how it influences the Air Force's project portfolio.

Portfolios Decision Analysis using Surveyed MDI Values

The project scores for facilities with surveyed MDI values on the FY 2015, 2016, and 2017 Langley and Fairchild AFB BCAMPs were calculated using the surveyed and CATCODE MDI values. This was done to determine if the surveyed MDI values influenced the linear additive value portfolio model enough to change funding groups in the respective project portfolio. The projects identified in the tables below are all projects that met the criteria for primary analysis.

FY 2015 Langley and Fairchild AFB BCAMPs

The fiscal year (FY) 2015 Air Force Comprehensive Asset Management Plan (AFCAMP) had a project score cut-line of 180. The Fairchild BCAMP did not have any projects that met the criteria for primary analysis as all projects "Above PB" were considered must-funds. The only project with a score influenced by a surveyed MDI was a project on the Utilities AMP and therefore not included in the 2008 survey.

The Langley BCAMP had one project that met the criteria for primary analysis; however, the surveyed MDI value did not result in portfolio changes. The project, listed in Table **2**, was to repair an aircraft parking ramp and had a surveyed MDI value of 99 while the category code (CATCODE) MDI was a 95. The use of surveyed MDI information did not alter the linear additive portfolio value model's funding recommendations for either the Langley or Fairchild FY 2015 BCAMPs.

Table 2. FY 2015 Langley and Fairchild BCAMPs

IPL #	**Fund Group**	**Project Title**	**Surveyed MDI**		**CATCODE MDI**	
			MDI	**Total Score**	**MDI**	**Total Score**
2253	Above PB	Repair Replace East Ramp	99	190.21	95	187.81

FY 2016 Langley and Fairchild AFB BCAMPs

The FY 2016 Air Force Comprehensive Asset Management Plan (AFCAMP) had a project score cut-line of 173.26. The Fairchild BCAMP had two projects that met the criteria for primary analysis. The first project, see Table 3, entitled "Repair (R&M) EOD

Move" planned to update the Explosive Ordinance Disposal Flight's facility to meet safety and space requirements. The CATCODE assigned MDI value was 75 or "relevant" while the surveyed MDI value was 52 or "moderate." This lowered the project score from 183.68 to 169.68, which was enough to be placed below the FY 2016 cut-line.

Alternatively, as shown in Table 3, the project entitled "Repair (R&M) Fire Suppression & Roof Hangar" had a CATCODE assigned MDI value of 99 and a surveyed MDI value of 85. This lowered the project score from 189.48 to 181.08, which did not affect the portfolio funding recommendation. It is not known why the surveyed MDI value was lower than the CATCODE assigned value; however, it is speculated that NAVFAC may have not known the importance of an alert hangar. It should be noted that this facility's CATCODE was incorrectly identified due to an error in either the AFCAMP spreadsheet or the real property records. This real property record error resulted in the project receiving an MDI value of 70.

Table 3. FY 2016 Fairchild BCAMP

IPL #	**Fund Group**	**Project Title**	**Surveyed MDI**		**CATCODE MDI**	
			MDI	**Total Score**	**MDI**	**Total Score**
3228	Above PB	Repair (R&M) EOD Move	52	169.68	75	183.68
3346	Below PB, In CTO	Repair (R&M) Fire Suppression & Roof Hangar	85	181.08	99	189.48
3355	Below PB, In CTO	ADD/RPR (R&M) Security Forces Kennel	Not Surveyed		64	170.90

The Langley BCAMP had five projects that met the criteria for primary analysis, as represented in Table **4**. The use of surveyed MDI information recommended funding the project entitled “REPAIR SITE #7 ELEC INFASTRUCTURE,” which had a CATCODE derived MDI value of 80 and project score of 161.57; however, the surveyed MDI score of 100 was significantly higher and resulted in a project score of 173.57. Although this project was below the project portfolio’s cut-line, it was still funded. This demonstrates that the use of surveyed MDI information better reflects the decision-making preferences of Headquarters Air Force (HAF), Air Force Installation Mission Support Center (AFIMSC), and the Air Force Civil Engineer Center (AFCEC). The use of surveyed MDI information altered the linear additive portfolio value model’s funding recommendations for one project while also reflecting the decision-maker’s preferences for a different project.

Table 4. FY 2016 Langley BCAMP

IPL #	Fund Group	Project Title	Surveyed MDI		CATCODE MDI	
			MDI	Total Score	MDI	Total Score
3187	Above PB	Repair Roof/Wall Leaks, HVAC and Utilities, 633CS	100	201.66	80	189.66
3253	Above PB	Repair Failing Infrastructure/Utilities Langley Club	68	178.37	72	180.77
3331	Above PB	Repair/Install Sprinkler Systems	86	175.94	82	173.54
3366	Below PB, In CTO	Repair Failing Infrastructure and Utilities, ACC Gym	71	169.16	71	169.16
3434	Below PB, In CTO	REPAIR SITE #7 ELEC INFRASTRC	100	173.57	80	161.57

FY 2017 Langley and Fairchild AFB BCAMPs

The FY 2017 AFCAMP had a project score cut-line of 172.57. The Fairchild BCAMP had four projects that met the criteria for primary analysis, represented in Table 5. The use of surveyed MDI information did not alter the portfolio's funding recommendations. All projects needed a deviation in MDI values ranging from 12 to 28 points for the project portfolio to recommend a different funding group. It should be noted one project met all other criteria for primary analysis, but it was not surveyed during the 2008 MDI survey.

Table 5. FY 2017 Fairchild BCAMP

IPL #	Fund Group	Project Title	Surveyed MDI		CATCODE MDI	
			MDI	Total Score	MDI	Total Score
2638	Above PB	Repair (SUS) 100 Slabs, Heavy MX Apron	99	191.40	95	189.00
2880	Above PB	REPAIR (SUS) Spot 56, Replace 21 ea. PCC Slabs	99	182.51	95	180.11
3460	Below CTO	REPAIR (SUS) Electric Power Distro Line, Feeder 3S	82	161.82	80	160.62
3598	Below CTO	REPAIR (R&M) 4-Bay Hangar Fire Protection System Ph 2	69	155.18	70	155.78

The Langley BCAMP had 10 projects that met the criteria for primary analysis, represented in Table **6**. The use of surveyed MDI information affected the portfolio's funding recommendation for only one of the projects. The project titled "TELECOMUNICATIONS FACILITY," had a CATCODE MDI value of 80 and a project score of 160.83 and a surveyed MDI value of 100 with a project score of 172.83.

HAF, AFIMC, and AFCEC did not decide to fund this project after receiving the initial recommendation from the IPL's project score criteria. Additionally, the project titled "APRON" had a CATCODE MDI value of 95 and project score of 182.26 and a surveyed MDI of 99 and project score of 184.66. It should be noted this facility's CATCODE was incorrectly identified due to an error in either the AFCAMP spreadsheet or the real property records. This error resulted in the project receiving an MDI value of 73 and a project score of 169.06, which was below the project model's cut-line; HAF, AFIMSC, and AFCEC still decided to fund the project though. It should also be noted one project met all other criteria for primary analysis, but it was not surveyed during the 2008 MDI survey.

Table 6. FY 2017 Langley BCAMP

IPL #	Fund Group	Project Title	Surveyed MDI		CATCODE MDI	
			MDI	Total Score	MDI	Total Score
2252	Above PB	LIGHTING, RUNWAY	99	202.08	99	202.08
2376	Above PB	ALERT HANGAR, FIGHTER AIRCRAFT	99	197.47	99	197.47
2455	Above PB	OVERRUN, PAVED	99	194.77	99	194.77
2695	Above PB	SQUADRON OPERATIONS	73	180.17	85	187.67
3226	Below PB, In CTO	APRON	99	184.66	95	182.26
2895	Above PB	RUNWAY	99	182.56	94	179.56
2896	Above PB	APRON	99	185.51	89	179.51
3038	Above PB	SQUADRON OPERATIONS	77	175.63	75	174.43
3097	Below PB, In CTO	EXPLOSIVE ORDNANCE DISPOSAL	79	167.95	86	172.15
3455	Below CTO	TELECOMMUNICATIONS FACILITY	100	172.83	80	160.83

The use of surveyed MDI information in lieu of the CATCODE assigned MDI values influenced the linear additive portfolio value model to fund one of Fairchild AFB's projects in the FY 2016 BCAMP and one of Langley AFB's projects in the FY 2017 BCAMP. The project which changed funding groups from "Above PB" to "Below PB" on the FY 2016 Fairchild AFB BCAMP, entitled "Repair (R&M) EOD Move," would have switched funding groups; however, there are questions on whether the surveyed MDI value accurately quantifies the consequence of facility failure. The project which changed funding groups on the FY 2017 Langley AFB BCAMP, entitled "TELECOMMUNICATIONS FACILITY," would have changed funding groups from "Below PB" to "Above PB" and was not included in "Below PB, In CTO" after the decision-maker applied their expert judgement.

In addition to understanding that 2 of the projects on the FY 2015, 2016, 2017 Langley and Fairchild AFB BCAMPs would change funding groups, further insights were gained after Table 7 was developed to illustrate the proportion of projects whose funding group could be influenced by the MDI metric. The influenceable region was a proportion of those projects whose funding group could be influenced by changes in the MDI metric compared to the total number of projects with surveyed MDI values included in this study. Although the influenceable region fluctuates between the different BCAMPs and this data set is subjected to the previously discussed assumptions and limitations, it suggests the surveyed MDI values could influence approximately 8 percent of the BCAMP's projects.

Table 7. Influenceable Region of Fairchild and Langley AFB BCAMPs

Projects	Langley AFB			Fairchild AFB			Total
	FY 15	FY 16	FY 17	FY 15	FY 16	FY 17	
Total	51	70	66	38	49	45	**319**
Not Surveyed	9	3	2	8	5	2	**29**
Influenceable Region	0	5	10	1	3	4	**23**
	0.0%	7.5%	15.6%	3.3%	6.8%	9.3%	**7.9%**

Deviation in Adjudicated and CATCODE assigned MDI Values

Installations advocated for a change in some MDI values, predominantly under the belief the MDI values should be higher and could possibly place the project in a more competitive position for funding on the AFCAMP. Therefore, the adjudicated facilities and MDI values are not a stratified and representative sample of the Air Force's real property portfolio. Further investigation into the adjudication data was required before the portfolio decision analysis model was created to gain further understanding of which Major Commands (MAJCOMs) had actively advocated for the adjudication of their facilities and how the CATCODE approach to assigning MDI values fails to accurately quantify the consequence of facility failure.

A scatter plot, represented in Figure 21, were created using the CATCODE assigned MDI values and the adjudicated MDI values as the x and y variables, respectively. This was done in order to determine if there was a need to perform additional statistical tests on the data to determine the reasons for MDI value deviation between the two data sets. The R squared value of the trendline was 0.4251. Although this R squared value was higher than the R squared values on the Langley and Fairchild

AFB scatterplots, this data set was subject to the previously discussed sample bias. Therefore, no further statistical tests, including an ANOVA, was performed to determine the factors influencing the changes in MDI values.

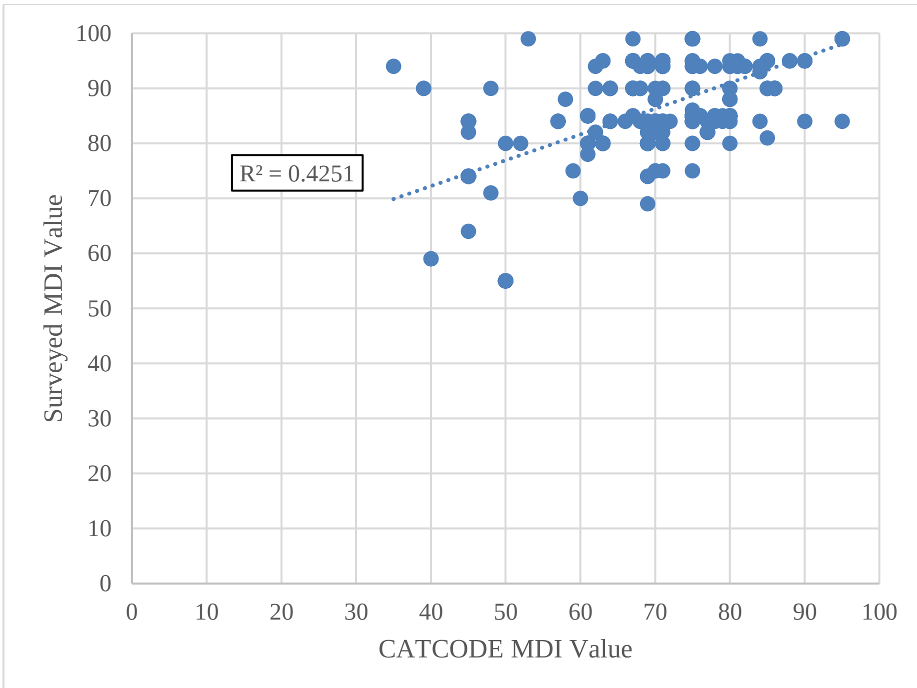

Figure 21. Adjudicated MDI Value Scatterplot

The deviation between the adjudicated and CATCODE assigned MDI was plotted on a histogram, as seen in Figure 22 and Figure 23, to better understand the deviation in MDI values produced by these two methodologies. The positive bins represent scenarios where the adjudicated MDI values were greater than the CATCODE assigned MDI values while the negative bins represent the opposite. The deviation was measured both in the change in MDI categories (Low, Moderate, Relevant, Significant, and Critical) and change in the ordinal values (i.e. 1 - 100). As previously stated in Chapter III, these categories were assigned a numerical value between 1 and 5, respectively, in order to numerically represent the deviations between adjudicated MDI categories and the CATCODE assigned MDI categories. The numerical value assigned to each bin represents the number of deviations between the adjudicated MDI categories and CATCODE assigned categories. Both the categorical and ordinal histograms are left skewed as they are subject to the previously discussed bias.

The majority of the successful MDI adjudications increased the categorical level of criticality as 672 facilities increased by one category level while 613 facilities increased by two categories. Overall, 1,290 facilities of the 1,607 facilities, or approximately 80 percent, increased in their categorical level of criticality. It is important to further examine the MDI adjudication data, as Air Force Global Strike Command (AFGSC) accounts for a significant majority of the adjudications.

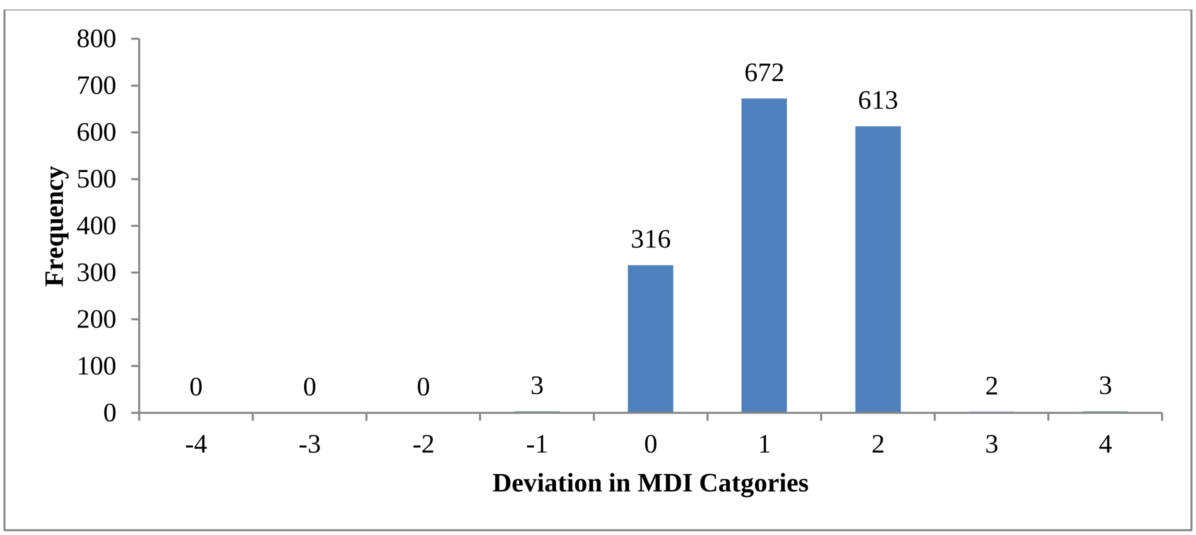

Figure 22. Histogram of Deviations in Adjudicated MDI Categories

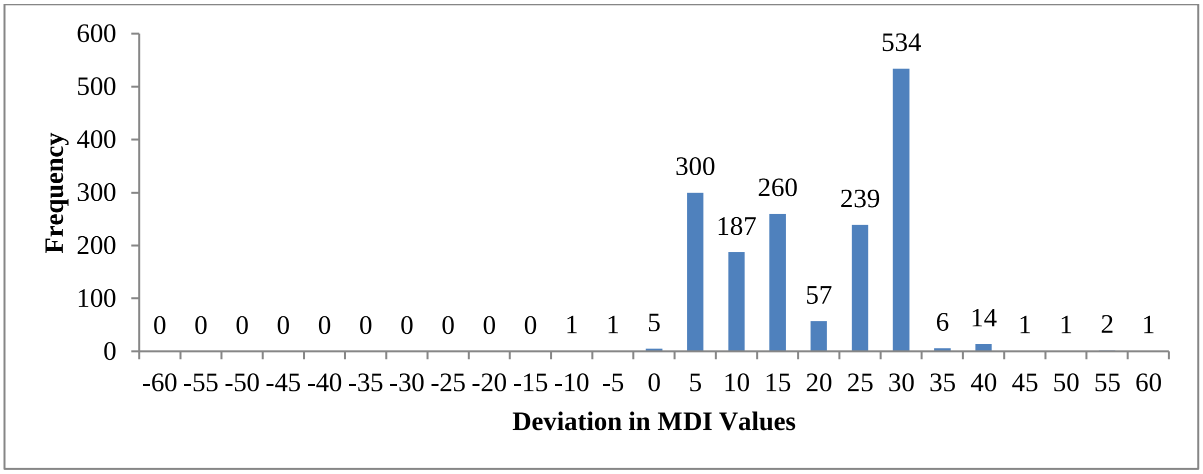

Figure 23. Histogram of Deviation in Adjudicated MDI Values

A pie chart of all the MDI adjudications, represented in Figure 24, for AFGSC and all other MAJCOMs was produced to demonstrate the significant majority or 93% of successful AFGSC adjudications with 1,490 facilities or having been assigned unique MDI values. Air Force Space Command (AFSC), Air Mobility Command (AMC), Air Combat Command (ACC), and Air Force Material Command (AFMC) had significantly lower numbers of adjudicated facilities with approximately 20 each. Pacific Air Forces (PACAF) and Air Education Training Command (AETC) each had 12 adjudicated facilities and United States Air Force Academy (USAFA) had 7 adjudicated facilities. The United States Air Forces in Europe (USAFE) and Air Force District Washington (AFDW each had one adjudicated facility, while Air Force Special Operations (AFSOC) did not have any successfully adjudicated facilities. It is important to investigate why AFGSC had a significantly higher number of adjudicated facilities.

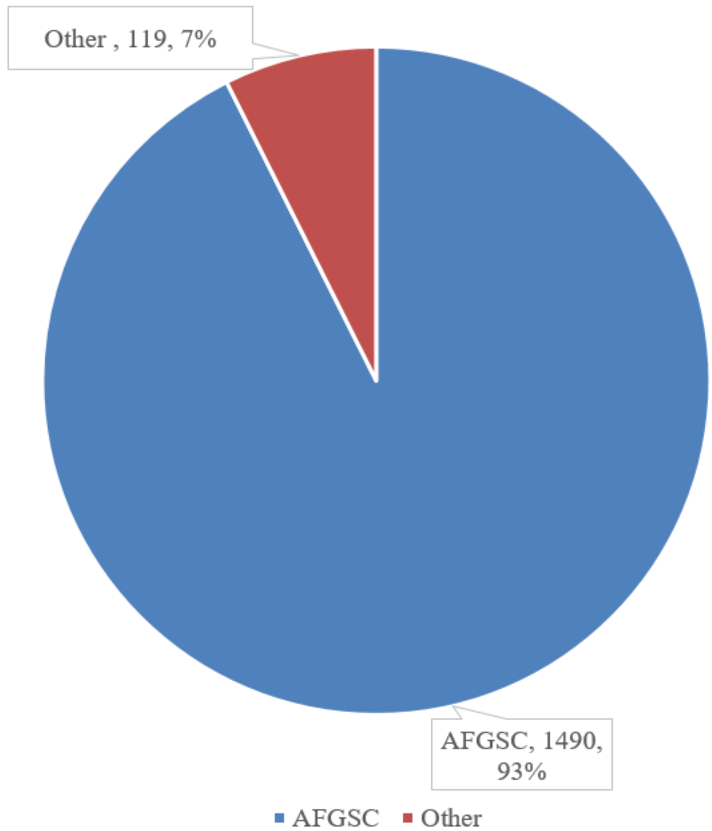

Figure 24. Pie Chart of MDI Adjudications for each MAJCOM

The adjudicated facilities within AFGSC were further examined to determine why this MAJCOM accounted for 1,490 of the 1,609, or approximately 88 percent, of all successfully adjudicated facilities. A histogram of the AFGSC adjudications real property CATCODE's was created, represented in Figure 25. It was determined that the significant majority of facilities adjudicated supported the nuclear deterrence mission of Minot AFB, Malmstrom AFB, Francis E. Warren AFB, and Whiteman AFB. The CATCODE assigned MDI values fail to capture the consequence of these facilities failing with respect to the critical nature of nuclear deterrence.

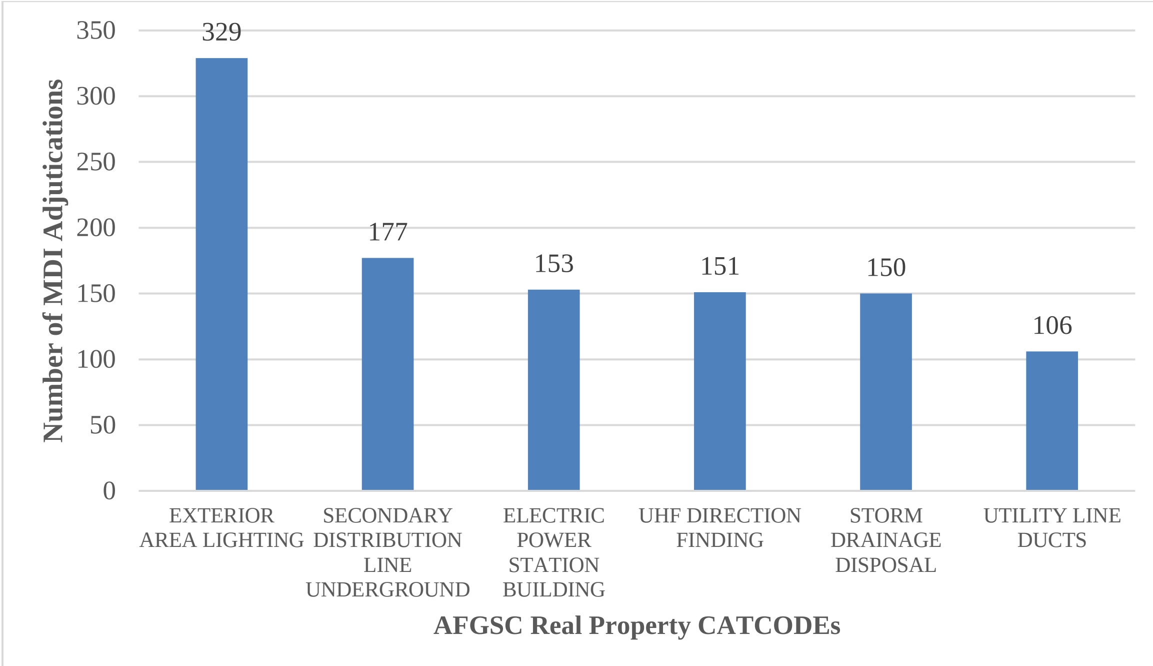

Figure 25. Histogram of AFGSC MDI Adjudications

It is important to understand both the deviations between the adjudicated and CATCODE assigned MDI values and the composition of successfully adjudicated CATCODEs to better understand the significance and limitations of the adjudicated MDI data. The deviation between the adjudicated and CATCODE assigned MDI values demonstrated that the CATCODE methodology did not accurately capture the categorical level of criticality; however, these adjudicated values were subject to a bias as installations advocated for these facilities under the belief that the CATCODE assigned MDI methodology did not accurately capture the consequence of facility failure. Additionally, a significant majority of the adjudicated MDI values were specific types of facilities directly supporting AFGSC's nuclear deterrence mission. It is important to understand the deviation between the MDI values and the composition of the adjudicated facilities to better understand how this information influences the linear additive value portfolio model's project portfolio recommendation.

Portfolio Decision Analysis using Adjudicated MDI Values

The project scores for facilities with adjudicated MDI values on the FY 2015/2016, 2016/2017, and 2017/2018 AFCAMP were calculated using the adjudicated and CATCODE MDI values. This was done to determine if the adjudicated MDI values influenced the linear additive value portfolio model enough to change funding groups in the respective project portfolio. Unlike the project portfolio decision analysis study using the 2008 Fairchild and Langley AFB surveyed MDI values, the projects included in the tables below are those that changed funding groups rather than all projects identified.

FY 2015 AFCAMP

The FY 2015 AFCAMP had a project score cut-line of 180.00. A total of 33 projects met the criteria for primary analysis which utilized an adjudicated MDI value in lieu of the CATCODE MDI value. Three of these projects changed funding groups, all of which would not have been recommended for funding by the linear additive project portfolio value model, as represented in Table 8. It should be noted seven other projects used adjudicated MDI values but were considered must-fund requirements.

Table 8. FY 2015 AFCAMP Project Changes

IPL #	Installation	Project Title	Adjudicated MDI		CATCODE MDI	
			MDI	Total Score	MDI	Total Score
2106	KIRTLAND AFB	Repair Redundant Power	99	197.80	67	178.60
2449	CAPE CANAVERAL AS	Repair Electrical Lines Supporting Launch Complexes (LET)	94	185.24	78	175.04
2475	PATRICK AFB	Repair Fire Protection Sys, Comm	94	183.46	80	175.06

Patrick AFB and nearby Cape Canaveral Air Force Station had two projects whose adjudicated MDI values changed the funding recommendation of the project portfolio model. The facilities at these installations are both operated by the 45th Space Wing, whose primary mission is to conduct space launch operations of evolved expendable launch vehicles (EELVs), more commonly referred to as rockets, and support other organizations, including the National Aeronautics and Space Administration (NASA). The 45th Space Wing falls under AFSC, a MAJCOM that deviates from the traditional aerial warfare mission. The CATCODE assigned MDI value did not accurately capture the consequence of facility failure because of the relationship between specific facilities and the EELV mission. In addition to the two facilities discussed below, Patrick AFB had successfully adjudicated six other facilities.

The project "Repair Fire Protection Sys, Comm Bldg," at Patrick AFB, was on the Facilities Asset Management Plan (AMP) and planned to install a fire protection system in a critical communications facility which directly supported space lift operations. There was no previous fire protection system as it was cited as a National Fire Protection

Association (NFPA) violation. The MDI value was changed from an 80 (Significant) to a 94 (Critical), thus increasing the project score from 175.06 to 185.24. The project "Repair Electrical Lines Supporting Launch Complexes (LET)," at Cape Canaveral Air Station (AS), was on the Utilities Asset Management Plan (AMP) and planned to replace deteriorated high voltage electrical lines which directly supported space lift operations. The MDI value was changed from a 78 (Significant) to a 94 (Critical), thereby increasing the project score from 175.04 to 183.46.

As previously discussed, the CATCODE approach to quantify the consequence of facility failure does not accurately capture the consequence of failure for some facilities which directly support the nuclear deterrence mission at AFGS. The project "Repair Redundant Power" at Kirtland AFB was on the Utilities Asset Management Plan (AMP) and planned to replace deteriorated redundant high voltage electrical lines which directly supported the nuclear deterrence mission. The MDI value was changed from a 67 (Relevant) to a 99 (Critical), thus increasing the project score from 178.60 to 197.80.

FY 2016 AFCAMP

The FY 2016 AFCAMP had a project score cut-line of 173.26 and a total of seven projects and three must-fund requirements that utilized an adjudicated MDI value in lieu of the CATCODE MDI value. No projects changed funding groups as a result of using adjudicated values despite the availability of adjudicated MDI information.

FY 2017 AFCAMP

The FY 2017 AFCAMP had a project score cut-line of 172.57 and a total of 61 projects, excluding must-fund requirements, which utilized an adjudicated MDI value in lieu of the CATCODE MDI value. Six of these projects changed funding groups, all of which would not have been recommended for funding by the project portfolio model, as represented in Table 9.

Table 9. FY 2017 AFCAMP Project Changes

IPL #	**Installation**	**Project Title**	**Adjudicated MDI**		**CATCODE MDI**	
			MDI	**Total Score**	**MDI**	**Total Score**
2865	USAF ACADEMY	Sust/Rpr HTHW - Phase 4	90	180.67	75	171.67
2891	MALMSTROM AFB	Repair MAF Water Wells	95	177.56	80	168.56
2926	USAF ACADEMY	Rpr Cadet Field House, Ph 1	90	178	71	166.6
2966	GOODFELLOW AFB	REPLACE AIR HANDLER UNITS/CHILL WATER/EMCS	88	177.13	80	172.33
3091	SHEPPARD AFB	Repair ENJJPT Dormitory	82	173.77	62	161.77

The USAFA had two projects whose adjudicated MDI values altered the funding group of the projects. The USAFA is a military academy and is one of the three officer commissioning sources for the Air Force. Although the USAFA is a direct reporting unit and does not align under a MAJCOM, its mission is to educate and train cadets, which deviates from a traditional aerial warfare mission. The consequence of facility failure for some infrastructure assets are significantly higher than other installations as the USAFA cadets live in dormitories on the installation and it could affect the quality of life of a higher proportion of the installation’s personnel. It should also be noted that the USAFA has requested adjudication of six other facilities for which the adjudicated MDI values deviated significantly from their CATCODE assigned counterparts.

The project "Sust/Rpr HTHW - Phase 4" at the USAFA was on the Utility Asset Management Plan (AMP) and planned to repair a hot water main. The hot water main distributed water from a central heat plant to the USAFA campus. The MDI value was changed from a 75 (Significant) to a 90 (Critical), thus increasing the project score from 171.67 to 180.67. The other project at USAFA, "Rpr Cadet Field House, Ph 1," planned to renovate the USAFA's indoor sports complex or Cadet Fieldhouse. The facility's CATCODE was labeled "Natatorium and Physical Education" while although correct, the CATCODE assigned MDI value of 71 (Significant) did not accurately reflect the consequence of facility failure as it was increased to a 90 (Critical) after adjudication. Thus, the project score increased from 166.6 to 180.67.

Malmstrom AFB also had one project whose adjudicated MDI values altered the funding group of the projects. Malmstrom AFB is part of the AFGSC and supports the nuclear deterrence mission. AFGSC requested the most amount of MDI adjudications with 560 of the approved MDI adjudications coming from Malmstrom AFB. The CATCODE approach to MDI does not accurately capture the consequence of facility failure at installations which operate ICBMs because of the mission's unique nature. The project "Repair MAF Water Wells" was on the Utility Asset Management Plan (AMP) and planned to repair drinking water wells with high concentrations of methane gas. The MDI value was changed from an 80 (Significant) to a 95 (Critical), thus increasing the project score from 171.67 to 180.67 and over the cut-line.

Goodfellow and Sheppard AFB each had a project whose adjudicated MDI values altered the funding group of the projects. These installations align under the Air Education Training Command (AETC) MAJCOM whose mission is to educate and train Air Force personnel. This mission deviates from the aerial warfare models as the CATCODE assigned MDI values do not necessarily capture the consequence of failure for facilities directly supporting the mission.

The project "Repair ENJJPT Dormitory" at Sheppard AFB was on the Facilities Asset Management Plan (AMP) and planned to update a dorm which had exceeded its service life. The dorm directly supported the primary mission of Sheppard AFB, which hosts the Euro-North Atlantic Treaty Organization (NATO) Joint Jet Pilot Training (ENJJPT) program. This program is the only advanced fighter pilot training program for NATO and not only supports the core mission of Air Supremacy but also Building Partnerships. The MDI value was changed from a 62 (Relevant) to an 82 (Significant), thus increasing the project score from 161.77 to 173.77.

The project at Goodfellow AFB, was "REPLACE AIR HANDLER UNITS/CHILL WATER/EMCS" planned to replace a Heating, Ventilation, and Air Conditioning (HVAC) system that had exceeded its expected service life. This project directly supported Goodfellow AFB's primary mission to educate and train Air Force personnel. The CATCODE assigned MDI value of 80 (Relevant) did not accurately reflect the consequence of facility failure so it was increased to an 88 (Significant) after adjudication. Thus, the project score increased from 172.33 to 177.13.

The use of adjudicated MDI values for the FY 2015, 2016, 2017 AFCAMPs changed the funding groups of 8 projects. Further insights were gained after Table 10 was developed to illustrate the proportion of projects whose funding group was changed by the MDI metric. Although it is possible to determine the proportion of project which could be influenced by the use of adjudicated MDI values, this data is subject to a sample bias. This ratio was excluded from Table 10 as it could falsely imply the use of surveyed MDI information has a greater influenceable region. This ratio was determined by comparing those projects whose funding group was changed with the used of adjudicated MDI values compared to the total number of projects which used adjudicated MDI values. Although this data is subjected to the previously discussed assumptions and limitations, it suggests the use of adjudicated MDI values could change approximately 6 percent of the AFCAMP's projects.

Table 10. Changes in AFCAMP Funding Groups using adjudicated MDI Values

Projects	**FY 15**	**FY 16**	**FY 17**	**Total**
Total	39	10	74	**123**
Changes in Funding Groups	3	0	5	**8**
	7.7%	0.0%	6.8%	**6.5%**

Summary

This chapter discussed the analysis and results of this research effort. It was shown that the surveyed and adjudicated MDI values greatly deviated from the CATCODE assigned MDI values as approximately 70 and 80 percent of the facilities had different MDI categories, respectively. Additionally, these deviations were shown to have some effect on their respective portfolios; however, these findings are subject to limitations as the MDI values available to this research effort are not necessarily considered a stratified and representative sample. The surveyed MDI values are believed to have been collected by a poorly calibrated team and the adjudicated MDI values are subject to a selective sample bias. Despite this, it was observed that the CATCODE assigned MDI values for the projects that changed funding groups did not accurately quantify the consequence of facility failure as they often directly supported their installation's core mission.

V. Conclusions and Recommendations

This chapter reviews the research effort's results and answers the investigative questions proposed in Chapter I. The investigation into the surveyed and adjudicated methodologies aimed to determine the amount of deviation between the values produced by these methodologies and the Categorical Code (CATCODE) assigned Mission Dependency Index (MDI) values. The deterministic approach to portfolio decision analysis was used to determine the influence of the deviation in MDI values on the United States Air Force's facility sustainment restoration and modernization (FSRM) annual project portfolio. Additionally, this chapter discusses the significance of the research, recommendations to the Air Force for future actions to be taken with respect to MDI, and recommendations for future research efforts.

Investigative Questions Answered

1. How much do the CATCODE assigned MDI values deviate from the MDI values assigned through a NAVFAC structured interview methodology?

The MDI values obtained during the 2008 joint MDI survey at Langley and Fairchild Air Force Base (AFB) greatly deviated from the CATCODE assigned values. The Naval Facilities (NAVFAC) Engineering Center and Air Force Civil Engineer Center (AFCEC) both maintain that the changes in MDI values only become significant if the categorical level of criticality changes as well. Seventy percent of the facilities surveyed had changes in their categorical levels of criticality; however, the insufficient training and poor calibration of the NAVFAC survey team may have introduced an unknown amount of error. Although the surveyed MDI values were shown to greatly deviate from the CATCODE values, the results from this investigative question are inconclusive due to the suspected source of error.

2. How does a project portfolio utilizing a CATCODE assigned MDI value compare to a project portfolio utilizing MDI values assigned through a NAVFAC structured interview methodology?

The Langley and Fairchild AFB fiscal year (FY) 2015, 2016, and 2017 Base Comprehensive Asset Management Plans (BCAMPs), or project portfolios, using the CATCODE assigned MDI values were compared to project portfolios derived from the surveyed MDI values. The analysis was limited to projects whose funding group could be influenced by changes in MDI values. Only 2 projects on the Langley AFB FY 2017 BCAMP were influenced enough by the surveyed MDI value to change funding groups; however, Headquarters Air Force (HAF), Air Force Installation Mission Support Center (AFIMSC), and AFCEC still decided to fund these projects after receiving the initial recommendation from the linear additive value portfolio model. The results from this investigative question indicate that a project portfolio based on surveyed MDI information frequently matches the preferences of the decision-makers. Additionally, it was determined the uncertainty of MDI information only affects about 8 percent of the

BCAMP. More MDI information needs to be surveyed to create a better stratified and statistically representative sample in order to better answer this investigative question; however, this indicate the expert judgement of HAF, AFIMSC, and AFCEC may overcome the limitations of the CATCODE assigned MDI methodology. Additionally, any future research requires the MDI survey team to be properly trained and calibrated to increase the confidence in the MDI results.

3. How much do the CATCODE assigned MDI values deviate from the adjudicated MDI values?

The MDI values obtained through the adjudication process greatly deviated from the CATCODE assigned values. As previously stated, changes in MDI values are significant if the categorical level of criticality changes as well. Eighty percent of the facilities surveyed had changes in their categorical levels of criticality; however, the selective sample bias created by the motivational factors for adjudicating MDI values limits the insights gained by answering this investigative question. Although the adjudicated MDI values were shown to greatly deviate from the CATCODE values, the results from this investigative question are inconclusive due to the selective sample bias.

4. How does a project portfolio utilizing a CATCODE assigned MDI value compare to a project portfolio utilizing adjudicated MDI values?

The FY 2015, 2016, and 2017 Air Force Comprehensive Asset Management Plan (AFCAMP) using the CATCODE assigned MDI values were compared to project portfolios derived from the adjudicated MDI values. The analysis was limited to projects whose funding group could be influenced by changes in MDI values and projects with an adjudicated facility. Only 8 or 6.5 percent of projects on the FY 2015/216 and 2017/2018 AFCAMP were influenced enough by the adjudicated MDI value to change funding groups. Although the adjudicated MDI data is subject to a selective sample bias, as AFCEC primarily adjudicated facilities with the understanding that the newly adjudicated value would change the facilities' MDI category, it was observed that projects changed funding groups if the deviation in MDI values was large enough to cause a change in the MDI's category as well. It was also observed that the adjudicated projects whose funding groups changed directly supported the core mission(s) of its respective installation.

A significant amount of time and resources was used to adjudicate facilities whose CATCODE assigned MDI values do not accurately quantify the consequence of facility failure. Additional research is needed to determine whether or not the MDI adjudication is an efficient asset management practice. Other approaches could overcome the CATCODE methodology's shortcoming by identifying projects which directly support the core mission(s) on the installation. Future research efforts could determine if this is a better alternative asset management practice than the surveyed MDI methodology.

Significance of Research

The Air Force is currently considering whether to fund additional MDI surveys at several Air Force installations and may allocate funds to survey all Air Force installations to assign a unique MDI value to every facility. This research effort measured the deviation in MDI values produced by the different methodologies and used a deterministic approach to portfolio decision analysis to provide insight into the surveyed MDI information's utility and the impact on the Air Force's project portfolio. Although future research is needed to overcome the limitations imposed on the data used by this research effort, the results can help AFIMSC and AFCEC's efforts to adopt the most optimal MDI methodology that quantifies the consequence of facility failure. The optimal MDI methodology would best produce the AFCAMP or project portfolio that best mitigates risk to the Air Force's mission.

Recommendations for Action and Future Research

Although initial findings determined that surveyed and adjudicated MDI information had some effect on project portfolios, additional research and analysis needs to be performed to better determine the optimal MDI methodology. This can be accomplished through an additional deterministic approach to portfolio decision analysis using the United States Navy's project portfolio. A probabilistic approach to portfolio decision analysis may be able to be performed if additional MDI surveys are conducted on Air Force installations. This would allow AFIMSC and AFCEC to determine the amount of uncertainty regarding a project's funding group.

AFIMSC and AFCEC should fund additional MDI surveys to obtain MDI values which are considered a stratified and representative sample of the Air Force's real property portfolio. This can be better accomplished by funding MDI surveys at installations which support various Air Force core missions. This additional data could be used to better examine the effect of surveyed MDI information on the Air Force's project portfolios. Additionally, data could be collected during these surveys to measure both the indirect cost of MDI surveys and the value created through stakeholder interaction and management. Furthermore, AFCEC and AFIMSC need to ensure the MDI survey teams are well calibrated, properly trained, and familiar with the Air Force's mission. Furthermore, additional research needs to be conducted to determine how the Air Force could identify projects on the AFCAMP which support the installation's core mission and whether this methodology is a more efficient and optimal asset management practice.

In addition to these future research opportunities, it is recommended AFIMSC and AFCEC adjust their business practices. The MDI adjudication process should be refined by focusing on adjudicating facilities with projects inside the influenceable region of the AFCAMP as the surveyed MDI information only has value when it can influence the project portfolio. Adjudicating MDI values for facilities with no upcoming competitive projects adds no value to the AFCAMP project portfolio. Adhering to this business practice would be a more prudent use of human resources. There is one limitation to the proposed change to the MDI adjudication process as it may increase the bias of requested adjudications. Installations may advocate for MDI adjudication when a project is competitive or close to the projected cut-line. Therefore, it is also recommended AFIMSC and AFCEC introduce a requirement to submit documentation signed by the installation's leadership indicating they believe the CATCODE assigned MDI value does not accurately reflect the consequence of facility failure, in order to reduce the potential bias of MDI adjudication requests.

Although this research effort is subject to the previously discussed limitations, it may be prudent to use the financial resources to fund more projects rather than fund a MDI survey at each installation. Additionally, time saved by streamlining the MDI adjudication process could be spent objectively looking at the model and applying expert judgement to select the optimal project portfolio. It is however still recommended that additional MDI surveys and research be conducted to overcome the assumptions and limitations made in this research effort.

Summary

This chapter discussed the results of this research effort and answered the investigative questions. The surveyed and adjudicated MDI values greatly deviated from the CATCODE assigned MDI values; however, these values are subject to scrutiny. The Langley and Fairchild AFB surveyed MDI values are believed to have been surveyed by a poorly calibrated team and the adjudicated MDI values are subject to a selective sample bias. These MDI values are not necessarily considered a stratified and representative sample and therefore the collection of additional MDI information is warranted. The deterministic approach to portfolio decision analysis determined that surveyed MDI information has an effect on the project portfolio recommendation produced by the Air Force's linear additive portfolio value model. It also identified a correlation between the change in project funding groups and those that supported the installation's core mission. However, as previously stated, additional MDI data needs to be collected to synthesize results and conclusions with greater integrity. Lastly, future research efforts were identified and recommendations were given to the organizations sponsoring this research.

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14. ABSTRACT
The United States Air Force partially integrated the Mission Dependency Index (MDI) into its portfolio project selection model by assigning an MDI value to a facility type or real property category code (CATCODE) in lieu of assigning a unique MDI value to each facility through a structured interview process. This took an initial step to improve the Air Force's asset management practices; however, it failed to accurately capture the consequence of facility failure in some cases. Although a process to adjudicate the MDI value of individual facilities was created, it is still unknown how much the surveyed MDI value deviates from the CATCODE assigned MDI value and how this influences the Air Force's annual project portfolio selection model.
The purpose of this research effort is to measure the deviation in MDI values produced from surveys and the adjudication process with the CATCODE assigned MDI values. It also uses a deterministic approach to portfolio decision analysis to determine the influence these surveyed and adjudicated MDI values have on the Air Force's project portfolio selection model. This research effort serves to provide insight to the Air Force Installation Mission Support Center and the Air Force Civil Engineer Center of the value and utility of surveyed and adjudicated MDI information when compared to their CATCODE assigned counterparts.

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