



**ORGANIZATIONAL STRATEGIC BASING FRAMEWORK WITH INFUSION
OF MULTI-DIMENSIONAL UNCERTAINTY**

THESIS

Amanda Reboulet, Civilian, USAF

AFIT-ENS-MS-17-S-068

**DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY**

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

DISTRIBUTION STATEMENT A.
APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

The views expressed in this thesis are those of the author and do not reflect the official policy or position of the United States Air Force, Department of Defense, or the United States Government. This material is declared a work of the U.S. Government and is not subject to copyright protection in the United States.

AFIT-ENS-MS-17-S-068

ORGANIZATIONAL STRATEGIC BASING FRAMEWORK WITH INFUSION OF
MULTI-DIMENSIONAL UNCERTAINTY

THESIS

Presented to the Faculty

Department of Operational Sciences

Graduate School of Engineering and Management

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the
Degree of Master of Science in Operations Research

Amanda M. Reboulet, MBA, B.S., B.A.

Civilian, USAF

September 2017

DISTRIBUTION STATEMENT A.
APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

AFIT-ENS-MS-17-S-068

ORGANIZATIONAL STRATEGIC BASING FRAMEWORK WITH INFUSION OF
MULTI-DIMENSIONAL UNCERTAINTY

Amanda M. Reboulet, MBA, B.S., B.A.

Civilian, USAF

Committee Membership:

Dr. Bradley Boehmke
Chair

Dr. Jeffrey Weir
Member

Dr. Theodore Lewis
Member

Dr. Jeremy Hendrix
Member

Abstract

Evidence suggests the United States Air Force executes capital investment decisions based on point estimates without sufficient consideration of uncertainty surrounding the data used in the estimate. This research seeks an alternative to this by coupling a multi-objective decision analysis approach with Monte Carlo simulation to adequately account for uncertainty in strategic basing decisions. In the context of this research, strategic basing decisions aspire to pick the highest valued, lowest cost installations to establish organizations. The inclusion of uncertainty in both input data to calculate an overall value score and cost parameters for each installation allows decision makers to better understand the entire decision space. Additionally, the incorporation of uncertainty permits analysts to test for statistical differences between installations and recommend trade-offs to decision makers.

Acknowledgments

I would like to express the sincerest appreciation to my faculty advisor, Dr. Bradley Boehmke, for his guidance and support throughout this thesis effort. His insight and experience was certainly appreciated and greatly informed this thesis. Additionally, I would like to thank Dr. Raymond Hill for making this opportunity a reality and guiding me through the entire program. I would also like to thank Dr. Jeffrey Weir for his support on my thesis committee.

Additionally, I would also like to thank my sponsors, Ms. Cynthia Abbott and Ms. Lynn Eviston, from the Air Force Materiel Command for both the support and latitude provided to me in this endeavor. Additionally, I would like to thank my boss Dr. Theodore Lewis for giving me the opportunity to go back to school and helping me immensely along the way. I would not have had this opportunity if it weren't for Dr. Lewis and my sponsors.

A special thanks to Dr. Paul Hartman for being a great mentor. Also, Dr. Jeremy Hendrix for his guidance on strategic basing. Finally, I would like to thank my husband and parents who supported me through the entire process.

Amanda M. Reboulet

Table of Contents

	Page
Abstract	iv
Table of Contents	vi
List of Figures	viii
List of Tables	xi
I. Introduction	1
1.0 Problem Background	1
1.1 Problem Statement	2
1.2 Research Objectives	3
1.3 Assumptions/Limitations	3
1.4 Preview	4
II. Literature Review	5
2.0 Overview	5
2.1 Strategic Basing Process Overview	5
2.2 Operations Research Approaches to Support Military Decision Making	7
2.3 Methods to Incorporate Uncertainty	10
2.4 Summary	15
III. METHODOLOGY	16
3.0 Overview	16
3.1 Decision Analysis Framework	16
3.2 Monte Carlo Simulation to Account for Uncertainty	35
3.3 Summary	37
IV. ANALYSIS AND RESULTS	39
4.0 Overview	39

4.1 Scenario 1 Results	39
4.2 Scenario 2 Results	41
4.3 Scenario 3 Results	43
4.4 Scenario 4 Results	44
4.5 Scenario 5 Results	49
4.6 Recommendation	50
4.7 Summary.....	51
V. Conclusions and Recommendations	52
5.0 Conclusions of Research	52
5.1 Recommendations for Future Research.....	53
Appendix A: Criteria and Attribute Definitions	55
Appendix B: Capacity Value Functions	56
Appendix C: Point Estimate Data	58
Appendix D: Sensitivity Analysis on Weights	59
Appendix E: Monte Carlo Simulation—Triangular Distribution Data.....	65
Appendix F: Monte Carlo Simulation—Custom Distribution Data	69
Bibliography	73

List of Figures

	Page
Figure 1. Charts to Depict Trade-Off Between Value and Cost [18]	13
Figure 2. MODA Process.....	17
Figure 3. Organizational Strategic Basing Decision Framework	19
Figure 4. Strategic Basing Value Hierarchy	20
Figure 5. Value Functions for Mission: Acquisition Professionals	23
Figure 6. Value Functions for Mission: Civilian Hiring Ability	24
Figure 7. Value Functions for Mission: Foreign Partner Presence	25
Figure 8. Value Functions for Mission: Availability of Education	25
Figure 9. Swing Weight Matrix	27
Figure 10. Weighted Value Hierarchy	27
Figure 11. Alternative Scoring.....	30
Figure 12. Cost versus Capability for Individual Installations	31
Figure 13. Value Gap Analysis	33
Figure 14. Sensitivity Analysis of Weights on Mission and Capacity	34
Figure 15. Triangular and Custom Distributions in Crystal Ball.....	36
Figure 16. Scenario 1 Results	40
Figure 17. Results of Two-Tailed t-Test comparing installation 2 and 3	41
Figure 18. Scenario 2 Results	42
Figure 19. Scenario 3 Results	44
Figure 20. Scenario 4 Results	45
Figure 21. Statistical Tests on Value and Cost	46

Figure 22. Scenario 4 Results with Point Estimate.....	47
Figure 23. Value vs Cost Scatter Plot	48
Figure 24. Value vs Cost Scatter Plot (Installations 2 and 3)	48
Figure 25. Scenario 5 Results	49
Figure 26. Two-Tailed t-tests Comparing Scenario 4 and 5	50
Figure 27. Facility Value Functions.....	56
Figure 28. Communication Availability	56
Figure 29. Availability of Housing	57
Figure 30. Security Vulnerability	57
Figure 31. Weights on Acquisition Professionals.....	59
Figure 32. Weights on Acquisition Professional Attributes	59
Figure 33. Weights on Civilian Hiring Ability	60
Figure 34. Weights on Foreign Partner Presence.....	60
Figure 35. Weights on Foreign Partner Presence Attributes.....	61
Figure 36. Weights on Availability of Education	61
Figure 37. Weights on Facility.....	62
Figure 38. Weights on Facility Attributes.....	62
Figure 39. Weights on Comm Availability.....	63
Figure 40. Weights on Housing Availability	63
Figure 41. Weights on Security Vulnerability	64
Figure 42. Installation 1 Data.....	65
Figure 43. Installation 2 Data.....	65
Figure 44. Installation 3 Data.....	66

Figure 45. Installation 4 Data.....	66
Figure 46. Installation 5 Data.....	67
Figure 47. Installation 6 Data.....	67
Figure 48. Installation 7 Data.....	68
Figure 49. Installation 8 Data.....	68
Figure 50. Installation 1 Data.....	69
Figure 51. Installation 2 Data.....	69
Figure 52. Installation 3 Data.....	70
Figure 53. Installation 4 Data.....	70
Figure 54. Installation 5 Data.....	71
Figure 55. Installation 6 Data.....	71
Figure 56. Installation 7 Data.....	72
Figure 57. Installation 8 Data.....	72

List of Tables

	Page
Table 1. Strategic Basing Criteria Definitions	6
Table 2. Strategic Basing Stakeholder Matrix	18
Table 3. Continuous and Discrete Attributes	22
Table 4. Monte Carlo Simulation Scenarios	37
Table 5. Point Estimate Installations 1-4	58
Table 6. Point Estimate Installations 5-8	58

ORGANIZATIONAL STRATEGIC BASING FRAMEWORK WITH INFUSION OF MULTI-DIMENSIONAL UNCERTAINTY

I. Introduction

1.0 Problem Background

Evidence suggests the United States Air Force (USAF) executes capital investment decisions based on point estimates without sufficient consideration of uncertainty surrounding the data used to generate the estimates [1], [2]. This is unrealistic since the USAF operates in an uncertain, ever-changing environment, as documented in *Air Force Future Operating Concept: A View of the Air Force in 2035* [3]. Currently, there is a discrepancy in capital investment decisions and overarching USAF policy accounting for uncertainty. This can be seen with various capital investment decision approaches such as Business Case Analyses and Cost Capability Analyses, which do not adequately account for uncertainty [1], [2]. This thesis acknowledges the shortfall in planning for capital investment decisions and examines an alternative approach for strategic basing decisions.

When significant additions or reductions occur for a particular weapon system, personnel, or both, the USAF implements a strategic basing process to generate a strategic basing decision. Over one hundred strategic basing decisions have been accomplished since 2009 using a variety of analytical techniques [4]. As resources become more constrained, strategic basing decisions receive more criticism and are often contentious since they impact local economies, force posturing, and public opinions. It is important that these are independent, transparent, data-driven, uncertainty-bound decisions to ensure buy-in from all stakeholders throughout the process [4].

According to the recent Research and Development (RAND) Corporation study on improvements to strategic basing, there are three main steps that support an enterprise strategic basing decision. First, criteria to assess each candidate installation's ability to support the mission are developed. Second, all installations receive a score based on the first step and a handful of those installations with the highest scores are selected for a site survey. Third, the final installation is recommended based on the highest score identified by the site survey. The outputs at each step are briefed to the Secretary of the Air Force (SECAF) and Congress. This level of interest highlights the necessity for a transparent, objective process [4].

An important distinction in research for this thesis is the emphasis on organizational strategic basing, which involves large fluctuations of personnel related to a specific weapon system. The foundation of the research comes from recent organizational strategic basing decisions and aims to incorporate uncertainty about data inputs and weights into strategic basing decisions. The results produced with this business case are based on randomly generated, notional data, to prove a concept vice support for a particular decision. The next USAF organizational strategic basing decision could utilize this uncertainty focused framework to ensure independent, transparent analysis while capturing elements of uncertainty to support decision makers.

1.1 Problem Statement

The infusion of uncertainty in multiple dimensions applied to organizational strategic basing decisions is the focus of this thesis. Fundamentally, the research objective is to create a tailorable uncertainty bound framework that could be utilized by

entities across the USAF engaged in the process yielding organizational strategic basing decisions. The injection of uncertainty into investment decisions strengthens the overall process since it provides decision makers insight into the impact of uncertainty surrounding a particular strategic basing option.

1.2 Research Objectives

This thesis is organized around three strategic objectives and focuses on methods for integrating and calculating uncertainty:

- 1) How is input data uncertainty obtained from various data sources incorporated across the decision space?
- 2) How is decision weighting uncertainty captured and accounted for throughout the model?
- 3) How does the interaction of (1) and (2) contribute to uncertainty within the decision space?

The findings presented here apply to other types of capital investment decisions; however, for the purposes of this thesis, only organizational strategic basing is discussed.

1.3 Assumptions/Limitations

Since strategic basing decisions tend to be somewhat contentious, actual data was not used in this thesis. The focus of this thesis is to develop a methodology for capturing uncertainty within capital investment decisions and, more specifically, strategic basing decisions concerning organizations. While this thesis strictly addresses those strategic decisions with significant personnel fluctuations, this methodology for integrating uncertainty could be expanded to include other capital investment decision processes such as cost capability and business case analyses.

A key limitation of this thesis is access to actual strategic basing data, since it is difficult to gather enough actual data to complete a thorough study involving uncertainty. Thus, data was randomly generated based on expert judgement from other strategic basing decisions to build the framework. The randomly generated data is discussed in more detail in the following chapters.

1.4 Preview

This thesis is organized into five chapters. Chapter 2 provides an in-depth literature review discussing different methodologies for capturing uncertainty as well as approaches to Multi-Objective Decision Analysis (MODA) problems. Chapter 3 discusses the methodology applied by implementing a MODA approach while Chapter 4 outlines the data description and analysis. Finally, Chapter 5 summarizes the findings and identifies additional research areas for the inclusion of uncertainty in capital investment decisions.

II. Literature Review

2.0 Overview

This chapter reviews the current strategic basing process, operations research approaches to support military decision making, and methods for integrating uncertainty across the decision space. The intersection of these will improve the execution of Air Force capital investment decisions.

2.1 Strategic Basing Process Overview

Currently, *Air Force Instruction (AFI) 10-503 Strategic Basing* provides a detailed overview of the strategic basing process and what events trigger the process [5]. Additionally, the instruction provides details of all the offices and organizations involved and their roles and responsibilities. While the overall instruction is incredibly detailed, it does not specifically discuss strategic basing of organizations [5].

Samaras et al. [4] discuss the current strategic basing policy in more general terms. They point out that the overall process is dependent on hundreds of data calls requesting information for over two hundred bases. Typically, an enterprise-wide “look” is conducted by the leading major command (MAJCOM). During this look, criteria is used to narrow down the candidate installations. There are three steps that support an enterprise strategic basing decision. First, criteria to assess each candidate installation’s capability to support the mission are developed. Second, all installations receive a score based on the first step and a handful of those installations with the highest scores are selected for a site survey. Third, the final installation is recommended based on the highest score identified in the site survey [4].

There are four main categories of data analyzed through this strategic basing process: mission, capacity, environment, and cost. Furthermore, each category has several key attributes, which are used to assess the respective category for each installation. In order to objectively compare each installation, a 100-point scoring system is utilized where each attribute for individual installations is measured and given a score. Definitions for mission, capacity, environment, and cost are provided in Table 1 [4].

Table 1. Strategic Basing Criteria Definitions

Criteria	Definition
Mission	Includes those attributes that measure the impact of weather, airspace, and proximity of ranges for each individual installation
Capacity	Evaluates the ability of each installation's existing infrastructure to meet mission
Cost	Includes attributes such as regional cost of living for federal employee salaries, construction capital costs, and military basic allowance for housing rates
Environmental	Evaluates the impact of accommodating the mission on air quality, land use, encroachment issues, noise pollution, etc.

In 2014, Air Force Material Command (AFMC) successfully utilized the strategic basing process coupled with decision analysis to determine the optimal location for the AF Installation & Mission Support Center (IMSC) Head Quarters [6], [7]. There were ten installations analyzed across the domestic enterprise. As mentioned in AFI 10-503 Strategic Basing, the criteria measured was mission, capacity, cost, and environmental. The study was met with praise from the AFMC/CC and the recommended location was selected [7].

2.2 Operations Research Approaches to Support Military Decision Making

The core of the strategic basing process allows decision makers to implement an informed decision based on knowledge of each installation. The Operations Research “toolbox” of methods provides a plethora of techniques and approaches to support decision making in a military context. Within this toolbox, there are recognized tools such as linear programming, network optimization, multiple criteria decision-making, decision analysis, stochastic models, simulation, and metrics [8]. Other tools incorporate Bayesian decision theory through info-gap robustness analysis and robust optimization [9]. This thesis uses decision analysis as a technique to assist stakeholders with multi-objective decisions presented in the strategic basing process. Specifically, MODA is utilized in this methodology.

Decisions are defined as:

A philosophy and social-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. Decision analysis is founded on an axiomatic decision theory and uses insights from the study of decision making [10].

Key characteristics of the above definition that assist in the context of organizational strategic basing decision processes are: conflicting objectives, complex alternatives, important uncertainties, and multiple stakeholders. This research emphasizes the uncertainties unveiled by the decision analysis process.

While there are many successful examples of decision analysis being applied across industry and government agencies, this literature review focuses on the military applications. More specifically, this literature review focuses on MODA as a way to characterize the trade space for decision makers. Parnell and Burk [11] suggest that

MODA is the most recognized method to address military portfolio decisions. The next most prominent technique is optimization typically in the form of binary programming or a knapsack-type formulation. Additionally, twenty-four military portfolio decision applications are listed with the various analysis techniques applied. Six of these military portfolio decision analysis case studies are discussed in detail: Marine Corps Program Budget, Air Force 2025 Study, National Reconnaissance Office (NRO) Operational Support (OSO) Program Budget, Air Force Space Command Investment, Air Force Space Technology R&D, and Army Base Realignment and Closure (BRAC) 2005 [11].

Parnell and Burk [11] discuss four technical issues that arise when conducting military portfolio decision analysis: portfolio value calculation; swing weight matrices; constraints and dependencies; and uncertainty and risk. This research focuses on a method to account for uncertainty. Parnell and Burk [11] state that most military decisions utilize scenarios, Monte Carlo simulation, and decision trees to account for uncertainty.

Parnell, Ewing, and Tarantio [12] illustrate the use of MODA to create a value model for each installation in the context of potential realignments and base closures, which is quite similar to strategic basing decisions. The successful implementation of ninety-five percent of the recommendations from this BRAC led to a cost savings of approximately \$1.5 billion annually. Their particular research introduced the creation of scales for independent attributes as well as the swing weight matrix for assessing weights. Furthermore, it delineated practical advice on how MODA techniques could be applied to diffuse complex, politically driven decisions similar to strategic basing decisions [12].

This research expands this by creating a value score for each installation similar to the BRAC study and exploring the uncertainty trade space.

Over the years, many lessons have been captured for developing a decision analysis framework for projects within the Department of Defense (DoD). Parnell et al. [13] detail many pitfalls to avoid; this literature review focuses on those most applicable pitfalls to develop a strategic basing framework. They first discuss selecting a model inappropriate for the problem and the issue of not quantifying uncertainty. They also mention developing inadequate objective hierarchies. Currently, the strategic basing process details a one-size fits all approach to the process without differentiating between weapon systems and organizations. Developing a robust organizational strategic basing framework could prove challenging. Conversely, another pitfall for strategic basing is not using constraints as screening criteria. However, since strategic basing decisions tend to have political undertones, it may prove difficult to implement constraints for initially screening installations. Another issue they bring up is including cost in the objectives hierarchy. Currently, AFI 10-503 includes cost as one of the key objectives/attributes to measure, which is contrary to the MODA techniques where cost is considered an independent variable [5]. It is standard acquisition practice to have cost as an independent variable (CAIV), which aims to separate cost and value [13].

Value measures should discriminate between different installations. If every installation scores the same for a particular attribute, then that attribute is not worth measuring. Parnell et al. [13] discuss the importance of conducting sensitivity analysis to add to the credibility of the framework. Inclusion of these lessons learned is imperative to

the overall success of the organizational strategic basing process as well as accounting for uncertainty around the values and weights [13].

In 2014, AFMC effectively used decision analysis coupled with the approved strategic basing process to determine the optimal installation for IMSC Head Quarters. Through the application of decision analysis, AFMC developed effective weights, calculated relative scores, and assigned an overall ranking. Additionally, robust sensitivity analysis on weights and the criteria considered in this action were analyzed. As part of the communication plan, this sensitivity analysis helped decision makers understand the trade space around the weights for each attribute or measure. Results showed that weights would have to drastically change in most cases to impact the recommended installation. Furthermore, the analysis showed that some categories such as environmental, did not impact the installation since all installations scored equally [7]. This method of sensitivity analysis is expanded in this research to include dynamic sensitivity analysis on both value and cost.

2.3 Methods to Incorporate Uncertainty

Parnell and Burke [11] remark that few military applications adequately model uncertainties. As the political and military decision environment evolves, it becomes increasingly important to account for uncertainties in both the values we measure and the weights we assign different criteria around a decision. According to Biery, Hudak, and Gupta [14], uncertainty is defined as, “a situation in which the outcome is subject to an uncontrollable event stemming from an unknown probability distribution” [p. 58]. Within the context of military applications, there are several categories of uncertainty:

technology maturity, requirements, design features, adversaries, competition, scenarios, system performance, value, schedule, and cost [15]. Interestingly, uncertainty is not frequently modeled even though military decisions are shrouded in uncertainty [11]. In fact, Parnell et al. [16] disclose that approximately sixty-eight percent of published articles on decision analysis applications do not include a discussion on uncertainty. The remaining thirty-two percent of published articles feature techniques such as decision trees, utility, Monte Carlo simulation, attack trees, risk-penalty function scenarios and risk measures [16].

A thorough literature review on methods that account for uncertainty revealed several approaches. One such method is the application of Bayesian networks. Bayesian networks provide a probabilistic framework that quantify risk and uncertainty through a graphical cause and effect method [17]. One benefit to this particular approach is that it illustrates the uncertainty probabilistically to the various stakeholders using a diagram or network.

Parnell and Burk [11] discuss and identify the methods used to account for uncertainty in six military case studies. In both the Marine Corps Program Budget and Air Force Space Command Investment projects, uncertainty was not explicitly modeled. For the Air Force 2025 study, four scenarios with various weights were utilized to capture the uncertainty. During the NRO OSO Program Budget study, a single project risk measure score was captured, but not employed in the value model. Likewise, with the Army BRAC 2005, uncertainty was an important piece of the portfolio capability requirement study, but not necessarily captured as part of the value model. Finally, the

Air Force Space Technology R&D used Monte Carlo simulation coupled with a triangular distribution to describe uncertainty around individual project scores [11].

Moreover, Parnell and Burk note that Monte Carlo simulation and decision trees are the most prominent methods used to assess uncertainty in the context of military operations. Additionally, they mention the employment of scenario analysis to assess risk and opportunities across different assumptions for a long-term timeframe. The authors compare and contrast the two most prominent methods of Monte Carlo simulation and decisions trees. They suggest that Monte Carlo be used with many, independent uncertainties and decision trees be employed for limited, dependent uncertainties. Both methods are utilized in shorter term decisions. Using Monte Carlo with many independent uncertainties is not only relevant to the attributes represented across military capital investment decisions, but specifically strategic basing, which is a short-term, one-time decision [11].

Parnell and MacCalman [18] describe probability management as a way to account for uncertainty through Monte Carlo Simulation in decision analysis processes. A major contribution of this article directly applicable to this research is the integration of modeling uncertainty with values and cost to help decision makers better understand the trade-space of individual alternatives. Furthermore, the authors suggest three types of charts to illustrate this trade-space between value and cost. Figure 1 provides examples of the three types of charts.

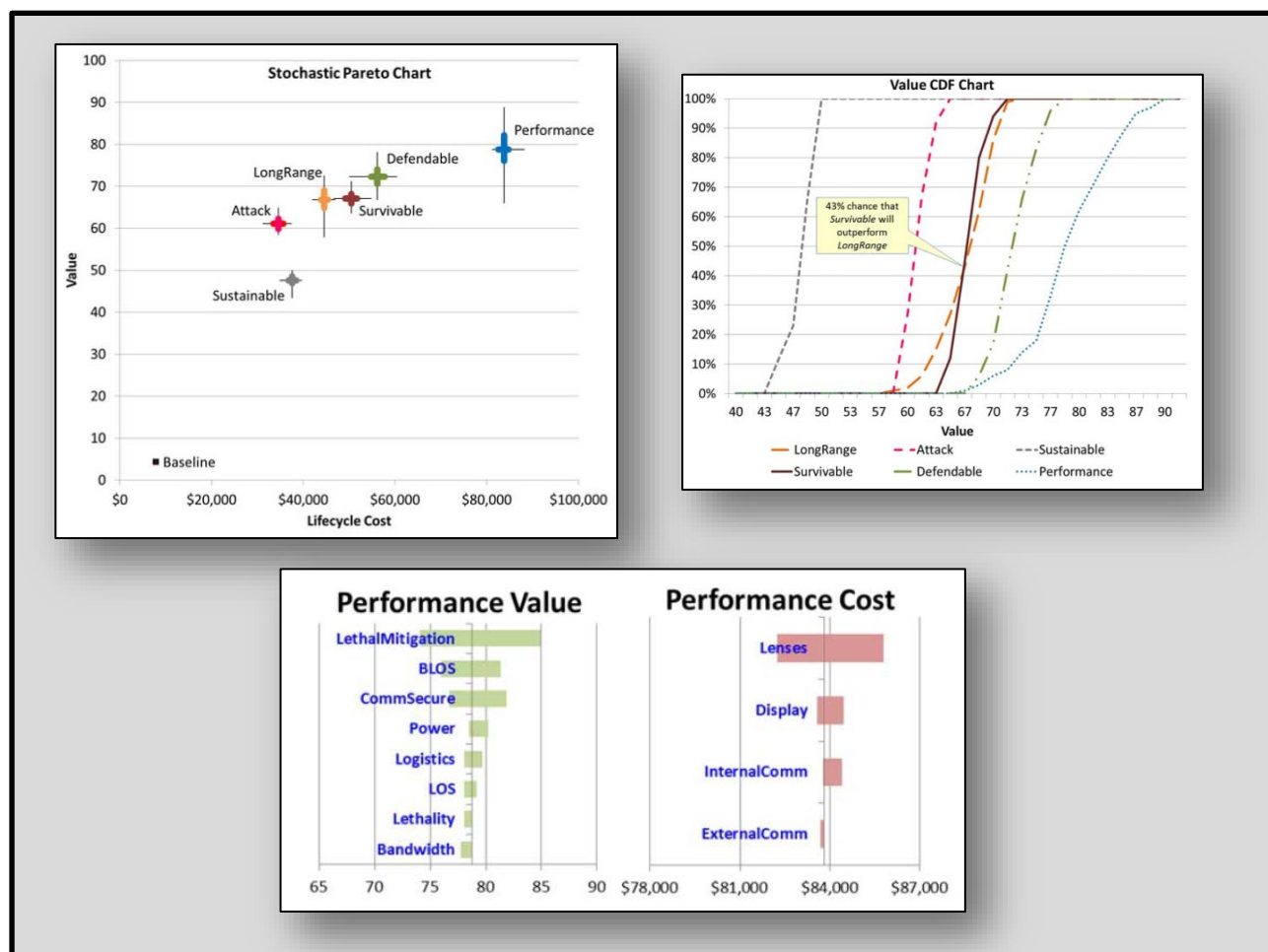


Figure 1. Charts to Depict Trade-Off Between Value and Cost [18]

Stochastic Pareto charts use box plots to show the uncertainty around the point estimates in both the value and cost direction for each alternative. In a strategic basing context, this helps decision makers eliminate those installations obviously dominated by other installations. Cumulative Distribution Function (CDF) charts illustrate each alternative's possible outcomes by accruing the area for each function (discrete or continuous). Tornado diagrams show which measures impact each alternative the most allowing decision makers to compare the importance of each value. Lastly, the authors

suggest three tools to conduct Monte Carlo simulation: Crystal Ball, @Risk, and Probability Management's free tool [18].

Biery, Hudak and Gupta [14] suggest that there are two main types of distributions coupled with Monte Carlo simulation: beta and triangular. Typically, in military application contexts, the triangular is used since it requires less data than needed to fit a beta distribution. In fact, when faced with limited or no data, a subject matter expert can provide all data that is necessary to define a triangular distribution. To use a triangular distribution, just three pieces of data are needed: optimistic, mostly likely, and pessimistic [14].

A successful military application implementing Monte Carlo simulation using triangular distributions is the Air Force Space Technology R&D study [11]. This study describes the development of a model to support AFRL with resource allocation decisions concerning various military capability projects. In order to best determine scores for the riskier projects, Monte Carlo Simulation coupled with triangular distributions were utilized. Monte Carlo simulation was then employed a second time to explore the outcomes across the value axis for each project [11].

A detailed literature review of inclusion of uncertainty across military applications demonstrated that uncertainty is not adequately being considered in military capital investment decisions. There were several techniques suggested to remedy this void; however, Monte Carlo simulation coupled with triangular distribution is the most widely used across military applications [15]. Strategic basing as a politically-ridden decision, suffers from multi-dimensional uncertainty. Monte Carlo simulation using a

triangular distribution could help decisions makers understand and examine the strategic basing decision trade-space.

2.4 Summary

This chapter analyzed and discussed the current strategic basing process, explored approaches to assist military decision making, and researched various methods for integrating uncertainty across the decisions space. The next chapter details the research methodology, which combines MODA techniques and Monte Carlo simulation to create a strategic basing framework. This approach is consistent with other similar military investment decision processes.

III. METHODOLOGY

3.0 Overview

This chapter describes how MODA coupled with Monte Carlo simulation can account for uncertainty in capital investment decisions such as organizational strategic basing. This chapter describes the MODA process, outlined by Parnell et al. [10], to create the generic, tailorable framework for an organizational strategic basing decision. The use of Monte Carlo simulation using a triangular distribution in Crystal Ball is discussed. Randomly generated data is utilized to illustrate a concept of injecting uncertainty throughout the strategic basing process, both into the various data inputs then weights associated with decision maker preferences. Finally, the interaction of these two dimensions of uncertainty is explored.

3.1 Decision Analysis Framework

Parnell et al. [10] describe a ten step MODA process. Most decisions the Air Force faces are complex and require conscious trade-offs to de-conflict multiple objectives. Decision analysis and, more specifically, MODA provides a means to turn disparate objectives into common units for equivalent comparison. This common unit is called value and allows decision makers to make more informed decisions by incorporating trade-offs between competing objectives [10].

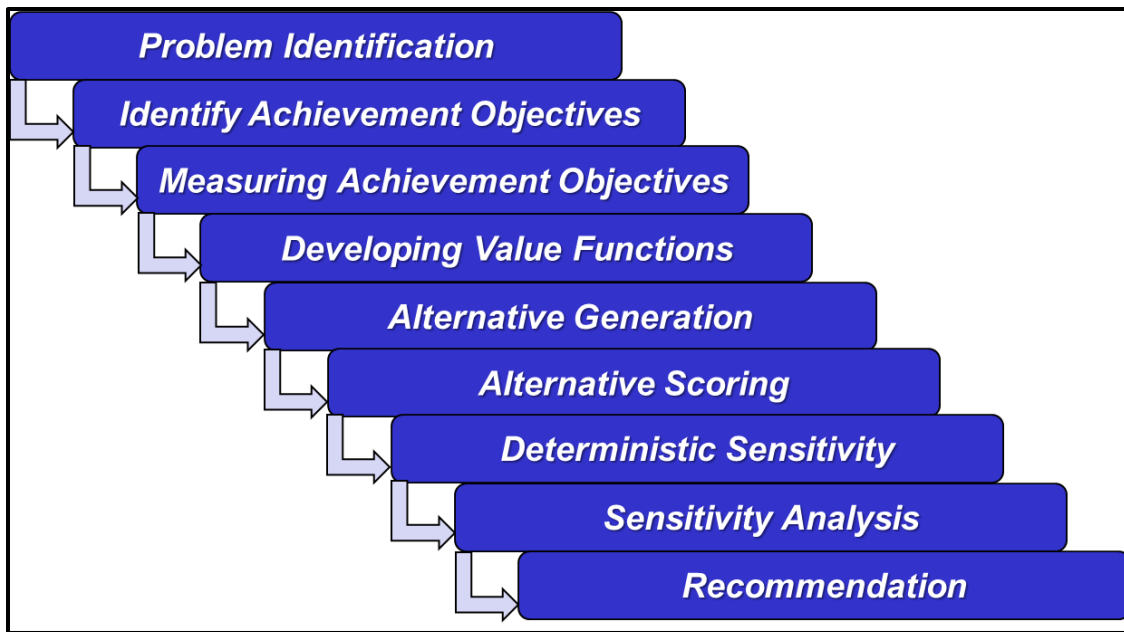


Figure 2. MODA Process

Problem Identification

The first step of any MODA process, problem identification, is arguably the most critical and most difficult piece to tackle. An important piece of developing this decision framework is the problem statement. It should incorporate the purpose, perspective, and scope of the decision while clearly describing the deliverables [10]. The purpose of applying MODA in this case is to determine the best installations from existing military installations to conduct site surveys and eventually choose the best valued, lowest cost installation from the subset. While conducting site surveys at every Continental United States (CONUS) location is arguably fair, it is too costly in both time and money; therefore, an unbiased framework is required to assist decision makers in paring down the site survey list.

The development of a stakeholder matrix specifically for strategic basing is imperative to successfully identify the problem. This matrix helps decision makers and stakeholders understand the decision space and the end goal since different stakeholders often view the strategic basing problem through a different lens. Reference Table 2 for more details about the stakeholders involved in the strategic basing process.

Table 2. Strategic Basing Stakeholder Matrix

	Decision Maker	Congressmen	Program Office	Potential Location Community Leaders
Cultural		Acceptance of decision	Support location chosen	Support community vision
Economic		Support for district		Impact to local industrial base
Emotional		Acceptance of decision		
Historical	Past similar decisions			
Legal			Compliance with regulations	
Moral/Ethical	Follow thru on decision	Follow thru on decision		
Natural Environment				Impact to environment
Organizational			Manpower support	
Political	Defend location chosen	Acceptance of decision		
Security				Impact to local traffic
Social				Impact to community culture
Technological				Industry opportunities

The decision hierarchy allows all stakeholders to understand the scope of the decision at hand while documenting the decisions that have already been made and those decisions remaining [10]. The clearly delineated focus areas allow stakeholders to focus on the imminent decision for strategic basing of a new organization. Reference Figure 3 for a generalized decision hierarchy for an organizational strategic basing decision.

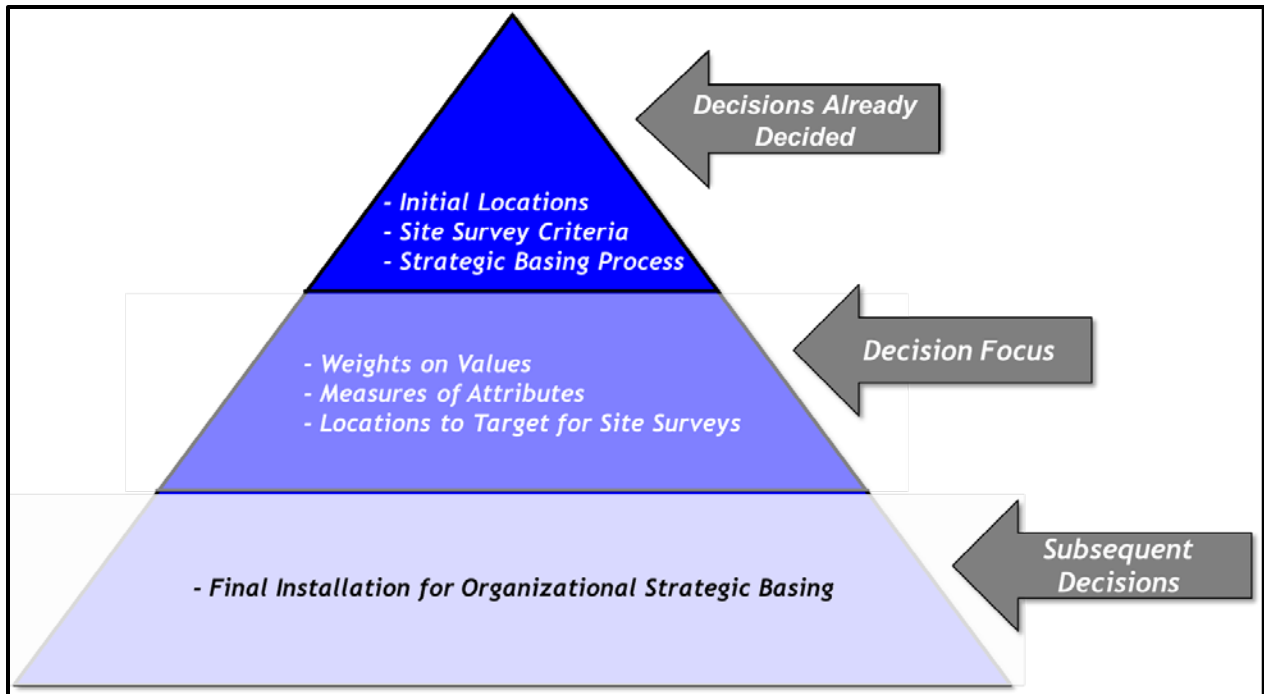


Figure 3. Organizational Strategic Basing Decision Framework

Identifying Achievement Objectives

The second step is to identify and structure objectives. Creating a value hierarchy is the core of this step and involves discussion among all stakeholders to include the decision maker. The objectives included in the hierarchy should be inclusive of all aspects important to the decision maker and stakeholders. Clear definitions at each level and ways to measure these objectives support the overall value hierarchy. Ultimately, a set of alternatives are measured using this value hierarchy to determine the best valued, lowest cost installation. It is important that this framework is inclusive, but only describes the decision context at hand [10].

To build the most inclusive framework possible, AFI 10-503, the RAND study on strategic basing, and the IMSC study were analyzed for commonalities and generic criteria [4], [5], [6]. Within all of these products, the first tier is made up of: mission, capacity, cost, and environmental. To maintain independence among values, the environmental objective was removed since the measures used correlated with measures under other criteria. Also, as seen in the IMSC study, environmental has little variability between installations and is not a discriminator [6]. Additionally, to further maintain independence, cost was removed from the value hierarchy since cost is a fundamental element in the trade-space between value and cost. Both adjustments to the overall strategic basing process are consistent with incorporating lessons learned from other capital investment decisions [13]. Reference Figure 4 for the organizational strategic basing value hierarchy.

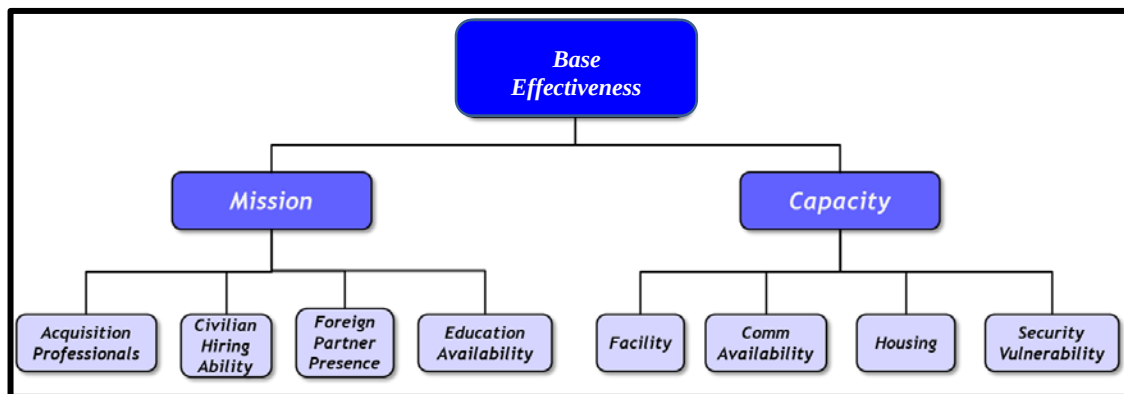


Figure 4. Strategic Basing Value Hierarchy

Another important aspect of the value hierarchy is the clear definition of each Tier 1 and Tier 2 criteria. In Figure 4, mission and capacity represent Tier 1 criteria and everything under those represent Tier 2 criteria. Reference Appendix A for criteria definitions.

Measuring Achievement of Objectives

The third step is to create value measure for the achievement of the objectives built in step two of the MODA process for each alternative. Kirkwood [19] suggests that there are two aspects of value measures or attributes: alignment with the objective and type of measure. To further define alignment with objectives, there are two types of measures: proxy or direct. A direct measure relates completely to the end objective, while a proxy loosely describes the end objective. The measures for this study are a mixture of both. The second aspect of value measures is the type of measure: natural or constructed. Natural measures are frequently used and easily understood measures such as profit or speed. If a measure does not currently exist for an objective, then it must be constructed. Most value hierarchies use a mix of these aspects to create the attributes to measure value within each objective [19]. For this particular research, a mix of natural and constructed measures are used; however, emphasis was placed on using natural measures since they are readily understood and collected.

The AFLCMC/LG-LZ director assisted with defining a set of realistic, tailorable ranges for each attribute for the generic framework defined in Figure 4 [20]. The ranges and measures can be modified for specific organizational strategic basing decisions. Reference Table 3 for the continuous and discrete measures for this generalized strategic basing framework.

Table 3. Strategic Basing Attributes

Criteria	Tier 1 Criteria	Attribute
Mission	Acquisition Professionals	# of Acquisition Professionals
		% of Acquisition Professionals with Specific Platform Experience
	Availability of Education	Availability of Educational Opportunities
	Civilian Hiring Ability	% Civilian Fill Rate
	Foreign Partner Presence	# Cooperative Program Personnel # Foreign Military Sales Foreign Liaison Officers
Capacity	Facility	# of Parking Spaces
		Size of Office Space
	Communication Availability	Access to NIPR, SIPR, and SAP
	Housing	Adequate Availability of Housing within 50 Mile Radius
	Security Vulnerability	Category of Security Vulnerability Issues

Developing Value Functions

The fourth step is to create value functions based on understanding the relationship between attainment of an objective and for each level of associated value attainment. Value functions can either be continuous or discrete and must encompass the entire decision space and allow the user to determine a value score for each one of the installation's attributes. For this thesis, the interview technique and previous strategic basing studies informed the bounds for each value function [19]. Weir's Value Focused Thinking (VFT) tool [21] illustrated the results of defining the value that merited a score of zero, the value that earned a score of one, and the half way point. Reference Figure 5 for the acquisitions professional's value functions.

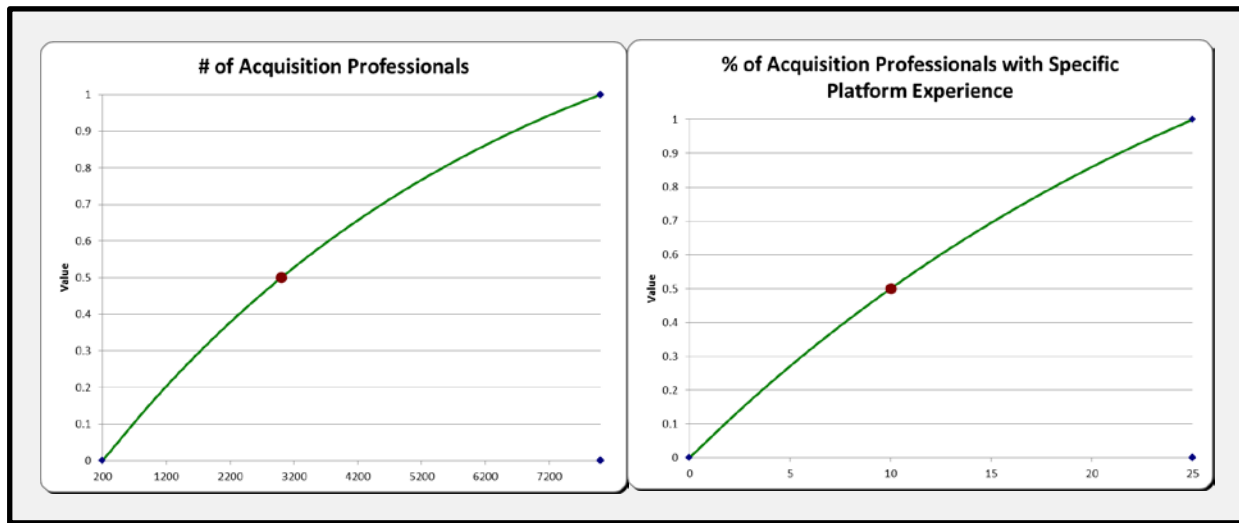


Figure 5. Value Functions for Mission: Acquisition Professionals

The graphs in Figure 5 are examples of value functions used to map attribute data to a value. The graph on the left-hand side is an increasing exponential function with the value of zero being two hundred acquisition professionals and the value of one or utopia as eight thousand acquisition professionals. The midpoint for this particular function is three thousand acquisition professionals, which created the shape of the exponential curve. The requirement for this particular strategic basing business case is five hundred acquisition certified civilians. The bounds on this exponential function ensure that other acquisition programs will not be degraded at any one of the other locations.

The graph on the right-hand side is also an increasing exponential function. The value of zero is zero percent of acquisition professionals with specific platform experience and the value of one is twenty-five percent acquisition professionals. The midpoint for this function is ten percent, which makes the function non-linear.

To determine the value based on the number of acquisition professionals for each installation, locate the number of acquisition professional on the x-axis and identify the

associated value on the y-axis. For example, assuming an installation has 4,262 acquisition professionals, the value associated is 0.6641. This can be found by typing the number of people into the VFT tool.

A linear function was used to define the civilian hiring percent fill rate. Reference Figure 6.

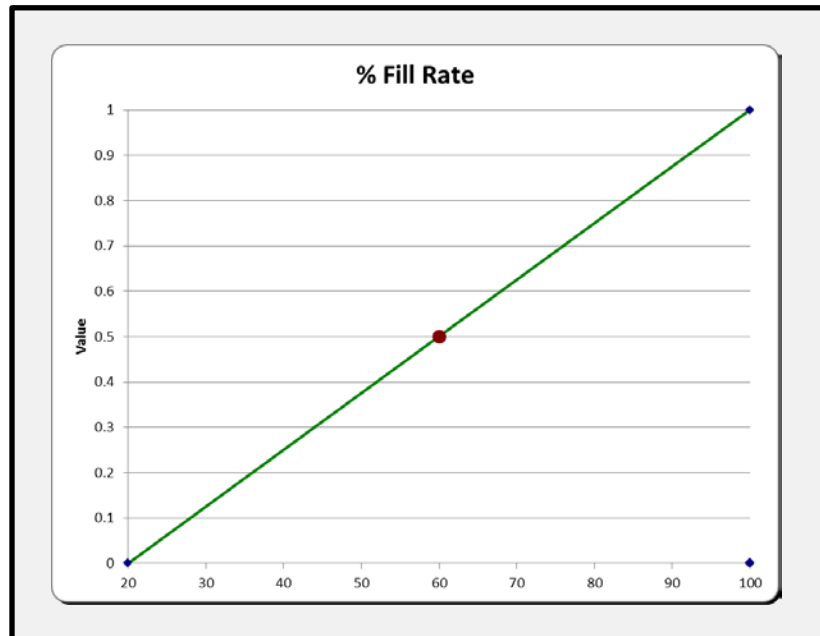


Figure 6. Value Functions for Mission: Civilian Hiring Ability

Both the value for cooperative program personnel and the number of foreign military sales foreign liaison officers are modeled using increasing exponential functions. Additionally, the midpoint for both is below the natural midpoint. Reference Figure 7 for value functions.

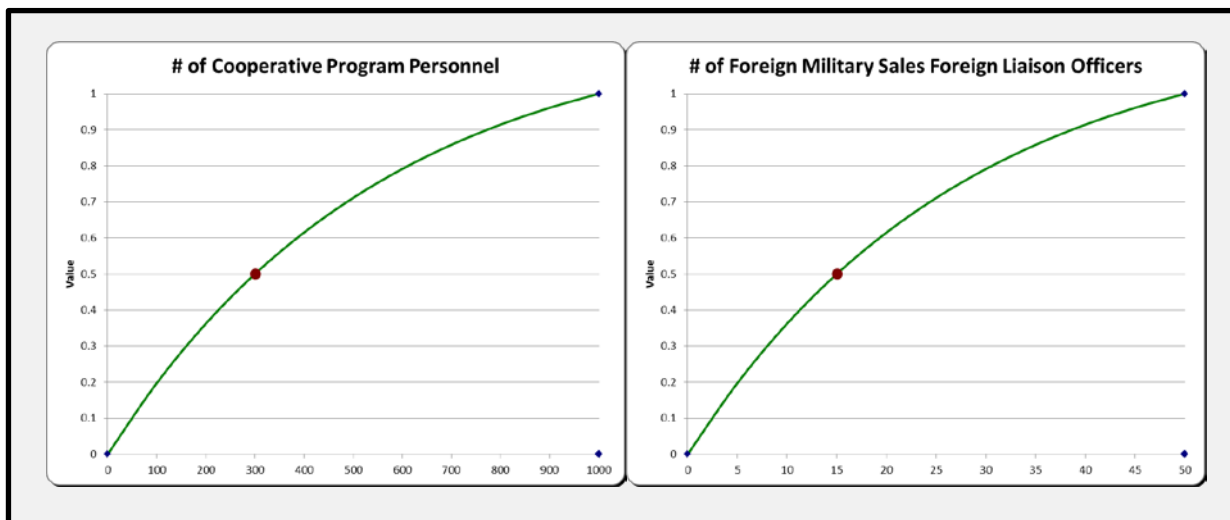


Figure 7. Value Functions for Mission: Foreign Partner Presence

The value function for availability of educational opportunities is a discrete function, with four possible categories with scores ranging from zero to one. Figure 8 depicts the value function.

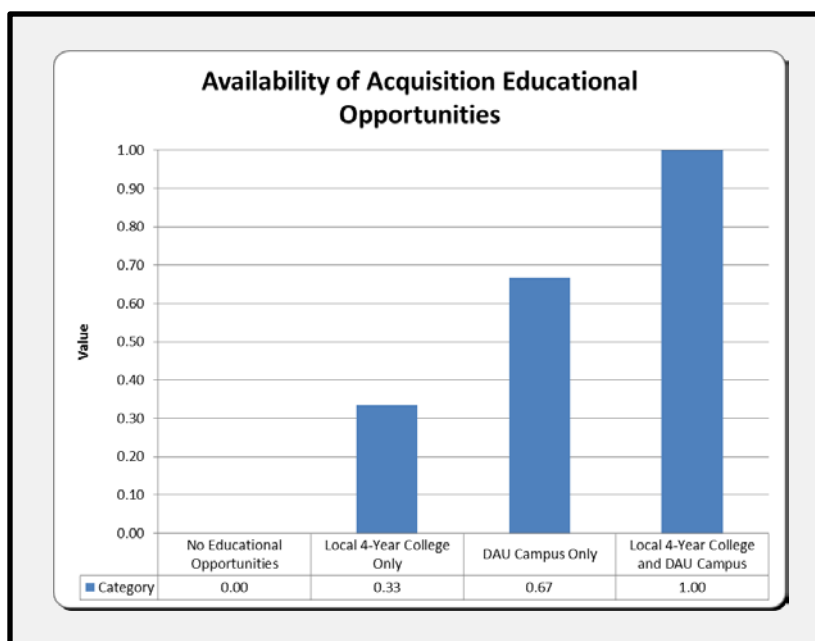


Figure 8. Value Functions for Mission: Availability of Education

Figures 5-8 illustrate all of the value functions for the mission criteria. Reference Appendix B for the four capacity criteria value functions.

Next, weights are assigned to each objective. Weights are crucial to trade-off analysis. This research uses the swing weight matrix to assess weights for each objective and attribute. This requires interviewing a decision maker to place each attribute on a matrix considering two key dimensions: the overall importance and the impact of the attribute's range on the overall decision. After each objective is placed on the matrix, points are assigned to each block of the matrix. After point values are assigned, the weights are normalized to create individual weights for each attribute and objective. Weights at each level sum to one. It is crucial after weights are identified, to validate with the decision maker that they adequately represent the decision space [10].

The AFCLCM/LG-LZ director selected the weights for the generic strategic basing framework based on her subject matter expertise. The director plays a large role in the overall strategic basing decision. The results of the swing weight matrix were used to determine the weights in the value hierarchy using the following formula [21]:

$$w_i = \frac{f_i}{\sum_{i=1}^n f_i} = \begin{array}{l} \text{normalized swing} \\ \text{weight} \\ \text{corresponding to} \\ \text{value measure } i. \end{array} \quad (1)$$

Reference Figure 9 for the swing weight matrix [20].

Importance of the Value Measure to the Decision

	<i>High</i>	<i>Medium</i>	<i>Low</i>
<i>High</i>	100 - # of Acquisition Professionals	90 - % of Acquisition Professionals with Tactical Fighter Platform - Size of Office Space - Access to NIPR, SIPR, and SAP	80
<i>Medium</i>	75 - % Fill Rate - Category of Security Vulnerability Issues	30 - # Cooperative Program Personnel	20 - Adequate Availability of Housing within 50 Mile Radius
<i>Low</i>	15	10 - Availability of Acquisition Educational Opportunities - # of parking spots available	1 - # of Foreign Military Sales Foreign Liaison Officers

Impact of the Value Measure Range Variation

Figure 9. Swing Weight Matrix

Figure 10 is the value hierarchy with the weights included.

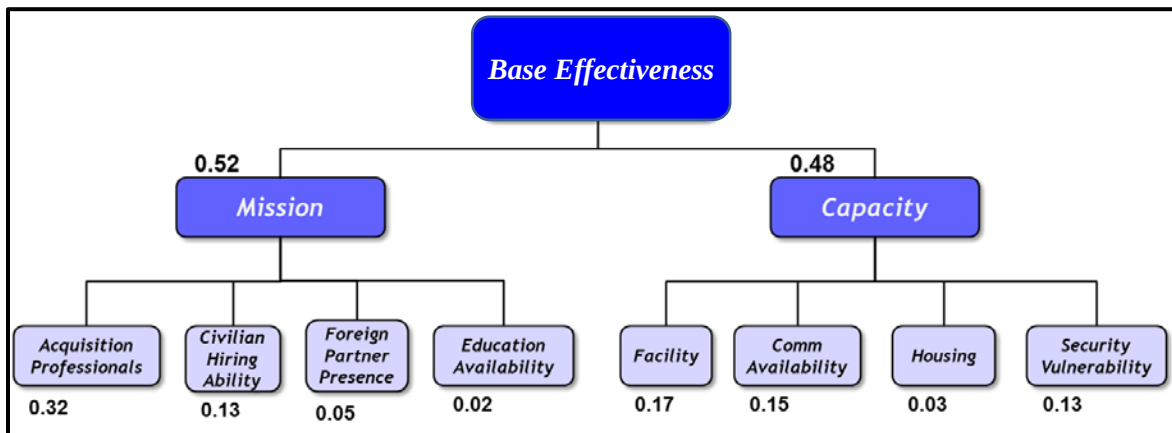


Figure 10. Weighted Value Hierarchy

Alternative Generation

Alternative generation and screening represents the sixth step of the MODA process. There are several methods to identify alternatives across the decision space. These methods include but are not limited to development of a strategy generation table or a means-ends network. It is important to identify alternatives inclusive of the entire decision space and not unfairly screen out alternatives [10].

Alternative generation is not part of this research since for most strategic basing decisions, alternatives or installations are provided. Generally, initial installations are provided for organizational strategic basing decisions based on early data calls that screen for favorable locations. The goal of this process is to reduce the number of installations to conduct site surveys thereby reducing cost and time from which one can choose the best valued, lowest cost option for the final installation.

Alternative Scoring

The seventh step of the MODA process scores the alternatives using the value functions [10]. An overall alternative score is created by incorporating the weights (w) for each alternative (x) to determine the value score of each alternative using the following formula [19]:

$$\text{Value Score} = \sum_{i=1}^n w_i(x_i) \text{ where } i \text{ is a particular attribute} \quad (2)$$

The highest valued alternative is the most preferred [10]. For this research, there are several installations that are chosen for a detailed site survey based on having the highest value.

Actual basing data was not used in this research due to the lack of available data, the contentious nature of strategic basing decisions, and the focus on developing a methodology for capturing uncertainty around organizational strategic basing decisions. To create the data for each attribute, the *Randbetween(bottom,top)* function, which is based on a uniform distribution was used in Excel. The top and bottom of the *Randbetween* function range is defined as the upper and lower bounds of each attribute. An overall value score for each installation at the attribute level was calculated using Weir's VFT tool. The VFT tool allows a user to type in a data point and obtain a value score for that level.

Additionally, cost was randomly generated by using the Office of Personnel Management (OPM) website to define the base salary (GS-13 step 5), the cost of living range, and the step range for five hundred GS-13 employees [22]. As before, the *Randbetween(bottom, top)* function in Excel was utilized to create a realistic range of reoccurring costs for personnel per year across the installations. It is important to incorporate these sources of uncertainty since it is highly unlikely all personnel will make the exact same salary. Reference Appendix C for the randomly generated data for each installation.

Next, Weir's VFT tool calculated an overall value score for each one of the installations against utopia [20]. The results are displayed in Figure 11. All of the locations fall short of the utopian installation, which naturally has a value of one. The utopian installation represents if all the attributes scored the highest value. The results show that quite a few locations score high on the most important attributes. Each of the colored bars represents the relative weight and score of each attribute as it contributes to

an alternative's overall value score. This information allows the decision maker and other stakeholders to understand how each installation stacks up.

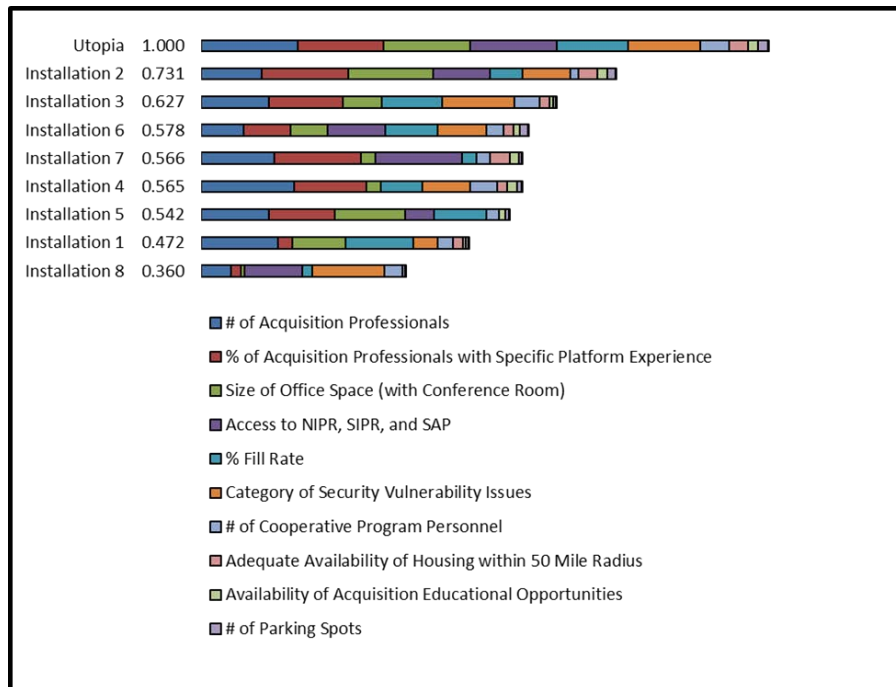


Figure 11. Alternative Scoring

The results show that installation 2 is the highest scoring alternative, but is still 0.269 below utopia. Moreover, installation 8 is the lowest scoring alternative and is about 0.64 below utopia. This particular graph supports the overall decision-making process as it promotes a decision maker and stakeholders to have a candid discussion about the viability of each installation. It also allows stakeholders to understand the trade-space between each installation. For example, one of the key differences between installation 2 and 3 is the office space. Installation 3 has about half of the space provided by Installation 2.

Deterministic Sensitivity

Deterministic sensitivity analysis is the eighth step of the MODA process. This includes cost versus value charts; value component breakout charts, tornado diagrams, waterfall charts, and value gap analysis. This allows all the stakeholders and the decision maker to better understand the trade-offs associated with each alternative being considered [22]. Value scores are coupled with cost data to populate a pareto diagram showing the relationship between value and cost [18]. For example, there could be a highly valuable alternative that is the most expensive, whereas a slightly lower valued alternative could have significant cost savings. Figure 12 illustrates the relationship between cost and value for each one of the potential installations and allows decision makers to understand the trade-space.

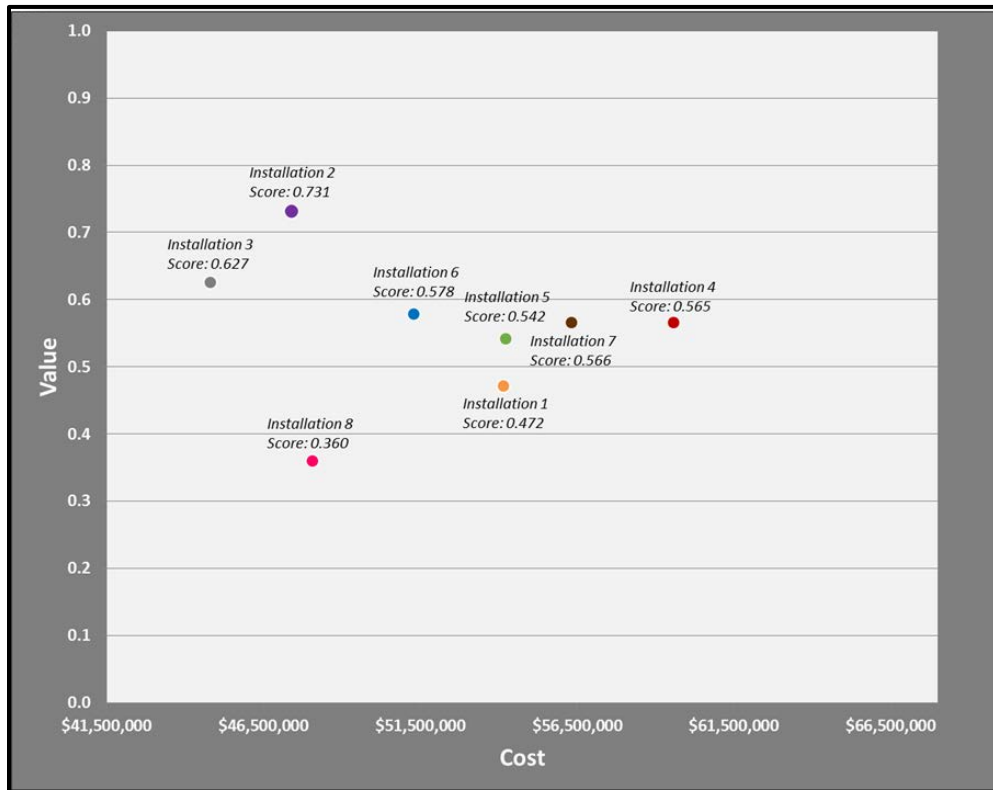


Figure 12. Cost versus Capability for Individual Installations

Based on the data presented in Figure 12, only installations 2, 3, and 6 should be considered for a site survey, the rest of the installations are dominated by more valuable, lower cost options. Even though installation 2 has the highest value score of 0.731, it costs approximately \$2.6 million dollars more than the next highest installation with a score of 0.627. When making the decision on the final installation, the decision maker and the stakeholders must understand the fundamental differences between those two installations and understand the trade-offs. Later in this chapter, Monte Carlo simulation is used to further explore the decision space in trade-off analysis.

A value gap analysis depicts how installations score for each individual attribute against utopia while considering weights. This helps the decision maker and stakeholders break down the value score into its weighted components to better understand how each installation scores for each attribute. Informed trade-offs for different attributes are discussed at this point. Figure 13 shows the value gap analysis for this particular set of data. For example, Installation 2 compared to Installation 3 scores exceptionally well in the heavy weighted attributes of percent of acquisition professionals with specific platform experience and size of office space. Interestingly, Installation 3 does not score any points for access to NIPR, SIPR, and SAP, but has a higher value in the number of acquisition professionals, percent fill rate, category of security vulnerability issues.

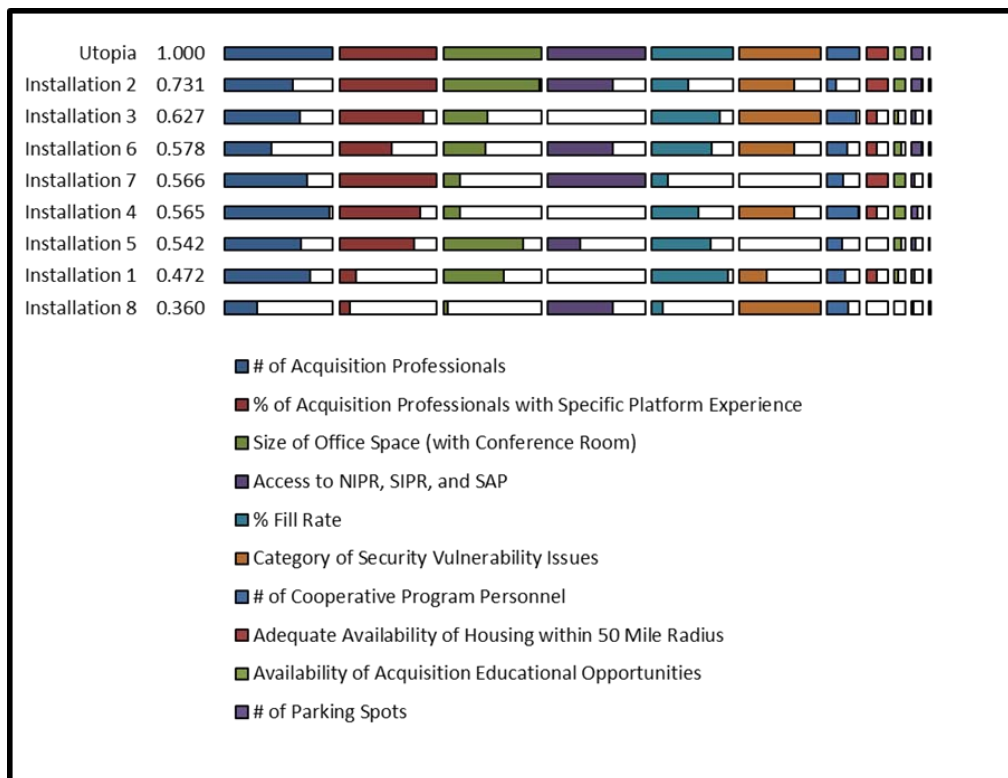


Figure 13. Value Gap Analysis

Sensitivity Analysis

The ninth step of the MODA process is sensitivity analysis. An important aspect of the MODA process is to understand how sensitive your model is to changes in weights [10]. The VFT tool allows sensitivity analysis on each attribute and criteria to identify the threshold at which there would be a change in preference for a particular alternative or installation. Sensitivity analysis for both mission and capacity are depicted in Figure 14. The mission graph shows that from a weight of zero to about 0.74, Installation 2 remains the preferred location. Likewise, the weight on capacity would have to fall below the 0.3 threshold for an installation other than Installation 2 to be the most preferred. This signifies that there would have to be drastic changes to the weights on mission and

capacity for a decision maker to not pick Installation 2. All of the sensitivity analysis on weights conducted at the attribute level are provided in Appendix D. Similar to mission and capacity, the analysis on the other attributes also illustrated the need for large fluctuations in weights to change the outcome. This is important because different decision makers place different emphasis on objectives.

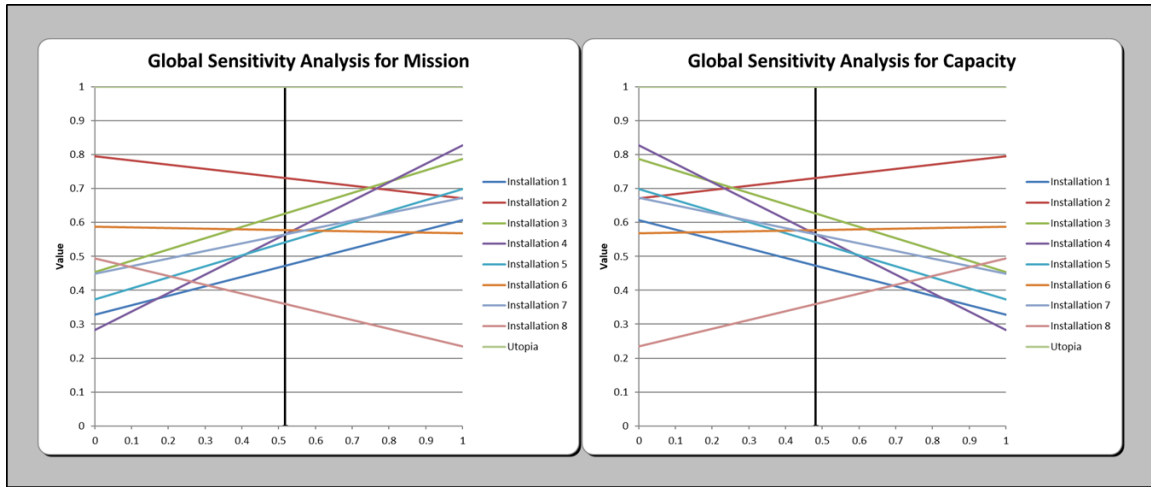


Figure 14. Sensitivity Analysis of Weights on Mission and Capacity

Recommendation

The last and final step within the MODA process is to provide the decision maker and stakeholders with a recommendation and supporting results [10]. Using the point estimate methodology, detailed site surveys should be conducted at installations 2, 3, and 6. Additionally, based on sensitivity analysis on the weights for mission and capacity, Installation 2 appears to be most preferred choice even after considering drastic swings in the objective preference weights.

This methodology for strategic basing does not account for the uncertainty surrounding data collected about the bases or the variation of cost at each installation.

Furthermore, it only accounts for the stagnant weights assigned by a single decision maker or group of stakeholders. It does not account for the uncertainty around other decision makers and stakeholders valuing attributes differently. The following section shows how MODA results can be enhanced with Monte Carlo simulation to create a more robust analysis for each installation by including uncertainty in the decision space.

3.2 Monte Carlo Simulation to Account for Uncertainty

This section details how to incorporate Monte Carlo simulation with the results of the MODA technique to identify the decision space under uncertainty regarding the three strategic objectives for this research: inputs, weights, and their interaction. Crystal Ball is used to conduct the Monte Carlo simulation [23]. Crystal Ball is widely used by cost analysts across the DoD to model, forecast, simulate, and optimize cost data [24].

Data uncertainty involves both triangular and custom distributions in Crystal Ball. The triangular distribution requires the most likely, optimistic, and pessimistic points. To impartially create triangular distributions, a point greater than the most likely point within fifteen percent and a point less than the most likely point within fifteen percent for each attribute was drawn using the *Randbetween* function in Excel. This was done for each attribute at each installation. Results of this algorithm are presented in Appendices E and F. The attributes that used the triangular distributions were represented by continuous functions in Table 3 and include number of acquisition professionals, percentage of acquisition professionals with specific platform experience, percentage civilian fill rate, number of cooperative program personnel, number of foreign military sales foreign liaison officers, number of parking spaces, and size of office space. As a result of the how

the simulated random data was created, the shape of the triangular distribution was typically not equilateral.

The discrete distributions from Table 3 are modeled as custom distributions in Crystal Ball. This allowed for probabilities from 0 to 1 to be assigned to values to create the uncertainty. These account for availability of educational opportunities, access to NIPR, SIPR, and SAP, adequate availability of housing within fifty-mile radius, and category of security vulnerability issues. Both the triangular and custom distributions are consistent with having access to limited information, which is prevalent during strategic basing decisions. Figure 15 depicts examples of both triangular and custom distributions within Crystal Ball.

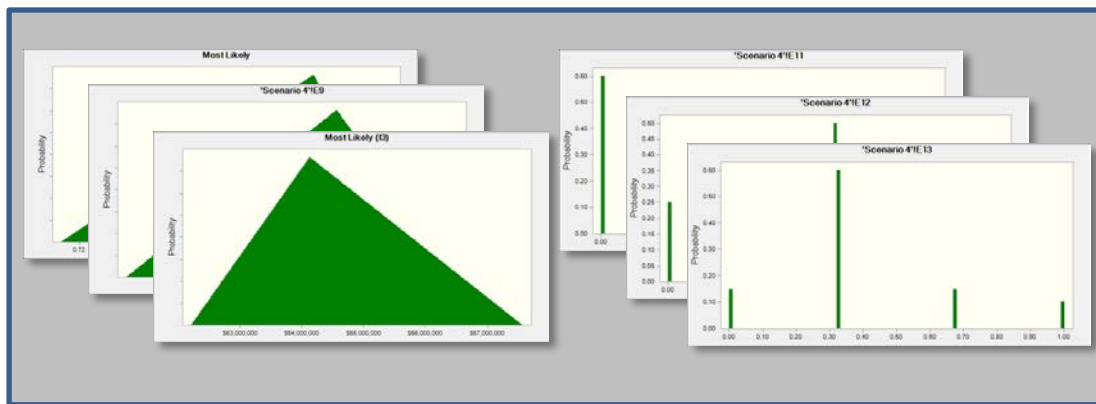


Figure 15. Triangular and Custom Distributions in Crystal Ball

A total of five scenarios were simulated in Crystal Ball. Each scenario involved the same random number seed to allow proper statistical testing between scenarios. Scenarios one, two, and four answer the first strategic objective of how to incorporate uncertainty around inputs obtained from various data sources. The second research objective of capturing uncertainty around weights is scenario three. Scenario five answers

the last research objective of how does the interaction of the two dimensions behave and account for uncertainty within the decisions space. Table 4 depicts the type of uncertainty used in each scenario.

Table 4. Monte Carlo Simulation Scenarios

	Strategic Objective	Value (y-axis)	Cost (x-axis)	Weights (y-axis)
Scenario 1	1	X		
Scenario 2	1		X	
Scenario 3	2			X
Scenario 4	1	X	X	
Scenario 5	3	X	X	X

Uncertainty captured in the value measurement represents events such as limited availability of data for an installation or that data varies over a period of time.

Uncertainty in the cost parameter represents events such as variation in the actual salary for individual employees due to their step and cost of living adjustment. Finally, uncertainty in diverse decision maker preferences is captured in the weights. The combination of these uncertainties for each scenario is represented in Table 4. The data from each scenario was collected and is discussed in greater detail in Chapter 4.

3.3 Summary

This chapter detailed how this research used a MODA process coupled with Monte Carlo simulation to account for uncertainty in organizational strategic basing decisions. The creation of a decision space is more useful to decision makers than a point estimate since it accounts for uncertainty in multiple dimensions. Both triangular and

custom distributions were used to define the uncertainty in value, cost, and weights. The results are discussed in the next chapter.

IV. ANALYSIS AND RESULTS

4.0 Overview

This chapter analyzes the modeling results associated with the five distinct scenarios for the business case. Findings are depicted in a stochastic pareto chart as described and provided as a template in [15]. The stochastic pareto chart shows the decision space for each installation's value and cost using a two-dimensional box plot. The colored bars are made up of the mean, second quartile and third quartile. The thin black lines represent the range created by the minimum and maximum values for the simulation. The decision space involves the uncertainty modeled by the Monte Carlo simulation. It allows decision makers to quickly understand the trade-space and enables analysts to conduct statistical testing among the installations. If two locations are not statistically different, it may come down to the decision maker's preference of value versus cost.

4.1 Scenario 1 Results

In the first scenario summarized in Figure 16, Monte Carlo simulation focused on the input data for value. This uncertainty accounts for limited data availability and data fluctuations across time. Both weights and costs were held constant. This allows stakeholders to understand the decision space identified by uncertain input values. As a result of the simulation, the widths of the box plot vary, which is representative of how actual data might behave.

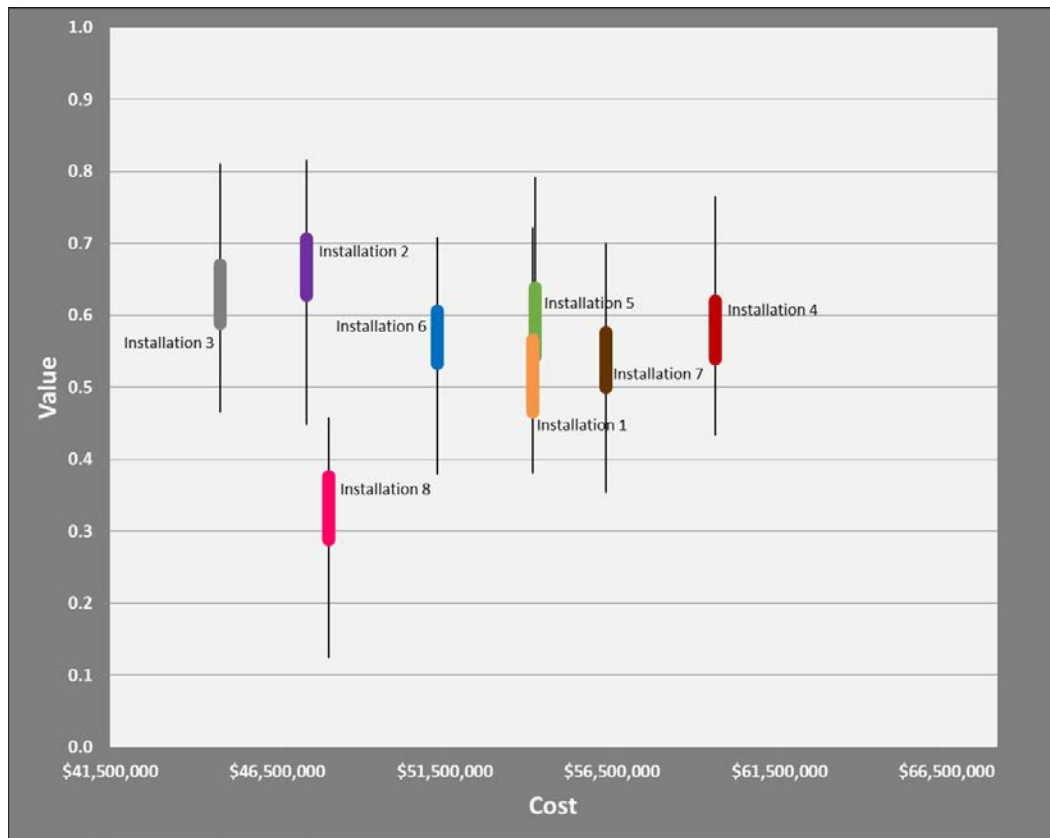


Figure 16. Scenario 1 Results

Uncertainty in the data makes it difficult to differentiate between Installation 2 and 3. While the mean value of installation 2 is higher than installation 3, installation 3 has a lower annual cost. To determine if there is a statistical difference, a two-tailed t-test assuming unequal variances with an alpha of 0.05 was accomplished. Figure 17 shows the results of the t-test.

Two-Tailed t-Test:		
$H_0: \mu_2 = \mu_3$		
$H_A: \mu_2 \neq \mu_3$		
t-Test: Two-Sample Assuming Unequal Variances		
	<i>Installation 2</i>	<i>Installation 3</i>
Mean	0.6658	0.6283
Variance	0.0034	0.0049
Observations	1000.0000	1000.0000
Hypothesized Mean Difference	0.0000	
df	1941.0000	
t Stat	12.9905	
P(T<=t) one-tail	0.0000	
t Critical one-tail	1.6456	
P(T<=t) two-tail	0.0000	
t Critical two-tail	1.9612	

Figure 17. Results of Two-Tailed t-Test comparing installation 2 and 3

The conclusion from this two-tailed t-test is reject the null hypothesis of equal means and conclude that there is a statistically significant difference between installation 2 and 3. A statistical test cannot be done on cost for this scenario since it is a point estimate.

4.2 Scenario 2 Results

The second scenario varied the cost input. This is consistent with cost estimating techniques used across DoD. For this simulation, both data inputs and weights were held constant. This allows stakeholders to understand the decision space identified by varying cost inputs. As with the first scenario, the triangular distributions caused the widths of the box plot to vary, which is representative of how actual data would behave. Figure 18 illustrates the results of scenario 2.

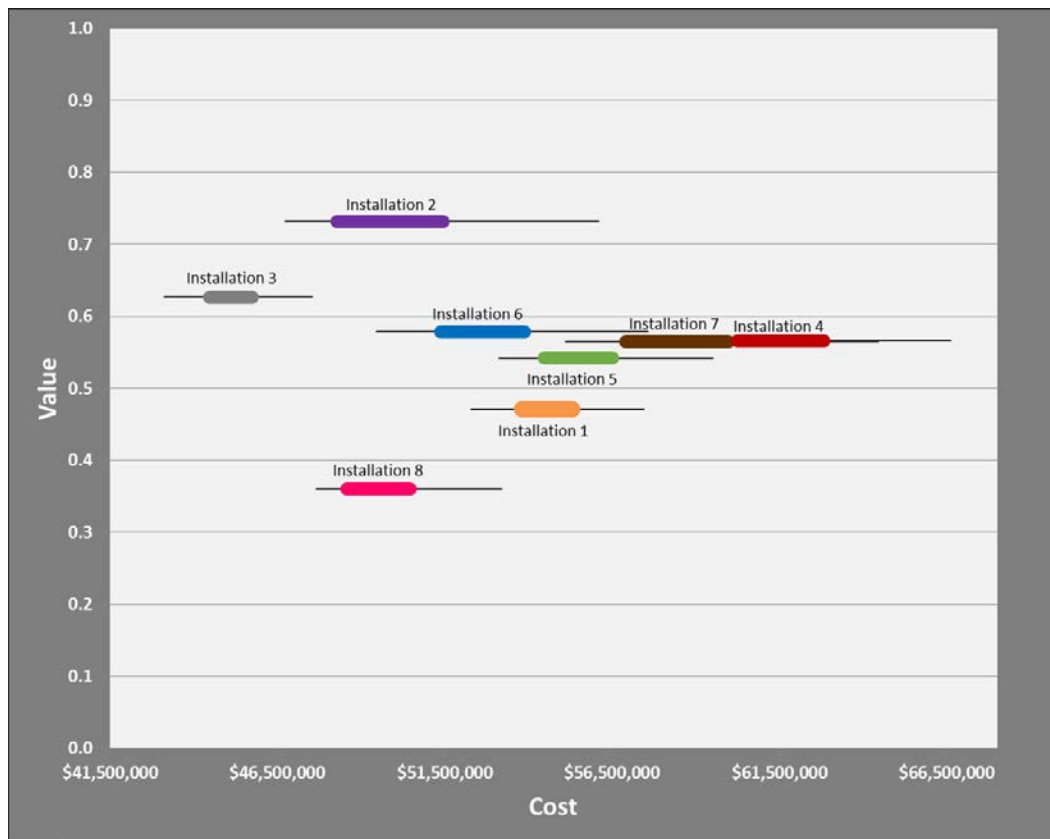


Figure 18. Scenario 2 Results

The widths of the cost vary more than the input data from scenario 1. Installation 2 and 3 do not overlap; therefore, they are statistically different without completion of a two-tailed t-test. Additionally, it is interesting to note that Installation 3 is the lowest cost and has the lowest cost variation of any installation.

4.3 Scenario 3 Results

The third scenario accounts for different decision maker preferences by creating uncertainty in the weights. This uncertainty was created by choosing a point greater than the most likely weight within twenty-five percent and a point less than twenty-five percent for each attribute. Weights are used in computing the overall value score on the y-axis. In order to vary the weights, a Monte Carlo simulation was used. Following the standard MODA process, it is important that the sum of all the attribute weights equals one. While the sum of the most likely weights was approximately one, the pessimistic weights were less than one and the optimistic weights were greater than one. This is not an issue for this business case since the analysis is concerned with the overall distance produced by the variation in weight rather than the actual score. Also, for this particular data set, it is not possible to achieve a score greater than one. As mentioned before, the most likely weight summed to approximately one. Additionally, the weights are used in the overall value scoring function from p. 29. Results for Scenario 3 are depicted in Figure 19.

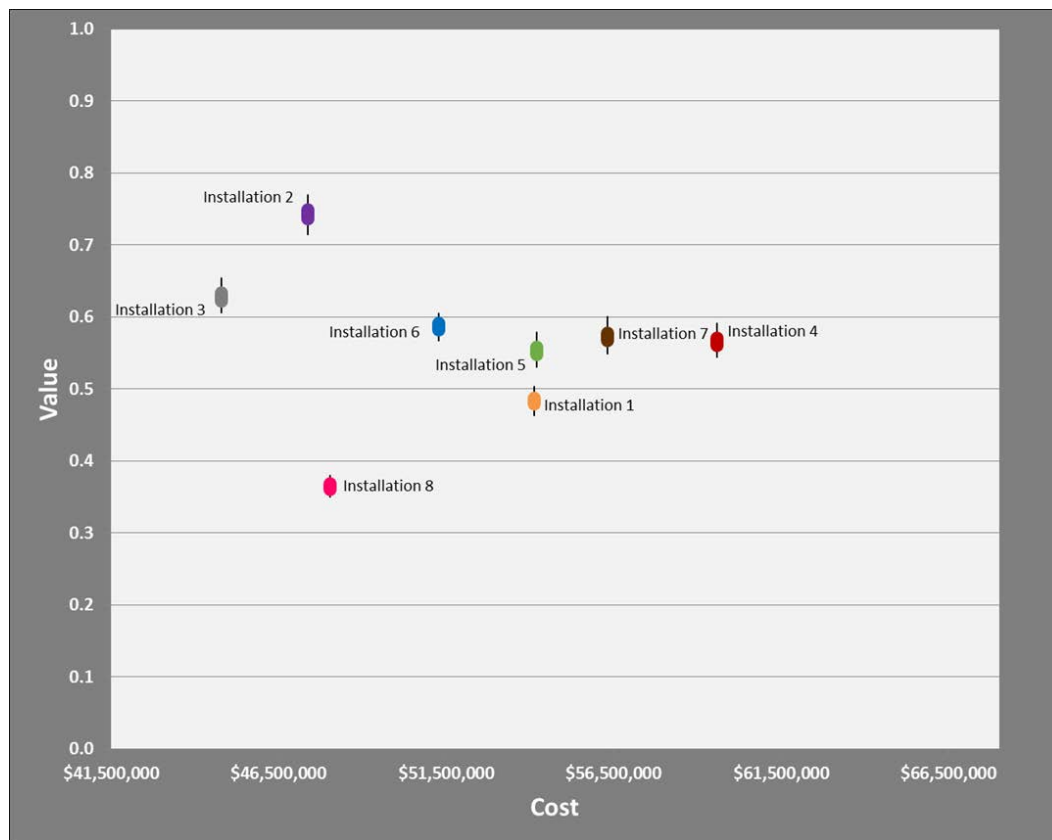


Figure 19. Scenario 3 Results

As reported in Chapter 3, weight does not have a great impact on the value score. In fact, the variation of weights ends up being approximately the same amount for each installation. This is because weights impact each attribute's worth, which is the same across all installations.

4.4 Scenario 4 Results

The fourth scenario varies both input data and cost. This is really the implementation of scenarios one and two at the same time. This impacts the entire decision space and readily illustrates the trade-offs. Figure 20 shows results.

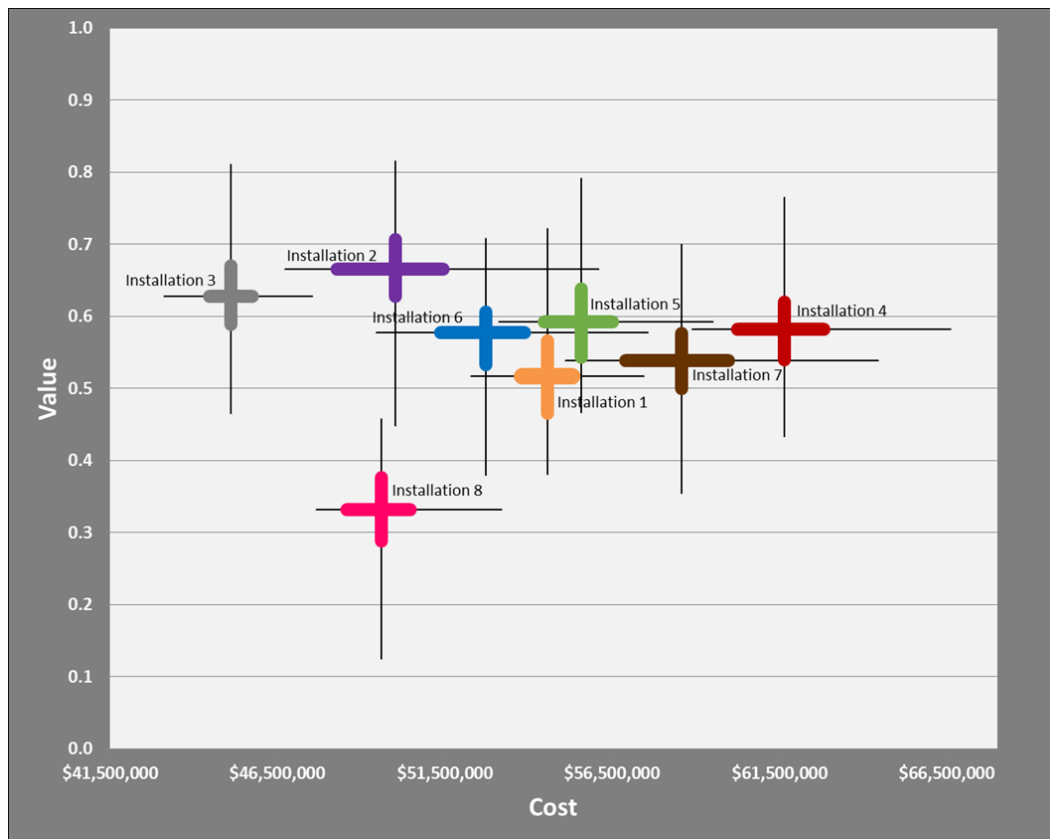


Figure 20. Scenario 4 Results

The results indicate difficulty differentiating between installation 2 and 3. Statistical testing was accomplished to determine if there is a significant statistical difference between installation 2 and 3. Since the value hierarchy and MODA process assume independence among both the x- and y-axis, statistical testing could be completed for each dimension without employing joint probability distributions. Both two-tailed t-tests reveal installation 2 and 3 are statistically different. Figure 21 documents these results.

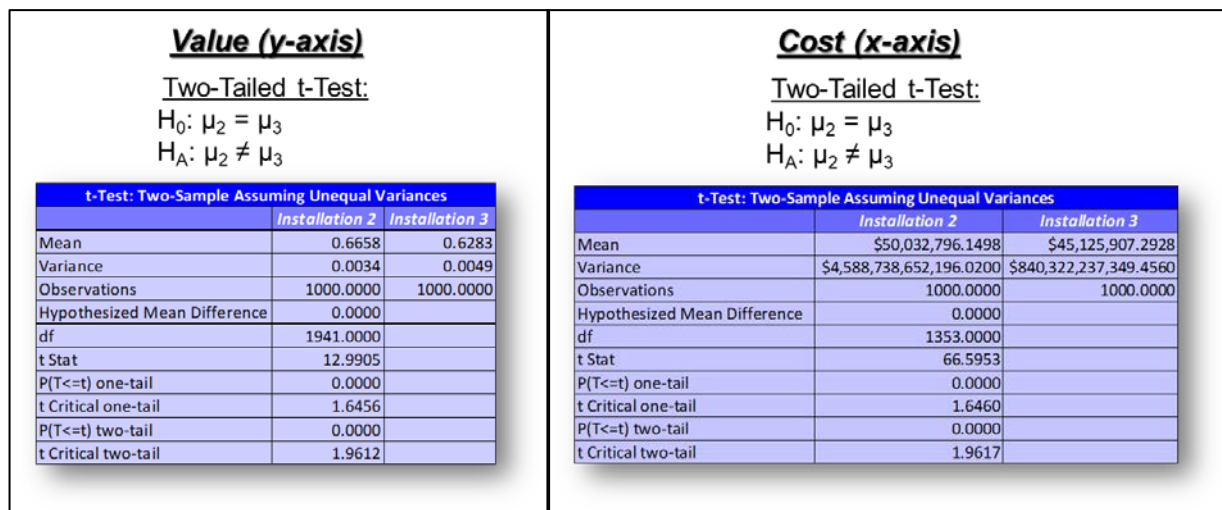


Figure 21. Statistical Tests on Value and Cost

Since the fourth scenario resembles the point estimate formulation the closest, Figure 22 overlays the point estimate with the results of the Monte Carlo on both input data and cost. The addition of uncertainty consideration using Monte Carlo simulation shows the impact of uncertainty on results as seen for Installation 2. Some installations, such as Installation 1, the point is within the mean, second quartile, and third quartile plot. The addition of uncertainty might influence the decision maker since it provides more information than the point estimate.

Today, decision makers act on single point estimates as seen in strategic basing decisions and other capital investment decisions. As demonstrated by Figure 22, the consideration of uncertainty modifies the decision space and provides decision makers with more information. Additionally, uncertainty facilitates statistical testing and promotes trade-offs between installations for more informed, stronger decisions.

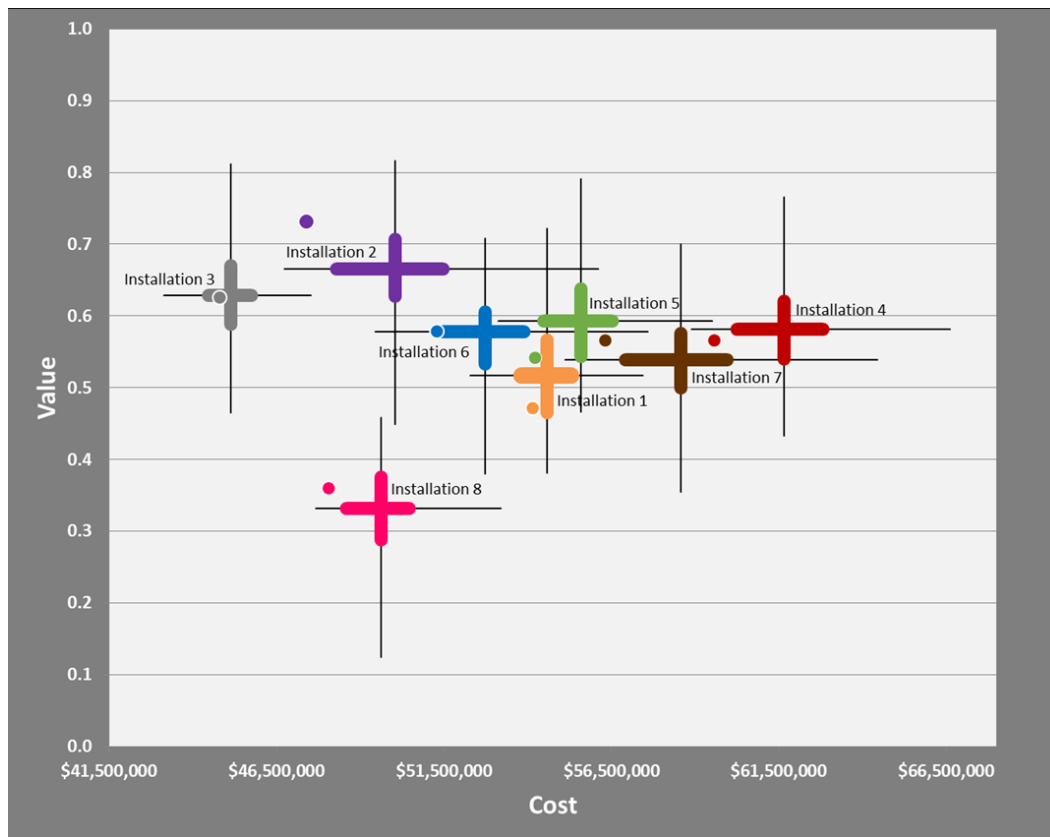


Figure 22. Scenario 4 Results with Point Estimate

Another way to view the Monte Carlo results is through a scatter plot where all one thousand points are plotted. This allows the decision maker and stakeholders to view the entire decision space and understand all possible, uncertain points that can occur. Additionally, it clearly shows the statistical difference between the first two locations. Reference Figure 23 for the scatter plot of all locations and Figure 24 for the comparison of installations 2 and 3 only.

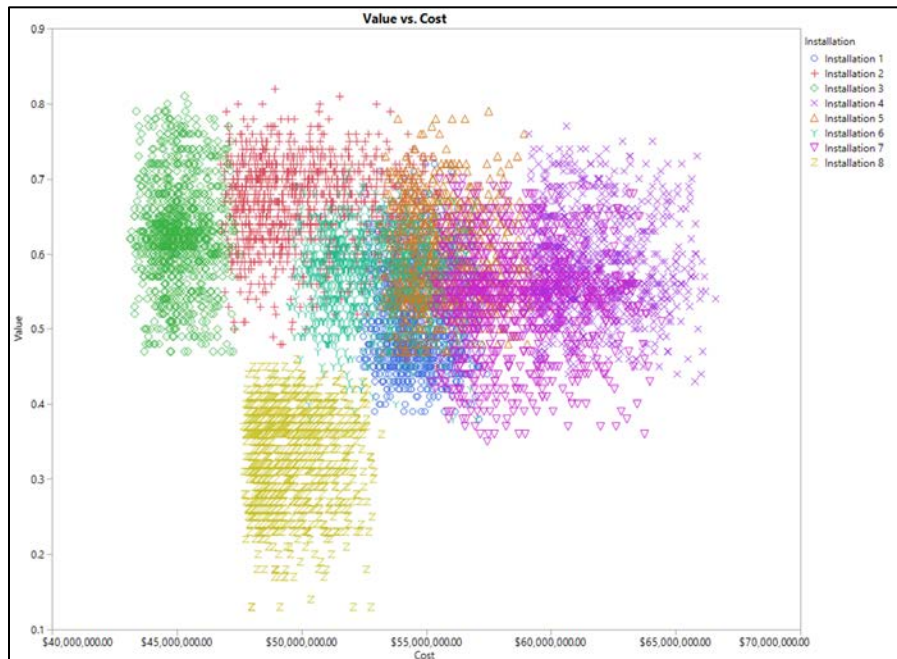


Figure 23. Value vs Cost Scatter Plot

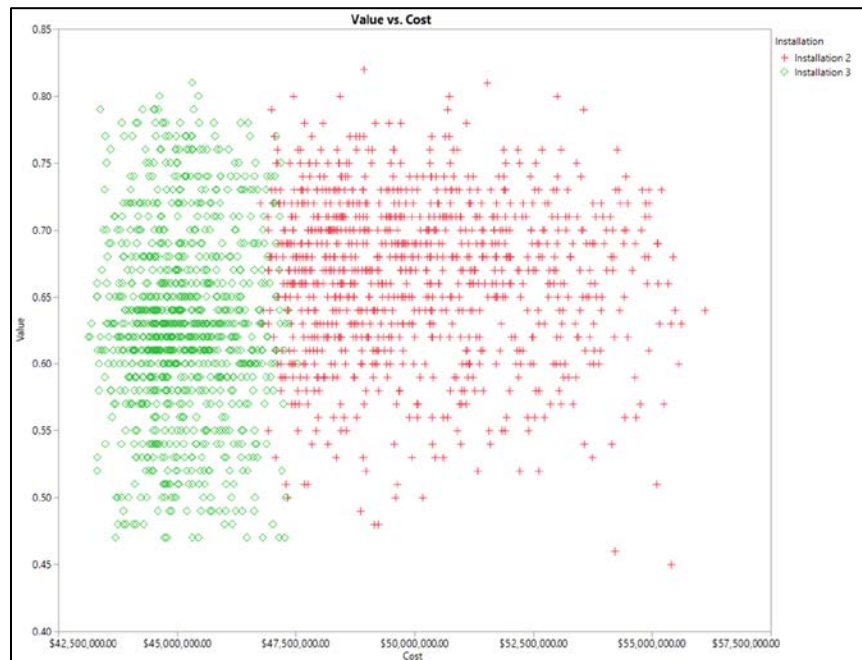


Figure 24. Value vs Cost Scatter Plot (Installations 2 and 3)

4.5 Scenario 5 Results

The final scenario involves uncertainty in data input, cost, and weights for attributes. This scenario accounts for all types of uncertainty within this strategic basing framework and allows stakeholders to understand the entire decision space. Results of scenario 5 are illustrated in Figure 25.

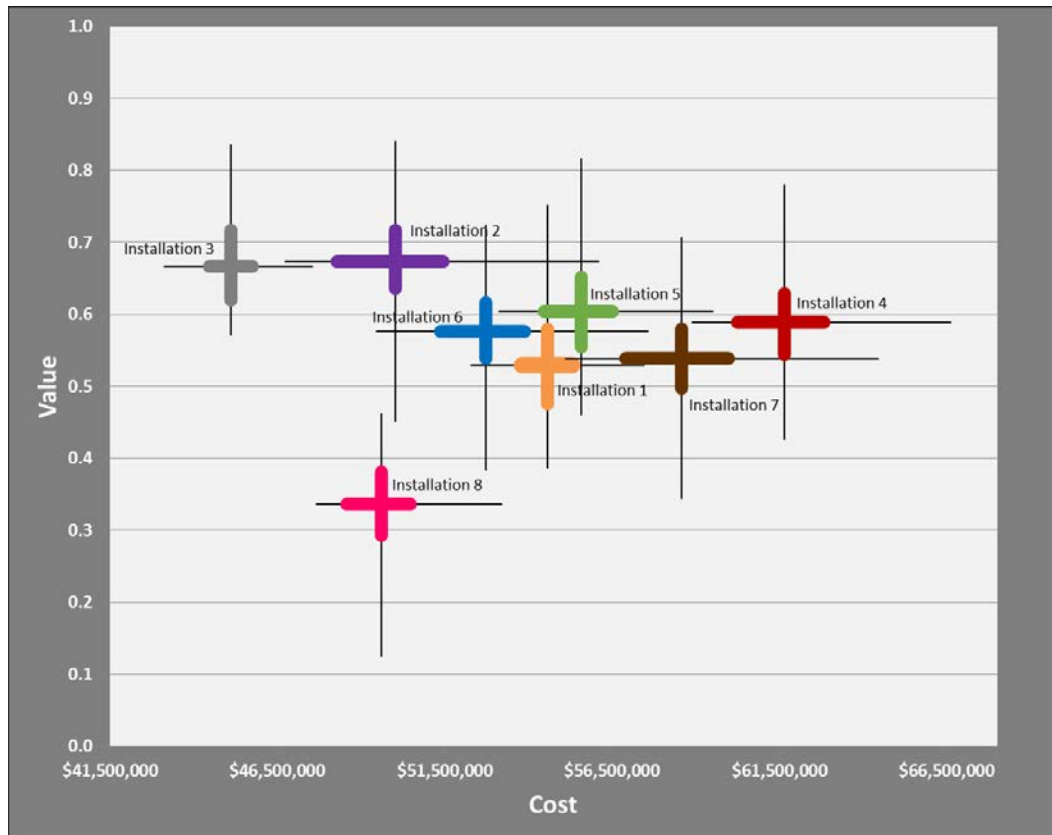


Figure 25. Scenario 5 Results

A two-tailed t-test comparing Installation 2 and 3 revealed that they are statistically different, as seen in previous scenarios. However, accomplishing a two-tailed t-test comparing the results for both installation 2 and 3 from scenario 4 to 5 revealed a statistical difference in both cases. Figure 26 shows the two-tailed t-tests. Since the

weights are identified at the attribute level, they correlate with the end value score. This could account for the difference in value between scenarios.

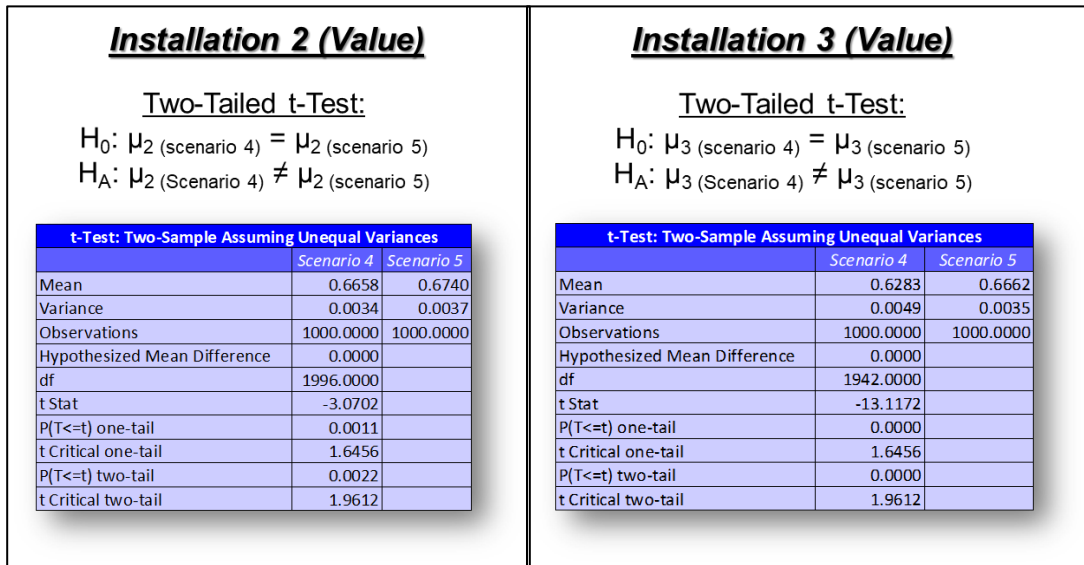


Figure 26. Two-Tailed t-tests Comparing Scenario 4 and 5

4.6 Recommendation

The fourth scenario adequately describes the decision space while considering uncertainty in both the input data and cost parameters. Coupled with the point estimate, it provides a complete depiction of the entire business case. Additionally, Monte Carlo simulation allows analysts to conduct statistical testing to determine if installations are significantly different. For this particular business case, the top two installations were found to be statistically different, but if the means were closer in value and not statistically different, then a trade-off could be made based on cost. Single point estimates do not allow for this level of fidelity or statistical testing.

Furthermore, the sensitivity analysis conducted as part of the MODA process illustrated that this model isn't sensitive to large weight changes. To adequately address

the weighting impact, additional analysis is needed. This represents an area for future research. In cases where sensitivity analysis shows little sensitivity, account for uncertainty in input and cost data.

The purpose of conducting MODA coupled with inclusion of uncertainty is to pick the top three to four locations to conduct a site survey. Based on the results from scenario four, installations 2, 3, and 6 would be chosen based on a decision maker placing more emphasis on value versus cost. Special attention would be given to installation 2 and 3 since they represent best valued options and lowest cost options respectively.

4.7 Summary

As stated in the recommendation, scenario 4 creates uncertainty across data inputs in the y-axis and cost parameters in the x-axis. This identifies the decision space for stakeholders and allows them to better understand trade-offs. Additionally, the methodology allows for statistical testing across the different locations to determine if locations are statistically different. For example, if values are not statistically different, a decision maker could use other criteria in the decision such as choosing a lower cost installation.

V. Conclusions and Recommendations

5.0 Conclusions of Research

Three research objectives were defined and accomplished to recommend an improved strategic basing decision methodology for this business case. The first research objective was to incorporate uncertainty around inputs obtained from various data sources to include data from each installation and cost. This interaction is best described and illustrated in scenario 4. Furthermore, accounting for uncertainty allows decision makers to understand the entire decision space and allows analysts to conduct statistical testing on installations. While this business case shows a statistical difference between the top two installations, this methodology could be used to explore trade-offs between installations not statistically different in the future.

The remaining two research objectives dealing with weight variation require more research since for this particular business case, they had weaker conclusions. For this data set, they do not help stakeholders or analysts differentiate between the various installations since the impact of the weights across the model is nearly equitable across installations. This is a result of the attribute's weight impacting each installation similarly. This analysis focused primarily on accounting for uncertainty around each installation's data inputs.

There are several managerial implications of this research. Clearly the inclusion uncertainty for data inputs can move each installation's most likely region. This can help decision makers make more informed decisions and understand how much certain

parameters such as cost can vary for a given installation. Additionally, it allows for statistical testing for significant differences. If two installations were not statistically different in value, the lower cost option could be chosen. This trade-off is more difficult to make with point estimates.

This methodology could be expanded beyond the scope of this business case to include other capital investment decisions. There is great value in understanding the trade-space beyond the point estimate. In general, it is an accepted idea that uncertainty exists for all AF decisions and the method described in scenario 4 accounts for and illustrates this uncertainty.

5.1 Recommendations for Future Research

Since this study was a single business case, there are several opportunities for future research. This research used randomly created data to illustrate a methodology. Next steps could include using this methodology coupled with actual data to understand if the inclusion of uncertainty supports more informed decision making.

Additionally, this methodology could be expanded into other capital investment decisions such as BCAs, AoAs, CCAs, etc. This would allow decision makers to understand the decision space around large capital investment decisions. It would also allow current process decisions to follow guidance, which seeks to account for uncertainty and risk in a quantitative way. Capital investment decisions made early in the life cycle have significant uncertainties that should be accounted for and disclosed to decision makers.

Lastly, accounting for decision maker weights on attributes could be expanded beyond the scope of this thesis. For this study, the variation of weights was almost equitable across installations; therefore, it did not help differentiate. This could be a result of the data set and more research is required to determine if accounting for uncertainty around weights supports more robust decision making.

Appendix A: Criteria and Attribute Definitions

Mission: Ability of installation to execute overall mission of strategic basing decision

Number of Acquisition Professionals: Access to talent pool of acquisition professionals without impacting other programs

Percent of Acquisition Professionals with Specific Platform Experience: Access to acquisition professionals with a specific aircraft life cycle experience (ex. Tactical aircraft)

Availability of Education Opportunities: Access to Defense Acquisition University and four-year college within a twenty-mile radius of the installation.

Percent Civilian Hiring Rate: Civilian hiring fill rate illustrates the ability to hire quickly at a given installation

Number of Foreign Program Personnel: Access to professionals with cooperative program personnel (CPP) experience

Number of Foreign Liaison Officers: Presence of foreign military sales foreign liaison officers

Capacity: Ability of an installation's existing infrastructure to accommodate the proposed action

Size of Office Space: Size of office space with conference room

Number of Parking Spaces: Represents the capacity of each installation's capacity to absorb an increase of cars

Communication Availability: Access to NIPR, SIPR, and SAP applications

Housing: Adequate housing availability within a fifty-mile radius of the installation

Security Vulnerability: Category of known security vulnerability issues

Appendix B: Capacity Value Functions

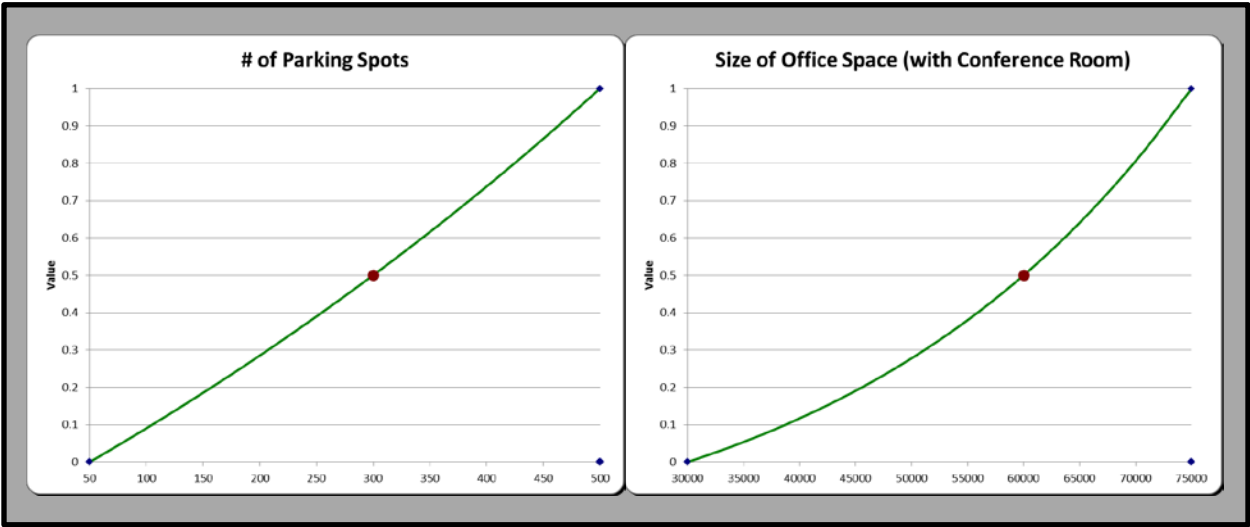


Figure 27. Facility Value Functions

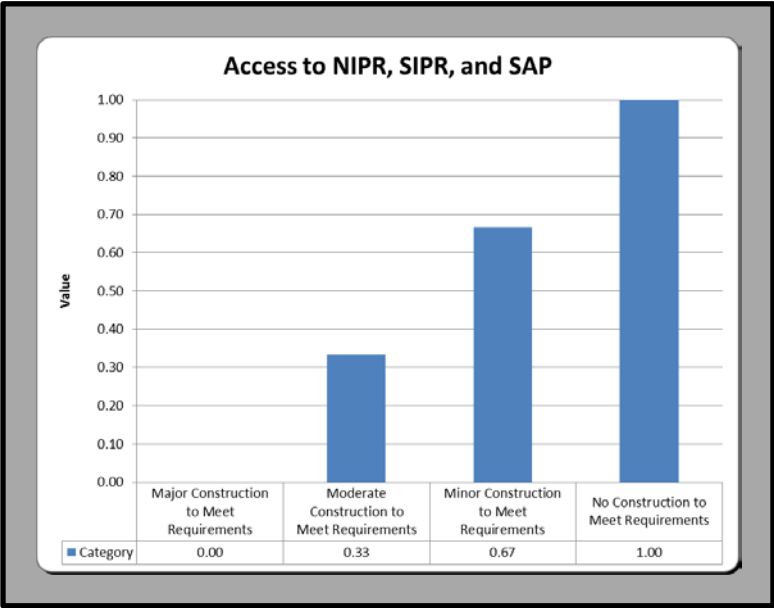


Figure 28. Communication Availability

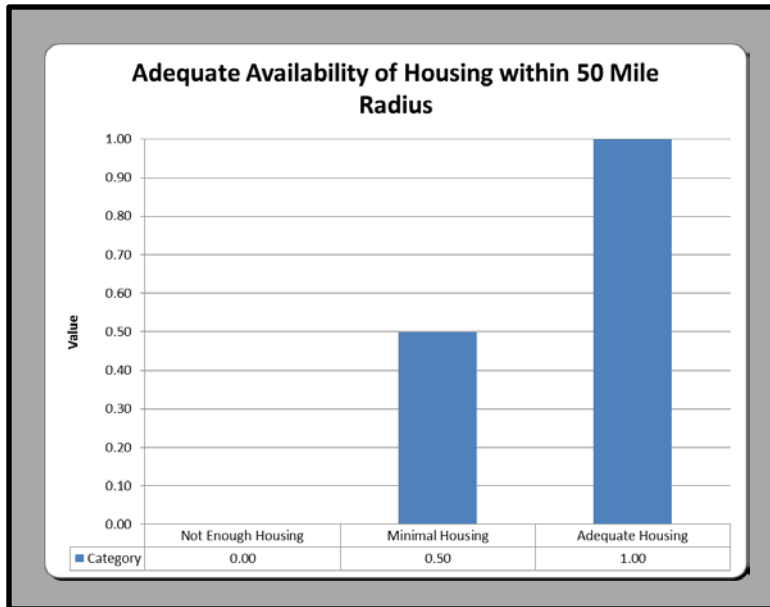


Figure 29. Availability of Housing

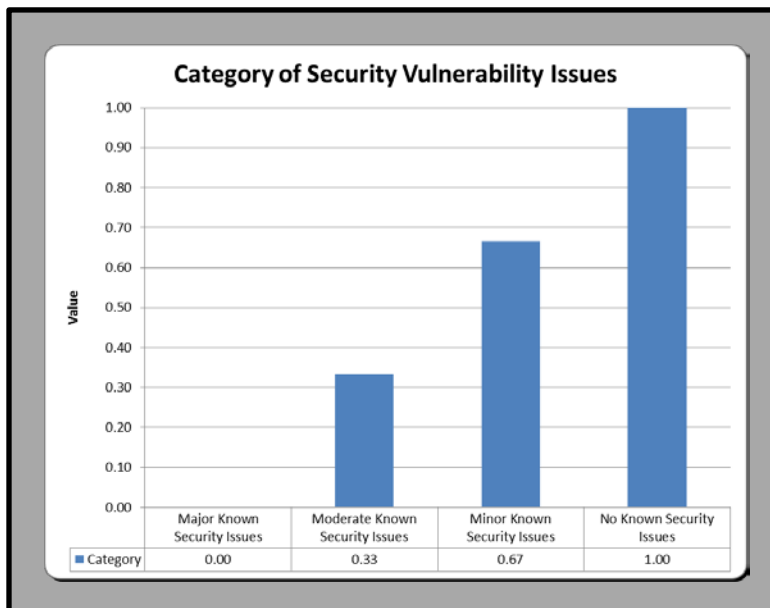


Figure 30. Security Vulnerability

Appendix C: Point Estimate Data

Note: This data was randomly generated using the RANDBETWEEN function in Excel and the bounds of the value functions.

Table 5. Point Estimate Installations 1-4

Attributes	Installation 1	Installation 2	Installation 3	Installation 4
# of Acquisition Professionals	5,482	3,959	4,558	7,542
% of Acquisition Professionals with Specific Platform Experience	3	25	20	19
Availability of Educational Opportunities	1	3	1	3
% Civilian Fill Rate	95	56	87	66
# Cooperative Program Personnel	338	141	758	874
# Foreign Military Sales Foreign Liaison Officers	47	27	28	5
# of Parking Spaces	190	449	234	324
Size of Office Space	64,296	74,533	58,214	43,639
Access to NIPR, SIPR, and SAP	0	2	0	0
Adequate Availability of Housing within 50 Mile Radius	1	2	1	1
Category of Security Vulnerability Issues	1	2	3	2
Cost	\$54,125,500	\$47,375,500	\$44,800,000	\$59,583,500

Table 6. Point Estimate Installations 5-8

Attributes	Installation 5	Installation 6	Installation 7	Installation 8
# of Acquisition Professionals	4,612	2,563	5,133	1,780
% of Acquisition Professionals with Specific Platform Experience	17	11	25	2
Availability of Educational Opportunities	2	2	3	0
% Civilian Fill Rate	78	79	36	31
# Cooperative Program Personnel	265	406	285	432
# Foreign Military Sales Foreign Liaison Officers	1	41	18	38
# of Parking Spaces	227	454	195	159
Size of Office Space	70,159	57,252	43,741	34,118
Access to NIPR, SIPR, and SAP	1	2	3	2
Adequate Availability of Housing within 50 Mile Radius	0	1	2	0
Category of Security Vulnerability Issues	0	2	0	3
Cost	\$54,218,500	\$51,285,500	\$56,318,000	\$48,051,000

Appendix D: Sensitivity Analysis on Weights

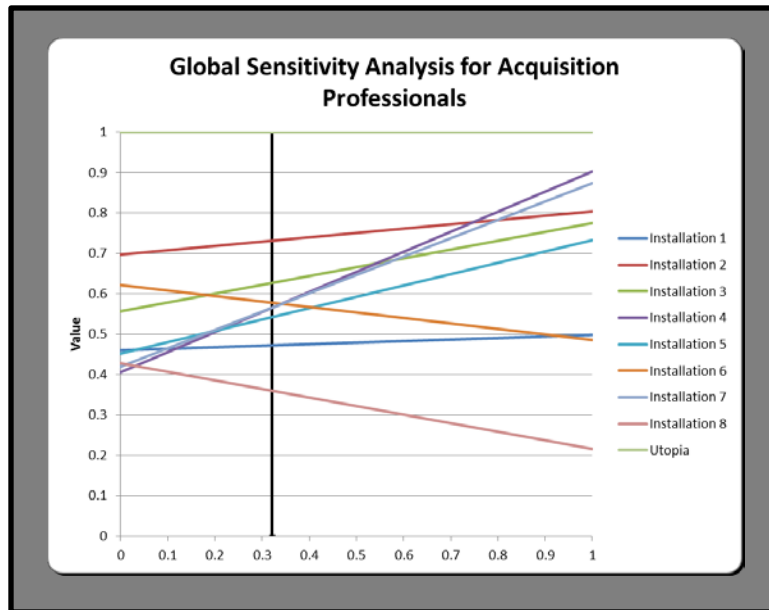


Figure 31. Weights on Acquisition Professionals

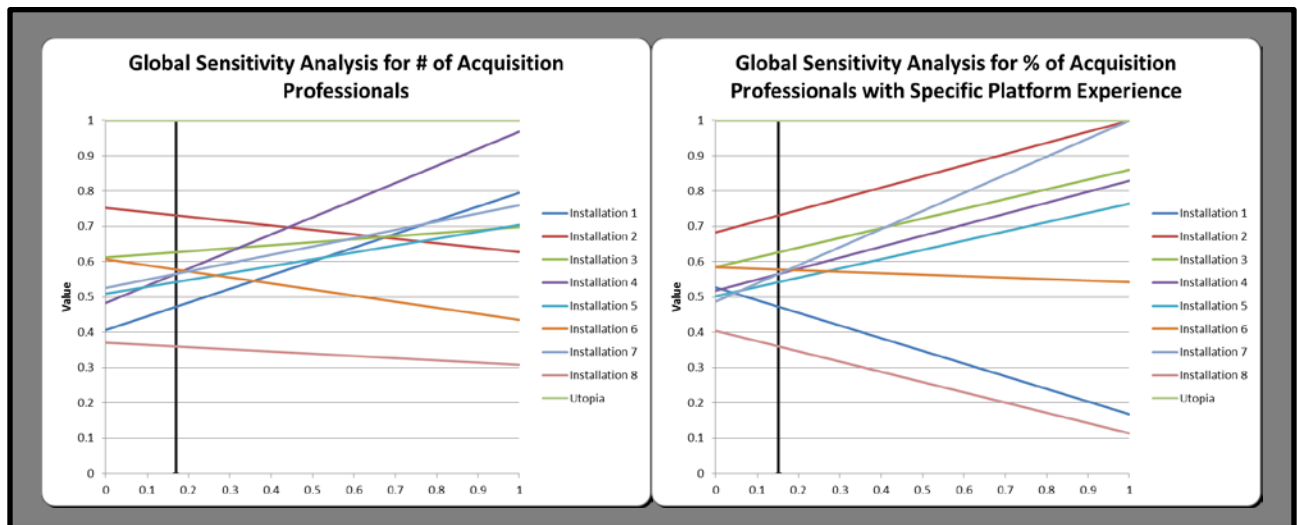


Figure 32. Weights on Acquisition Professional Attributes

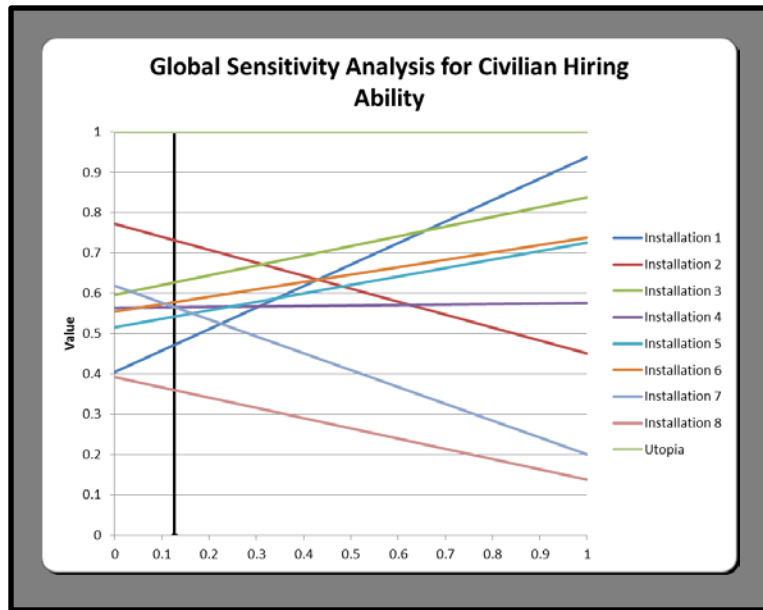


Figure 33. Weights on Civilian Hiring Ability

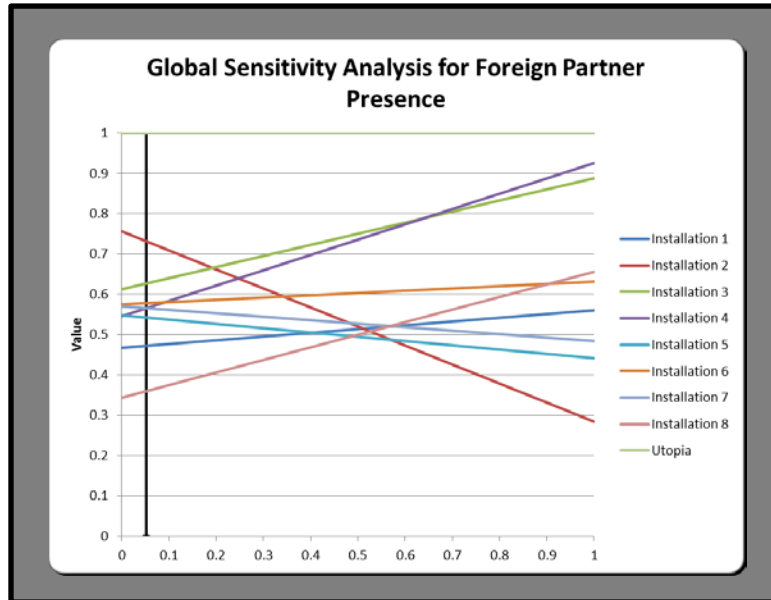


Figure 34. Weights on Foreign Partner Presence

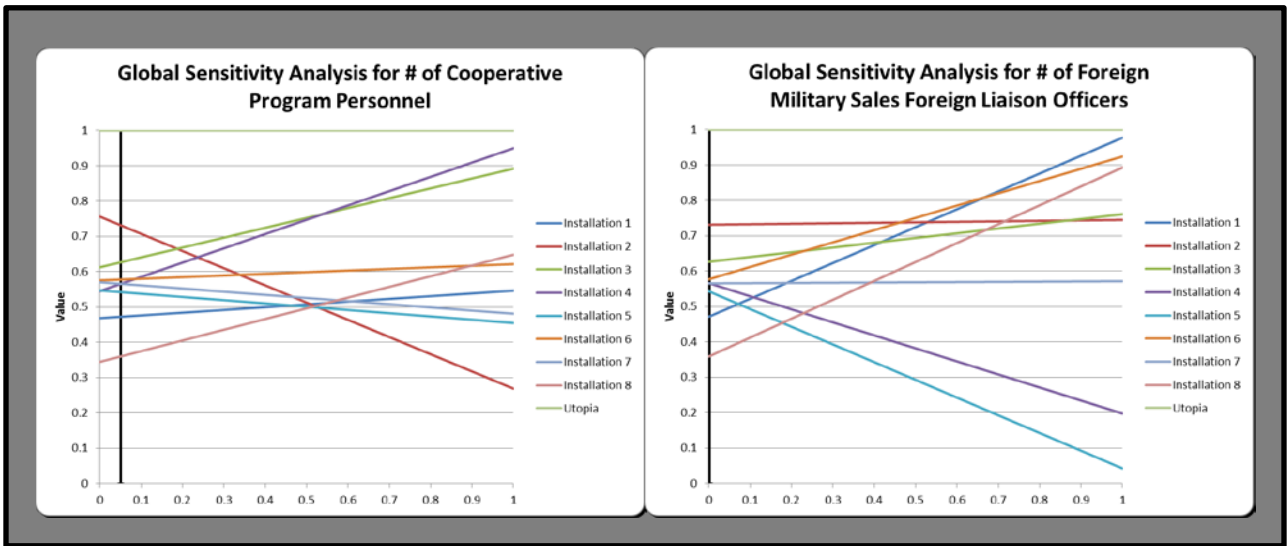


Figure 35. Weights on Foreign Partner Presence Attributes

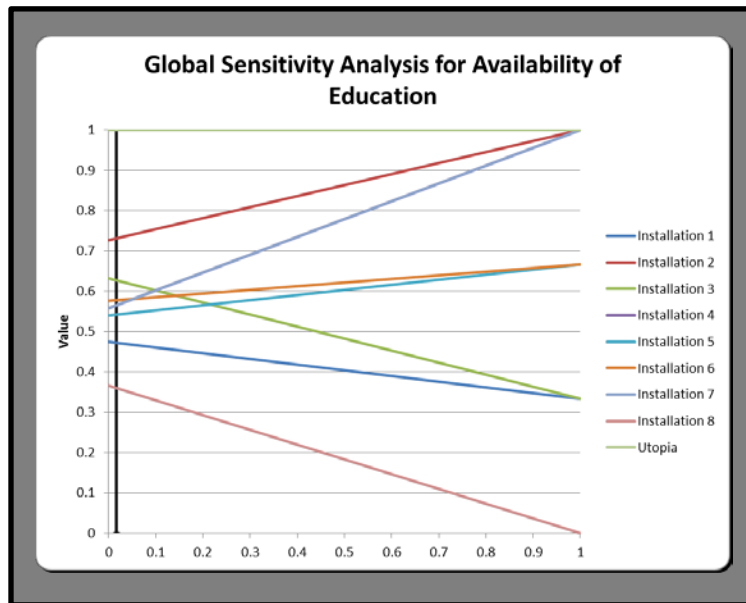


Figure 36. Weights on Availability of Education

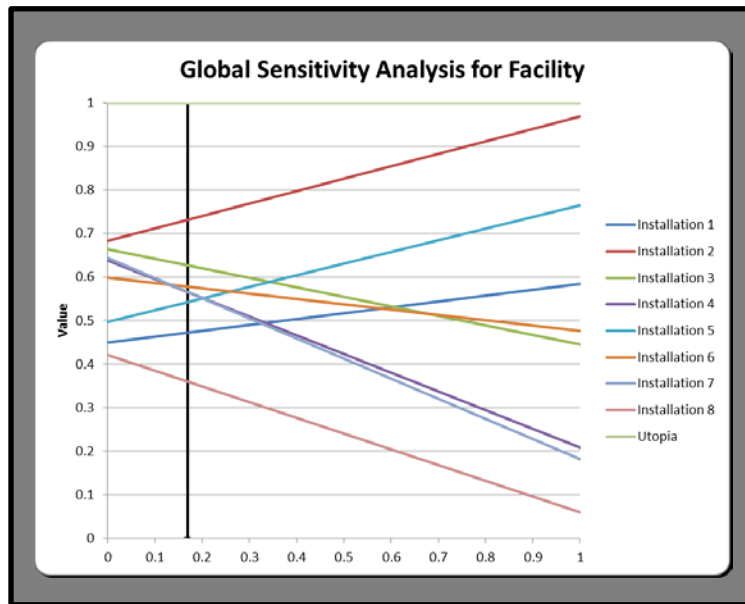


Figure 37. Weights on Facility

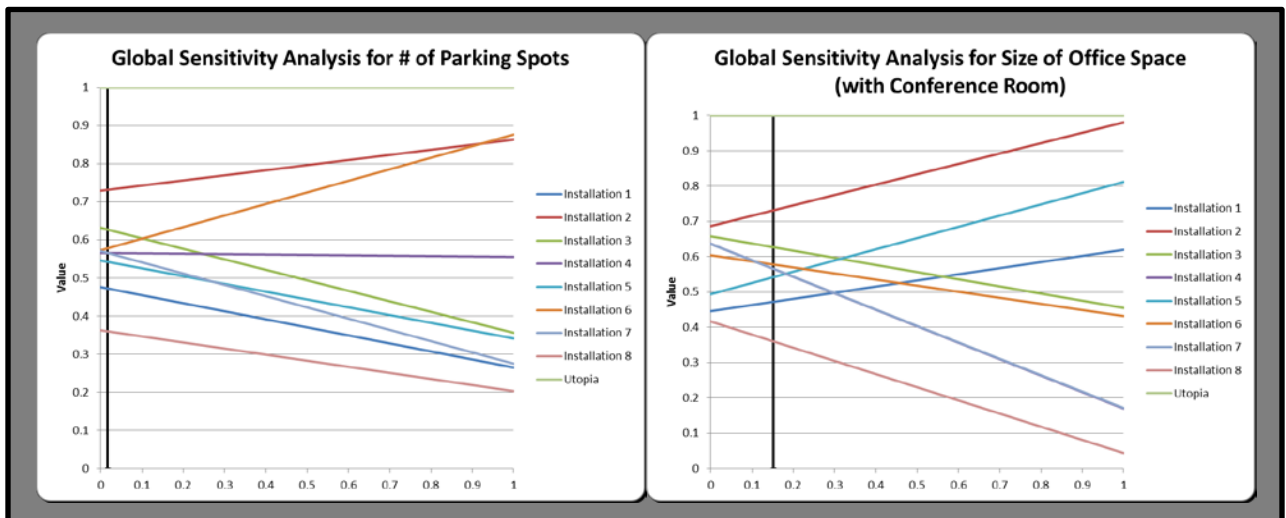


Figure 38. Weights on Facility Attributes

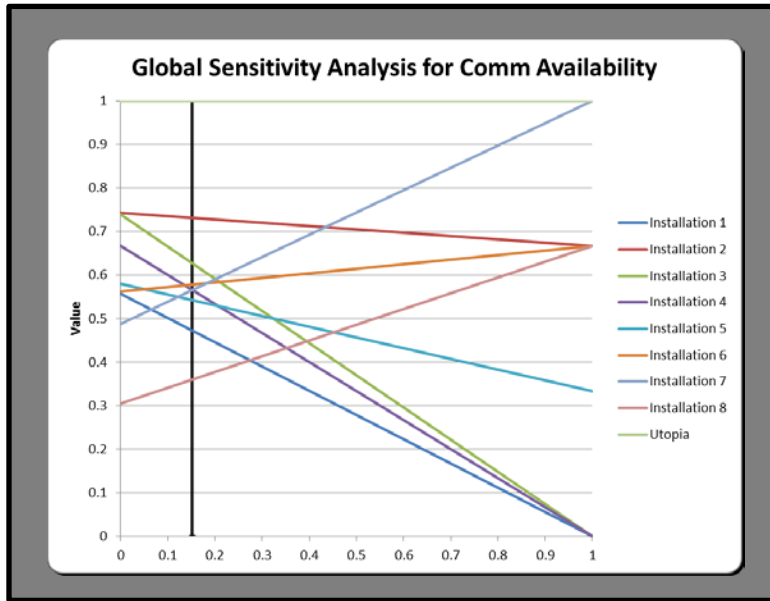


Figure 39. Weights on Comm Availability

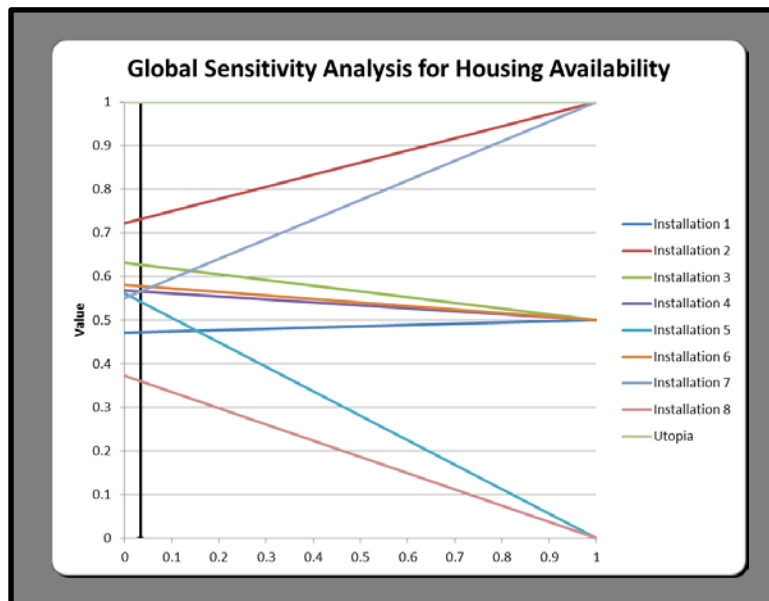


Figure 40. Weights on Housing Availability

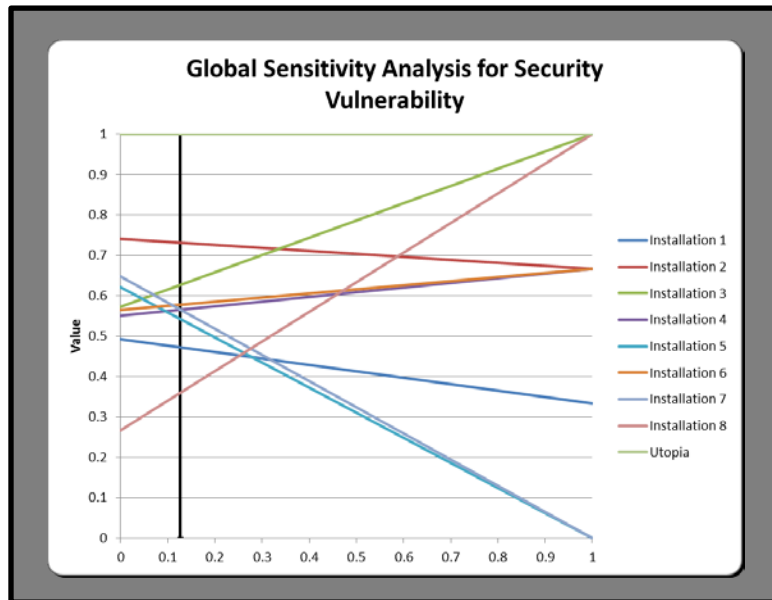


Figure 41. Weights on Security Vulnerability

Appendix E: Monte Carlo Simulation—Triangular Distribution Data

Installation 1 Cost			
Most Likely	Optimistic	Pessimistic	
\$54,125,500	\$57,569,631	\$52,206,194	

Attributes	Most Likely	Optimistic	Pessimistic
# of Acquisition Professionals	5,482	5,744	4,700
% of Acquisition Professionals with Specific Platform Experience	3	3	3
% Civilian Fill Rate	95	100	84
# Cooperative Program Personnel	338	360	327
# Foreign Military Sales Foreign Liaison Officers	47	50	45
# of Parking Spaces	190	194	183
Size of Office Space	64,296	72,068	55,833

Figure 42. Installation 1 Data

Installation 2 Cost			
Most Likely	Optimistic	Pessimistic	
\$47,375,500	\$56,384,817	\$46,684,476	

Attributes	Most Likely	Optimistic	Pessimistic
# of Acquisition Professionals	3,959	4,504	3,378
% of Acquisition Professionals with Specific Platform Experience	25	25	21
% Civilian Fill Rate	56	57	55
# Cooperative Program Personnel	141	150	135
# Foreign Military Sales Foreign Liaison Officers	27	29	26
# of Parking Spaces	449	452	392
Size of Office Space	74,533	74,651	60,875

Figure 43. Installation 2 Data

Installation 3 Cost			
Most Likely	Optimistic	Pessimistic	
\$44,800,000	\$47,646,230	\$43,064,255	

Attributes	Most Likely	Optimistic	Pessimistic
# of Acquisition Professionals	4,558	4,725	4,287
% of Acquisitoion Professionals with Specific Platform Experience	20	20	19
% Civilian Fill Rate	87	93	80
# Cooperative Program Personnel	758	777	713
# Foreign Military Sales Foreign Liason Officers	28	31	25
# of Parking Spaces	234	250	234
Size of Office Space	58,214	61,719	51,737

Figure 44. Installation 3 Data

Installation 4 Cost			
Most Likely	Optimistic	Pessimistic	
\$59,583,500	\$66,830,753	\$58,843,011	

Attributes	Most Likely	Optimistic	Pessimistic
# of Acquisition Professionals	7,542	7,813	6,679
% of Acquisitoion Professionals with Specific Platform Experience	19	22	17
% Civilian Fill Rate	66	70	57
# Cooperative Program Personnel	874	944	809
# Foreign Military Sales Foreign Liason Officers	5	6	5
# of Parking Spaces	324	343	302
Size of Office Space	43,639	45,874	42,130

Figure 45. Installation 4 Data

Installation 5 Cost			
	Most Likely	Optimistic	Pessimistic
	\$54,218,500	\$59,690,371	\$53,061,518

Attributes	Most Likely	Optimistic	Pessimistic
# of Acquisition Professionals	4,612	4,952	4,522
% of Acquisitoin Professionals with Specific Platform Experience	17	20	15
% Civilian Fill Rate	78	79	69
# Cooperative Program Personnel	265	280	240
# Foreign Military Sales Foreign Liason Officers	1	1	1
# of Parking Spaces	227	242	215
Size of Office Space	70,159	72,694	66,557

Figure 46. Installation 5 Data

Installation 6 Cost			
	Most Likely	Optimistic	Pessimistic
	\$51,285,500	\$57,798,380	\$49,362,519

Attributes	Most Likely	Optimistic	Pessimistic
# of Acquisition Professionals	2,563	2,670	2,336
% of Acquisitoin Professionals with Specific Platform Experience	11	13	11
% Civilian Fill Rate	79	90	79
# Cooperative Program Personnel	406	450	380
# Foreign Military Sales Foreign Liason Officers	41	45	39
# of Parking Spaces	454	471	414
Size of Office Space	57,252	59,230	57,093

Figure 47. Installation 6 Data

<i>Installation 7 Cost</i>			
<i>Most Likely</i>	<i>Optimistic</i>	<i>Pessimistic</i>	
\$56,318,000	\$64,707,842	\$55,046,886	

<i>Attributes</i>	<i>Most Likely</i>	<i>Optimistic</i>	<i>Pessimistic</i>
<i># of Acquisition Professionals</i>	5,133	5,645	4,454
<i>% of Acquisitoin Professionals with Specific Platform Experience</i>	25	25	24
<i>% Civilian Fill Rate</i>	36	39	35
<i># Cooperative Program Personnel</i>	285	306	242
<i># Foreign Military Sales Foreign Liason Officers</i>	18	19	16
<i># of Parking Spaces</i>	195	198	190
<i>Size of Office Space</i>	43,741	47,564	38,536

Figure 48. Installation 7 Data

<i>Installation 8 Cost</i>			
<i>Most Likely</i>	<i>Optimistic</i>	<i>Pessimistic</i>	
\$48,051,000	\$53,372,240	\$47,637,100	

<i>Attributes</i>	<i>Most Likely</i>	<i>Optimistic</i>	<i>Pessimistic</i>
<i># of Acquisition Professionals</i>	1,780	1,826	1,591
<i>% of Acquisitoin Professionals with Specific Platform Experience</i>	2	2	2
<i>% Civilian Fill Rate</i>	31	34	29
<i># Cooperative Program Personnel</i>	432	454	414
<i># Foreign Military Sales Foreign Liason Officers</i>	38	38	37
<i># of Parking Spaces</i>	159	174	141
<i>Size of Office Space</i>	34,118	34,434	32,367

Figure 49. Installation 8 Data

Appendix F: Monte Carlo Simulation—Custom Distribution Data

<i>Attributes</i>	<i>Data</i>	<i>Value Score</i>	<i>Probability</i>
<i>Availability of Educational Opportunities</i>	1	0.00	0.15
		0.33	0.60
		0.67	0.15
		1.00	0.10
<i>Access to NIPR, SIPR, and SAP</i>	0	0.00	0.60
		0.33	0.15
		0.67	0.15
		1.00	0.10
<i>Adequate Availability of Housing within 50 Mile Radius</i>	1	0.00	0.25
		0.50	0.50
		1.00	0.25
<i>Availability of Educational Opportunities</i>	1	0.00	0.15
		0.33	0.60
		0.67	0.15
		1.00	0.10

Figure 50. Installation 1 Data

<i>Attributes</i>	<i>Data</i>	<i>Value Score</i>	<i>Probability</i>
<i>Availability of Educational Opportunities</i>	3	0.00	0.10
		0.33	0.15
		0.67	0.15
		1.00	0.60
<i>Access to NIPR, SIPR, and SAP</i>	2	0.00	0.10
		0.33	0.15
		0.67	0.60
		1.00	0.15
<i>Adequate Availability of Housing within 50 Mile Radius</i>	2	0.00	0.25
		0.50	0.25
		1.00	0.50
<i>Availability of Educational Opportunities</i>	2	0.00	0.10
		0.33	0.15
		0.67	0.60
		1.00	0.15

Figure 51. Installation 2 Data

<i>Attributes</i>	<i>Data</i>	<i>Value Score</i>	<i>Probability</i>
<i>Availability of Educational Opportunities</i>	1	0.00	0.15
		0.33	0.60
		0.67	0.15
		1.00	0.10
<i>Access to NIPR, SIPR, and SAP</i>	0	0.00	0.60
		0.33	0.15
		0.67	0.15
		1.00	0.10
<i>Adequate Availability of Housing within 50 Mile Radius</i>	1	0.00	0.25
		0.50	0.50
		1.00	0.25
<i>Availability of Educational Opportunities</i>	3	0.00	0.10
		0.33	0.15
		0.67	0.15
		1.00	0.60

Figure 52. Installation 3 Data

<i>Attributes</i>	<i>Data</i>	<i>Value Score</i>	<i>Probability</i>
<i>Availability of Educational Opportunities</i>	3	0.00	0.10
		0.33	0.15
		0.67	0.15
		1.00	0.60
<i>Access to NIPR, SIPR, and SAP</i>	0	0.00	0.60
		0.33	0.15
		0.67	0.15
		1.00	0.10
<i>Adequate Availability of Housing within 50 Mile Radius</i>	1	0.00	0.25
		0.50	0.50
		1.00	0.25
<i>Availability of Educational Opportunities</i>	2	0.00	0.10
		0.33	0.15
		0.67	0.60
		1.00	0.15

Figure 53. Installation 4 Data

<i>Attributes</i>	<i>Data</i>	<i>Value Score</i>	<i>Probability</i>
<i>Availability of Educational Opportunities</i>	2	0.00	0.10
		0.33	0.15
		0.67	0.60
		1.00	0.15
<i>Access to NIPR, SIPR, and SAP</i>	1	0.00	0.15
		0.33	0.60
		0.67	0.15
		1.00	0.10
<i>Adequate Availability of Housing within 50 Mile Radius</i>	0	0.00	0.50
		0.50	0.25
		1.00	0.25
<i>Availability of Educational Opportunities</i>	0	0.00	0.60
		0.33	0.15
		0.67	0.15
		1.00	0.10

Figure 54. Installation 5 Data

<i>Attributes</i>	<i>Data</i>	<i>Value Score</i>	<i>Probability</i>
<i>Availability of Educational Opportunities</i>	2	0.00	0.10
		0.33	0.15
		0.67	0.60
		1.00	0.15
<i>Access to NIPR, SIPR, and SAP</i>	2	0.00	0.10
		0.33	0.15
		0.67	0.60
		1.00	0.15
<i>Adequate Availability of Housing within 50 Mile Radius</i>	1	0.00	0.25
		0.50	0.50
		1.00	0.25
<i>Availability of Educational Opportunities</i>	2	0.00	0.10
		0.33	0.15
		0.67	0.60
		1.00	0.15

Figure 55. Installation 6 Data

<i>Attributes</i>	<i>Data</i>	<i>Value Score</i>	<i>Probability</i>
<i>Availability of Educational Opportunities</i>	3	0.00	0.10
		0.33	0.15
		0.67	0.15
		1.00	0.60
<i>Access to NIPR, SIPR, and SAP</i>	3	0.00	0.10
		0.33	0.15
		0.67	0.15
		1.00	0.60
<i>Adequate Availability of Housing within 50 Mile Radius</i>	2	0.00	0.25
		0.50	0.25
		1.00	0.50
<i>Availability of Educational Opportunities</i>	0	0.00	0.60
		0.33	0.15
		0.67	0.15
		1.00	0.10

Figure 56. Installation 7 Data

<i>Attributes</i>	<i>Data</i>	<i>Value Score</i>	<i>Probability</i>
<i>Availability of Educational Opportunities</i>	0	0.00	0.60
		0.33	0.15
		0.67	0.15
		1.00	0.10
<i>Access to NIPR, SIPR, and SAP</i>	2	0.00	0.10
		0.33	0.15
		0.67	0.60
		1.00	0.15
<i>Adequate Availability of Housing within 50 Mile Radius</i>	0	0.00	0.50
		0.50	0.25
		1.00	0.25
<i>Availability of Educational Opportunities</i>	3	0.00	0.10
		0.33	0.15
		0.67	0.15
		1.00	0.60

Figure 57. Installation 8 Data

Bibliography

- [1] AFLCMC/XP-OZ, *Air force Life Cycle Management Center Standard Process for Cost Capability Analysis (CCA)*, 2016.
- [2] SAF/FMCEE, *Air force Instruction 65-509: Business Case Analysis (BCA)*, 2016.
- [3] D. L. James and M. A. Welsh III, *Air Force Future Operating Concept: A View of the Air Force in 2035*, 2015.
- [4] C. Samaras, R. Costello, P. DeLuca, S. Guerra, K. Kuhn, A. Narayanan, M. Nixon, S. Pettyjohn, N. Sweeney, J. Vesely and L. Burgette, *Improvements to Air Force Strategic Basing Decisions*, Santa Monica, California: RAND, 2016.
- [5] HQ AF/A8PB, *Air Force Instruction 10-503: Strategic Basing*, 2010.
- [6] T. Bridges, "Strategic Basing," in *Executive Steering Group (ESG)*, WPAFB, 2014.
- [7] J. Hendrix, Interviewee, *IMSC Strategic Basing Lessons Learned*. [Interview]. 17 July 2017.
- [8] J. D. Weir and M. U. Thomas, *Operations Research and Management Science Handbook*, vol. Chapter 25: Military Applications, A. R. Ravindran, Ed., Boca Raton, Florida: Taylor & Francis Group, LLC, 2008.
- [9] O. Pokrovsky, "Operational Research Approach to Decision Making," [Online]. Available: https://www.researchgate.net/publication/226262902_Operational_Research_Approach_to_Decision_Making. [Accessed 04 July 2017].
- [10] G. S. Parnell, T. A. Bresnick, S. N. Tani and E. R. Johnson, *Handbook of Decision Analysis*, New Jersey: John Wiley & Sons, Inc., 2013.
- [11] G. S. Parnell and R. C. Burk, "Portfolio Decision Analysis - Lessons from Military Applications," *Advances in Portfolio Decision Analysis Method for Improved Resource Allocation*, pp. 29-51, 2011.
- [12] P. L. Ewing, W. Tarantino and G. S. Parnell, "Use of Decision Analysis in the Army Base Realignment and Closure (BRAC) 2005 Military Value Analysis," *Decision Analysis*, vol. 3, no. 1, pp. 33-49, March 2005.

- [13] R. L. Dillon-Merrill, G. S. Parnell, D. L. Buckshaw, W. R. Hensley and D. J. Caswell, "Avoiding Common Pitfalls in Decision Support Frameworks for Department of Defense Analyses," *Military Operations Research*, vol. 13, no. 2, pp. 19-31, 2008.
- [14] F. Biery, D. Hudak and S. Gupta, "Improving Cost Risk Analyses," *The Journal of Cost Analysis*, vol. 11:1, pp. 57-85, 1994.
- [15] Parnell, Gregory S., Trade-Off Analytics, G. S. Parnell, Ed., Hoboken, New Jersey: John Wiley & Sons, Inc., 2017, pp. 36-37.
- [16] G. S. Parnell, D. W. Hughes, R. C. Burk, P. J. Driscoll, P. D. Kucik, B. L. Morales and N. R. Lawrence, "Invited Review--Survey of Value-Focused Thinking: Applications, Research Developments and Areas for Future Research," *JOURNAL OF MULTI-CRITERIA DECISION ANALYSIS*, vol. 20, pp. 49-60, 2013.
- [17] N. Fenton and M. Neil, Risk Assessment and Decision Analysis with Bayesian Networks, Boca Raton, Florida: Taylor & Francis Group, LLC, 2013.
- [18] A. MacCalman and G. S. Parnell, "Multiobjective Decision Analysis with Probability Management for Systems Engineering Trade-off Analysis," 2016.
- [19] C. W. Kirkwood, Strategic Decision Making: Multiobjective Decision Analysis with Spreadsheets, Belmont: Brooks/Cole, Cengage Learning, 1997.
- [20] C. Abbott, Interviewee, *Personal Interview*. [Interview]. 19 April 2017.
- [21] J. Weir, *VFT Tool*, WPAFB: Air Force Institute of Technology, 2017.
- [22] U. S. O. o. P. Management, "Office of Personnel Management," 2017. [Online]. Available: <https://www.opm.gov/>. [Accessed 20 July 2017].
- [23] Oracle, *Crystal Ball (excel add-in)*, 2017.
- [24] Oracle, "Crystal Ball," Integrated Cloud Applications and Platform Services, 2017. [Online]. Available: www.oracle.com/us/products/applications/crystalball. [Accessed 07 08 2017].

REPORT DOCUMENTATION PAGE				Form Approved OMB No. 074-0188	
The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of the collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.					
1. REPORT DATE (DD-MM-YYYY) 14-09-2017		2. REPORT TYPE Master's Thesis		3. DATES COVERED (From – To) September 2016-September 2017	
TITLE AND SUBTITLE Organizational Strategic Basing Framework with Infusion of Multi-Dimensional Uncertainty				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Reboulet, Amanda M,				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(S) Air Force Institute of Technology Graduate School of Engineering and Management (AFIT/EN) 2950 Hobson Way, Building 640 WPAFB OH 45433-8865				8. PERFORMING ORGANIZATION REPORT NUMBER AFIT-ENS-MS-17-S-068	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Intentionally left blank				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT DISTRIBUTION STATEMENT A. APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.					
13. SUPPLEMENTARY NOTES This material is declared a work of the U.S. Government and is not subject to copyright protection in the United States.					
14. ABSTRACT Evidence suggests the United States Air Force executes capital investment decisions based on point estimates without sufficient consideration of uncertainty surrounding the data used in the estimate. This research seeks an alternative to this by coupling a multi-objective decision analysis approach with Monte Carlo simulation to adequately account for uncertainty in strategic basing decisions. In the context of this research, strategic basing decisions aspire to pick the highest valued, lowest cost installations to establish organizations. The inclusion of uncertainty in both input data to calculate an overall value score and cost parameters for each installation allows decision makers to better understand the entire decision space. Additionally, the incorporation of uncertainty permits analysts to test for statistical differences between installations and recommend trade-offs to decision makers.					
15. SUBJECT TERMS Strategic basing, decision analysis, uncertainty, Monte Carlo					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT U	18. NUMBER OF PAGES 87	19a. NAME OF RESPONSIBLE PERSON Dr. Bradley Boehmke, AFIT/ENS
a. REPORT U	b. ABSTRACT U	c. THIS PAGE U			19b. TELEPHONE NUMBER (Include area code) (937) 255-3636, ext 4276 (NOT DSN) (bradley.boehmke@afit.edu)

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