Calhoun: The NPS Institutional Archive
DSpace Repository

Theses and Dissertations 1. Thesis and Dissertation Collection, all items

2020-09

# A PROCESS TO SCORE FUTURES COMMAND R&D EFFORTS AND PROVIDE A DECISION SUPPORT TOOL TO SELECT AND EVALUATE THOSE EFFORTS

Brooks, Paul A.; Cox, Brad D.; Firmature, Brandon J.; Gillum, Jennifer L.; Holcomb, John M.; Horn, Kevin M.; Obrien, Steven H.

Monterey, CA; Naval Postgraduate School

http://hdl.handle.net/10945/66117

This publication is a work of the U.S. Government as defined in Title 17, United States Code, Section 101. Copyright protection is not available for this work in the

*Downloaded from NPS Archive: Calhoun*

DUDLEY KNOX LIBRARY

Calhoun is the Naval Postgraduate School's public access digital repository for research materials and institutional publications created by the NPS community. Calhoun is named for Professor of Mathematics Guy K. Calhoun, NPS's first appointed -- and published -- scholarly author.

Dudley Knox Library / Naval Postgraduate School
411 Dyer Road / 1 University Circle
Monterey, California USA 93943

http://www.nps.edu/library

# NAVAL POSTGRADUATE SCHOOL

**MONTEREY, CALIFORNIA**

# SYSTEMS ENGINEERING CAPSTONE REPORT

**A PROCESS TO SCORE FUTURES COMMAND R&D EFFORTS AND PROVIDE A DECISION SUPPORT TOOL TO SELECT AND EVALUATE THOSE EFFORTS**

by

Paul A. Brooks, Brad D. Cox, Brandon J. Firmature, Jennifer L. Gillum, John M. Holcomb, Kevin M. Horn, and Steven H. O'Brien

September 2020

| | |
|---|---|
| Advisor: | Joel J. Hagan |
| Co-Advisors: | Paul T. Beery |
| | John T. Dillard |
| | Joyce B. Stewart |

**Approved for public release. Distribution is unlimited.**

THIS PAGE INTENTIONALLY LEFT BLANK

| REPORT DOCUMENTATION PAGE | *Form Approved OMB No. 0704-0188* |
|---|---|

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, 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 this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington, DC 20503.

| **1. AGENCY USE ONLY** ***(Leave blank)*** | **2. REPORT DATE** September 2020 | **3. REPORT TYPE AND DATES COVERED** Systems Engineering Capstone Report |
|---|---|---|

**4. TITLE AND SUBTITLE**
A PROCESS TO SCORE FUTURES COMMAND R&D EFFORTS AND PROVIDE A DECISION SUPPORT TOOL TO SELECT AND EVALUATE THOSE EFFORTS

**5. FUNDING NUMBERS**

**6. AUTHOR(S)** Paul A. Brooks, Brad D. Cox, Brandon J. Firmature, Jennifer L. Gillum, John M. Holcomb, Kevin M. Horn, and Steven H. O’Brien

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
Naval Postgraduate School
Monterey, CA 93943-5000

**8. PERFORMING ORGANIZATION REPORT NUMBER**

**9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)**
N/A

**10. SPONSORING / MONITORING AGENCY REPORT NUMBER**

**11. SUPPLEMENTARY NOTES** The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

**12a. DISTRIBUTION / AVAILABILITY STATEMENT**
Approved for public release. Distribution is unlimited.

**12b. DISTRIBUTION CODE**
A

**13. ABSTRACT (maximum 200 words)**

Army Futures Command (AFC) manages technology development projects in response to identified threats. These projects support future Multi-Domain Operations (MDO) capabilities, which are diverse in duration, cost, and technical requirements. The potential outcomes range from software upgrades to revolutionary concepts in vehicle or weapons technology. AFC must evaluate each program annually to determine priority and funding levels for recommendation in the Program Objective Memorandum (POM). AFC does not currently have a methodology in place that is capable of scoring projects based on their potential future impacts. This project develops a methodology and common metrics to score diverse technology development projects, and the methodology will provide a decision tool to support AFC POM submission. Due to the complexity of the decision-making model, as well as limits in time and available information, this project develops the methodology up to the point of demonstrating its function with simulated data. Taking these factors into consideration, this project does not perform validation and testing.

**14. SUBJECT TERMS**
value, metrics, project portfolio management, research and development, privatization, research on research

**15. NUMBER OF PAGES**
89

**16. PRICE CODE**

| **17. SECURITY CLASSIFICATION OF REPORT** | **18. SECURITY CLASSIFICATION OF THIS PAGE** | **19. SECURITY CLASSIFICATION OF ABSTRACT** | **20. LIMITATION OF ABSTRACT** |
|---|---|---|---|
| Unclassified | Unclassified | Unclassified | UU |

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

THIS PAGE INTENTIONALLY LEFT BLANK

**Approved for public release. Distribution is unlimited.**

**A PROCESS TO SCORE FUTURES COMMAND R&D EFFORTS AND PROVIDE A DECISION SUPPORT TOOL TO SELECT AND EVALUATE THOSE EFFORTS**

Paul A. Brooks, Brad D. Cox, Brandon J. Firmature,

Jennifer L. Gillum, John M. Holcomb, Kevin M. Horn, and Steven H. O'Brien

Submitted in partial fulfillment of the
requirements for the degree of

**MASTER OF SCIENCE IN SYSTEMS ENGINEERING MANAGEMENT**

from the

**NAVAL POSTGRADUATE SCHOOL**
**September 2020**

Lead Editor: Brad D. Cox

Reviewed by:

Joel J. Hagan
Advisor

Paul T. Beery
Co-Advisor

John T. Dillard
Co-Advisor

Joyce B. Stewart
Co-Advisor

Accepted by:
Ronald E. Giachetti
Chair, Department of Systems Engineering

THIS PAGE INTENTIONALLY LEFT BLANK

# ABSTRACT

Army Futures Command (AFC) manages technology development projects in response to identified threats. These projects support future Multi-Domain Operations (MDO) capabilities, which are diverse in duration, cost, and technical requirements. The potential outcomes range from software upgrades to revolutionary concepts in vehicle or weapons technology. AFC must evaluate each program annually to determine priority and funding levels for recommendation in the Program Objective Memorandum (POM). AFC does not currently have a methodology in place that is capable of scoring projects based on their potential future impacts. This project develops a methodology and common metrics to score diverse technology development projects, and the methodology will provide a decision tool to support AFC POM submission. Due to the complexity of the decision-making model, as well as limits in time and available information, this project develops the methodology up to the point of demonstrating its function with simulated data. Taking these factors into consideration, this project does not perform validation and testing.

THIS PAGE INTENTIONALLY LEFT BLANK

# TABLE OF CONTENTS

.

# LIST OF FIGURES

THIS PAGE INTENTIONALLY LEFT BLANK.

# LIST OF TABLES

THIS PAGE INTENTIONALLY LEFT BLANK.

# LIST OF ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| AFC | Army futures command |
| AHP | analytic hierarchy process |
| CBRS | concept-based requirements system |
| CCDC | combat capabilities development command |
| CFT | cross functional team |
| CSD | combat systems directorate |
| DA | Department of the Army |
| DAG | Defense Acquisition Guidebook |
| DOD | Department of Defense |
| EE PEG | equipping program equipment group |
| FACT | futures assessment capability tool |
| FCC | futures and concepts center |
| FYDP | future years defense programs |
| IPR | in-process review |
| JCIDS | joint capabilities integration and development system |
| LCC | life-cycle cost |
| MDO | multi-domain operations |
| MOSA | modular open systems approach |
| MRDC | Medical Research and Development Command |
| NATO | North Atlantic Treaty Organization |
| NPD | new product development |
| POM | program objective memorandum |
| PPM | project portfolio management |
| R&D | research and development |
| RFID | radio frequency identification |
| SE | systems engineering |
| SEIWG | security equipment integration working group |
| SIV-T | SEIWG interoperability verification tool |

| | |
|---|---|
| SMART | simple multi-attribute rating technique |
| SME | subject matter expert |
| STANAG | standard agreement |
| TRP | Technology Review Panel |
| TEI | theater/echelon/threat |
| TRAC | The Research and Analysis Center |
| TVP | technology value pyramid |
| VA | Veterans Administration |

# EXECUTIVE SUMMARY

How does one evaluate programs against each other when they can be as different as a communication system, unmanned tank, or unmanned aircraft? That has been a question the Army has had to address since its inception. The Army Future Command (AFC) has asked for assistance in a process to help alleviate this problem. Which program should we use our limited resources on? The allocation of resources in a value driven way is of the utmost importance to the U.S. Army in a time of fiscal uncertainty. This capstone project sets out to help alleviate this problem by creating a process that would be theater agnostic, scalable, and result in a ranking system to prioritize a list of projects. The system engineering (SE) process was used as the capstone team followed the SE V-diagram (Figure 1). For the purposes of this study, the areas of “Test & Evaluation” and “Transition, Operations, & Maintenance” were considered beyond the scope of what was assigned.

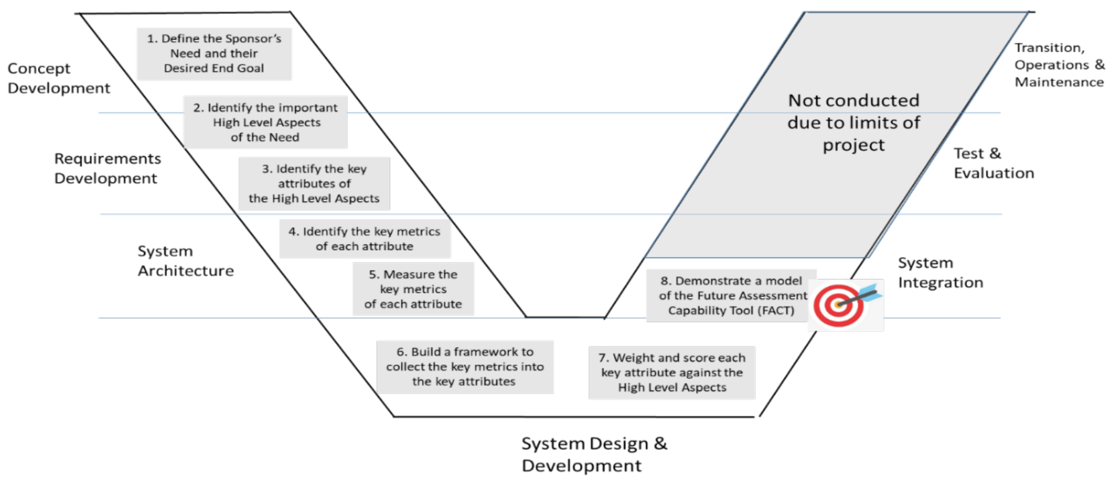



Figure 1. The Systems Engineering (SE) V-diagram

The capstone team started by getting a better understanding of AFC and learning what they value in projects. Acquiring stakeholder requirements was important to guide what our final product would be. AFC wanted effective warfighting capabilities that will eliminate U.S. threats. Our sponsor provided key objectives and attributes important for us to evaluate. Next, the capstone team did a comprehensive literature review on different value models. Several different models were ruled out immediately, but three models were applicable enough to compare. A comparative analysis was conducted on those three value models on how effective they would be in four key criteria that AFC would need in order to be a successful model (Table 1). The criteria evaluated are simplicity, objectivity, qualitative, and adaptiveness. The criteria were scored as either a "yes" for meeting or exceeding the desired criteria, or a "no" for not meeting the criteria towards a desired AFC methodology.

Table 1. Comparative Analysis

| **Methodology Type** | **Evaluation Criteria** | | | |
|---|---|---|---|---|
| | **Simplistic** | **Objective** | **Qualitative** | **Adaptive** |
| Decision Analysis Methodologies. (AHP) | No | Yes | Yes | No |
| Optimization Type Methodologies. (Boeing) | No | Yes | No | Yes |
| Soring Methodologies. (Parnell) | Yes | Yes | Yes | Yes |

.

The capstone team chose concepts from *Decision-making in Systems Engineering and Management* by Parnell, Driscoll, and Henderson (2011) in attempts to define and develop our project methodology. The Scoring methodology was chosen due to it being relatively simple for end user comprehension, and for its highly objective-adaptable usability. Once the methodology was selected, functions, objectives, and value measures of the hierarchy framework were developed through a series of critical reviews with the sponsors. The logical evaluation criteria (subjects and alternatives) were decomposed in a fashion similar to functional decomposition processes found in common system definition projects. The following hierarchy framework is representative of the capstone team's methodology (Figure 2):

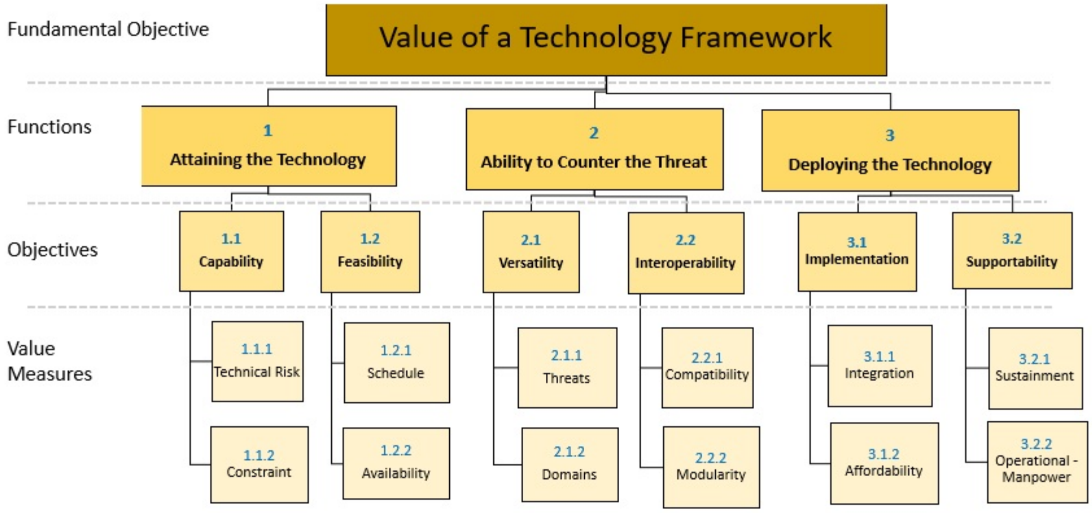



Figure 2. The Hierarchy Framework of the Modified Parnell Methodology

Once the hierarchy framework was established, the capstone team had to identify the key attributes of the value measures and decide how to score them so that the scores reflected the true value of achieving each value measure. To do this, scaling functions and priority weighting were used to mold the user input into a score that represented how valuable each value measure was for each project. Once the foundation was formed on how the Parnell methodology was going to be used, the Futures Assessment Capability Tool (FACT) was built to demonstrate the methodology.

The FACT was to be simple for the user to input data into and receive a total project value for each project. A challenging portion of the typical Parnell methodology for users to understand without full understanding of the applicable rules would have been the swing weight matrix. In FACT, the swing weight matrix was broken down into a couple different spreadsheet tabs as a simplified priority ranking and sensitivity weighting matrix, without the need for any hard to follow rules of the swing weight matrix.

To demonstrate FACT, the capstone team used notional data for three different projects which were a small representation of possible AFC projects.

1. Long Flight Unmanned Bomber Unmanned Aerial System (UAS) (LF-UBU): A UAS project designed to provide precision aerial first strike combat capability.

2. Unmanned Light Tank (ULT): A Ground Combat Vehicle (GCV) project designed to provide armored direct fire capability in support of inserted infantry combat operations.

3. Single Channel Ground and Airborne Radio System (SINCGARS) Update Version 20.5: A combat communications project designed to integrate all battlefield command and control assets.

Before using FACT, the notional data for all three projects was reviewed, and it appeared that the SINCGARS would come out on top based on comparing its scores in the three highest priority categories (Technical Risk, Availability, and Threats) that were designated. After placing the notional data into FACT, the results were indeed that the SINCGARS came out on top. Since SINCGARS came out as the best score in both methods gives us a degree of confidence that FACT will be able to accurately rank projects with a higher sample size.

The FACT uses a modified Parnell methodology that is capable of producing a priority list of AFC Technologic Development Projects based on its value to the warfighter. At the point when decisions must be made, critical aspects of projects are not well defined or understood. Data on cost, schedule, and performance are speculative. In spite of this, decisions must be made. FACT has demonstrated the ability to produce a logical result. It meets the critical requirements of being a simple to use tool that allows for subjective inputs to produce and value score that is comparable from project to project. It has shown potential and is worthy of further development and integration into the AFC project selection process.

**References**

Parnell, Gregory, Patrick Driscoll, and Dale Henderson. 2011. *Decision-making in Systems Engineering and Management*. Hoboken, NJ: John Wiley & Sons.

# ACKNOWLEDGMENTS

We would like to first thank our sponsors, LTC Brian Wade and MAJ Jenifer McClary, for offering us the opportunity to tackle this stimulating capstone project and for your availability throughout.

We would also like to thank our professors and the NPS faculty for your willingness to always support the team when we needed it (which was often). We believe your direction helped us shape our project to be the best possible product we could deliver.

A special thanks to the teammates on Team 3 for their unwavering collaboration through rearranging schedules, sleepless nights, and openness to have the difficult conversations. We would like to give a special acknowledgement to our buds who were always there to support us through this program:  Jim, Rita, Johnny, and Jack. When COVID hit they were there to sustain us on a daily basis and guide us through the capstone. Now, hold your drinks high and toast that we survived the “Hulkinator.” CHEERS!

THIS PAGE INTENTIONALLY LEFT BLANK.

# I. BACKGROUND AND PROBLEM STATEMENT

## A. BACKGROUND

Modern warfare is a rapidly evolving landscape requiring modernization efforts to keep the U.S. Army superior in today's global warfighting arena. The critical need to maintain operational readiness is paramount in maintaining America's national security. As stated in a Department of the Army (DA) 2018 article "Training and Doctrine Command (TRADOC)" Pamphlet 525-3-1 General Mark Milley stated:

> emerging technologies like artificial intelligence, hypersonics, machine learning, nanotechnology, and robotics are driving a fundamental change in the character of war … [and] the impacts have the potential to revolutionize battlefields. …Strategic competitors like Russia and China are synthesizing emerging technologies with their analysis of military doctrine and operations. They are deploying capabilities to fight the U.S. through multiple layers of stand-off in all domains—space, cyber, air, sea, and land. The military problem we face is defeating multiple layers of stand-off in all domains in order to maintain the coherence of our operations. …We must examine all aspects of our warfighting methods and understand how we enable the joint force on the future battlefield. We must challenge our underlying assumptions, and we must understand the capabilities and goals of our potential enemies. That is how we change our warfighting techniques and build the fighting forces we need in the future. It is also how we maximize deterrence and, if necessary, win future wars. (DA 2018, Foreword)

A long-time complaint about the U.S. Army Acquisition System has been the speed at which new technology goes from initial conception to being fielded, which is often more than a decade from when a capability gap was first discovered. The antiquated acquisition system was not originally designed to facilitate a rapidly changing warfighting environment. The number of emerging threats and the speed of new technological advancements has become a major risk to the U.S. Army. Modernization of the U.S. Army and the equipment soldier's use has become a critical focus given the vast and rapid changes in the operational environments of our enemies. In response to the critical need for modernization, the U.S. Army created the Army Futures Command (AFC) in July 2018. The mission of AFC is to "lead a continuous transformation of Army modernization in order to provide future warfighters with concepts, capabilities, and organizational structures they need to dominate a future battlefield" (Bradley 2019).

To separate areas of responsibility and expertise within the AFC, the organization is separated into four major sub-elements: the Futures and Concepts Center (FCC), the Combat Capabilities Development Command (CCDC), Medical Research and Development Command (MRDC), and the Combat Systems Directorate (CSD). The FCC assesses upcoming threats, possible future operational environments, develops future concepts, defines capability requirements, and solidifies an integrated modernization pathway for increase lethality and over-match of the U.S. Army. The CCDC pushes the boundaries of modern science, technology, and engineering by housing the Army's largest talent pool of scientists and engineers. The MRDC is the Army's medical materiel developer, with responsibility for medical research, development, and acquisition that are critical to the Army's needs to remain ready and lethal on the battlefield. The CSD maintains oversight of the cost, schedule, integration, and technical performance of all programs aligned within and between the Army's top priorities.

The AFC headquarters is located in Austin, Texas and did not become fully mission capable until 2019. What makes the AFC peculiar is that it was designed to establish and maintain unity of effort, purpose, and prioritization across the entire organization. Even though there are four separate sub-elements of the AFC, each sub-element is involved with a top priority of the Army by use of Cross Functional Teams (CFT). Each CFT is named after an Army priority and each CFT is composed of several personnel from each sub-element. It creates a truly diversified and interdisciplinary team with a unified focal point aligned with an Army priority. Currently, there are a total of eight CFT. They are Long-Range Precision Fires (at Fort Sill, Oklahoma), Next Generation Combat Vehicle (at Detroit Arsenal, Warren, Michigan), Future Vertical Lift (at Redstone Arsenal, Huntsville, Alabama), Network (at Aberdeen Proving Ground, Maryland), Air and Missile Defense (at Fort Sill, Oklahoma), Soldier Lethality (at Fort Benning, Georgia), Assured Positioning, Navigation and Timing (at Redstone Arsenal, Huntsville, Alabama), and Synthetic Training Environment (at Orlando, Florida).

The AFC manages emerging technology development efforts that project far into the Future Years Defense Programs (FYDP). There are many programs that span a broad spectrum of threats, technology, and domains. Currently, portfolio analysis is executed at the individual project level within each CFT. The AFC hosts a review panel annually to facilitate decision making for accelerating, holding, decelerating, or defunding each project. Each CFT prepares a review of its projects to explain and defend the funding rationale and urgency.

## B. PROBLEM STATEMENT

The Research and Analysis Center (TRAC), located in Monterey California, is a section of the sub-element FCC within AFC. TRAC is interested in an unbiased assessment of their problem. The problem the capstone team is trying to solve is finding AFC the best methodology to assist with prioritizing a variety of different types of future programs against future threats, while still remaining theater agnostic, scalable, and in alignment with Multi-Doman Operations (MDO) to enhance combat capability. The methodology should determine the projects with the best value to invest resources and funding. It needs to remain very simple to use and flexible to accommodate changes in future requirements. Since TRAC is interested in an unbiased assessment, they will not completely divulge what current processes they use for evaluating and ranking the relative value of each program; all we know is that they are not completely satisfied with that process. The primary reason this approach was taken was so that all options were considered when trying to solve the portfolio management problem.

All programs are important, so how do you determine which programs have the most value to the future Army? In what programs should we invest our limited budget? Conflicting priorities among the various CFT are possible when evaluating what AFC should fund versus what should not be funded. In these early program stages, another complication is that not all aspects of a future program may be defined or fully understood enough to initiate funding. Without an approved objective and standardized method of measuring future priorities and relevance, there exists a risk of funding programs that may not be mature enough for the Program Objective Memorandum (POM) submission.

AFC currently has no standardized metrics that everyone agrees upon to evaluate projects across all CFT. To date, AFC does not use a single universal methodology across all programs to aid top-level decision makers in evaluating and ranking the relative value of each program. With so many new programs across the command, the AFC has a critical need for a process that can utilize information from forecasted data, or from similar historical programs, to determine and inform future investments. These project reviews provide minimal visibility for a cross portfolio review at the AFC staff level.

## C. ENVIRONMENT

The capstone team was informed by TRAC that the metrics and process should be theater agnostic, scalable, and result in a ranking system to prioritize and defend POM submissions. The methodology used to rank these programs will be enabled by AFC inputs based on feasibility, alignment with MDO, and the potential to enhance Army combat capability. The data requirements will be identified through decomposition using systems engineering (SE) processes that will generate and define the appropriate metrics. TRAC also stated that the methodology should only cover efforts from the initial submission to AFC through inclusion in a Joint Capabilities Integration and Development System (JCIDS) program of record.

The identification of standardized metrics for use across all technology development efforts will allow AFC to have a valid comparison tool that would span across all the AFC portfolios collectively. It will ultimately prioritize and defend POM submissions as part of the resource management process. In the end, the AFC Commander, as co-chair of the Equipping Program Equipment Group (EE PEG) will use data to submit funding recommendations for inclusion into the POM.

The tool will also provide top-level decision makers a visual representation of the data to assist them in making decisions effectively. Additionally, it will help ensure excessive amounts of data, which often times convolute or distort conclusions, are not included in the final metrics. The proposed metrics would be capable of being briefed at the higher levels of AFC and would be relatively simple to interpret by those who are not Subject Matter Experts (SME) on the programs being measured. Common metrics will be measured, sorted, and scored by using a standardized process across all programs to ensure an objective outcome.

# II. LITERATURE REVIEW

The purpose of this literature review is to research applicable methodologies for the process of prioritizing future program decisions. The research will assist with determining if there is an existing methodology to meet AFC's requirements or if the capstone team will need to develop one. A review of the sponsor's requirements and the approaches of other similar projects was conducted in preparation for recommending an appropriate methodology. The literature review has been divided into four sections. The first section is the Sponsor's Guidance. It will include a description of the outcomes the sponsor desires from the methodology, the inputs that are available, and the constraints it must operate in. These details will help guide the research towards any current suitable methodologies. The second section, Valuation Methodologies, will summarize the literature researched on the various methodologies used to make prioritization decisions. The third section, Metric Selection, will review the literature on how other valuation efforts selected the criteria used to make decisions. The fourth and last section, Metric Weighting, anticipates it is likely not all metrics will be considered equal. The nature and effectiveness of various weighting procedures must be considered for possible application in the AFC prioritization process.

## A. SPONSOR'S GUIDANCE

The capstone team met with TRAC personnel to discuss the overall problem statement in detail and to lay out any specific underlying requirements. TRAC provided some initial guidance for the desired prioritization process, which was presented in terms of the outcomes that were desired, the inputs that could be available, and the environment in which the methodology would have to work effectively within. Regular meetings were held with TRAC to ensure the details of the project were aligned with the TRAC requirements for solving their project prioritization dilemma.

TRAC personnel stated that the final outcome of the methodology should produce a prioritized list of projects in order of best value to least value. The prioritization should be based on metrics that are well defined, avoiding relative comparisons between the projects being evaluated. It should function well, whether evaluating new projects, existing projects, or a combination of both. Finally, the tool should produce a record of the decision-making process allowing users to explain why one project was selected over another. Additionally, it would enable a traceable and reasonable defense against any selections that were made using the methodology.

TRAC personnel also stated that several data inputs could be available to use in the methodology. Each project would be initiated as the result of an identified and documented threat. The threat documentation is expected to provide information on the nature, timing, and prioritization of the threats. Projects begin as proposals and are vetted through a gating process before being prioritized using any methodology. The project proposal is expected to provide a forecast on the cost, schedule, and technical approach. The AFC will also have access to a wide array of technical experts from government, industry, and academia that would be available to review projects to assess their potential application into MDO environments.

Personnel from TRAC stated that the methodology must have the flexibility to operate within typical AFC constraints. The methodology must support uncertainty in cost and schedule data. The methodology needs to allow projects to be added, subtracted, or rerun periodically through the methodology to account for project updates or changes. It could be annually to match budget cycles or more frequently as needed. The tool should be able to be run in a limited amount of time (about 60 days) from data collection to final report. It would allow for changes in Army priorities, new threats, and updated information on existing projects to be considered.

## B. VALUATION METHODOLOGIES

Now that a foundation has been laid for the desired outcomes, available inputs, and the required environments the methodology must work in effectively, it is time to explore known valuation methodologies. Valuation methodologies are sets of procedures used to establish levels of value for whatever is being evaluated. This could be a financial value denominated in units of money, relative value to define the "better" option, or an evaluation against an established value criteria.

The section will be presented in three parts. Part 1 will provide an overview of the various valuation methodologies commonly used in government, industry, and academia. Part 2 will consider the sponsor's guidance to help determine what types of methodologies are not suitable for further consideration as AFC methodologies. Part 3 will discuss those methodologies that require further consideration for use with AFC.

### 1. Overview of Methodology Types

Measuring the potential value of any technology development project proves to be challenging because of the many uncertainties. Even if the technical objectives could eventually be achieved, it is often difficult to forecast what form the technology will take and how it could be integrated into a system (Henriksen and Traynor 1999).

In the 1999 article "A Practical R&D Project-Selection Scoring Tool," Anne Henriksen and Ann Traynor reviewed 55 studies conducted over 40 years on Research and Development (R&D) project selections. They identified the eight categories of models as depicted in Table 1.

Table 1. R&D Project Selection Methods. Adapted from Henriksen and Traynor (1999, 158).

| ID # | Methodologies Under Review |
|---|---|
| 1 | Unstructured peer review |
| 2 | Scoring, such as the Parnell methodology |
| 3 | Mathematical programming, including integer programming (IP), linear programming (LP), nonlinear programming (NLP), goal programming (GP), and dynamic programming (DP) |
| 4 | Economic models, such as internal rate of return (IRR), net present value (NPV), return on investment (ROI), cost-benefit analysis, and option pricing theory |
| 5 | Decision analysis, including multi-attribute utility theory (MAUT), decision trees, risk analysis, and the AHP |
| 6 | Interactive methods, such as Delphi, -sort, behavioral decision aids (BDA), and decentralized hierarchical modeling (DHM) |
| 7 | Artificial intelligence (AI), including expert systems and fuzzy sets |
| 8 | Portfolio optimization, such as a Boeing methodology example |

Note: Light green highlighting indicates the methodologies that are most applicable to AFC for further comparative analysis, which are ID #s 2, 5, and 8.

## 2. Application of Methodologies to AFC Project Prioritization

The methodology types listed in Table 1 offer a different approach to establishing the values of projects being analyzed. Some are more appropriate than others depending on a given situation. After reviewing the initial guidance provided by TRAC, the following methodologies were factored out from further consideration.

### *a. Unstructured Peer Review (#1) and Interactive (Delphi) Methodologies (#6)*

These techniques are time and manpower intensive, and are not likely to produce results in the time frame required (Parnell, Driscoll, and Henderson 2011). They provide limited insight into the reasoning behind the decision. The techniques are more focused on producing an answer and less on the rationale behind the comparisons (Andrews and Allen 2002). Finally, they tend to compare projects to each other in ranking, not against a set criteria. The inability of these methodologies to meet the general TRAC guidance caused them to be excluded from further consideration.

### *b. Mathematical Programming (#3) and Economic Methodologies (#4)*

Henriksen and Traynor made some interesting observations about projects early in their life cycle. Projects involving basic research generally have great uncertainty as to costs and potential results. The inability to obtain detailed measurement data reduces the accuracy of quantitative analysis. In these cases, the unknown costs, outcomes, and the likelihood of future events makes the use of qualitative judgment more reasonable (Henriksen and Traynor 1999). This is also noted in statements from Michael Greiner and John Fowler:

> For economic measures including increased profits, revenue generation, increased market share, and increased shareholder value represents some of the more common measures of NPD (new Product Development) success in the commercial industry. However, success in weapon systems development cannot easily be measured in economic terms and success criteria are often more qualitative in nature. (Greiner and Fowler 2003, 192)

The uncertainty of the available data and the need to apply subjective criteria caused them to be excluded from further consideration.

#### *c. Artificial Intelligence (AI) Methodologies (#7)*

These models require large investments to set up and tend to be complex to use (Provost and Weiss 2003). Henriksen and Traynor also found that complex tools or tools requiring analytic support showed a tendency to be used less often than those that simply qualify results (Henriksen and Traynor 1999). Additionally, the projects to be evaluated by AFC are widely varied. AI systems require large volumes of background data correlating choices to results to "train" the system (Provost and Weiss 2003). For AFC, there is limited data available to "train" an AI system. These factors caused AI methodologies to be excluded from further consideration.

### 3. Methodologies for Further Consideration

After eliminating five of the eight families of methodologies, consideration was given to the remaining three methodologies. An overview of each of them follows.

#### *a. Decision Analysis Methodologies (#5)—AHP*

The AHP methodologies is one of the primary methods now used to support decision theory (Vargas 2010). The process can be carried out with multiple levels of criteria, but the complexity of the calculations increases with each succeeding level. Once the AHP is set up and in use, additional results, such as checking for data inconsistencies and optimizing for select variables, can be added to the model.

A hybrid AHP methodology was recommended to the Air Force for evaluation of their future flight technology projects (Greiner and Foster 2003). Even though AHP is capable of making a recommendation for a preferred course of action, it cannot optimize on a selected variable. AHP can rank order the choices but cannot recommend the best combination of projects when constraints, such as a limited budget are considered. (Greiner and Fowler 2003).

#### *b. Optimization Type Methodologies (#8)—Boeing Methodology*

Optimization Models are based on the concept that the decision-maker intends to optimize a value while managing constraints (Greiner and Fowler 2003). This could be optimizing the Net Present Value of an investment portfolio or the number of vehicles produced at a plant. It evaluates a number of defined variables to produce a "Best Fit" result. As mentioned in "An introduction to Optimization Models and Methods" by Loucks and van Beek (2017), deciding what variable to optimize and what variable to allow to change defines what the model is optimizing. Similarly, holding variables constant can set constraints, and allowing variables to move shows what is being altered in order to achieve the optimization. Optimization is a mathematical model, so before designing the model the inputs must be definable in terms of consistent units (dollars, quantities, value scores, etc.) The art of designing an optimization model is designing an algorithm that will evaluate these variables to solve for the desired outcomes (Loucks and van Beek 2017). An example of an Optimization Type Methodology that the capstone team will discuss in Chapter 3 is taken from the article "Technology Portfolio Management: Optimizing Interdependent Projects over Multiple Time Periods." Boeing has experimented in past years with this model.

#### *c. Scoring Methodologies (#2)—Parnell Methodology*

Henriksen and Traynor recommend using a scoring methodology to evaluate basic research projects in uncertain environments where a low degree of interdependence between projects exists. Scoring is a methodology where each project is rated against a set of metrics and the results of scoring are then processed through an algorithm allowing weighting to produce a figure of merit. The figure of merit is the "score" of the project. They note that scoring,

> is quantitative enough to possess a certain degree of rigor, yet not so complex as to mystify and hence discourage potential users. Scoring can accommodate non-quantitative criteria into the selection process by relating question responses to a constructed, ordinal scale. It can also incorporate peer review. Scoring does not require detailed economic data, some of which may not be readily available for basic research. Furthermore, scoring tools can be customized by an organization to articulate the characteristics it wishes to emphasize. (Henriksen and Traynor 1999, 162)

Four additional articles were analyzed for the use of scoring methodologies, each recommending the concept of scoring for evaluating early stages of research and development projects (Bitman and Sharif 2008; Greiner and Fowler 2003; Jolly 2003; Moore and Baker 1969). A common theme among all authors was to use scoring to assist in decision making simplicity and effective transparent communication. An example of a Scoring Methodology is the Parnell Methodology which will discussed in Chapter III.

## C. METRICS SELECTION

The selection process seeks the "best balance in terms of return, investment, risk, timing, sustainability and other factors depending on each organization sector and business environment" (Elbok and Barrado 2017, 2160). Various programs have contrasting schedules, compete for limited resources, and exhibit differing objectives. The decision-makers may not be in alignment regarding the overall strategic goals, and they may be competing for the same resources. An improper selection of decision-making metrics can lead the organization towards not achieving its strategic objectives. Research conducted in this section led to the conclusion that identifying the right metrics is key (Elbok and Barrado 2017).

The article, "Towards an Effective Project Portfolio Selection Process" by Elbok and Barrado, highlights the project portfolio selection problem as having been researched for more than four decades.

> The project portfolio selection problem has … been approached in different methodologies, techniques and decision support systems. However, there is no agreement today on a universal approach addressing this problem's major aspects in a flexible and practical way. (Elbok and Barrado 2017, 2158)

The authors' definition of how this selection process is used to assess a set of projects to determine which group of projects will best achieve the strategic goals is depicted in Figure 1. They stress that an organization's success relies on the selection metrics for the portfolio supporting its vision, mission, and values.

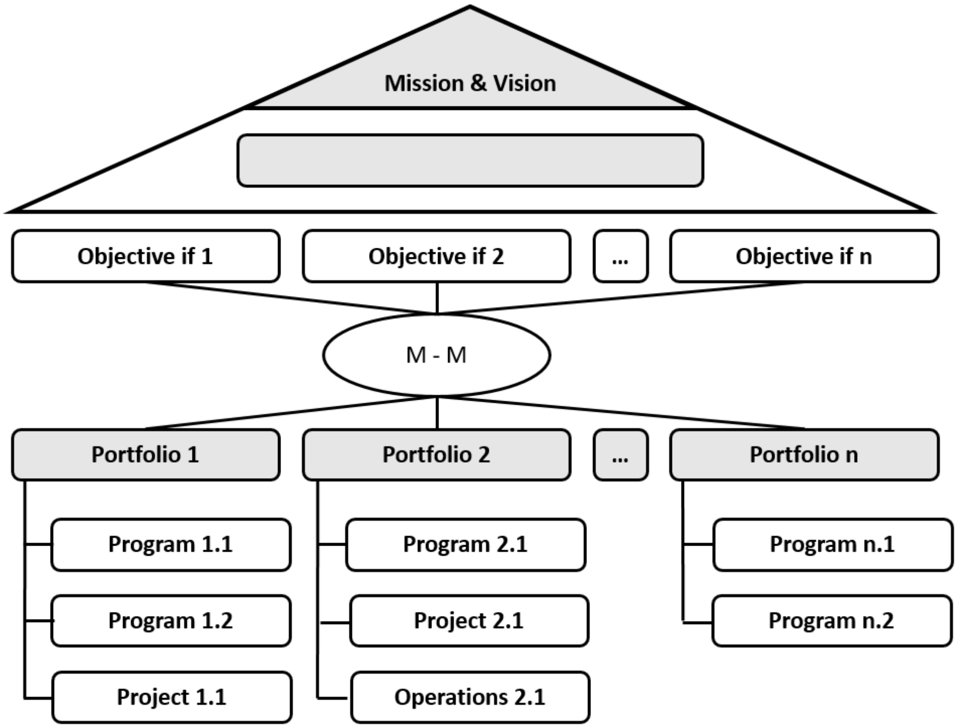



Figure 1. Portfolio Management and Organizational Strategy. Adapted from Elbok and Barrado (2017, 2159).

In the research article, “Looking for the Right Metrics to Define Projects Portfolio,” the authors concluded that universal decision metrics exist that can be used to select projects (Padovani et al. 2008). These universal criteria are identified as the “characteristics of projects; motivation for projects; value of projects and business areas of companies” (Padovani et al. 2008, 127). They studied six different institutions that applied the AHP for project selection and prioritization. This was done knowing they would have a well-defined set of metrics. The study intended on identifying the gaps between theory and practice. Utilizing a multiple case approach allowed a comparative analysis of the selection and prioritization of metrics. The authors were able to compare similarities, differences, and benefits among the different institutions in attempts to relate practical application to critical success factors. The results showed the primary metrics applied by all the companies in the study were the following: “Complexity, risk, technical feasibility, project performance, and stakeholder satisfaction” (Padovani et al. 2008, 127).

Research on which metrics should be used to evaluate R&D efforts was presented in the article "Measuring the Effectiveness of R&D." In the article, the authors recognized that R&D efforts function on a much longer timeline than most other business processes, with more subjective aspects (Schwartz et al. 2011). For the metrics to remain relevant, they observed that metrics required continuous change over the life of a product. The metrics used to measure basic research is very different from those used in product development and integration (Schwartz et al. 2011).

The authors presented a model that had been published by the Industrial Research Institute in 1994. The model was called the Technology Value Pyramid (TVP) (Figure 2). The TVP was created to classify metrics that have been used to measure various R&D projects (Schwartz et al. 2011).

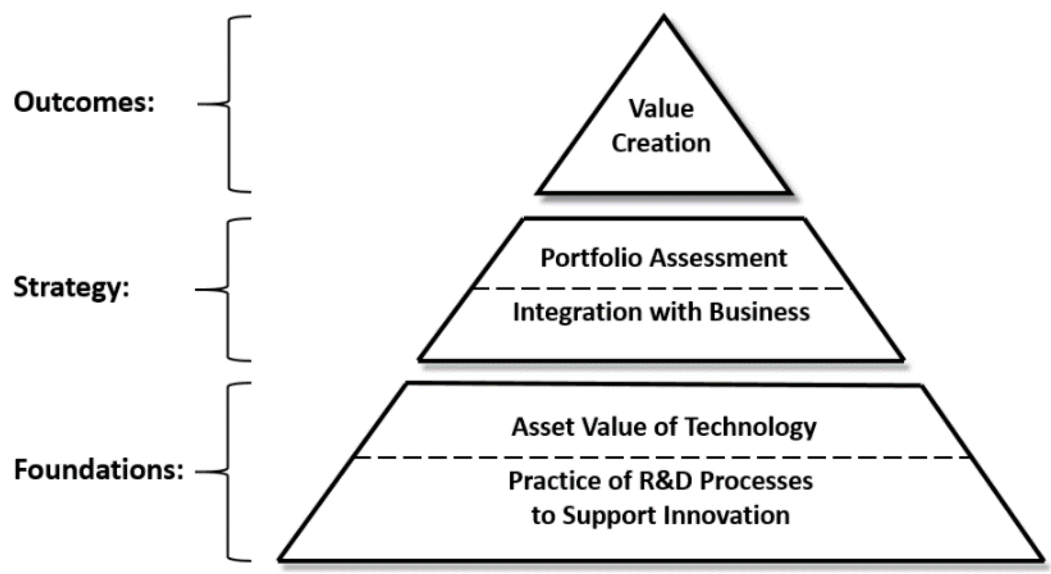



Figure 2. Technology Value Pyramid.
Source: Schwartz et al. (2011, 31).

The TVP offers a structured format of metrics founded on the elements of R&D value (Schwartz et al. 2011). In the development of the TVP, the designers determined that contrasting decisions are made by different individuals at varying levels of the organization (Schwartz et al. 2011). At the foundations level, the decisions made by a research scientist may relate to the success or relevance of a given experiment. At the strategy level, the decisions made by a Program Manager may relate to funding or the implications of a given line of research. At the outcomes level, organizational leadership make decisions related to project alignment with organizational goals and visions of the future. Just as the level and relevance of the decisions change at each level of the pyramid, so does the metric for those decisions. They concluded, when people know what is valued, it is easier to understand and weigh in on the decision-making process (Schwartz et al. 2011).

## D. METRIC WEIGHTING

The previous section focused on metrics selection, and placed emphasis on selecting the appropriate metrics in order to end up with the best possible option that is affordable, sustainable, performs, and has minimal risk. Metric weighting is crucial due to the importance of what is a priority at the time of evaluation. This section will cover how metrics are weighted, and will explain how it affects the outcome.

There are several ways to weight metrics. Ideally, users want to use an objective method; however, for that to be possible you must be able to have strong data that can be used to mathematically calculate the weighting. Strong data is necessary for producing results with a high degree of statistical integrity. In many cases, the data needed to attain a sound metric weighting may not be available; this may result in more subjective methods of evaluation, such as point allocation, direct ranking, and Simple Multi-Attribute Rating Technique (SMART). Although simplistic, point allocation can be an effective weighting method if used properly. For point allocation, points are allocated then assigned by rank. In particular, this approach is very dependent on a decision maker’s judgment; however, by forming a panel of SME to rank the evaluation criteria, it may avoid any one individual’s personal bias (Jolly 2003). The SME panel approach also tends to control some of the subjectivity. This may not be the best approach in some cases though, especially when the availability of using other weighting methods is more applicable. The direct ranking method is similar to point allocation, and also fairly simple to use. Taking this approach can be enhanced by giving stakeholders or SME the task of assigning values to various metrics used. In most cases, overlaps should be avoided or minimized when conducting metric weighting. Excessive overlaps can cause overweighting of metrics. This can skew results that may impact the decision-makers ability to properly choose the best project (Moore and Baker 1969).

The SMART method, pioneered by Ward Edwards in 1971, and further improved throughout its use (Olson 1996). SMART has been used often by military manufacturing organizations. Engineers use it to plan for more effective and efficient production of development initiatives (Patel, Bhatt, and Vashi 2017). Decision makers choose attributes that achieve the highest value, and assign the highest weighting to those attributes. The SMART method is considered the most desirable weighting method for most circumstances; however, it is still dependent on the decision-maker's subjective choices. An example of a SMART method is using a swing weight matrix, which will be discussed in Chapter III.

THIS PAGE INTENTIONALLY LEFT BLANK.

# III. METHODOLOGY

This chapter defines the process taken to identify and modify the best methodology to meet the AFC requirement for prioritizing future projects. After conducting a thorough literature review of methodologies from both the private and government industry, three methodologies were determined to have the most potential of meeting the AFC project prioritization requirements. In this chapter, the capstone team will work through the systems engineering (SE) process to determine if one of the three remaining methodologies will achieve the AFC project prioritization requirements. There will be four sections discussed in detail (Sections B through E) to step through the SE V-diagram phases, with the comparative analysis of the three remaining methodologies located in Section D: System Design and Development.

## A. THE SYSTEMS ENGINEERING V-DIAGRAM

The SE V-diagram in Figure 3 demonstrates the decomposition process used from "Concept Development" through "System Integration." For the purposes of this study, the phases of "Test & Evaluation" and "Transition, Operations, & Maintenance" were considered beyond the scope of what was assigned.

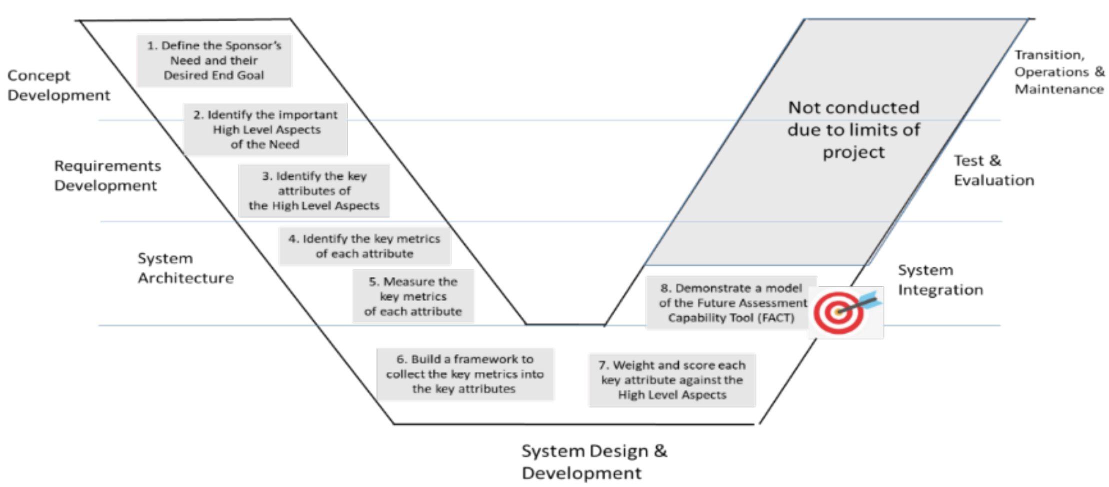



Figure 3. The SE V-diagram

## B. CONCEPT AND REQUIREMENTS DEVELOPMENT

The key TRAC objective was to establish a standardized set of value measures to be used by AFC to evaluate, score, and prioritize both existing and new projects across multiple system development portfolios. Personnel at TRAC desire a simple to use tool that will allow for some subjective inputs, yet still produce an accurate value determination that could be compared from project to project. A Technology Review Panel (TRP) will be a key element required to review all current and future project submittals for evaluation into a prioritization methodology. The professional insights and opinions of each panel member will help avoid any one individual's personal bias affecting the project evaluation. Panel members should be composed of cross-functional team members with diverse backgrounds and technical skills.

Personnel at TRAC placed a heavy emphasis on two key risks- operational and programmatic. These will be invaluable when evaluating various projects and how they should be prioritized for POM submissions. Operational risks were considered top priority in order to better address the concerns of field officers utilizing these systems in a training and/or combat environment. Emphasis on effectively countering the threat and the ability to operate in the MDO environment is paramount when determining what needs to be measured.

Over the course of several weeks, the capstone team concluded there are three questions any proposed methodology would need to answer. Each question along with the objectives and value measures seeks to address either operational or programmatic risks.

1. What is the level of difficulty in attaining the technology?

2. Will the technology counter a portion of a threat, or multiple threats?

3. What level of burden will the technology have once it has been fielded/ deployed?

Depending on whether the projects are established or conceptual, the method of measuring the data would differentiate due to the uncertain nature of information for newer or immature projects. If there were empirical data available, the desired method of measurement would be quantitative; nevertheless, if the project had many unknowns, a qualitative method of measurement would be a better approach. When evaluating operational risks, special consideration must be given to whether the proposed project meets the end users expectations. Furthermore, it would be evaluated on whether it effectively supports MDO, to include the logistical burdens and impacts once it is fielded.

Programmatic risks were the secondary concern of AFC when evaluating projects. These risks are more oriented towards costs and schedule, where operational risks are more about performance and fielding. In most cases, programmatic risks are more suitable for a quantitative measurement. But even for new R&D projects, there would have to be some informed assumptions made for potential cost and schedule impacts.

## C. SYSTEM ARCHITECTURE

In this section, a value hierarchy will be built by identifying the high-level key functions, which will then be decomposed into objectives, and then further decomposed into value measures. Each value measure will include a definition designed to assist decision-makers in understanding exactly what was being measured, and the preferred method of measurement.

### 1. Building the Value Hierarchy

Building the value hierarchy model for evaluating future types of technology development projects started with the question, "What is the overall meaning of value for every type of technology development project that goes through AFC?" The answer to this question was identified as a requirement in the stakeholder analysis, which produced value metrics to measure the projects across the different portfolios. These stakeholder values and the functional requirements were decomposed into the value hierarchy (Parnell 2008). The structure of the hierarchy began with the Fundamental Objectives. These would clearly define statements to address the decision-making problem. The Functions would be the major functional components of the decision as identified in the functional analysis. Objectives would be statements that relate to each function that describes how value would be added to that function. The value measures would be tangible and measurable criteria that would indicate how well a given project should achieve the objectives.

As with any good decision-making metric, they must be complete, show true relevance, be measurable, and have little to no overlap (Moore 1999). A complete set of value measures will help ensure no important decision metrics were omitted. True relevance indicates that value measures have a relevant and direct impact on the decision at hand. Any metric with little importance or relevance should be avoided in the value hierarchy model. All metrics must be measurable in some form in order to be considered usable data. There should be very little to no overlap in the metrics; allowing overlap could cause duplication in the metrics or overweight of some factors, which could result in biased decisions.

### 2. Value Measure Scoring

Observations captured during literature review concluded measuring value would be challenging, particularly when little or no data was available. Predicting the future value to a technology project is a challenge to every decision-maker, particularly when there are finite resources that can be allocated (Sun et al. 2008). The likelihood a project will meet its technical objectives is difficult to determine at the onset , further complicating the decision to prioritize (Henriksen and Traynor 1999). As a result of these inferences and limited data, the value modeling for this methodology will contain primarily qualitative measures.

For the sake of standardization and making user entry repeatable and simple, each value measure will be initially scored uniformly, meaning a raw score of one will always mean low value measure achievement, and a raw score of five will always mean high value measure achievement. At this point in scoring, there would be no perceived value in the raw scores themselves. Some value measures such as Technical Risk, Constraints, and Operational Manpower actually have a negative meaning, such that a high value of five would not actually be wanted when assigning value to the value measure. These types of value measures will have the raw scores transposed by use of decreasing scaling functions when applied to each value measure. Once the scaling functions are applied, each value measure would be expressed in the perceived value of the score. A high-scaled score would be perceived as having high value for that value measure. To maintain simplicity for user input, each value measure will always have the same meaning when inputting a raw score of a value measure, a depiction of whether the value measure was achieved at a level of low, medium, high. The raw score will not necessarily have any meaning of true value until a scaling function has been applied to it.

### 3. Function, Objective, and Value Measure

Three functions were developed in order to reach the fundamental objective of capturing the value of a technology project. A total of twelve value measures will be qualitatively measured for either existing or new technology projects across all AFC programs and portfolios. What follows is a descriptive breakdown and definition for each function, objective, and value measure of the value hierarchy shown in Figure 4. For the purpose of brevity, Tables 2 through 7 will summarize the meaning for each raw score value as a one, three, or five. There may be situations where a higher level of granularity would be necessary, which the user would apply their own discretion for assigning any values between a raw score value of one through five.

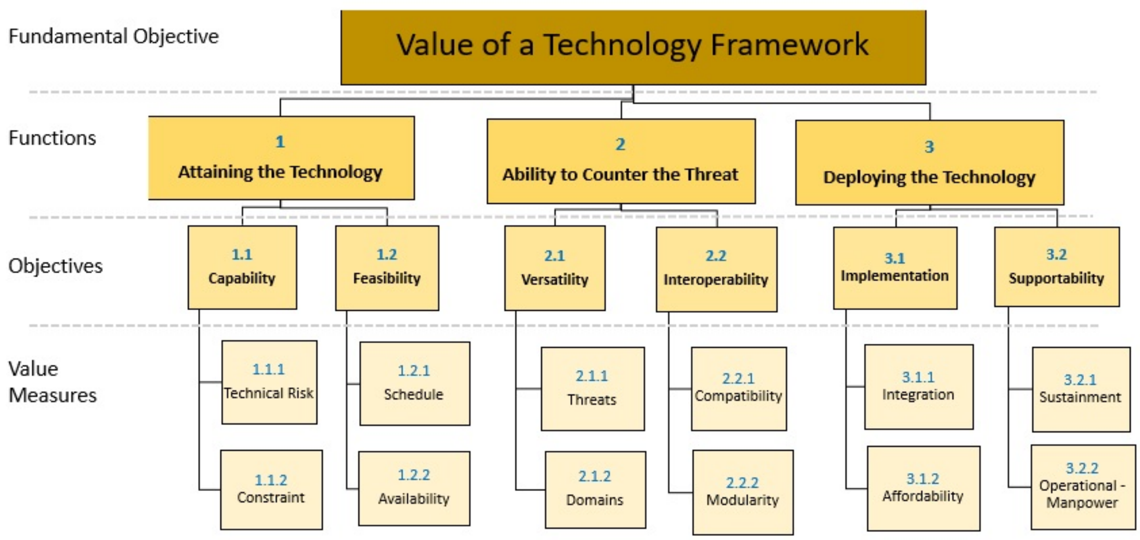



Figure 4. The Hierarchy Framework

Function 1—Is the Technology Attainable?—This function relates to the research and innovation elements of technology development. It looks at the project proposal and evaluates the potential of the project to develop a technology to counter the related threat(s). It considers if the goal is attainable and if we have the human capital and research institutions with a likelihood to succeed. The objectives related to this function indicate the likelihood that a technology will be developed and that the development will occur in a period that mitigated the related threat(s).

Objective 1.1—Capability—The objective attempts to predict if the technology will be attained in accordance with the project proposal. It evaluates the defined intent of the project, the approaches proposed, the team working on the project, and the environment they are working in to predict the likelihood of success. The objective's value measure and its method of measurement is captured in Table 2.

Value Measure 1.1.1—Technical Risk—The measure considers the technical hurdles and application of engineering and/or scientific standards required for the project to meet its technical goals. It also accounts for whether the project has clearly stated goals. It is evaluated by the TRP through application of their knowledge of the current state of the proposed technology, recent advances in the field, and the Technology Readiness Level (TRL) described in the project proposal. The panel would express their perspective by selecting a low, medium or high-risk level for the project.

Value Measure 1.1.2—Constraints—The measure considers whether highly qualified people, institutions, and facilities are available for the project. Examples of what constitutes as minimal constraints are as follows: highly qualified engineering support, experienced in the applied technology, credible technical institutions that supported similar efforts, and existing facilities capable of supporting the effort. The constraints would be determined as minimal, moderate or high based on what is established by the TRP. It considers the data provided in the project proposal and the panels evaluation of the skill set of the project team and supporting institutions. Another big consideration is if any of the raw materials are scarce or environmentally restricted in a way that would really constrain the overall project. Funding is not considered a constraint as it will be analyzed elsewhere in the hierarchy. If the project as proposed requires skills or facilities that do not currently exist, then they would not be evaluated as constraints, rather they would be scored under the value measure of technical risk.

Table 2. Capability Objective

| Value Measure | Method of Measurement | Raw. Score |
|---|---|---|
| Technical Risk | High—Poorly defined technical goals, immature or undeveloped technology, new and novel techniques | 5 |
| | Medium—Legacy project or program exists | 3 |
| | Low—Well defined technical goals, conventional approach, next logical step in development, similar mature technology, technology has a legacy project or program that it's improving | 1 |
| Constraints | High—The project team has little or no experience in applying the methods proposed, the supporting institution does not have background in similar development work and the team does not have access to facilities required to complete the project. Another big consideration is if any of the raw materials are scarce or environmentally restricted in a way that would really constrain the overall project | 5 |
| | Medium—Neither minimal nor high | 3 |
| | Low—Highly qualified personnel, experienced in the technology to be applied, working in institutions that have a successfully supported similar efforts with existing facilities to support the project as planned. There are no raw material limitations nor environmental constraints with the overall project | 1 |

Objective 1.2—Feasibility—The objective attempts to predict when the technology will be available. It also evaluates the timeline of the threat that the project is intended to counter to determine if the capability is likely to be available when needed. The objective's value measure and its method of measurement is captured in Table 3.

Value Measure 1.2.1—Schedule—The measure captures if the project schedule is well defined with a high degree of granularity. Do the proposed timelines seem realistic or vague? Also under consideration is if the project schedule has a lot of flexibility to be adjusted in duration or timing to meet a variation of scheduling needs throughout AFC POM planning, or is it very ridged and inflexible in schedule.

Value Measure 1.2.2—Availability—The measure evaluates if the project is likely to deliver a capability in time to counter the corresponding threat. Projects are initiated in response to threats. Threats evaluations are expected to have a timeframe where they present risk (for example, a potentially hostile country will have a new anti-ship capability in ten years). Project proposals are expected to have a schedule that indicates when a capability would be ready to deploy and be used in theater. It is evaluated as timely (high) if the project proposal forecasts an anticipated capability delivery date with a margin 25% of the total project schedule before the estimated threat maturity date. It is evaluated as at risk (medium) if there is a margin of at least 5% and less than 25% of the total project schedule before the estimated threat maturity date. It is evaluated as late (low) if the schedule margin is less than 5% of the estimated threat maturity date.

Table 3. Feasibility Objective

| Value Measure | Method of Measurement | Raw. Score |
|---|---|---|
| Schedule | High—The project schedule is well defined with a high degree of granularity and the proposed timelines seem realistic. The project schedule also has a lot of flexibility to be adjusted in duration or timing to meet a variation of scheduling needs throughout AFC POM planning | 5 |
| | Medium—The project schedule is moderately defined, but missing some much needed granularity to determine if the proposed timeline is realistic. The project schedule has some flexibility to be adjusted in duration or timing to meet a variation of scheduling needs throughout AFC POM planning, but not a whole lot. | 3 |
| | Low—The project schedule is not well defined and missing a lot of the granularity needed to determine if the proposed timeline is realistic. The project schedule is rigid or has an immovable start and end date. | 1 |
| Availability | High—The project proposal forecasts an anticipated capability delivery date with a margin 25% of the total project schedule before the estimated threat maturity date and procurement lead-time is a not a constraint. | 5 |
| | Medium—There is a margin of at least 5% and less than 25% of the total project schedule before the estimated threat maturity date and has some flexibility for moving procurement lead-time to meet mission. | 3 |
| | Low—The schedule margin is less than 5% of the estimated threat maturity date and is inflexible regarding procurement lead- times that could result in inability to meet the mission. | 1 |

Function 2—Ability to counter the threat—The function relates to the threats that motivate the technology development project. It assumes the technology is developed in accordance with the project proposal. The potential for that technology to partially or fully counter the threat is evaluated. It looks at the urgency for that threat to be countered and the potential risk of the threat if not countered. The objectives related to this function indicate the likelihood a technology will adapt to multiple threats and multiple domains of

operation, as well as the technology operating with a current systems of systems architecture.

Objective 2.1—Versatility—The objective is the degree to which a project is capable of being utilized for multiple purposes or multiple mission sets. Any product or system is more valuable if it can be utilized for multiple mission types. Therefore, the more types of missions the product or system can accomplish, the more versatile it is, thereby raising its value. The objective's value measure and its method of measurement is captured in Table 4.

Value Measure 2.1.1—Threats—The measure considers the amount of threats a project can counter. Threats are a hostile action with an intention to inflict pain, injury, or damage. A military threat can be defined as an escalation of international conflict that may result in coercive action through diplomatic threat to deploy military action. For the sake of operational effectiveness, each project must counter the threat it was designed to achieve. If possible, any project or system that can counter more than one threat would be advantageous to the AFC. The TRP will apply their knowledge of the current threat situations and rate the project accordingly.

Value Measure 2.2.1—Domains—The value measure considers the amount of domains a project can be used in effectively. Domains are an area of territory owned or controlled by a ruler or Government such as land, air, maritime, space, and cyberspace, and across the electromagnetic spectrum.

> MDO describes how the U.S. Army, as part of the joint force (Army, Navy, Air Force, and Marines) can counter and defeat a near-peer adversary capable of contesting the U.S. in all domains [air, land, maritime, space, and cyberspace] in both competition and armed conflict. The Army's central idea is to prevail by competing successfully in all domains short of conflict, and thus deterring a potential enemy. (Feickert 2020)

Operational effectiveness within a number of domains other than one is desirable for MDO operations. The optimal number of domains is more than three if possible. The amount of domains that the project can be used in effectively will be determined based on the opinion of the TRP using the data provided in the project proposal and the panel's evaluation of the applicability of project to different domains.

Table 4. Versatility Objective

| Value Measure | Method of Measurement | Raw. Score |
|---|---|---|
| Threats | High—Effectively counters more than one threat in an MDO environment | 5 |
| | Medium—Effectively counters one types of threat in an MDO environment | 3 |
| | Low—Responds to no threats or supports countering an established threats in an MDO environment | 1 |
| Domains | High—Performance in two or more domains | 5 |
| | Medium—Performance in one domain | 3 |
| | Low—Supports an established project or program that is performing in an existing domain | 1 |

Objective 2.2—Interoperability—The ability for systems, sub-systems, and organizations to work together effectively during training or battlefield events. The Defense Standardization Program "aims to improve military operational readiness by achieving interoperability with U.S. allies and among the Military Departments; improving logistics support, modernizing existing systems and equipment; and ensuring relevance of standards to the warfighter" (DSP 2020). The objective's value measure and its method of measurement is captured in Table 5.

Value Measure 2.2.1—Compatibility—Compatibility with other systems is important to ensure that downtime is avoided, and availability of the system is maximized. Compliance with Security Equipment Integration Working Group (SEIWG) Interoperability Verification Tool (SIV-T). The SEIWG is responsible for influencing system architecture and systems integration to foster interoperability. They developed interoperability standards to guide military services and their industry partners to meet physical security standards and ensure new systems integrate with existing systems to minimize architecture redesign. The NATO Standard Agreement (STANAG) is the standard for interoperability of information systems. The value measure will be evaluated by the TRP applying their knowledge of the current equipment in relation to the proposed technology. The panel would express their opinion by selecting a low, medium, or high compatibility level for the project.

Value Measure 2.2.2—Modularity—It refers to a "design that is built around the idea of modular components that can be independently created, easily configured, and reconfigured into different systems" to perform different mission sets. The Modular Open Systems Approach (MOSA) "can be defined as a technical and business strategy for designing an affordable and adaptable system." The MOSA is the Department of Defense (DOD) "preferred method for implementation of open systems" (Title 10 U.S.C. 2446a.(b), Sec 805).

The 2017 National Defense Authorization Act (NDAA) establishes

MOSA as an integrated business and technical strategy that:

- employs a modular design with major system interfaces between a major system platform (such as a ground vehicle, ship, or aircraft) and its major system components (such as sensors or communication equipment) or between major system components and platforms;
- is subjected to verification to ensure major system interfaces comply with widely supported and consensus-based standards;
- uses a system architecture that allows severable major system components at the appropriate level to be incrementally added, removed, or replaced throughout the life cycle of a major system platform to afford opportunities for enhanced competition and innovation while yielding: significant cost savings or avoidance, schedule reduction, opportunities for technical upgrades, increased interoperability, or other benefits; and
- complies with requirements for technical data rights (NDAA 2017, Section 805)

The modularity value measure will be evaluated by the TRP by applying its knowledge of the current equipment in relation to the proposed technology. The panel would express their opinion by selecting a low, medium or high modularity architecture level for the project.

Table 5. Interoperability Objective

| Value Measure | Method of Measurement | Raw. Score |
|---|---|---|
| Compatibility | High—Fully joint compatibility and/or NATO compatibility | 5 |
| | Medium—Only Army compatibility with other Army systems | 3 |
| | Low—Not Compatible with other similar systems/platforms and lacks joint compatibility and/or NATO compatibility | 1 |
| Modularity | High—Maximum modularity - modular components independently developed, easily configured, and reconfigured into different systems to perform different mission sets | 5 |
| | Medium—Some modularity, but very limited mission set variety when modularity the different components are used | 3 |
| | Low—No modularity of the system exists | 1 |

Function 3—Deploying the technology—Even if the technology is attainable, and the capability will counter the associated threat, the likelihood of being able to deploy the technology is of the utmost importance to the end user (warfighter). The most advanced and effective technologies require the proper implementation and logistical support possible to ensure it can be implemented for use in a MDO environment.

Objective 3.1—Implementation—Implementation of a new project or program into the MDO environment involves integrating the system and any costs associated with fielding and sustaining the effort. These factors along with technical processes play a key role in a project's success. The objective's value measure and its method of measurement is captured in Table 6.

Value Measure 3.1.1—Integration—The process of achieving unity of effort between the supporting functions of a project and ensuring alignment between the project and the needs of the parent organization. Integration is measured based on the likelihood of the technologies ability to fit in designated organizations construct without issues. Questions that would be asked could be "has this been done before, was the previous integration troublesome, how similar was it to a like technology and system architecture that integrated well." The project planning data will be collected and compiled by SME. The SME will note various complexities within the systems that have downstream interfaces required with other systems for mission success (any hardware and software);

these interfaces will be looked for in the project design and architecture to ensure they are thought out for positive interfaces prior to system deployment.

Value Measure 3.1.2—Affordability—The results obtained from the Affordability Analysis of the Life-Cycle Cost (LCC) of a proposed acquisition will be obtained. The purchase will be checked to be in accord with the resources and long term requirements of the receiving commodity. The *Defense Acquisition Guidebook* (DAG), updated in 2017, defines affordability as

> the degree to which the LCC of an acquisition program is in consonance with long-range modernization, force structure, and manpower plans of the individual DOD Component, as well as the Department as a whole. An affordability assessment is required at Milestone B and C. Affordability is considered in four aspects of DOD acquisitions. (DAG 2017)

SME and team leaders within the CFTs may conduct an affordability analysis. Data will be collected and complied by noting various complexities. Examples of this are estimated life cycle expectancy, system uniqueness, and production/operational considerations.

Table 6. Implementation Objective

| Value Measure | Method of Measurement | Raw Score |
|---|---|---|
| Integration | High—Simplistic to integrate with known traits that possess existing training, maintenance, and sustainment | 5 |
| | Medium—Moderately complex systems or unknown low risk technologies that have similar training, maintenance, and support available | 3 |
| | Low—Complex systems with unknown technologies that require specialized training, maintenance, and sustainment | 1 |
| Affordability | High—Favorable results such as low life cycle cost | 5 |
| | Medium—Neither minimal nor high | 3 |
| | Low—Unfavorable results such as a high life cycle cost or complexities that make it unknown | 1 |

Objective 3.2—Supportability—Supportability is of high interest to the sponsors and can be used to assess a concept or project or programs ability to be acquired, produced, integrated, fielded, operated, and sustained throughout its life cycle. The objective's value measure and its method of measurement is captured in Table 7.

Value Measure 3.2.1—Sustainment—Sustainment activities that support the effort are critical in mission success during deployment. The major portion of supportability is sustainment. The 12 Integrated Product Elements (IPS) make up the majority of what it takes to support a system. These elements can be considered as attributes, for measuring sustainment. Projects or concepts with unknown traits in order to measure the twelve IPS elements would be considered a higher risk, thus have a lower raw score. Elements that would increase the logistics burden (cost and schedule) would also be a higher risk.

The twelve IPS elements are as follows: Product Support Management, Design Interface (Suitability, Human Systems Integration [HSI], Sustaining Engineering, Supply Support, Maintenance Planning and Management, Packing, Handling, Storage & Transportation (PHS&T), Technical Data, Support Equipment, Training and Training Support, Manpower & Personnel, Facilities and Infrastructure, and Computer Resources/ Information Technology Systems Continuous Support (ITSCS).

An end user would need to reference the IPS Element Guide book and make assumptions based on comparisons of like systems when possible. As noted previously scoring for each element would be unique and separate based on the information available. Unknown traits with complex technologies will be considered higher risk, and scored accordingly, based on the likelihood that the individual element will be addressed. Known elements will be scored based on project information and technology complexity for similar systems that have been previous or current programs of record.

Value Measure 3.2.2—Operational Manpower—What is required to operate systems in their environment can impact the cost and schedule of a project? Projects that require extensive operational manpower would be considered less favorable, especially if they were not already existing Military Operation Specialty (MOS). Projects that were highly automated and require less manpower would be favorable. This value measure seeks to answer the questions of "Does the projects or system require new unique skills?"; "Is a new MOS required?"; "Is there established doctrine and training requirements that may be necessary to support this new system?"; and "Is there adequate manpower staffing to ensure completion of the mission or operation of the system?"

SME will work with educational institutions or training centers to conduct doctrine/ training reviews and seek expertise from other advisory groups in order to gain the necessary information. There would be an evaluation of existing MOS skillsets and the feasibility to be able to cross train under an existing MOS with minimal impact. Scoring will be applied accordingly providing the need for high operational manpower or severe increases in training would receive a raw score of high. In instances where a system would use an existing MOS and there would be no increase in operational manpower compared to like systems, the raw scoring would be reflected as low.

Table 7. Supportability Objective

| Value Measure | Method of Measurement | Raw Score |
|---|---|---|
| Sustainment | High—IPS elements that are easily supported, with like or known existing technologies for comparison | 5 |
| | Medium—Neither high nor low | 3 |
| | Low—IPS elements that are difficult to measure or complex, with no like or existing systems for comparison, or like/existing systems that have an abundance of negative impacts | 1 |
| Operational Manpower | High—Requires new MOS, School House, increases in personnel, and extensive doctrine changes | 5 |
| | Medium—Neither minimal nor high | 3 |
| | Low—Existing MOS and School House, as infrastructure could be utilized | 1 |

## D. SYSTEM DESIGN AND DEVELOPMENT

Up to this point, the TRAC requirements were identified, and a value hierarchy was developed that defined the main attributes and cultivated meaningful value measures. But, in order to use the value hierarchy, we must determine which methodology would best suit AFC with project prioritization. To determine which methodology is best suited for AFC, the capstone team conducted a comparative analysis of the three remaining methodologies, with the following details and end results.

### 1. Comparative Analysis

The comparative analysis is conducted to compare the sponsor’s expectations against the top three methodologies identified from chapter two. The criteria evaluated are simplicity, objectivity, qualitative, and adaptiveness. These were scored as either a “yes” for meeting or exceeding the desired methodology criteria, or a “no” for not meeting the criteria. A thorough explanation of each criteria is as follows.

Simplicity was determined as a desirable trait by TRAC for two reasons- to minimize confusion for the end user and to allow it to be briefed at a top-level. Paraphrased, simplicity is the ability for a process to be easily understood and applied by a common person. Adding unnecessary levels of complexity not only convolutes information but can also mislead or confuse end users and leadership. In most industry applications, it is not a technical expert such as an engineer or scientist inputting the data in a model. It will most likely be an associate level employee inputting the data to provide to their leadership.

Objectivity pertains to independence from personal feelings, biases, or perceptions. When making decisions, it is best to utilize definitive facts or data when applying inputs whether it be in a matrix, methodology, or database. Making decisions based on independent inputs can greatly diminish biases when making top-level decisions. Subjectivity can skew results and sway decision-makers in a direction if based on data that would most likely benefit a small group rather than the whole. For example, if criteria were to be evaluated based on a dollar amount being lowest for a program or project, the emphasis on lowest price projects would take priority. This gives it an unfair advantage against other programs that may be projected to be more costly. Affordability would be a more objective way of measurement because it does not emphasize lowest price, but instead asks if it can be procured for a reasonable cost compared to the perceived value of the product.

Qualitative data needs to be used given uncertainties and limitations of forecasted data for future technical projects. Methodologies exist in industry that require historical data that can be formulated for a consistent desired output. Many newer projects have insufficient data to be able to make a definitive output, thus a qualitative methodology is best suited for AFC application.

Adaptiveness is the ability for a methodology to be adapted or tailored towards the AFC mission. Many existing methodologies are fixed and allow no room for altering formatting, weights, or scaling. During evaluation of the remaining three methodologies, being able to modify these with minimal effort is the most desirable to TRAC.

#### *a. Decision Analysis Methodologies—AHP Methodology*

The first methodology evaluated is the Analytic Hierarchy Process (AHP). As described in Chapter two, AHP can carry out multiple levels of criteria, but the complexity of the calculations increase with each successive level of analysis.

AHP is not considered simplistic for this project due to the large amount of levels and variables you will have. When constraints are considered along with criteria and alternatives that are being decomposed into a hierarchy, it will add undesired complexity that could confuse users and leadership (Hass and Meixner 2005).

In respect to objectivity, the AHP model can benefit from independent inputs and multiple levels of criteria, which can reduce biases. It then uses quantitative numbers for measurement and converts them to qualitative values. If a project were evaluated on cost data as a criteria, AHP would then favor the project with the lowest cost (Hass and Meixner 2005). The conclusion is that AHP is objective.

When considering qualitative analysis, AHP has the potential to rank order projects when the inputs are reduced to normalized numeric values. However, AHP establishes a prioritization based on hierarchical factors by evaluating and analyzing them against preferred criteria. Most of the AFC data available for upcoming technology development projects is qualitative, not quantitative. A “comparison may use concrete data from the alternatives or human judgments as a way to input” subjective information (Vargas 2014, 4). The conclusion is that AHP is qualitative.

In respect to adaptability, there is some degree of variability that can applied to scenarios and projects; however, AHP lacks adaptability because it is generally used in sequential order with little deviation. Because of the inability to optimize on a selected variable, and make recommendations of projects when constraints exist, such as a limited budget, make it less adaptable (Greiner and Fowler 2004). The AFC contends with a myriad amount of constraints and conditions that need to be tailored toward missions, which increases their desire for adaptability. The conclusion is that AHP is not adaptable.

#### *b. Optimization Type Methodologies—Boeing Methodology*

A great example of an optimization type methodology is from a Boeing example taken from the article "Technology Portfolio Management: Optimizing Interdependent Projects over Multiple Time Periods." Its objective is to quantify and account for interdependencies between multiple projects within the Boeing Company. The value methodology categorizes projects and places them into a non-linear model. It considers all identified risks, how they relate to a desired objective, cost projections, and return on investments.

When considering simplicity of use, there are multiple variables that feed into the evaluation process and numerous interdependencies which make it very challenging for non-technical professionals to utilize. Additionally, it would be challenging to brief evaluation results to leadership due to the complexity and variety of metrics that feed into the process. It consists of many approval gates that expand from concept through implementation. The Boeing Company has traditionally accounted for many interdependencies and risks when implementing its valuation methodology. These interdependencies are referred to as the dependency network. In some cases, the network had too many links, and/or associated variables which often made it difficult to interpret, and confusing those responsible for making decisions (Dickinson 1999). Due to the interdependencies and complexity of the multiple variables, the Boeing methodology is not simplistic.

Regarding objectivity, the methodology can support many various projects across other portfolios deploying common formulas, which provide a consistent objective method of measurement. Each project is rated on its probability of success, strategic alignment, and risk (Dickinson 1999). The broad criteria eliminate biases when evaluating projects.

Even though there are interdependencies between criteria, the quantitative data input into the methodologies eliminates any biases due to it being external from any human influence. Taking this into consideration, the Boeing methodology is objective.

When considering qualitative application, the Boeing methodology requires inputs from historical or real time data, and it requires a method of quantitative measurement. Its application to the AFC mission is not desirable given the multiple unknowns with typical technology development projects, making it unsuitable for a qualitative applications.

In respect to adaptability, there are countless variables and interdependencies required for the Boeing methodology. This makes it challenging to be modified and still meet its purpose. The study states the Boeing methodology is an optimization model which "identifies the funding strategy that maximizes the estimated financial return of the portfolio subject to the portfolio balance and budget constraints" (Dickinson 1999). The inputs of this optimization model must use existing data and a dependency matrix, which make it incompatible for AFC. It cannot compute qualitative data, nor can it convert quantitative to qualitative. The conclusion is that the Boeing methodology is not adaptable.

#### *c. Scoring Methodologies—Parnell Methodology*

Scoring type models are inherently simple to use (Moore and Baker 1969). The users of the model are selected for their expertise in the criteria they will evaluate. The designers of the model prepare questionnaires with set standards for the user to base their evaluations on. Users do not need training on sampling or model design. They are asked to express expert opinions in a set format within their field of expertise. Because for the clear and open method of data collection the scoring type model produces results that are understandable to common users and easily briefed to decision makers. From the total score the data can be drilled into to explain what features of a program scored well and what did not. This aids in explaining the "why" of the decision (Moore and Baker 1969).

With regards to objectivity, well designed scoring models exhibit low bias (Parnell, Driscoll, and Henderson 2011). The ability to drill down in the data supports strong objectivity. The raw scoring of each criteria is normally done by multiple experts. Dispersion in the scores provides for opportunities to review who produced what score.

From here users can discuss and come to an understanding of why each score was generated. Data outliers can be identified and either acknowledged or corrected. Although subjectivity is required in evaluating technology development projects, scoring models provide an opportunity to limit self-serving or unsubstantiated opinions (Parnell, Driscoll, and Henderson 2011).

When measuring qualitative data a scoring model can provide accurate results (Henriksen and Traynor 1999). Technology development projected, especially this early in their life cycle, are difficult to forecast. Many of the characteristics that define value (cost, return on investment, time to market) are inaccurate or unpredictable (Henriksen and Traynor 1999). The best source of data is a carefully collected qualitative score. A well designed scoring type model allows for the use of qualitative data to produce valid results (Henriksen and Traynor 1999).

Considering adaptability, scoring models are very adaptable. Once the basic model is built there is great flexibility to adjust value measures (those discrete items that are scored), the criteria used to score those value measures or who will be asked to provide those scores (Moore and Baker 1969). These can be adapted to the current situation and used to fine tune the model as changes occur. Additionally, once the scores have been normalized they easily lent themselves to scaling and weighting allowing increased flexibility (Parnell, Driscoll, and Henderson 2011).

#### *d. The Comparative Analysis Results*

The three methodologies final evaluation against all the criteria is presented in Table 8. Taking all of the evaluation factors of the criteria into consideration, the scoring methodologies (like the Parnell methodology) is the only methodology that met all of the evaluation criteria. It could definitely serve as a functional basis for the AFC decision-making methodology and be tailored towards the AFC mission. A modified methodology would complement the AFC decision-making process, provide a simplistic method to be utilized by the end-user, and provide relevant data to top-level decision makers when evaluating projects.

Table 8. Comparative Analysis Results

| Methodology Type | Evaluation Criteria | | | |
|---|---|---|---|---|
| | Simplistic | Objective | Qualitative | Adaptive |
| Decision Analysis Methodologies (AHP) | No | Yes | Yes | No |
| Optimization Type Methodologies (Boeing) | No | Yes | No | Yes |
| Scoring Methodologies. (Parnell) | Yes | Yes | Yes | Yes |

### 2. The Future Assessment Capability Tool (FACT)

The most suitable methodology was identified as the Parnell methodology, the next step was to develop a tool to demonstrate the methodology. The demonstration model of a prioritization tool was developed by the capstone team and was aptly named the FACT. It demonstrates how the methodology would address the most critical issues that affect existing and forecasted technology development projects in AFC.

There were minor modifications to the Parnell methodology, specifically how weighting was implemented. A typical Parnell methodology makes use of a swing weight matrix, which would require some knowledge of how to build and use matrices; by use of the sequential tabs in an Excel spreadsheet and requiring minimal weighting data input, the knowledge of matrices is no longer required, which will be further explained in detail. The modified Parnell methodology concepts were used to build the demonstrative beta version of FACT. The methodology used was based on the qualitative value hierarchy model that was previously defined. The use of scaling and weighting functions tailor the output data towards any AFC priorities.

### 3. Scaling and Weighting

As discussed briefly earlier, for the sake of standardization and making user entry repeatable and easy, each value measure will be initially scored uniformly, meaning a raw score of one will always mean low value measure achievement, and a raw score of five will always mean high value measure achievement. At this point in scoring, there would be no value in the raw scores themselves. Some value measures like technical risk, constraints, and operational manpower have a negative meaning, such that a high value of five would not be desired when assigning value to the value measure. These types of value measures will have raw scores transposed by use of decreasing scaling functions when the scaling functions are applied to each value measure. Once the scaling functions are applied, each value measure would now be expressed in the perceived value of the scaled score; a high-scaled score would now be perceived as having high value for that inverse type of value measure.

There are several different scaling functions that may be applied to give the raw scoring meaning in relation to the desired perceived value for each value measure. Common scaling function shapes are shown in Figure 5. Each scaling function has a specific purpose to scale the data in a slightly different direction in order to align the output score to the intended result and aligning a high-scaled score with a high perceived value. Each value measure in FACT will have its own scaling factor to assign value specific to the value measure. The AFC would need to have SME validate each scaling function in a final version of FACT prior to use for the most applicable use of scaling functions. The notional scaling functions that will be used in FACT for each value measure will be discussed further in Chapter IV.

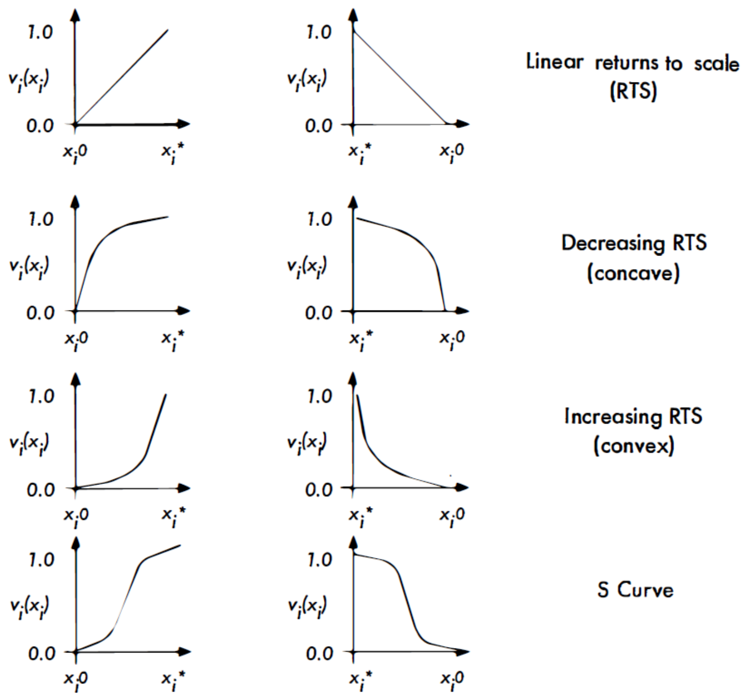



Figure 5. Scaling Functions. Source: Parnell, Henderson, and Driscoll (2011).

Weighting is used to align relative value measure priorities with the stakeholder point of view; however, Parnell uses a swing weighting process that requires user knowledge of matrix based weighting concepts and rules that govern it. Consequently, the capstone team modified the Parnell process to make it more intuitive and easier use than a typical swing weight matrix. To use this modified Parnell weighting approach, AFC would prioritize each value measure in FACT from the highest priority to the lowest priority-twelve being highest and one being lowest. There may be instances where particular value measures could be restrictive in priority. If this were the case, it would be acceptable and reflected accordingly. The value measure priority rankings would then be recorded and used to contribute to a one column linear weight matrix. The value measure priority rankings would then weight the relative importance of each scaled score for each value measure. For instance, this could mean that the highest priority value measure (a 12) could be inflated 12 times more important than the lowest priority value measure (a one) when weighting is applied. An inflated weight of that magnitude would be rather severe and would lean towards value measure bias. To correct this issue, a sensitivity factor was also incorporated into FACT to adjust the ratio between the highest and lowest weighting functions. That would mean the end user could now adjust sensitivity of the weighting to a more realistic 2:1 ratio or 3:1 ratio of importance between the highest and lowest priority value measures.

#### 4. Cumulative Project Values

Once a value measure raw score has a scaling function applied, the value measure scaled score will represent an initial value of that value measure for that project or program. The true value of the value measure score is only determined after the weighting function is applied to the scaled score by multiplying the weighting factor and the scaled value measure score. Once completed, this would now be the completed true value measure score. To calculate the total project value, an additive approach would be utilized towards each final value measure score, thus creating a total project value score. The project that achieves the highest total project value score would be prioritized first as the most valuable project. The remainder of the projects could be ranked according to their final total project value score, highest to lowest (Figure 6).

$$\text{Total Project Value Score} = v(x) = \sum_{i=1}^{n} s_i(x_i) * w_i$$

$i$ = 1 to n for the number of value measures
$x_i$ = the raw score of the $i$th value measure
$s_i$ = the scaling function for the $i$th value measure
$w_i$ = the weighting factor for the $i$th value measure

Figure 6. The Total Project Value Equation

To demonstrate FACT in Chapter IV, notional data will be input into FACT to help build confidence and understanding for how FACT could be used for AFC.

# IV. RESEARCH AND ANALYSIS

The chapter will utilize notional data for input into FACT, an attempt to demonstrate the effectiveness of the capstone team's modified Parnell methodology. Three different types of projects have been selected for a comparison of future projects from different types of portfolios. It will enable AFC to gain a firm understanding of the tool and its application for prioritizing system development projects. The conclusion of this study will demonstrate why the proposed methodology best suits AFC for evaluating both existing and forecasted technology development projects across multiple portfolios.

## A. NOTIONAL PROJECTS AND DATA

The following project examples were selected based on potential needs and challenges anticipated while conducting the AFC project value measurement and trade-off analysis processes. These projects represent our theory, which are measured, prioritized, weighted, and ranked for allocation of developmental resources.

1. Long Flight Unmanned Bomber Unmanned Aerial System (UAS) (LF-UBU): A UAS project designed to provide precision aerial first strike combat capability

2. Unmanned Light Tank (ULT): A Ground Combat Vehicle (GCV) project designed to provide armored direct fire capability in support of inserted infantry combat operations

3. Single Channel Ground and Airborne Radio System (SINCGARS) Update Version 20.5: A combat communications project designed to integrate all battlefield command and control assets

These projects are a small representation of project types that AFC has been required to evaluate, which has been hard to do in the past due to the high amount of variability in what makes a project valuable to the warfighter. They were derived from trending Army R&D subjects with extrapolated future capabilities (AFC 2020). The projects selected for demonstrating are aligned with three different cross-functional teams currently defined under AFC's organizational structure.

The following process flow illustrates the steps used in demonstrating the value measures analysis methodology. The FACT consists of a single Microsoft Excel workbook, which consists of seven worksheets containing formulas and data entry procedures to process data. The operational workflow of FACT is represented in Figure 7 as well as a descriptive list following it. The notional data for each of the project examples used in FACT is listed in Table 9.

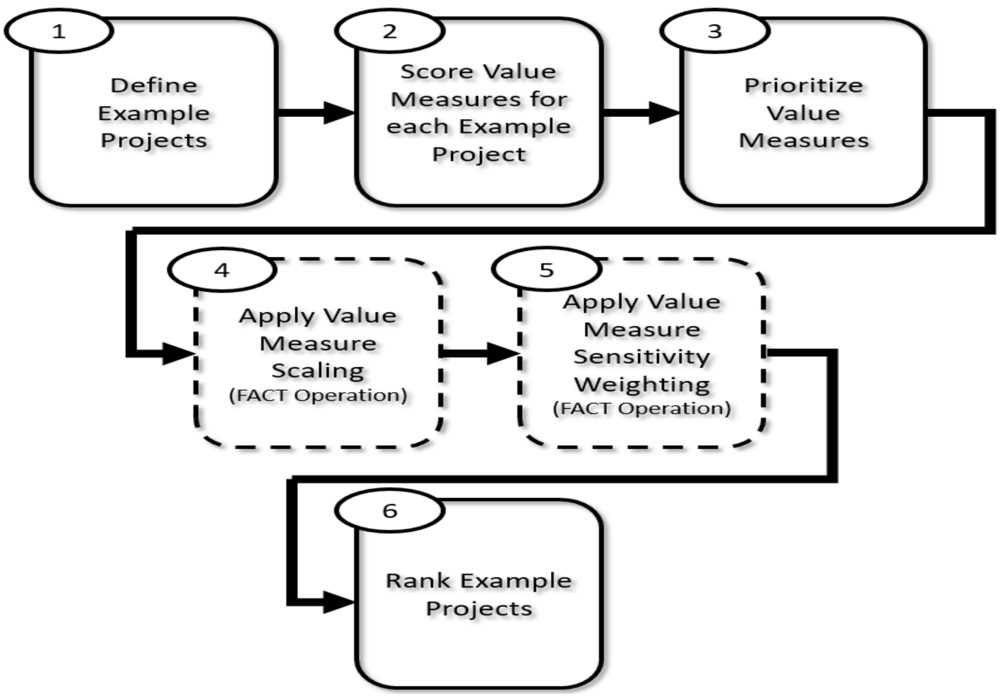



Figure 7. FACT Operational Workflow

1. List and define all example projects to be evaluated (Project Type, Project Control Numbers, and Project Nomenclature).

2. Score all value measures based on the level of value measure achievement for each of the projects, using the values of one (lowest) to five (highest).

3. Prioritize each of the value measures from 12 (highest priority) to 1 (lowest priority), and select a weighting sensitivity ratio between the highest and lowest priority value measures.

4. FACT will automatically apply value measure scaling based on each predetermined value measure scaling function.

5. FACT will automatically apply value measure weighting based on the previously selected value measure priorities and the overall sensitivity ratios from step 3.

6. The example projects are ranked based on FACT data output of perceived project value.

Table 9. The Notional Value Measure Data

| Value Measure | Project Name | | |
|---|---|---|---|
| | Long Flight Unmanned Bomber UAS | Unmanned Light Tank | SINCGARS Update Version 20.5 |
| 1.1.1 Technical Risk | 4 | 5 | 1 |
| 1.1.2 Constraint | 3 | 3 | 2 |
| 1.2.1 Schedule | 3 | 3 | 4 |
| 1.2.2 Availability | 4 | 3 | 4 |
| 2.1.1 Threats | 1 | 2 | 3 |
| 2.1.2 Domains | 3 | 2 | 4 |
| 2.2.1 Compatibility | 5 | 4 | 5 |
| 2.2.2 Modularity | 3 | 2 | 4 |
| 3.1.1 Integration | 4 | 2 | 5 |
| 3.1.2 Affordability | 2 | 2 | 4 |
| 3.2.1 Sustainment | 3 | 3 | 5 |
| 3.2.2 Operational Manpower | 5 | 4 | 2 |

When looking at the notional value measure data of all three projects, the SINCGARS appears it should come out the best of the three programs when comparing the raw scores in the three highest priority categories (Technical Risk, Availability, and Threats). It has by far the lowest Technical Risk, a value of one compared to four for the Bomber and five for the Tank. For Availability it shares the high score of four with the

Bomber. For Threats, SINCGARS beats the other projects with a high score of three. SINCGARS leads the next three highest priority categories (Domains, Modularity, and Compatibility) as well. Predicting the 2nd and 3rd place projects would take a little more evaluation; it appears close when looking at the top six priority categories. Now the capstone team will demonstrate FACT to see if it comes to the same conclusions, ranking the SINCGARS project as the most valuable.

The notional data will be inserted into FACT. The data used best represented the advantages, disadvantages, and challenges anticipated to develop, integrate, and deploy the notional projects. These attributes are typically measured, prioritized, weighted, and ranked before making a program resource decision. What follows is the rationale behind the notional data used for each project.

## B. LF-UBU PROJECT NOTIONAL DATA RATIONALE

1.1 Capability: Technical Risk, Constraint

1.1.1 Technical Risk: The raw score of 4 or “moderately high” technical risk was given to LF-UBU as a technology will need to be developed to reduce the fuel consumption required for long range flights to accommodate the heavier weight of the munition.

1.1.2 Constraint: The raw score of 3 “moderately” risk of constraint was given to LF-UBU. Although there are qualified experts available in the UAS industry, there are risks associated with the raw materials required to support alternate fuel development options for a heavy weight configuration.

1.2 Feasibility: Schedule, Availability

1.2.1 Schedule: The raw score of 3 or “moderate schedule assurance” was given to LF-UBU. Although the separate schedules provided for the UAS and the munition were well-developed, the schedule for the integration of the system lacked clarity.

1.2.2 Availability: The raw score of 4 or “moderately high” risk was given to LF-UBU based on a 25% probability the system will be available prior to the risk of the threat.

2.1 Versatility: Threats, Domains

2.1.1 Threats: The raw score of 1 or “low” was given to LF-UBU based on the assessment that it is unknown if the system will be able to respond a threat in the MDO environment.

2.1.2 Domains: The raw score of 3 or “the system can perform in one domain” was given to LF-UBU as it will not perform air-to-air operations; it will only perform air-to-ground.

2.2 Interoperability: Compatibility, Modularity

2.2.1 Compatibility: The raw score of 5 or “high compatibility” was given to LF-UBU due to it being completely compatible with existing systems the Army, Air Force, and the Navy.

2.2.2 Modularity: The raw score of 3 for “moderate modularity” was given to LF-UBU although it has some modularity with other UAS platforms components, but it is limited with the configuration changes and weight restrictions to adapt a majority of existing components.

3.1 Implementation: Integration, Affordability

3.1.1 Integration: The raw score of 4 or “moderately high ease integration” was given to LF-UBU due to its ability to integration into the Future Airborne Capability Environment (FACE) open avionics standards. It has some limitations with the integration into ground operating systems.

3.1.2 Affordability: The raw score of 2 or “moderately low system affordability” was given to LF-UBU resulting from increased cost due to the potential of some higher life cycle material expenses.

3.2 Supportability: Sustainment, Operational Manpower

3.2.1 Sustainment: The raw score of 3 or “moderate sustainability” was given to the LF-UBU system. The IPS element sustainability is considered moderate because the existing UAS and munitions are easily supported, but there are some difficulties measuring sustainment requirements for the alternate fuel option.

3.2.2 Operational Manpower: The raw rating of 5 or "moderately high operational manpower requirements" was given to LF-UBU as the system will require a new MOS and increase in personnel to support the new long-range lighter fuel alternative option.

## C. ULT PROJECT NOTIONAL DATA RATIONALE

1.1 Capability: Technical Risk, Constraint

1.1.1 Technical Risk: The ULT is in its second phase of development. However, challenges in meeting unmanned operational requirements pose a substantial level of technical risk at this time. Consequently, the project was given a raw score of 5 or "high risk" to develop a technical solution.

1.1.2 Constraint: The raw score of 3 or "moderate risk of constraint" was assigned to the project. Given the qualified resources, institutions, and facilities available for program utilization.

1.2 Feasibility: Schedule, Availability

1.2.1 Schedule: The raw score of 3 or "moderate for adhering to the development schedule." Due to the existence of alternative functional / physical definitions the project has potential, more flexibility in meeting the development schedule.

1.2.2 Availability: The raw score of 3 or "moderate for resource availability." Given the historical research performed to date, the likelihood of the project being available to meet the time line of the emerging threat.

2.1 Versatility: Threats, Domains

2.1.1 Threats: The raw score of 2 or "can easily respond to a single defined threat" was assigned to the ULT project. The ability to counter an active AFV threat.

2.1.2 Domains: The raw score of 2 or "can easily perform in a single defined domain" was assigned to the ULT project. The ability to effectively perform on stable, irregular, and littoral ground.

2.2 Interoperability: Compatibility, Modularity

2.2.1 Compatibility: The raw score of 4 or "moderately high compatibility" was assigned to the ULT project given the program is in its second phase of development. Many compatibility issues with other support systems were resolved during the first phase of the development program.

2.2.2 Modularity: The raw score of 2 or "moderately low modularity" was assigned to the ULT project. It's anticipated that the new transmission will not be as modular as first anticipated.

3.1 Implementation: Integration, Affordability

3.1.1 Integration: The raw score of 2 or "moderately low in ease of integration" was assigned to the ULT project. This is due to recently discovered issues discovered while integrating a new LDAR technology with the current drive system software.

3.1.2 Affordability: The raw score of 2 or "moderately low in program affordability" was assigned to the ULT project. This is based on an updated estimate, projecting a 25% growth in anticipated development costs.

3.2 Supportability: Sustainment, Operational Manpower

3.2.1 Sustainment: The raw score of 3 or "moderately sustainable" was assigned to the ULT project. Initial maintainability analysis suggests the project will meet some supportability targets.

3.2.2 Operational Manpower: The raw rating of 4 or "moderately high operational manpower requirements" was assigned to the ULT project. Early ILSC man power loading analysis suggests the project will require less personnel to deploy and maintain than originally estimated.

## D. SINCGARS PROJECT NOTIONAL DATA RATIONALE

1.1 Capability: Technical Risk, Constraint

1.1.1 Technical Risk: The raw score of 1 or "low" technical risk was given to SINCGARS due to the assumption that this version will be a minor update to the proven technology.

1.1.2 Constraint: The raw score of 2 or "moderately low" risk of constraint was given to SINCGARS given the highly qualified human resources, institutions, and facilities available for utilization. However, some risk is assumed given the fact that the industry is very competitive and resources are in high demand.

1.2 Feasibility: Schedule, Availability

1.2.1 Schedule: The raw score of 4 or "moderately high schedule assurance" was given to SINCGARS because the provided project schedule provided was detailed, but also very adaptable and flexible depending on the available resources and funding structures at the time of project initiation.

1.2.2 Availability: The raw score of 4 or "moderately high resource availability" was given to SINCGARS as it was believed that the project would be available before the threat maturity date.

2.1 Versatility: Threats, Domains

2.1.1 Threats: The raw score of 3 or "can respond to two threats" was given to SINCGARS as it allows the warfighter to respond to threats on the ground and in the air.

2.1.2 Domains: The raw score of 5 or "can perform in two domains" was given to SINCGARS as it will perform in the Ground and Air domains.

2.2 Interoperability: Compatibility, Modularity

2.2.1 Compatibility: The raw score of 5 or "high compatibility" was given to SINCGARS due to it being completely compatible with all existing systems the Army and NATO currently use.

2.2.2 Modularity: The raw score of 4 or “moderately high modularity” was given to SINCGARS as the project will be designed based on the current SINCGARS Modular Open Systems Approach (MOSA).

3.1 Implementation: Integration, Affordability

3.1.1 Integration: The raw score of 5 or “high ease of integration w/SOS” was given to SINCGARS due to it being able to be integrated into a unit with ease as the operation. It will be very similar to the previous version in usage and functions.

3.1.2 Affordability: The raw score of 4 or “moderately high ‘like system’ affordability” was given to SINCGARS as the project was projected to cost within 5–10% of the previous version.

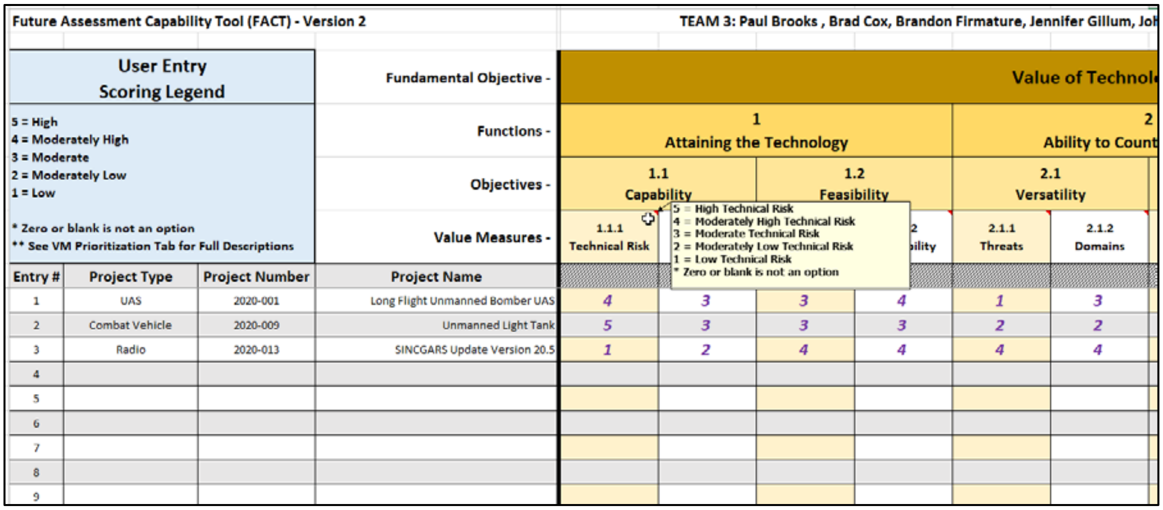
3.2 Supportability: Sustainment, Operational Manpower

3.2.1 Sustainment: The raw score of 5 or “highly sustainable” was given to SINCGARS due to the track record of previous versions.

3.2.2 Operational Manpower: The raw rating of 2 or “moderately low operational manpower requirements” was given to SINCGARS as the original version was over 30 years old and the training is already in place. Minimal new skills will be required to learn the updated version.

## E. FACT DEMONSTRATIVE WALK THROUGH

In the following paragraphs and figures, the capstone team will walk through the steps required in using FACT. Figure 8 illustrates the process of entering the value measure raw scores for each project into FACT under the first tab of the worksheet, labeled “(Input) Raw Entries.” The purple text color indicates which numbers were input into the worksheet.



Future Assessment Capability Tool (FACT) - Version 2

TEAM 3: Paul Brooks , Brad Cox, Brandon Firmature, Jennifer Gillum, Jo

User Entry Scoring Legend

5 = High
4 = Moderately High
3 = Moderate
2 = Moderately Low
1 = Low

* Zero or blank is not an option
** See VM Prioritization Tab for Full Descriptions

5 = High Technical Risk
4 = Moderately High Technical Risk
3 = Moderate Technical Risk
2 = Moderately Low Technical Risk
1 = Low Technical Risk
* Zero or blank is not an option

| | | | Fundamental Objective - | Value of Technol | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Functions - | 1 Attaining the Technology | | | | 2 Ability to Count | |
| | | | Objectives - | 1.1 Capability | | 1.2 Feasibility | | 2.1 Versatility | |
| | | | Value Measures - | 1.1.1 Technical Risk | | | 2 ility | 2.1.1 Threats | 2.1.2 Domains |
| Entry # | Project Type | Project Number | Project Name | | | | | | |
| 1 | UAS | 2020-001 | Long Flight Unmanned Bomber UAS | 4 | 3 | 3 | 4 | 1 | 3 |
| 2 | Combat Vehicle | 2020-009 | Unmanned Light Tank | 5 | 3 | 3 | 3 | 2 | 2 |
| 3 | Radio | 2020-013 | SINCGARS Update Version 20.5 | 1 | 2 | 4 | 4 | 4 | 4 |
| 4 | | | | | | | | | |
| 5 | | | | | | | | | |
| 6 | | | | | | | | | |
| 7 | | | | | | | | | |
| 8 | | | | | | | | | |
| 9 | | | | | | | | | |

Figure 8. “(Input) Raw Entries” Tab—MS Excel Worksheet

Next, on the second tab labeled “(Input) VM prioritization,” each value measure will be ranked by the TRP in order of highest to lowest priority. Priority is measured on a scale from 1 to 12, with 1 having the least priority and 12 having the highest priority. Each value measure will be ranked in priority of importance to best support AFC’s decision making process. Typically, not all value measures are equal in the view of the stakeholder. The measures are weighted in the additive value model to arrive at an overall value for selection of the most appropriate candidate solutions. These weights depend on the importance and variation of the stakeholder’s requirements.” (Parnell, Driscoll and Henderson 2011, 297). Table 10 identifies the notional priority ranking of the value measures, which will affect the weighting of each value measure in tab 3 of the FACT Excel workbook. The priority ranking is meant to be flexible, in order for the user/sponsor to account for the constant change in national security focus across different time periods. What may be a priority one year, may not be the same the next, and allows for emphasis to be placed where it needs to be. It is acceptable for any of the value measures to have a tie priority ranking. For demonstration purposes, in this case, Technical Risk, Availability, and Threats are all tied for top priority as indicated by having a ranking value of 12. Constraints and Operational Manpower are tied for the lowest priority by having a ranking of the value of 1. The reason for this particular notional ranking is to highlight the importance of certain measures, which were selected to demonstrate the flexibility of the model.

Table 10. Value Measure Prioritization

| Value Measure | Ranking of Importance |
|---|---|
| Technical Risk | 12 |
| Constraints | 1 |
| Schedule | 5 |
| Availability | 12 |
| Threats | 12 |
| Domains | 11 |
| Compatibility | 10 |
| Modularity | 11 |
| Integration | 9 |
| Affordability | 8 |
| Sustainment | 7 |
| Operational Manpower | 1 |

The shape of its distribution (curve) plays an important part in the normalization (scaling) of the final measurement scoring. Scaling functions will change the returns on each of the project example value measures to a scaled scoring number associated with a meaning of value. For simplicity, the scaling functions in FACT will follow five basic notional shapes to show how the scaling functions would be used in FACT. Once the scaling functions are applied, each value measure would now be expressed in the perceived value of the inputted score; a high-scaled score would now be perceived as having a high value for that value measure.

Table 11 identifies the notional population data used to calculate FACT value measure scaling. Figure 9 illustrates the resultant basic nominal shapes of the distribution curves used for value measure scaling. Figure 10 illustrates the applied scaling functions used to normalize the resulting value measure output. In a finalized FACT, the actual scaling functions would need to be supported by statistical data and be validated by an expert in the field represented by the value measurement. For some examples on how and why the raw scores are changed with scaling functions, look at the value measures of Compatibility, Technical Risk, Availability, and Threats in Table 12 for the SINCGARS project. The Availability example provides scaling at an increasing rate of return as more availability is achieved. The raw score is comparable to the intended value output, but as the raw score increases the value of Availability increases exponentially. This depicts that Availability is important to the stakeholder, so it is heavily rewarded.

Table 11. Scaling Function Output Values

| Raw Entry | Increasing Linear RTS Scaled Score | Decreasing Linear RTS Scaled Score | Increasing Decreasing RTS Scaled Score | Decreasing Decreasing RTS Scaled Score | Increasing Increasing RTS Scaled Score | Decreasing Increasing RTS Scaled Score |
|---|---|---|---|---|---|---|
| 1 | 1.0 | 5.0 | 5.0 | 1.0 | 5.0 | 1.0 |
| 2 | 2.0 | 4.0 | 4.8 | 3.0 | 3.0 | 1.2 |
| 3 | 3.0 | 3.0 | 4.2 | 4.2 | 1.8 | 1.8 |
| 4 | 4.0 | 2.0 | 3.0 | 4.8 | 1.2 | 3.0 |
| 5 | 5.0 | 1.0 | 1.0 | 5.0 | 1.0 | 5.0 |

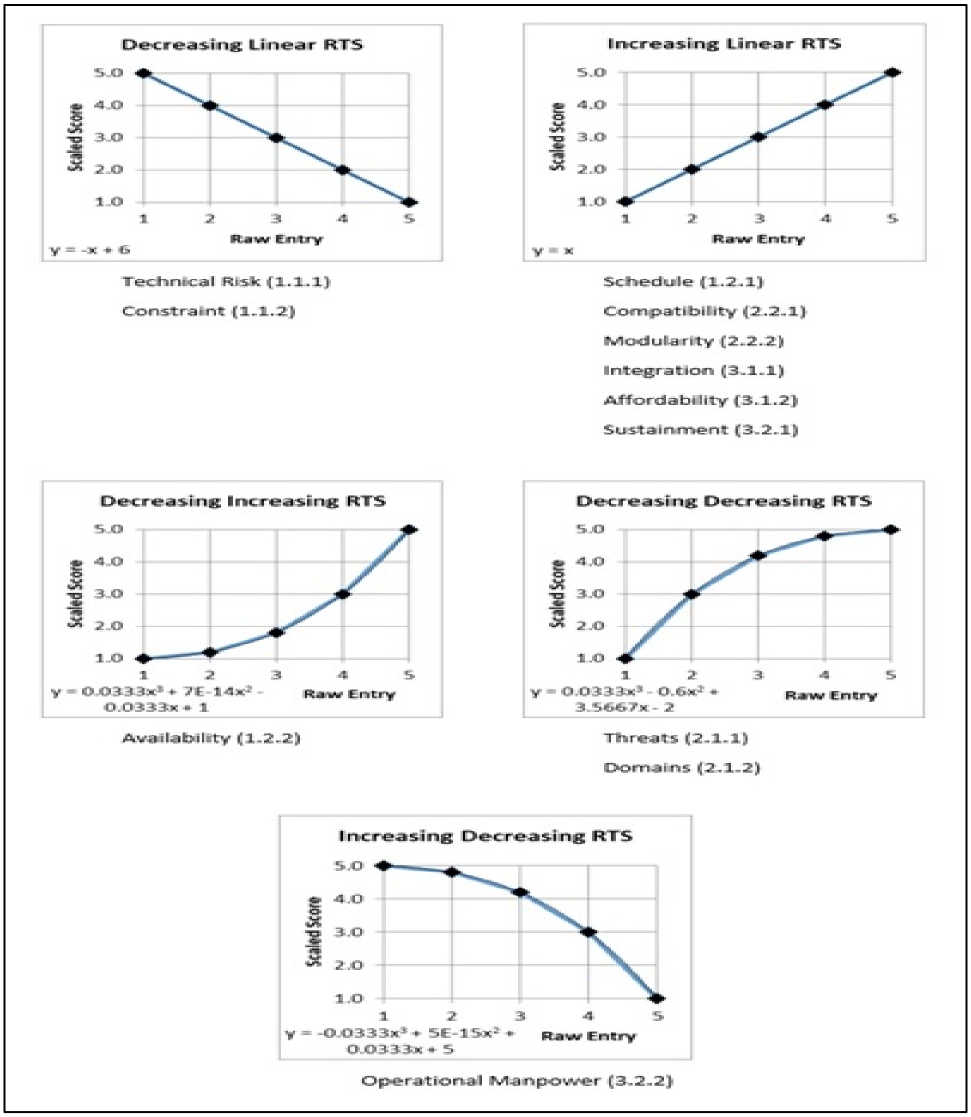



Figure 9. “Curve Builder” Tab—MS Excel Worksheet

| | | | Value Measures - | 1.1.1 Technical Risk | 1.1.2 Constraint | 1.2.1 Schedule | 1.2.2 Availability | 2.1.1 Threats | 2.1.2 Domains | 2.2.1 Compatibility | Mo |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Value Function Model - | | | | | | | | |
| Entry # | Project Type | Project Number | Project Name | | | | | | | | |
| 1 | UAS | 2020-001 | Long Flight Unmanned Bomber UAS | 2.0 | 3.0 | 3.0 | 3.0 | 1.0 | 4.2 | 5.0 | |
| 2 | Combat Vehicle | 2020-009 | Unmanned Light Tank | 1.0 | 3.0 | 3.0 | 1.8 | 3.0 | 3.0 | 4.0 | |
| 3 | Radio | 2020-013 | SINCGARS Update Version 20.5 | 5.0 | 4.0 | 4.0 | 3.0 | 4.8 | 4.8 | 5.0 | |
| 4 | | | | | | | | | | | |
| 5 | | | | | | | | | | | |
| 6 | | | | | | | | | | | |
| 7 | | | | | | | | | | | |
| 8 | | | | | | | | | | | |

Figure 10. “(Output) VM Scaling” Tab—MS Excel Worksheet

Table 12. SINCGARS Scaling Functions Explained

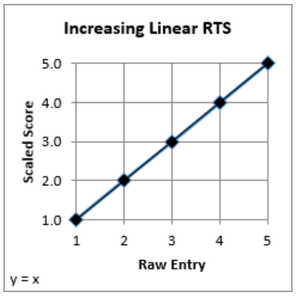
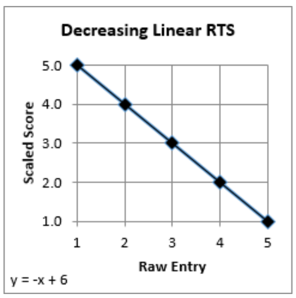
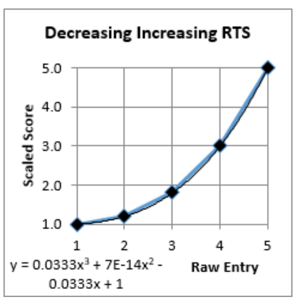
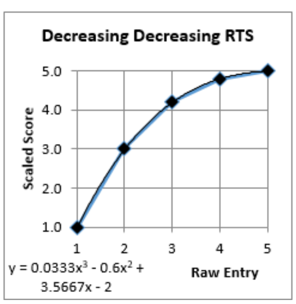
| Value Measure | Scaling Function Used | Raw Score | Scaled Score | Reasoning |
|---|---|---|---|---|
| Compatibility |  | 5 | 5.0 | Scaling provides a linear 1:1 return. The Raw Score matches the intended value output. The value of more Compatibility is linear in nature as more Compatibility is achieved. Having a low Compatibility is a bad thing and is discouraged. |
| Technical Risk |  | 1 | 5.0 | Scaling provides an inverse linear 1:1 return. The Raw Score has the inverse meaning of the intended value output. The value of more Technical Risk is linear in nature as less Technical Risk is achieved. Having a high Technical Risk is a bad thing and is discouraged. |
| Availability |  | 4 | 3.0 | Scaling provides an increasing rate of return as more Availability is achieved. The Raw Score has a similar meaning of the intended value output, but the value increases at a higher rate as the Raw Score increases. The value of more Availability is exponential in nature as more Availability is achieved. Having very high Availability is a good thing and rewarded heavily. |
| Threats |  | 4 | 4.8 | Scaling provides an increasing rate of return as more Threats are achieved. The Raw Score has a similar meaning of the intended value output, but the value decreases at a slower rate as the Raw Score increases. The value of more Threats is polynomial in nature as more Threats are achieved. Having very low Threats is a bad thing and heavily discouraged. |

Figure 11 shows how the value measures are weighted based on how they were prioritized in the "(Input) VM Prioritization" Tab. In this example, the highest priority value measures of Technical Risk, Availability, and Threats are weighted more important than the lowest priority value measures of Constraint and Operational Manpower, but by how much? This is where the sensitivity factor comes into play. By adjusting the sensitivity factor, the weighing will have an "identified magnitude" between the highest and lowest priority value measures. In this example with an arbitrary sensitivity factor of 4 selected, the highest priority value measures will now be weighted 4 times more than the lowest priority value measures. When FACT is used by AFC, they would have to collectively decide on a sensitivity factor that aligns with their organizations goals and objectives when it comes to value measure priorities, and how much more important the highest priorities are when compared to the lowest priorities. All the other value measures between the highest and lowest value measures will be linearly weighted accordingly. The only cell modified by the user in this tab is the sensitivity factor itself; everything else will be auto-populated based on previously selected value measure priorities.

| Value Measure | Adjusted Swing Weight | Measure Weight |
|---|---|---|
| 1.1.1 Technical Risk | 4.0 | 0.112 |
| 1.1.2 Constraint | 1.0 | 0.028 |
| 1.2.1 Schedule | 2.1 | 0.059 |
| 1.2.2 Availability | 4.0 | 0.112 |
| 2.1.1 Threats | 4.0 | 0.112 |
| 2.1.2 Domains | 3.7 | 0.104 |
| 2.2.1 Compatibility | 3.5 | 0.097 |
| 2.2.2 Modularity | 3.7 | 0.104 |
| 3.1.1 Integration | 3.2 | 0.089 |
| 3.1.2 Affordability | 2.9 | 0.081 |
| 3.2.1 Sustainment | 2.6 | 0.074 |
| 3.2.2 Operational Manpower | 1.0 | 0.028 |
| Total = | 35.7 | 1.000 |
| | | |
| Identified Sensitivity | 4 | |

| Typical Sensitivity Definitions are the following: |
|---|
| A value of ***6*** means the most important VM is up to ***6 times more important*** than the least important VM. |
| A value of ***4*** means the most important VM is up to ***4 times more important*** than the least important VM. |
| A value of ***3*** means the most important VM is up to ***3 times more important*** than the least important VM. |

Figure 11. "(Input) VM Weighting" Tab—MS Excel Worksheet

Figure 12 illustrates each scaled score multiplied by each value measure weight, which produces a final value score for each value measure. When each value measure score for each project is summed across the spreadsheet, a final project total value is calculated. Figure 13 illustrates the final ranking of the project examples within FACT. The project with the highest value number is the project determined to be the best value to AFC.

| 1.1.1 Technical Risk | 1.1.2 Constraint | 1.2.1 Schedule | 1.2.2 Availability | 2.1.1 Threats | 2.1.2 Domains | 2.2.1 Compatibility | 2.2.2 Modularity | 3.1.1 Integration | 3.1.2 Affordability | 3.2.1 Sustainment | 3.2.2 Operational Manpower | Project Total Value |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.112 | 0.028 | 0.059 | 0.112 | 0.112 | 0.104 | 0.097 | 0.104 | 0.089 | 0.081 | 0.074 | 0.028 | |
| Project Value Results for each Value Measure (Scaled Score X Measure Weight) | | | | | | | | | | | | |
| 0.224 | 0.084 | 0.176 | 0.336 | 0.112 | 0.438 | 0.483 | 0.313 | 0.356 | 0.163 | 0.221 | 0.028 | 2.9 |
| 0.112 | 0.084 | 0.176 | 0.201 | 0.336 | 0.313 | 0.387 | 0.209 | 0.178 | 0.163 | 0.221 | 0.084 | 2.5 |
| 0.560 | 0.112 | 0.234 | 0.336 | 0.537 | 0.501 | 0.483 | 0.417 | 0.445 | 0.326 | 0.369 | 0.134 | 4.5 |

Figure 12. "(Output) Project Values" Tab—MS Excel Worksheet

| Sort Rows to Rank Projects in order from Highest to Lowest Value | | | | |
|---|---|---|---|---|
| **Ranked Value** | **Project Value** | **Project Type** | **Project Number** | **Project Name** |
| 1 | 4.5 | Radio | 2020-013 | SINCGARS Update Version 20.5 |
| 2 | 2.9 | UAS | 2020-001 | Long Flight Unmanned Bomber UAS |
| 3 | 2.5 | Combat Vehicle | 2020-009 | Unmanned Light Tank |

Figure 13. “(Output) Project Ranking” Tab—MS Excel Worksheet

In summary, FACT calculates the final value of each value measure by the input of the initial value measures (for each of the projects), application of a scaling factor, and multiplying them by a weighting factor based on value measure prioritization and sensitivity selection. The final value measure scores are then summed up and recorded in the (Output) Project Values tab in the worksheet. This in-turn calculated a Total Value of each of the example projects selected for this demonstration. The output of the (Output) Project Values tab worksheet is then fed into the (Output) Project Ranking tab, which re-orders (ranks) each of the projects based on their calculated total project value, from highest to lowest.

THIS PAGE INTENTIONALLY LEFT BLANK.

# V. CONCLUSIONS AND RECOMMENDATIONS

## A. CONCLUSIONS

The problem the capstone team is solving for AFC is to pinpoint a methodology to assist with prioritizing a variety of different types of future programs against future threats while remaining theater agnostic, scalable, and in alignment with MDO to enhance combat capability. The methodology needed to determine the projects with the best value to invest resources and funding. Additionally, the methodology needed to remain very simple to use and flexible to accommodate changes in future requirements. The FACT demonstrated a possible solution for AFC that met the provided AFC requirements.

The results of FACT conclude that the SINCGARS project had the highest value, winning the simulated competition for resources. These results are explained by taking into account the notional data value inputs and notional priority inputs. The results from FACT were compared to when the capstone team critically looked at the projects independent of placing the data through the model and resulted in the same conclusion. SINCGARS ranked the highest, the FB-UBU came in second, and the ULT third, but much closer to each other than the first place winner. Since SINCGARS came out on top in both methods it gives a degree of confidence that FACT will be able to accurately rank projects with a higher sample size.

An additional benefit of FACT is that it provides a record of how the decision was made. A review of the summarized scores allows users to quickly compare projects. The value measure scores for each project indicates its strengths and weaknesses in that measure. This information can be used to provide a basis for explaining the ranking of the projects and justifying project priorities.

## B. LIMITATIONS AND RECOMMENDATIONS

As currently constructed FACT should be used to prioritize projects for AFC. However, due to limits on scope and time available, there are several significant aspects of the process that were not addressed. These will require further effort to fully implement FACT.

The TRP is a key element of FACT. The TRP will review all project submittals and score the various projects. Their insights and opinions drive the evaluation of the subjective criteria. The size and skill set of the TRP will affect the TRP's ability to express sound opinions on the various value measures. The number of persons and the skills represented must be fully considered to ensure the TRP has a sufficient knowledge base to evaluate each technical field and each value measure.

The FACT as it is currently designed uses a mathematical average of the TRP's scores for each value measure per project. As a future improvement to the process, data continuity checking can be added. This would identify scores that are inconsistent with the scores of other members on a specific value measure and project. Disparate scores may be the result of differing opinions and valid to average in. They may also represent uneven knowledge across the panel and require discussion to accurately produce a final score. A process to identify and resolve inconsistent scoring would improve the quality of the FACT results.

The spreadsheet tool used by FACT to collect data can be altered or enhanced. During trial runs of data collection, one improvement was identified. Protect all fields except those required for data entry. During the trial runs, several users inadvertently modified formulas requiring additional work after the fact to consolidate scores.

The capstone team believes FACT demonstrated a logical result in prioritizing projects. To continue developing FACT, the next step would be to validate the model. Prioritizing projects is essential to AFC, but they will also have the option to accelerate, continue, or cancel the project. FACT produces a score based on a set of value measures. The score is not relative to other projects. Theoretically, there should be a point in the value score indicating when a project is high enough value to accelerate or low enough value to cancel. Additional research would be required to determine if these points exist.

A major limitation of FACT is that it does not account for the interaction of the various projects. There is the potential for synergies or conflicts between the projects.

For example, a long-range fire system and a sensor system individually may not score highly in FACT. If the outcomes of both projects considered together they may become a higher priority than either would individually. Future study is recommended on how to identify potential interactions among projects and how those interactions may be accounted for in FACT.

THIS PAGE INTENTIONALLY LEFT BLANK.

# LIST OF REFERENCES

Andrews, Charles G., and Jeff M. Allen. 2002. “Utilization of Technology-Enhanced Delphi Techniques.” *Workforce Education Forum* 29, (1): 1-15. https://digital.library.unt.edu/ark:/67531/metadc31077/m2/1/high_res_d/Allen-2002-Utilization_of_Technology-Enhanced_Delphi.pdf.

Army Futures Command. n.d. “About.” Accessed August 9, 2020. https://www.army.mil/futures#org-about.

Bitman, William R., and Sharif, Nawaz. 2008. “A Conceptual Framework for Ranking R&D Projects.” *IEEE Transactions on Engineering Management,* 55. no. 2 (May):267-278. https://doi.org/10.1109/TEM.2008.919725.

Bradley, Joanna. 2019. “AFC Commander Visits Aviation, Missile Center.” CCDC Aviation & Missile Center Public Affairs. April 11, 2019. https://www.army.mil/article/220037/.

Defense Acquisition University. n.d. S.v. “MOSA Community Definitions.” Accessed August 16, 2020. https://www.dau.edu/cop/mosa/Pages/Topics/Terms-and-Definitions.aspx.

Dickinson, Michael. 1999. “Technology Portfolio Management: Optimizing Interdependent Projects Over Multiple Time Periods.” *IEEE Transactions on Engineering Management*, 48. No. 4 (Nov):518-527. https://doi.org/10.1109/17.969428.

Dillon-Merrill, Robin, Gregory Parnell, Donald Buckshaw, William Hensley, Jr., and David Caswell. 2008. “Avoiding Common Pitfalls in Decision Support Frameworks for the Department of Defense Analysis.” *Military Operations Research 13,* (2) 19–31. https://www.jstor.org/stable/43920755.

DiMiero, Thomas, Michael Kee, Jacob Austin, Derek Johnson, and Ruben McCurdy. 2019. “USASOC Valuation Model.” Capstone Project, Naval Postgraduate School, 2019. https://calhoun.nps.edu/handle/10945/64017.

Department of the Army. 1986. *Concept Based Requirements.* TRADOC 11–15, Fort Monroe, VA. TRADOC.

———. 2018. *The U.S. Army in Multi-Domain Operations 2028*. TRADOC Pamphlet 525-3-1. Washington, DC: Department of the Army. https://www.tradoc.army.mil/Portals/14/Documents/MDO/TP525-3-1_30Nov2018.pdf.

Elbok, Ghizlane, and Abdelaziz Barrado. 2017. “Towards an Effective Project Portfolio Selection Process.” In *Proceedings of the International Conference on Industrial Engineering and Operations Management*. 2158–2169. http://ieomsociety.org/ieom2017/papers/508.pdf.

Feickert, Andrew. 2020. *Defense Primer: Army Multi-Domain Operations (MDO).* CRS Report No. IF11409. Washington, DC: Congressional Research Service. https://fas.org/sgp/crs/natsec/IF11409.pdf.

Greiner, Michael, and Fowler John. 2003. “A Hybrid Approach Using the Analytic Hierarchy Process and Integer Programming to Screen Weapon Systems Projects.” *IEEE Transactions on Engineering Management* 50, no. 2 (May): 192–203. https://doi.org/10.1109/TEM.2003.810827.

Haas, Rainer, and Oliver Meixner. 2005. “An Illustrated Guide to Analytic Hierarchy Process.” DocPlayer. https://docplayer.net/14799088-An-illustrated-guide-to-the-analytic-hierarchy-process.html.

Henriksen, Anne, and Ann Traynor. 1999. “A Practical R&D Project-Selection Scoring Tool.” *IEEE Transactions on Engineering Management* 46, no. 2, (May): 158–170. https://www.researchgate.net/profile/Anne_Henriksen4/publication/3076585_A_practical_RD_project-selection_scoring_tool/links/542953ea0cf2e4ce940c9ea0/A-practical-R-D-project-selection-scoring-tool.pdf?origin=publication_detail.

JohnSaunders. n.d. “A Comparison of Decision Accuracy in the Analytic Hierarchy Process and Point Allocation.” Accessed 12 March, 2020. http://www.johnsaunders.com/papers/ahpvpa/ahpvpa.htm.

Jolly, Dominique. 2003. “The Issue of Weightings in Technology Portfolio Management.” *Technovation* 23, no. 5 (May): 383–391. https://doi.org/10.1016/S0166-4972(02)00157-8.

Kinnunen, Tuomo, Aki Pekuri, Harri Haapesalo, and Pasi Kuvaja. 2011. “Business Case Analysis in New Product Development.” *Global Journal of Management and Business Research* 11. No. 2 (Feb) https://www.researchgate.net/publication/277760046_Business_case_analysis_in_new_product_development.

Krawiec, Frank. 2016. “Evaluating and Selecting Research Projects by Scoring.” *Research Management* 27. No. 2 (Mar):21–25. https://doi.org/10.1080/00345334.1984.11756823.

Loucks, Daniel P., and Eelco van Beek. 2017. “An Introduction to Optimization Models and Methods.” In *Water Resource Systems Planning and Management*, 93–177. Cham, Switzerland: Springer, Cham. https://doi.org/10.1007/978-3-319-44234-1_4.

Miller, Jean. 2002. “A Proven Project Portfolio Management Process.” Paper presented at Project Management Institute Annual Seminars & Symposium, San Antonio, TX. Newtown Square, PA: Project Management Institute. https://www.pmi.org/ learning/library/proven-project-portfolio-management-process-8503.

Modica, Jose, Rabechini Junior, and Edison Braun. 2010. “Prioritization of a Portfolio of Projects.” Paper presented at PMI® Global Congress 2010 — North America, Washington, DC. Newtown Square, PA: Project Management Institute.

Moore, John, and Norman Baker. 1969. “An Analytical Approach to Scoring Model Design — Application to Research and Development Project Selection.” *IEEE Transactions on Engineering Management* EM-16, no. 3 (Aug): 90–98. https://doi.org/10.1109/TEM.1969.6447060.

Newman, Joseph. 1971. *Management Application of Decision Theory.* New York: Harper & Row.

Olson D.L. 1996. “Smart. In: Decision Aids for Selection Problems. Springer Series in Operations Research. Springer,” New York, NY. Springer.

Padovani, Marisa, Antonio Muscat, Roberto Camanho, and Marly de Carvalho. 2008. “Looking for the Right Criteria to Define Projects Portfolio: Multiple Case Study Analysis.” *Product Management and Development* 6. no. 2 (Dec):127-134. https://www.researchgate.net/publication/291023893_Looking_for_the_ right_criteria_to_define_projects_portfolio_Multiple_case_study_analysis.

Parnell, Gregory, Roger Burk, Deborah Westphal, Aaron Schulman, Lauren Kwan, Jack Blackhurst, Phillip Verret, and Harry Karasopoulos. 2004. “Air Force Research Laboratory Space Value Technology Model: Creating Capabilities for Future Customers.” *Military Operations Research* 9, no. 1:5-17. https://www.jstor/stable/ 43940960.

Parnell, Gregory, Patrick Driscoll, and Dale Henderson. 2011. *Decision-making in Systems Engineering and Management.* Hoboken, NJ: John Wiley & Sons.

Patel Meera, Bhasker Bhatt, and Manisha Vashi. 2017. “SMART-Multi-criteria decision-making technique for use in planning activities.” Conference: New Horizons in Civil Engineering (NHCE-2017) March 2017. https://www.researchgate.net/ publication/315825133_SMART-Multi-criteria_decision-making_technique_for_ use_in_planning_activities.

Provost, Foster, and Gary M. Weiss. 2003. “Learning When Training Data are Costly: The Effect of Class Distribution on Tree Induction.” *Journal of Artificial Intelligence Research* 19. (October): 315–354. https://doi.org/10.1613/jair.1199.

Saaty, Thomas. 2008. *Decision Making for Leaders: The Analytic Hierarchy Process for Decisions in a Complex World*. Pittsburgh, PA: RWS Publications.

Saaty, Thomas, and Mujgan Sagir. 2009. “Extending the Measurement of Tangibles and Intangibles.” *International Journal of Information Technology & Decision Making* 8. no.1 (June): 7–27. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=1483438.

Schwartz, Lawrence, Roger Miller, Daniel Plummer, and Alan Fusfeld. 2011. “Measuring the Effectiveness of R&D.” *Research-Technology Management* 54, no 5 (Dec): 29–36. https://www.tandfonline.com/doi/abs/10.5437/08956308X5405008.

Sun, Yong-Hong, J. Ma, Z. Fan, and J. Wang. 2008. “A Group Decision Support Approach to Evaluate Experts for R&D Project Selection,” IEEE Transactions on Engineering Management 55. No. 1 (Feb): 158–170. doi: 10.1109/TEM.2007.912934.

Vargas, Ricardo. 2010. “Using the Analytic Hierarchy Process (AHP) to Select and Prioritize Projects in a Portfolio. Paper presented at PMI® Global Congress 2010—North America, Washington, DC. Newtown Square, PA: Project Management Institute.

# INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center
   Ft. Belvoir, Virginia

2. Dudley Knox Library
   Naval Postgraduate School
   Monterey, California