NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

MANAGING THE PUBLIC SECTOR RESEARCH & DEVELOPMENT PORTFOLIO SELECTION PROCESS: A CASE STUDY OF QUANTITATIVE SELECTION AND OPTIMIZATION

by

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September 2016

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13. ABSTRACT (maximum 200 words)

    This thesis presents a detailed process and model describing how public sector organizations can implement a research and development (R&D) portfolio optimization strategy to maximize the cost-adjusted benefit metric of a portfolio while simultaneously seeking to maintain and improve a national strategic technologic advantage. The model is applied to an R&D dataset from the FY 17 Naval Research Program (NRP) at the Naval Postgraduate School. The process presented follows a framework incorporating proposal filtering for initial selectivity, proposal weighting based on defined criteria and alignment with the organization's mission and purpose, proposal value and risk determinations, and concludes with portfolio optimization. The optimization's objective function sought to maximize the sum of a portfolio's cost-adjusted benefit calculation, subject to remaining within the NRP's research and development budget. The model effectively resulted in predominantly selecting proposals with medium, high and very high probabilities of success in the risk category and valuations predominantly in the medium, high and very high range. The completion of this thesis has provided a new perspective on R&D selection strategies for public sector investment and highlighted the challenges of placing a value on a public sector R&D proposal.

14. SUBJECT TERMS research and development, R&D, portfolio optimization, public sector valuation			**15. NUMBER OF PAGES** 55
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UU

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SELECTION AND OPTIMIZATION**

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN SYSTEMS ENGINEERING MANAGEMENT

from the

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LIST OF ACRONYMS AND ABBREVIATIONS

ACA   Affordable Care Act

CHIP   Children's Health Insurance Program

CNO   Chief of Naval Operations

DOD   Department of Defense

FY   fiscal year

GDP   gross domestic product

GPS   global positioning system

IRM   Integrated Risk Management®

KVA   knowledge value added

LCDs   liquid crystal displays

MROC   Marine Requirements Oversight Council

NASA   National Aerospace and Space Administration

NIST   National Institute of Standards and Technologies

NPS   Naval Postgraduate School

NPV   net present value

NRP   Naval Research Program

ONR   Office of Naval Research

R&D   research and development

R3B   Resources and Requirements Review Board

ROA   real options analysis

ROI   return on investment

S&T   science and technology

SMEs   subject matter experts

SoS   system of systems

TRL   technical readiness level

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ACKNOWLEDGMENTS

I would like to acknowledge and thank my thesis advisors for their continued support in the completion of this thesis. They provided insight from a variety of academic perspectives, which enhanced my thesis overall. I would also like to acknowledge and thank all the professors and my fellow cohort students whom I have encountered during the course of this Systems Engineering Management program. I have truly learned a great deal from each of you. Finally, I would like to thank my family for their continued support over the past two years—this has been a challenging program, and I couldn't have completed it without your support.

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I. INTRODUCTION

A. PROBLEM STATEMENT

Global technological advancements necessitate that the United States maintain its commitment to technology innovation to maintain preeminence in national security, global projection of power and private sector innovation. Secretaries of Defense and industry leaders alike have shared this commitment. Secretary of Defense Ash Carter has made a commitment "to the future—to stay ahead of a changing world, to stay competitive, to stay aware of new generations and attract them to our mission of serving the country, and to stay abreast of technology" (Carter 2015) and the American private sector has expressed its commitment to supporting technology development by outpacing federal R&D expenditures beginning in the late 1980s (Figure 1).

With the commitment and financial resources in place, the execution of public and private sector R&D expenditures requires a portfolio selection process to identify which R&D efforts are worthy of support. While there are numerous R&D portfolio selection models for the private sector (Henriksen 1999), models to perform the same function are not as straightforward for the public sector. Due to the inherent differences between the financial structures of public and private sector organizations (private sector organizations are profit-driven, whereas public sector organizations are not), this thesis presents an R&D portfolio selection process and optimization model for use by public sector entities seeking to maximize the value of their R&D efforts while reducing the risk of their R&D portfolios. The model also seeks to reduce the number of proposals and resulting time required for individual review. The resulting model includes proposal filtering, proposal weighting, proposal valuation, stochastic proposal risk assessments and optimization all designed to identify the best use of a public sector's limited resources. Finally, the model is applied to a public sector DOD case study.

B. CURRENT STATE OF R&D

Federally funded research and development (R&D) combined with private sector R&D investments result in technology advancements critical to the national economy and

the nation's defense. In particular, federal R&D funding has been a critical component in the overall American R&D system by providing the necessary funding to catalyze technology development in areas that may not otherwise receive private sector investment. Federal investment enables the possibility for R&D returns to far exceed the initial investment. For example, Larry Page and Sergey Brin developed the algorithm that ultimately became the Google search engine while the two were graduate students at Stanford and funded with a part of a $4.5 million National Science Foundation grant supporting a digital library effort (Lane 2012). The revolutionary Apple iPod leveraged lithium-ion battery technology, liquid crystal displays (LCDs), digital signal processing and magnetic storage devices, all of which were developed through federally funded basic research expenditures (Lane 2012).

Private sector R&D funding is also critical to an organization's success and competitiveness. In 2006, Microsoft spent $6.6 billion on R&D with Intel and IBM each spending approximately $6 billion on R&D efforts (The Economist 2007). Methods to place a value on these investments have been a lingering challenge, particularly for R&D efforts in the public sector.

1.   Domestic R&D Expenditures

R&D funding in the United States for both private and public sector entities is a limited resource facing perpetual budgetary pressure and contention from competing interests. Private sector resources invested in long duration R&D efforts reduce near-term profits. Therefore, decreasing R&D spending results in an immediate decrease in expenses and an increase in profits, which ultimately satisfies shareholders and corporate boards (Dugan 2013). Additionally, basic research is viewed as high risk and its output is difficult to value (Dugan 2013). R&D expenditures by the federal government, while closely aligned with private sector R&D funding from 1953 through 1988, peaked in 2009 at approximately $127 billion and have since continued to decrease through 2013 (National Science Foundation 2016) (Figure 1).
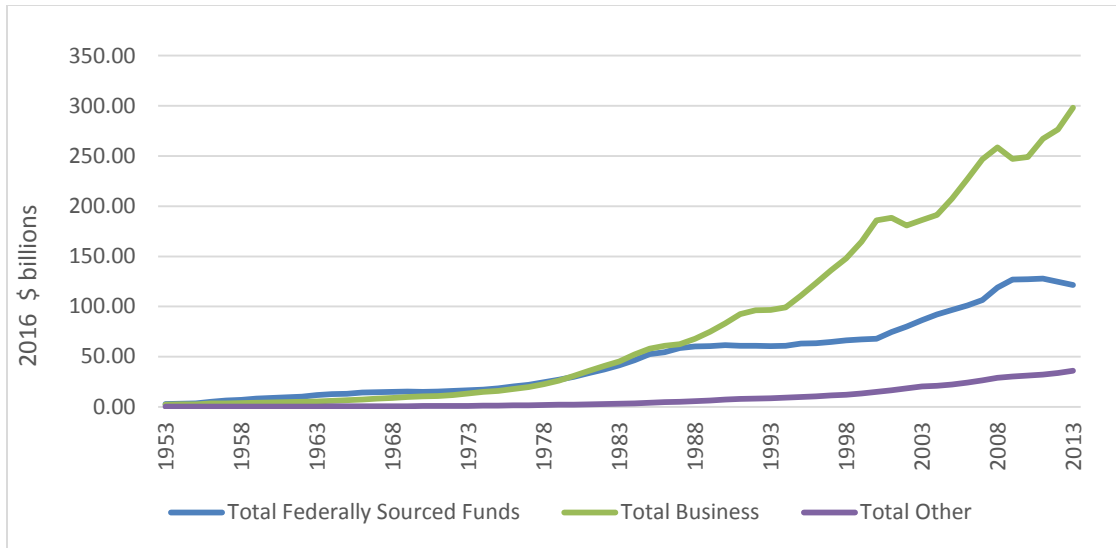
Figure 1.   U.S. R&D Expenditures, by Source of Funds: 1953–2013. Source:
National Science Foundation (2016).

In 1979, private sector spending surpassed federal R&D spending when viewed as
a total percentage of R&D expenditures (Figure 2) (National Science Foundation 2016).
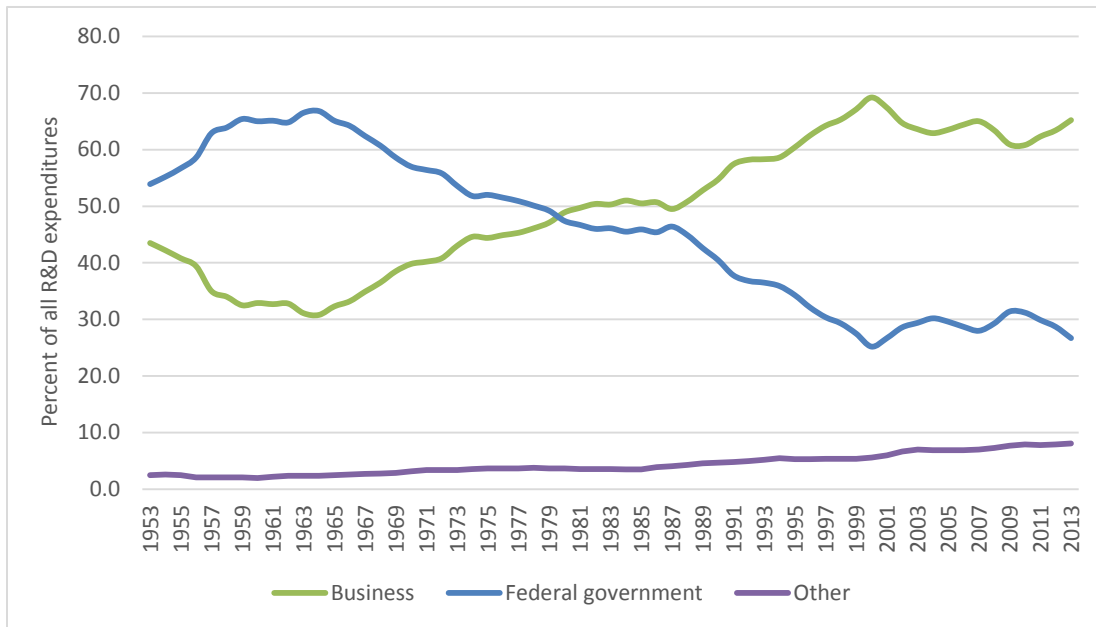
Figure 2.   U.S. total R&D Expenditures, by Source of Funds: 1953–2013. Source:
National Science Foundation (2016).

For general comparison purposes, in 2015, U.S. federal expenditures equaled $3.8 trillion (Figure 3). The three major expenses amount to $938 billion (25%) on Medicare, Medicaid Children's Health Insurance Program (CHIP) and the Affordable Care Act (ACA) marketplace subsidies, $888 billion (24% of the budget) on Social Security payments, and $602 billion (16%) on defense and international security assistance (United States Office of Management and Budget 2016) while in 2013 (the most recent figures available), the federal government spent approximately $122 billion on R&D.
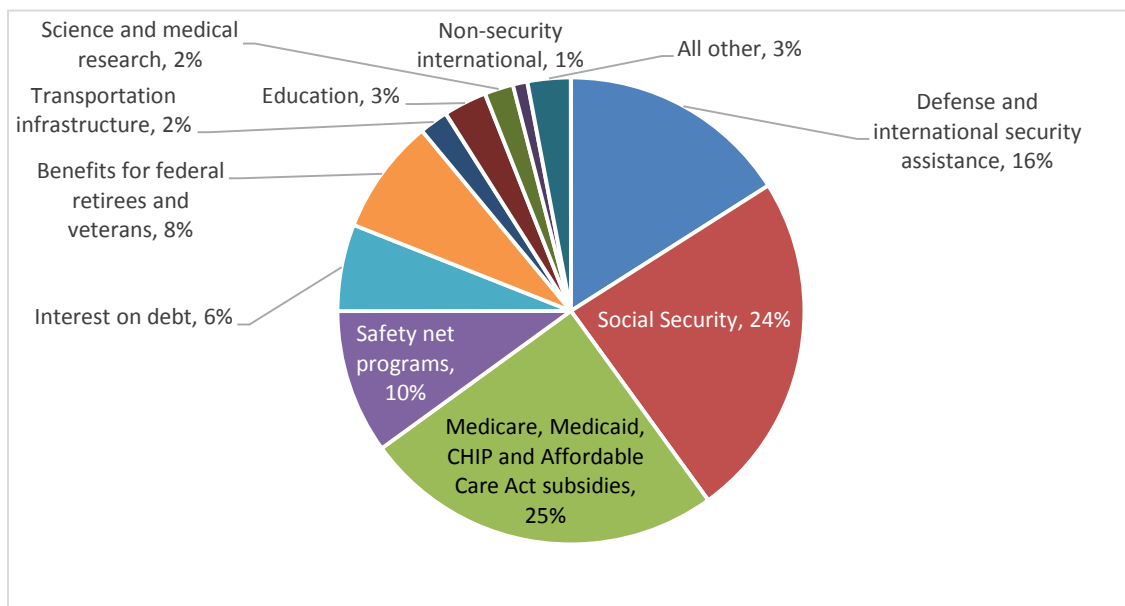
Figure 3.   United States Federal Budget for 2015. Source: Center on Budget and Policy Priorities (2016).

2.   International R&D Expenditures

The current state of international R&D funding provides insight into strategic efforts by allies of the United States, as well as near-peers and strategic competitors. While R&D expenditures by the United States lead international efforts, China is rapidly increasing its R&D expenditures as they emerge on the global stage (Figure 4). The United States' investments in R&D, as a percentage of its gross domestic product (GDP), remained relatively flat between 1981 and 2013, investing between 2.25% and 2.82% of

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GDP on R&D ($457 billion in 2013) (National Science Foundation 2016). For comparison, China invested 0.73% of its GDP on R&D in 1991 (the first year these figures were available for that country) and as of 2013, invested 2.08% ($336 billion in 2013), a 185% increase in 22 years (National Science Foundation 2016).
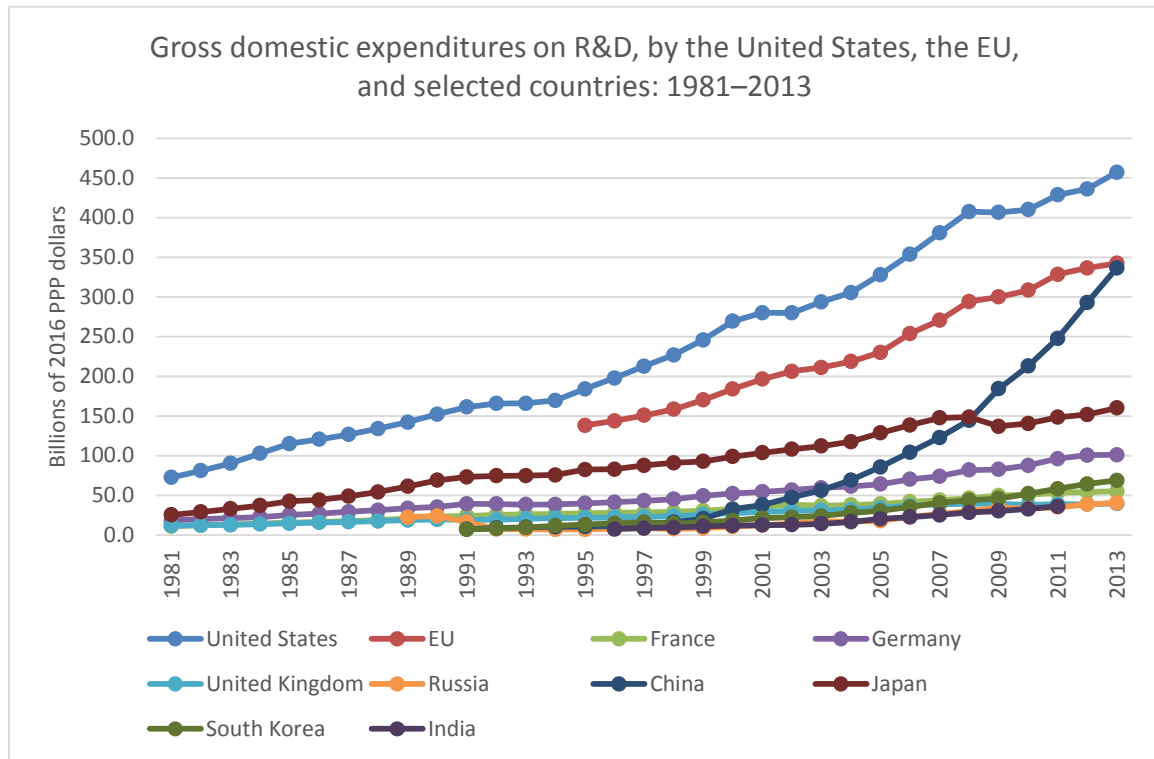
Figure 4.   China's Rapid Increase in Annual R&D Spending. Source: National Science Foundation (2016).

In response to the changing geopolitical landscape and increased R&D efforts by countries like China and Russia, the U.S. Department of Defense (DOD) has requested funding for a "third offset strategy" to develop capabilities enabling the military to counter an enemy despite rising global competition (Gady 2016; Eaglen 2016). As Secretary of Defense Chuck Hagel stated in his offset strategy announcement, "America does not believe in sending our troops into a fair fight" (Hagel, 2014). The DOD has sought $71.8 billion in the fiscal year 2017 budget to conduct R&D with $3.6 billion identified for the third offset strategy. This strategy has identified six specific investment areas to "identify and invest in innovative ways to sustain and advance America's

military dominance for the 21st century." These investment areas are: access and area-denial, guided munitions, undersea warfare, cyber and electronic warfare, human-machine teaming, and war gaming and development of new operating concepts (Hagel 2014). With billions of R&D dollars now allocated to invest in an R&D portfolio meeting the DOD's strategic objectives, selecting those investments in an effective manner becomes the next challenge.

C.   THE R&D PORTFOLIO SELECTION PROBLEM

The R&D portfolio selection problem is characterized by an abundance of R&D proposals of varying strategic fit, value and risk all seeking limited funding. Since funding entities often cannot fund all the submitted proposals, this thesis presents criteria to identify and select proposals meeting an organization's respective strategic goals.

The simplest strategy for R&D portfolio selection involves analyzing all proposals applying for funding in a given year by evaluating each against qualitative and quantitative criteria. Proposals are then prioritized against the total R&D budget. The highest ranked proposals within the budget are selected, and those falling outside the budget are either tabled until the following year or denied. This strategy, however, fails to factor the inherent value and risk associated with each proposal.

This thesis presents an alternative strategy involving the use of criteria to develop an optimization framework aiding proposal analysis and selection and providing a solution to the R&D portfolio selection problem. An optimized R&D portfolio selection process can play an important role in an organization's strategic success by enabling organizations to tailor the portfolio to align with their strategic needs. Just as with financial portfolios, portfolio analysis and optimization enables organizations to diversity their investments to maximize value and reduce risk across the portfolio. Through optimization, the pool of R&D proposals can be analyzed and an R&D portfolio can be identified and selected, meeting a funding entity's goals while maximizing their budget.

There are several R&D portfolio optimization strategies available to organizations. Most strategies, however, are better suited for the private sector due to their reliance on a calculation to determine a proposal's value. This valuation is used to

determine if the proposal should be included in the R&D portfolio and may use tools such as calculating a project's Net Present Value (NPV), Discounted Cash Flow (DCF), Return on Investment (ROI), or the use of real options (Mun 2006).

The methods available to public and private sector entities for R&D proposal valuation differ due to the nature of each entity. Private sector firms are measured by their financial performance and position within highly competitive sectors, so their R&D efforts value market applicability and profit. R&D efforts in the public sector, and the DOD specifically, have historically valued efforts delivering capabilities either exclusively intended or initially intended for national security use by the government such as stealth technology or global positioning system (GPS). In these public sector cases, traditional means of valuation do not apply due to the lack of a profit concept. In fact, traditional ROI valuation strategies for public sector R&D efforts were abandoned in the 1970s and 1980s by NASA and the National Institute of Standards and Technologies (NIST) due to "methodological problems" associated with efforts to calculate the outputs from R&D investment (United States Government Accountability Office 1997).

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II. R&D PORTFOLIO SELECTION MODEL

A. OVERVIEW

The research of this thesis culminates in the creation of a model that public sector entities can apply to their own R&D portfolio optimization problem sets. The model runs in Microsoft Excel, and incorporates relevant elements of Johnathan Mun's Integrated Risk Management (IRM) process. A visualization of the process is provided in Figure 5. The process begins with a funding organization creating the framework to establish a competitive R&D funding program. Subsequently, applicants seeking funding to complete R&D efforts must submit proposals to the program, creating the initial portfolio of proposals. From the initial portfolio, the proposals are filtered down and weighted, reducing and shaping the portfolio into a group of proposals meeting the funding organization's mission goals and strategic objectives. The filtered and weighted proposals are each assigned a value and risk profile, then run through an optimization model to identify the optimal portfolio makeup.
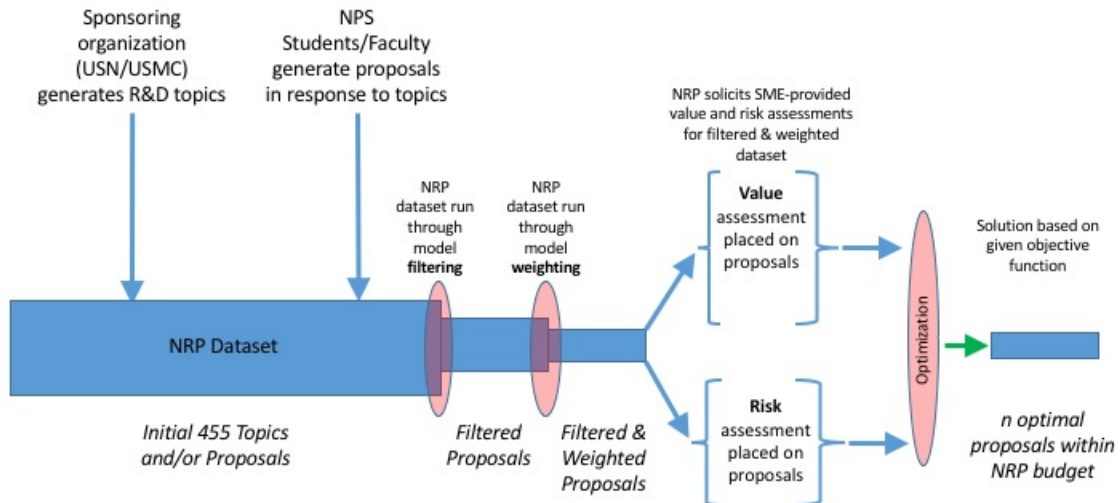
Figure 5.   Public Sector R&D Portfolio Selection Process

The model's goals are to provide public sector organizations seeking to identify an R&D portfolio with the means to make the most of their resources while reducing the risk they take on. The primary output of this process is an optimized R&D portfolio, meeting an organization's objective function. Secondary outputs include a means to reduce subjective decisions being factored into the portfolio, and a reduction in the amount of time spent manually reviewing proposals that do not meet an organization's criteria.

B.   INTEGRATED RISK MANAGEMENT PROCESS

Mun's IRM provides a comprehensive and sophisticated framework for a private sector entity to develop an optimal R&D portfolio and serves as a starting point for the development of the public sector R&D portfolio model. Mun's IRM includes the following eight steps (Mun 2006):

1. *Qualitative management screening*

2. *Time-based regression, econometric, and stochastic forecasting*

3. *Base case net present value analysis*

4. *Monte Carlo simulation*

5. *Real options problem framing*

6. *Real options modeling and analysis*

7. *Portfolio and resource optimization*

8. *Reporting and update analysis*

For the purposes of this thesis, five of the eight IRM steps were used due to their applicability to a public sector financial structure: qualitative management screening, valuation, risk assessment, portfolio optimization and finally reporting and update analysis. The forecasting step within the IRM was not incorporated in the model since it focuses on forecasting future revenues and related sales data which are not applicable to a public sector R&D investment. Additionally, real options framing, modeling and analysis were omitted from the model. Real options identify and place a value on an organization's option to expand, contract, cease or switch an effort and require the use of

a discounted cash flow model. A discounted cash flow model requires cash flow to be analyzed and forecasted, which is a financial structure a public sector organization also lacks.

1.   Qualitative Management Screening

The IRM framework begins by conducting "qualitative management screening" to determine the strategic fit of a proposed project (Mun 2006). An organization must determine if identified proposals align with the organization's goals/mission and merit further analysis. An outcome of this screening is either elimination of a proposed project, or a prioritization assigned by a sponsoring organization's management. To help facilitate objective feedback from identified experts regarding each proposal, the Delphi Method can be utilized. The Delphi Method strives to eliminate groupthink or experts consciously or unconsciously delivering biased input to a group seeking to make a collaborative decision. By replacing the group setting with individual questionnaires, biases are removed (Helmer-Hirschberg 1967). The result is an unbiased assessment of the proposal. If utilized, the Delphi Method can determine which of the proposed projects should be included in the process leading up to R&D portfolio optimization.

The public sector R&D model uses qualitative management screening in the form of filtering and weighting steps to identify proposals meeting the funding organization's strategic objectives or criteria. Proposals that do not meet these objectives and criteria are removed from the selection process. By eliminating proposals lacking the strategic fit and goals of the funding organization, the resulting portfolio is tailored to the funding organization's goals and the pool of proposals requiring subsequent analysis is reduced. The filtering and weighting assessment is performed in accordance with specific established criteria defined by the funding program and verified through the proposal application process.

The information solicited by the funding organization as part of the application is critical to ensure the model's utility. First, information obtained from an applicant is filtered to eliminate proposals lacking the strategic fit or specific criteria of the organization. Second, the information submitted by an applicant has weights applied to it.

The fields an applicant must fill out should be conducive to applying filtering and weighting during the selection process. For example, requiring applicants to provide their anticipated solution timeframe provides program representatives objective means to filter out proposals exceeding the sponsor's timeframe. Additionally, requiring applicants to identify an end user for their proposal supports technology transfer and increases applicability of the research. This identification can also ensure R&D efforts align with the sponsor's mission and provides another means to filter out a proposal. Other filtering criteria include alignment with established sponsoring organization objectives such as the DOD's third offset strategy.

The weighting process is appropriate for R&D portfolios lacking interdependence among the projects (Henriksen 1999). The criteria for weighting is funding organization-dependent, however, good criteria for weighting purposes involve characteristics which can either be answered yes/no or grouped into categories such as low, medium, or high. Weighting criteria should also be independent of the filtering criteria (although the filtering and weighting steps can be consolidated into one step—this thesis separates them for simplicity of explanation).

Recommended weighting criteria include requiring applicants to indicate if their proposal is supported by a third-party board within their organization. Another weighting criterion may require applicants to indicate a prioritization of their efforts. In the public sector it is not uncommon for the entity providing the R&D funding to be different from the entity sponsoring the R&D proposal seeking funding. In this case, the sponsor may determine the priority that can then be weighted. Other weighting criteria include preferences for the work to be completed by an interdisciplinary team composed of operations, logistics, IT, communications, etc., or a team of a certain composition such as teams with new hires working along with senior mentors.

Filtering and weighting criteria for an R&D portfolio selection model will need to be evaluated and adapted based on the fields a funding program solicits from applicants. Once the criteria are complete, however, the filtering and weighting steps can effectively eliminate proposals falling outside an R&D program's target efforts and the portfolio will begin to focus on those proposals aligning with the program's strategic goals.

2. Valuation

The following two steps, valuation and risk assessments, are completed in parallel and are applied to filtered and weighted proposals. An approach for making the proposal selection process more sophisticated in its efforts to maximize the use of limited funding involves determining a valuation for filtered and weighted proposals. This is particularly difficult for the public sector. The private sector valuation techniques incorporate forecasted revenues, sale prices, sales figures and production quantities to develop Net Present Value (NPV) or a Return on Investment (ROI) for a project. Since the public sector's financial incentives and structure differ from the private sector, the valuation of a proposal in the R&D portfolio selection model leverages subject matter expertise and is an area where subjective assessments of a proposal will be difficult to eliminate.

Valuation of the filtered and weighted proposals is, for the purposes of the model, defined as the project's perceived magnitude of success based on a subject matter expert's assessment. The magnitude of success of each proposal is broken down into a five-category Likert scale: very low, low, medium, high and very high with a corresponding figure for each category; very low equates to a "1" up to very high equating to a "5." This magnitude of success is then factored into subsequent steps of the model.

3. Risk Assessment

Risk is viewed in terms of a proposal's complexity and the probability of a proposal successfully meeting its objectives. The Department of Defense's "Risk, Issue, and Opportunity Management Guide for Defense Acquisition Programs" further defines risk by identifying "what can go wrong" and the impact of that situation (Department of Defense 2015). The goal for the model is to reduce the risk present in the optimized model. To achieve this, each of the filtered and weighted proposals are assigned a probability of success value, also based on a five category Likert scale: very low, low, medium, high and very high and again, with a corresponding figure for each category; very low equates to a "1," up to very high equates to a "5."

The value figure of each proposal is then multiplied by the risk figure to obtain a proposal "benefit." The benefit of a proposal, however, does not fully reflect the characteristics of a proposal. To address this, the benefit of each proposal is divided by the cost of each proposal to obtain the overall cost-adjusted benefit ratio. This ratio is then factored into the objective function of the next step, portfolio optimization. Table 1 provides an example of this process.

Table 1.   Example Risk and Valuation Strategy to Obtain the Cost-Adjusted Benefit

Applicant Provided Data		Value Magnitude of success (SME-provided)		Risk Probability of success (SME-provided)		Benefit	Cost-Adjusted Benefit
	Proposal Cost	Magnitude Category	Magnitude Figure	Risk Category	Risk Figure	Magnitude x Risk	Benefit / Cost
1	$60,000	VL	1	L	2	2	0.000033
2	$472,000	VH	5	VH	5	25	0.000053
3	$1,000,000	H	4	M	3	12	0.000012
4	$105,000	M	3	H	4	12	0.000114
5	$500,000	H	4	L	2	8	0.000016
6	$110,000	VH	5	VH	5	25	0.000227
7	$100,000	H	4	VH	5	20	0.000200

4.   Portfolio and Resource Optimization

The last step of the R&D portfolio selection model uses the cost-adjusted benefit ratio obtained in previous step as input for the objective function of the model. Specifically, the objective function is to maximize the sum of the cost-adjusted ratio based on binary decisions (whether to select a project or not) subject to the funding organization's budget.

5.   Reporting and Update Analysis

Finally, considering the complexity of the model's framework and the R&D portfolio optimization process, deliberate steps to effectively communicate the results should be exercised. AN R&D selection exercise by BMW highlights the importance of identifying a "diffusing agent" to communicate the details of the process for increased acceptance (Loch 2001). In addition, for continuity, the BMW team emphasizes educating members of the organization as a form of technology transfer to increase the likelihood of the R&D portfolio selection method's perpetuity. As demonstrated by BMW, this model and the corresponding complex R&D portfolio optimization process can seem like a black box to those unfamiliar with the steps. This may lead to dismissal of the results by key stakeholders, ultimately defeating the purpose. For this reason, deliberate steps to effectively communicate the results of the model should be exercised. Data to be communicated includes a profile of the resulting portfolio.

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III. NAVAL POSTGRADUATE SCHOOL'S NAVAL RESEARCH PROGRAM

A. INTRODUCTION

Recognizing the value of continued R&D funding for U.S. Navy and Marine Corps strategic positioning, the Secretary of the Navy established the Naval Postgraduate School's Naval Research Program (NRP) in 2013 to research new capabilities and topics on behalf of the Navy and Marine Corps. The program leverages the knowledge and expertise found at the Naval Postgraduate School to solve problems related to naval research and "supports the Navy in reaching well-informed, objective decisions on strategic, operational, and programmatic issues through collaborative research, which integrates academic studies and analysis with advanced decision-support tools" (Naval Postgraduate School 2013).

The program has proven very popular, attracting 527 proposals in FY 16 and 421 proposals for FY 17 (Figure 6). The NRP faces the fundamental R&D portfolio selection problem; despite the popularity and abundance of proposed solutions, not all the proposals can be funded. The NRP's FY 17 annual budget is $13,261,000, while submissions for all FY 17 topics totaled $30,826,111. As a result, the NRP R&D portfolio selection process is an excellent case study and opportunity to develop and implement an optimization model tailored to the public sector.
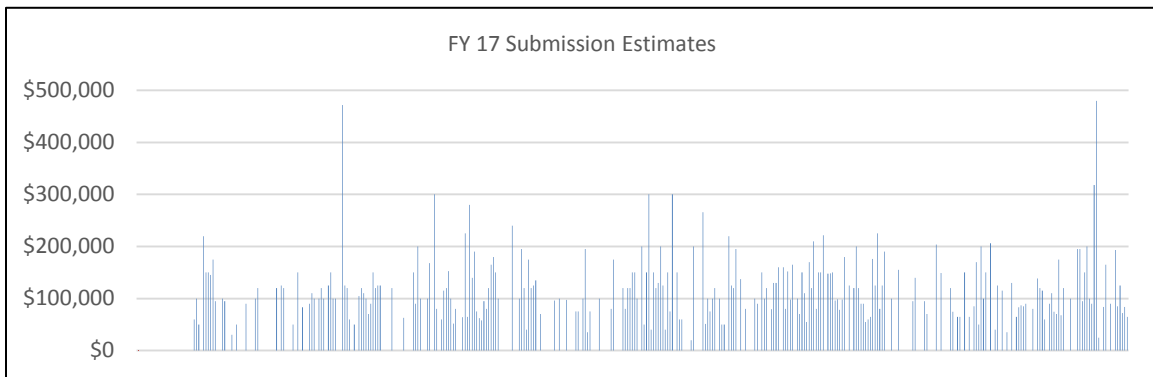

Figure 6.   Requested Funding Profile for all 421 FY 17 Submissions (note: gaps along horizontal axis reflect topics lacking budgets)

B.   NRP PROCESS

Most Naval Research Program topics are research questions developed by sponsor organizations from the U.S. Navy or U.S. Marines. Additionally, NPS faculty are able to propose their own research question, but these must be adopted by a sponsor to be funded. After the research questions are submitted, NPS faculty then develop proposals for posted topics and generate budget estimates to solve the research problem. Occasionally, multiple NPS faculty provide proposals for the same problem. When this occurs, each proposal's budget may differ depending on the applicant's proposed solution. In some instances, sponsor-provided topics remain unaddressed by NPS faculty, resulting in the absence of a proposed solution and budget. For example, while there were 421 proposals for the FY 17 NRP, only 255 possessed a proposed solution and associated budget, and were removed from the portfolio as part of the effort to identify an optimal portfolio.

The NRP requires applicants to provide traditional administrative data about their proposals, but due to the inability to fund all the proposals, applicants are also asked to provide data that aids in the filtering and weighting of the proposals. Administrative fields include a topic title, topic description, multiple potential research focus areas and whether the topic is well suited for a thesis or a broad area study. Applicants are also required to inform the NRP administrators if their proposal has received advance high-level support from the Navy's Resources and Requirements Review Board (R3B), staffed by Navy Admirals, or the Marine Requirements Oversight Council (MROC), staffed by Marine Corps Generals. The NRP acknowledges that confirmation of review by either of these boards will place a greater priority on a proposal. Given the high level of each of these boards, only twenty submissions had obtained the support of these boards and of these, only eleven were associated with proposals that had budgets ($1,125,000 for all eleven). The total of $1,125,000 is well within the NRP's budget, so additional evaluation criteria is required to determine which other non-R3B and MROC supported proposals should be selected.

A second criteria used to evaluate the proposals is whether or not they meet stated Navy or Marine S&T objectives as determined by the Office of Naval Research (ONR).

Of the 255 proposals with budgets, 116 meet the ONR's S&T objectives. The ONR topics align with the DOD's third offset strategy and proposals contributing to one of these areas will receive a higher weighting:

1. *Assure Access to Maritime Battlespace*

2. *Autonomy and Unmanned Systems*

3. *Electromagnetic Maneuver Warfare*

4. *Expeditionary and Irregular Warfare*

5. *Information Dominance (Cyber)*

6. *Platform Design and Survivability*

7. *Power and Energy*

8. *Power Projection and Integrated Defense*

9. *Warfighter Performance*

A third criteria used to evaluate the proposals in the NRP dataset is a prioritization of the topic as determined by the sponsor organization. The sponsoring organization classifies topics as either "Low," "Medium" or "High." This prioritization, however, does not provide a substantial filtering capability because, as expected, the majority of the proposals have been deemed "High" priority by their sponsoring organization; 196 received a "High" prioritization out of the 255 proposals with budgets.

Viewed across all three criteria, the twenty overall R3B/MROC supported submissions are reduced to fourteen when you apply the constraint that they must be meet Navy/Marine S&T objectives *and* they be deemed a "High" priority by the topic's sponsor. Of these elite fourteen submissions, only eight were associated with a solution resulting in a proposal budget and the opportunity to be funded.

With a budget of $13.261M to fund the FY 2017 proposals, the NRP can simply winnow down the list of proposals from 255 at a total portfolio cost of $30,826,111 by applying criteria filters until the total number of proposals is maximized within the budget constraint. This strategy, however, does not account for the value or risk each proposal poses to the NRP. Similarly, each proposal represents a different risk to the

NRP. Since the NRP is structured as a grant-arrangement, if a proposal exceeds its budget, additional funds are not available to an applicant to complete the proposed work. If a funded proposal exceeds its budget, goals set forth in the proposal are not accomplished. As a result, the NRP seeks to make the best use of its funding, by maximizing the value derived from the pool of selected proposals, while minimizing the risk present in each of the selected proposals not meeting its objectives.

IV. MODEL IMPLEMENTATION WITH NRP DATA SET

The NRP dataset served as a case study for the implementation of the R&D portfolio selection process developed by this thesis. To begin, a copy of the FY 17 NRP dataset was obtained in the form of a Microsoft Excel file. The same filtering, weighting, valuation, risk and optimization steps were applied with the objective of maximizing the value of selected proposals while minimizing the risk present. As an added benefit, the filtering and weighting steps minimize both the subjective input applied during the proposal selection processes and reduce the amount of time NRP proposal evaluators are required to spend on proposal evaluation. The following steps describe the process followed to analyze the NRP dataset and develop the optimization model as depicted in Figure 7.
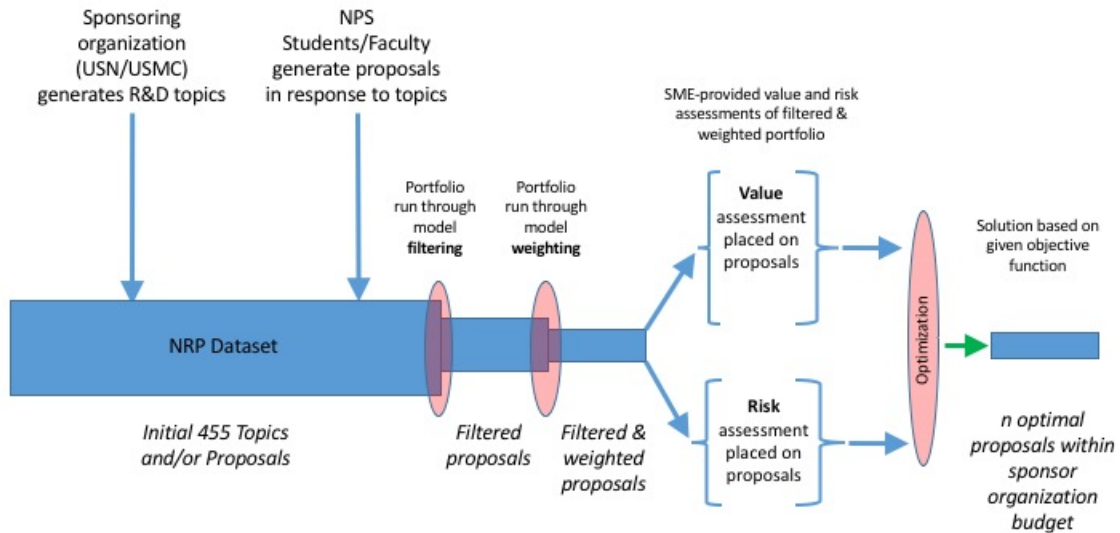

Figure 7.   R&D Portfolio Selection Process for Public Sector Entities Applied to NRP Dataset

A. FILTERING PROCESS USING QUALITATIVE MANAGEMENT SCREENING

An additive filtering process was utilized to implement the qualitative management screening step from the Integrated Risk Management framework and analyze the dataset across various filtering criteria. The NRP dataset was incorporated into a Microsoft Excel spreadsheet and analyzed by incorporating pivot tables into the Excel workbook for efficient evaluation. The first filter applied determined whether or not a budget had been generated for the respective topic. If NPS faculty had not identified a solution for a given topic, a budget was not generated, and the proposal was not incorporated into the filtering or subsequent weighting process. The application of this first filter resulted in the total number of proposals being reduced from 421 to 255 (the total portfolio cost, however, remained the same because this filter simply removed budgets of zero).

Various filtering combinations were evaluated to determine the corresponding portfolio count and total portfolio cost (Table 2 and Figure 8). While the additive use of filtering can be a relatively simple evaluation method for final portfolio selection, it assumes an equal weight, value and risk have been applied to all of the eligible proposals. After analyzing multiple combinations, filter method #4 (Table 2) was selected, eliminating proposals lacking a budget or prioritized "Low" or "Medium" by their sponsoring organization. This reduces the portfolio down from 421 proposals, to 196 with a total cost of $24,315,927. Additional filters were not implemented because there were no subsequent filtering criteria that if applied, kept the overall portfolio above the NRP's overall budget, therefore defeating the purpose of optimizing a portfolio for a given objective function. Proposals remaining in the dataset after filtering, are subject to the weighting step, which enables another evaluation perspective.

Table 2.　　　　2017 NRP Proposal Breakdown by Increasing Filtering Constraint
Reflecting Resulting Proposal Count and Portfolio Cost

| Filter Method	Filter Description	Proposal Count	Portfolio Cost
1	No filtering	421	$30,826,111.00
2	Only those submissions with a budget	255	$30,826,111.00
3	Only those submissions with a budget and prioritized as "Medium" or "High" by their sponsor organization	246	$30,000,111.00
4	Only those submissions with associated budgets and prioritized solely as "High" by their sponsor organization	196	$24,315,927.00
5	Only those submissions with associated budgets and prioritized as "High" by their sponsor organization and meeting Navy/ Marine S&T objectives	90	$10,806,600.00
6	Only those submissions with associated budgets and prioritized as "High" by their sponsor organization and meeting Navy/ Marine S&T objectives and confirming R3B/ MROC supported topics	8	$765,000.00
7	Only R3B/MROC supported submissions with a budget	11	$1,125,000.00
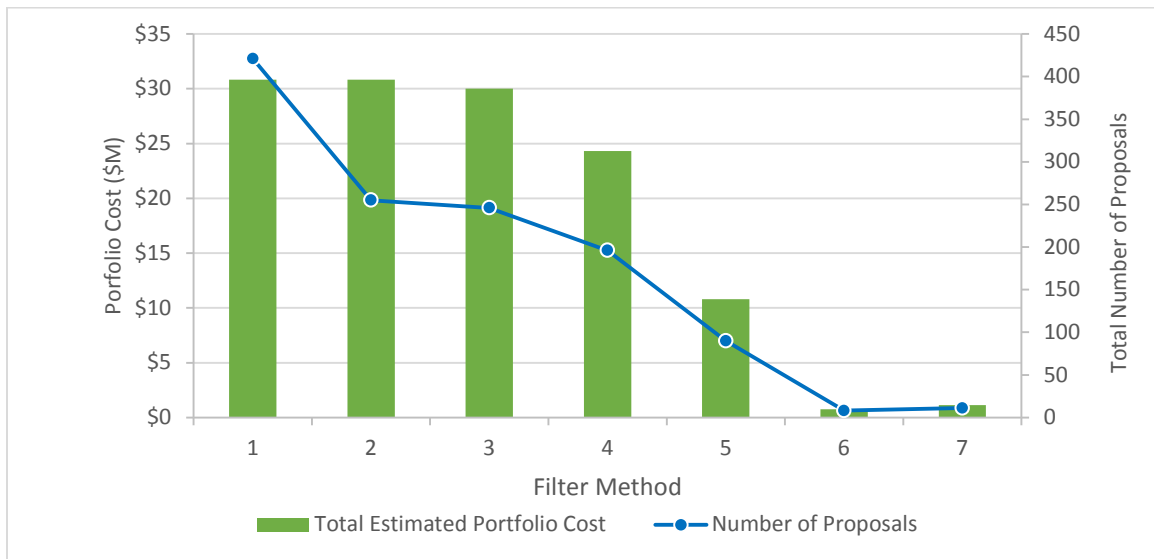
Figure 8.　　2017 NRP Proposal Breakdown by Increasing Filtering Constraint with
Resulting Proposal Count and Portfolio Amount

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B.   WEIGHTING PROCESS

The weighting process (Table 3) leverages the analysis completed in the filtering step and supplements the results with a weighting criteria to complete further objective selection within the NRP dataset. If a proposal was supported by the R3B or MROC, it received a weight of "5" to force these proposals to stand out from non-R3B or MROC supported proposals due to the high profile support. Topics not supported by the R3B or MROC received a weight of "0." Proposals meeting Navy/Marine S&T objectives received a weight of "3" and a "0" otherwise. The Topic Sponsor Organization Priority category served as a weighting category, as well as a filtering criteria because in some instances, despite a proposal being prioritized as "High," it was not R3B/MROC supported, and also lacked alignment with Navy/Marine S&T objectives. Without retaining Topic Sponsor Prioritization as a weighting criteria, these proposals would have no weight otherwise.

Table 3.   NRP Dataset Weighting Example

Topic ID	R3B or MROC Supported	Navy/Marine S&T Objectives	Topic Sponsor Priority	R3B or MROC Supported?	Navy/Marine S&T Objectives?	Topic Sponsor Organization Priority	Weighted Score
NPS-17-M052			High	-	-	3	3
NPS-17-M057		Yes	High	-	3	3	6
NPS-17-M071	Yes	Yes	High	5	3	3	11
NPS-17-M078		Yes	High	-	3	3	6
NPS-17-M087			High	-	-	3	3

The weights applied for each proposal's R3B or MROC Support, Navy/Marine S&T Objectives and Topic Sponsor Priority were then summed to determine the topic's overall weighted score. Resulting scores, as depicted in Figure 9, range from "3" where the only weight applied was due to a proposal being ranked "High" by their sponsoring

organization, to "11" for proposals with R3B or MROC support, which met Navy/Marine S&T objectives and were prioritized as "High" by their respective topic sponsor organization.
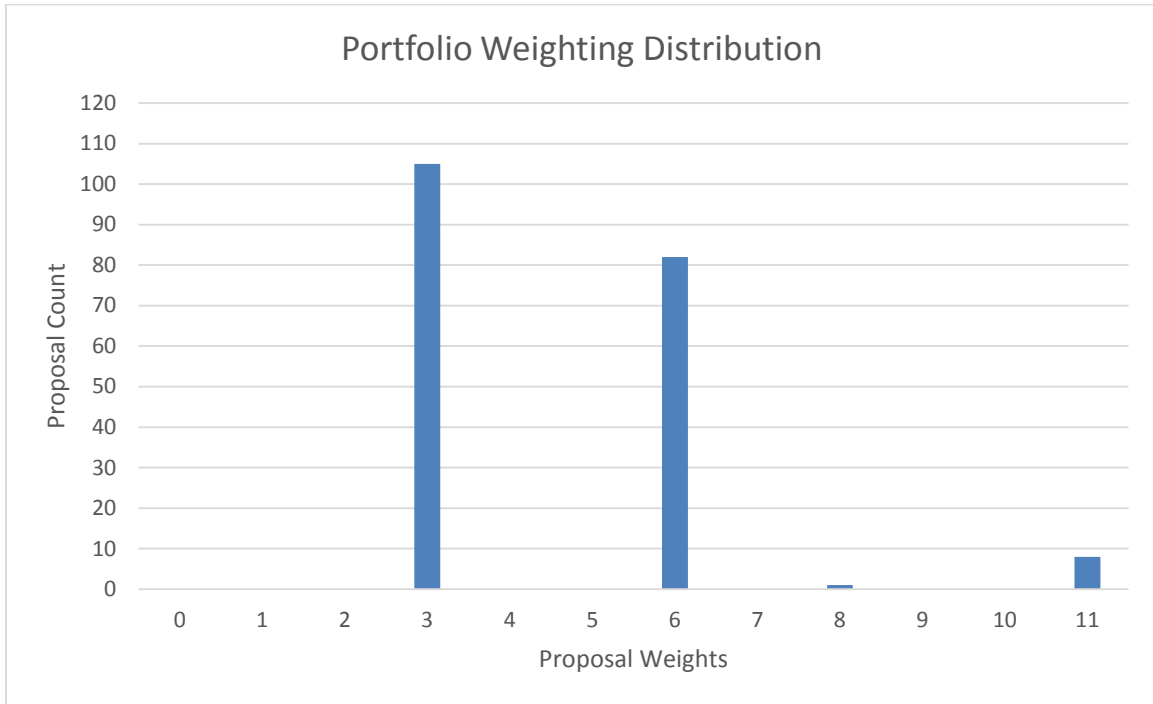

Figure 9.   FY 17 NRP Proposal Weights (196 weighted proposals post-filtering)

Additionally, this objective weighting process reduced the NRP portfolio from 255 proposals requiring detailed review, down to a portfolio consisting of 196 proposals. The reduction of the number of proposals from 255 down to 196 also represents a considerable time savings for subsequent evaluation. Assuming 20 minutes per proposal review, this results in a time savings of nearly 20 hours to review the weighted portfolio. Considering that this review is likely to be completed by more than one person, this time savings can be multiplied by each person reviewing the portfolio, further increasing the benefits of reducing the portfolio early in the selection process. Members of the NRP are not assigned to the NRP full time, so any time savings they can realize in their efforts to support the NRP selection process enables them to resume their primary professional roles. In addition, by reducing the amount of time each reviewer is required to support the

review process, the NRP would likely be able to solicit the input of additional reviewers, thus providing a more diverse and comprehensive perspective on proposal evaluation.

C.   PROPOSAL VALUE

Placing a value on a public sector investment cannot be approached in the same manner as valuing an investment in the private sector. ROI, NPV, DCF are not appropriate means to value a public sector R&D project due to the lack of appropriate financial metrics. Since, for example, ROI measures an investment's profitability, it is not appropriate for the public sector since profitability is not part of the public sector's financial structure. Net present value factors a discount rate, or the targeted interest rate an entity needs to make on an amount of money today, to reach a targeted amount of money in the future, into a calculation to determine if an investment is worth pursuing; discount rates and interest rates are not part of a public sector entity's financial structure. Finally, discounted cash flow is used to estimate an investor's anticipated revenues, based on the time value of money (assumes a dollar today is worth more than a dollar tomorrow), factoring in interest rates—again, a metric the public sector lacks.

As a result, and for the purposes of the case study to demonstrate the model process, valuations for the proposals were simulated to replicate an assessment by a subject matter expert (SME). These valuations were applied across a five-point Likert scale of very low, to very high, with a number, one through five, assigned to each. Subject Matter Experts could use various criteria to determine which value to apply. These could include impact to the sponsoring organization, improvement over current capabilities or cross-service benefit. These associated value figures were then used to obtain a benefit figure in collaboration with the outcome of the subsequent risk step.

D.   RISK EVALUATION OF PROPOSALS

Each of the filtered and weighted proposals were then evaluated for their probability of success. As with the valuation step, this assessment would be completed by SMEs, however for the purposes of this case study, the risk assessments (also completed on a five point Likert scale from very low probability of success to very high probability of success) were simulated. As with the valuation step, proposals assessed to be of very

low probability of success were assigned a figure of "1" up to "5" for proposals assessed to be of very high probability of success.

Upon completion of the risk and value assessments, the resulting value figure and resulting risk figure are multiplied by each other to determine an overall benefit. The benefit figure for each proposal is then divided by the cost of the respective proposal to calculate a cost-adjusted benefit ratio, which is then used in the optimization step (Table 4).

E.   OPTIMIZATION

The final step leveraged the results of all prior steps to identify an optimal R&D portfolio for the NRP. Several optimization strategies were evaluated, all subject to remaining within the NRP's annual budget. These strategies included maximizing the optimized portfolio cost, maximizing the optimized portfolio value figure, minimizing the portfolio's risk figure and maximizing the portfolio's percent obligated. These approaches, however, did not address the benefits of consolidating multiple criteria by selecting a portfolio representing the greatest cost-adjusted benefit.

The resulting objective function incorporates the valuation and risk assessments completed in previous steps to maximize the sum of the individual cost-adjusted benefit ratios for all filtered and weighted proposals, subject to the annual NRP budget. Decision variables for optimization were defined as binary where if a proposal was selected for the final portfolio, the solution reflected a "1" and a "0" otherwise. An example of the optimization process is provided in Table 4.

Table 4.   Example Optimization Process; Maximize Sum of Cost-Adjusted Benefit Ratio Subject to $500,000 Maximum Investment

Applicant Provided Data		Value: Magnitude of success (SME-provided)		Risk: Probability of success (SME-provided)		Benefit	Cost-Adjusted Benefit	Optimization: Project Selected (1 = yes, 0 = no)	Selected Project Cost	Selected Project Cost-Adjusted Benefit Ratio
Proposal Number	Proposal Cost	Magnitude Category	Resulting Figure	Risk Category	Resulting Figure		Benefit/Cost			
NPS-17-M001	$60,000	VL	1	L	2	2	0.000033	1	$60,000	0.000033
NPS-17-M005	$50,000	VH	5	VH	5	25	0.000500	1	$50,000	0.000500
NPS-17-M014	$220,000	H	4	M	3	12	0.000055	0	$-	0
NPS-17-M022-A	$175,000	M	3	H	4	12	0.000069	0	$-	0
NPS-17-M022-B	$95,000	H	4	L	2	8	0.000084	1	$95,000	0.000084
NPS-17-M051	$100,000	VH	5	VH	5	25	0.000250	1	$100,000	0.000250
NPS-17-M052	$95,000	H	4	VH	5	20	0.000211	1	$95,000	0.000211
Total	$795,000								$400,000	Obj Fxn: Max Sum of Cost-Adjusted Benefit Ratio
							Subject to:		<=	
							Max Program Budget:		$500,000	0.0010781

F.   ANALYSIS

The optimization process resulted in an interesting, but not an unexpected outcome. Considering the objective function, proposals with higher value and higher probabilities of success (lower risk) were selected. Figure 10 reflects the proposal valuation breakdown by selected versus non-selected proposals. Figure 11 reflects the proposal probability of success breakdown by selected versus non-selected proposals. Finally, the portfolio's cost-adjusted benefit ratios are depicted in Figure 12, with a Paredo frontier appearing around 0.00005.
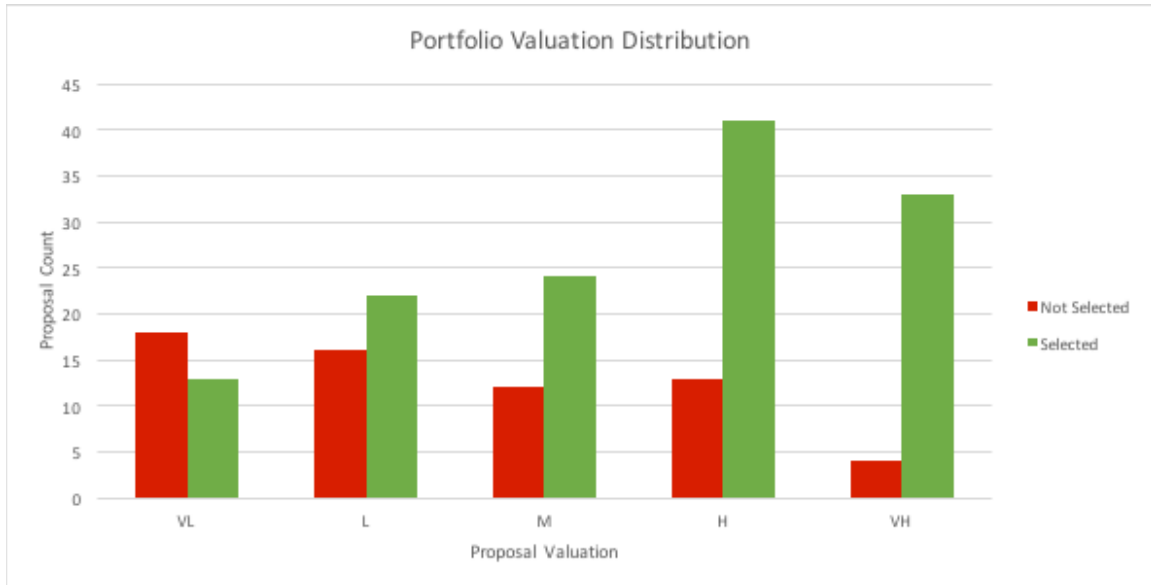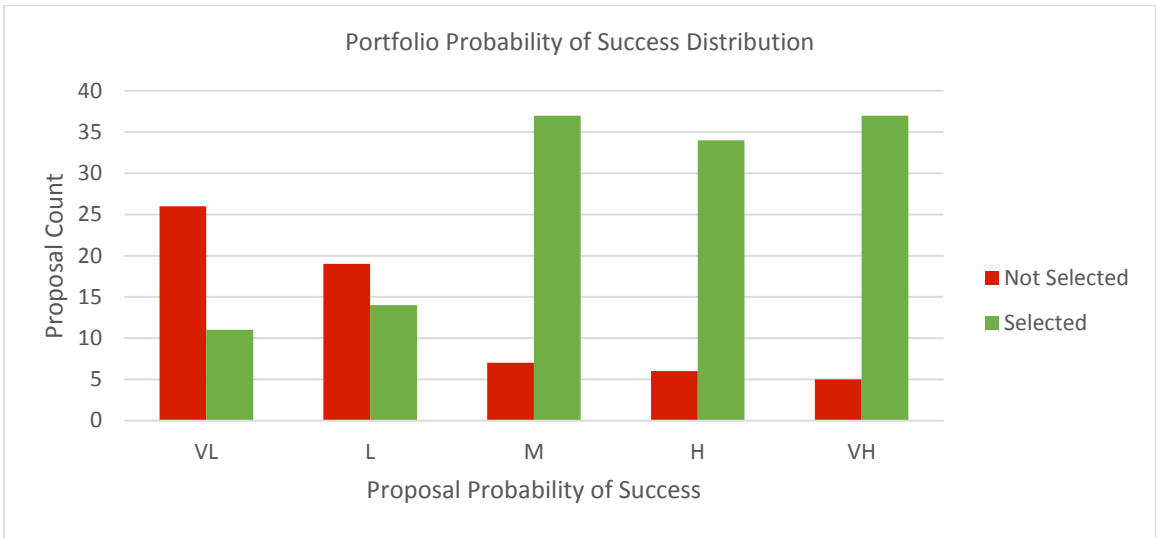

Figure 10.   Proposal Valuation Distribution

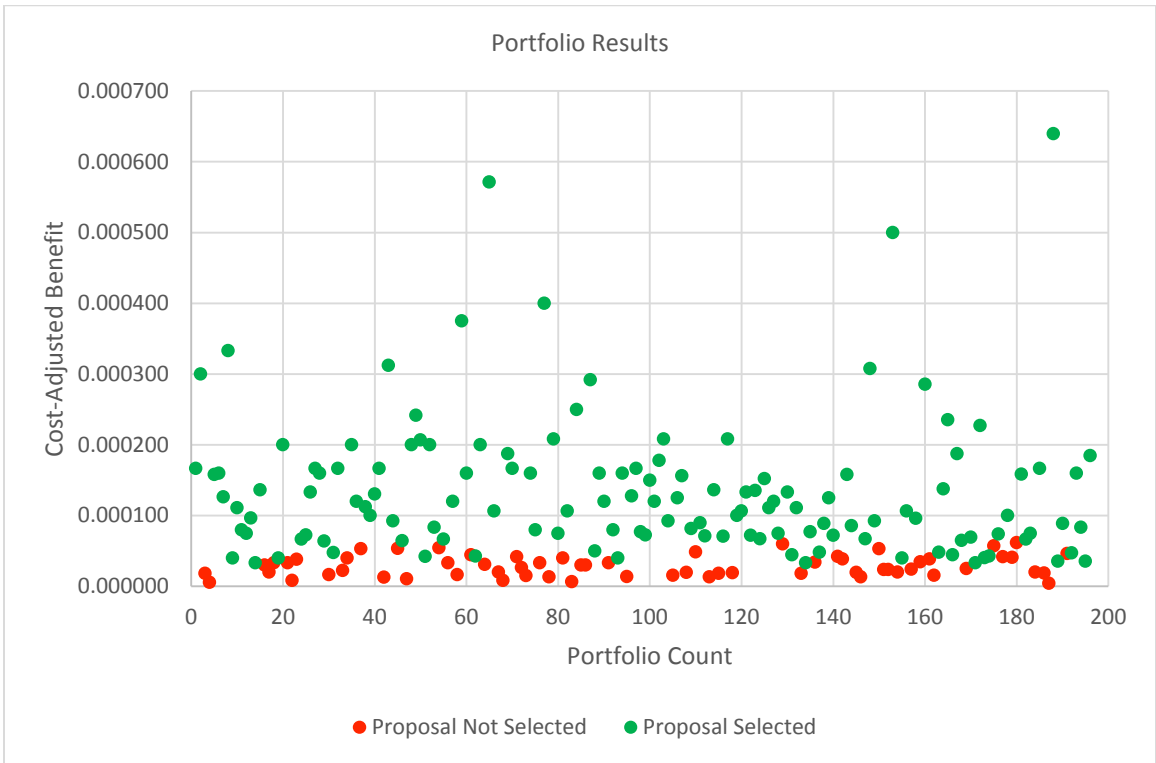Figure 11.   Proposal Probability of Success Distribution

Figure 12.   Proposal Distribution across Cost-Adjusted Benefit Ratio

G. RECOMMENDATIONS

To better assess a proposal's probability of failing to meet its stated objectives, and refine the risk assessments for each proposal, future NRP funding applications may wish to specifically require an applicant to submit what the anticipated deliverables will be should their proposal be selected for funding. Proposals focusing on completing a study or developing an analytical product would likely specify their intent to deliver a written report along with the delivery of accompanying software models (Excel, Risk Simulator, MATLAB, etc.). Alternatively, proposals identifying a physical technological product to be built could identify the complexity of the proposed system or Technical Readiness Levels (TRLs) of the system, its assemblies or components. Highlighting a TRL would identify the complexity of a proposed development or integration effort, better informing the risk assessment. For both technical developments and research-oriented proposals, risk assessments could include applicant-provided risk identification and mitigation plans. Research-oriented topics could, for example, identify the anticipated source of data to be analyzed and an assessment of the difficulty in obtaining that dataset. This would also aid NRP proposal evaluators in making risk assessments considering that one of the biggest problems in data analysis is obtaining the data in the first place. Similarly, technical developments may identify the risk associated with integrating a commercial piece of hardware into a DOD system. Having this additional data would likely aid the NRP staff and SMEs assigned as they evaluate the inherent risk of the project being successfully completed.

Additionally, the existing NRP application contains fields that could be leveraged as weighting criteria if the NRP chose to expand the model's weighting criteria. The inclusion of additional metrics to improve the weighting capability of the overall portfolio optimization process could further reduce the size of the portfolio requiring subsequent NRP manual review. For example, if the NRP were able to identify which NPS academic departments valued Broad Area Studies over Thesis Topics, and correlated each proposal to the departments, a weighting structure could be applied to these criteria, based on the department's perspective of the topic type. Another recommended weighting option is the inclusion of criteria for interdisciplinary or team

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composition to provide additional factors for weighting a proposal and would likely aid in differentiating the initial pool of proposals.

V.   CONCLUSION

Maintaining our nation's technologic edge is a persistent requirement and has historically been led by or supported by public sector investment. The Department of Defense has committed to financially support this edge by allocating billions of dollars towards its "third offset strategy." With such large sums of money and the strategic advantages provided by the technology developed by this funding at stake, efficient strategies must be used to make the best use of limited resources.

This thesis has presented one such method, and applied it to an R&D effort sponsored by the Naval Research Program (NRP) as a case study. The method reinforces objective means of proposal selection, while integrating subjective feedback from experts to support the proposal identification steps leading to an optimal R&D portfolio being selected. The methods included filtering and weighting steps, assessing a proposal's value, assessing a proposal's risk and culminated in an optimization effort identifying an R&D investment portfolio meeting a specific objective function. The objective function sought to maximize the sum of the chosen proposals' cost-adjusted benefit calculation subject to the NRP's annual budget. The results of the optimization identified 133 proposals. The results, as expected, predominately chose higher valued proposals characterized as lower risk (higher probability of success).

The key takeaway from this overall effort is that while R&D portfolio selection can leverage many of the private sector's techniques to identify an optimal R&D investment portfolio, the valuation strategies are unique and not interchangeable. This difference, however, is not insurmountable, and valuation and risk efforts for the public sector can be achieved by soliciting input from experts.

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