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Acquiring Enterprise Systems as a Portfolio of Real Options

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Naval Postgraduate School

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Preface & Acknowledgements

Welcome to our Ninth Annual Acquisition Research Symposium! This event is the highlight of the year for the Acquisition Research Program (ARP) here at the Naval Postgraduate School (NPS) because it showcases the findings of recently completed research projects—and that research activity has been prolific! Since the ARP's founding in 2003, over 800 original research reports have been added to the acquisition body of knowledge. We continue to add to that library, located online at www.acquisitionresearch.net, at a rate of roughly 140 reports per year. This activity has engaged researchers at over 60 universities and other institutions, greatly enhancing the diversity of thought brought to bear on the business activities of the DoD.

We generate this level of activity in three ways. First, we solicit research topics from academia and other institutions through an annual Broad Agency Announcement, sponsored by the USD(AT&L). Second, we issue an annual internal call for proposals to seek NPS faculty research supporting the interests of our program sponsors. Finally, we serve as a "broker" to market specific research topics identified by our sponsors to NPS graduate students. This three-pronged approach provides for a rich and broad diversity of scholarly rigor mixed with a good blend of practitioner experience in the field of acquisition. We are grateful to those of you who have contributed to our research program in the past and hope this symposium will spark even more participation.

We encourage you to be active participants at the symposium. Indeed, active participation has been the hallmark of previous symposia. We purposely limit attendance to 350 people to encourage just that. In addition, this forum is unique in its effort to bring scholars and practitioners together around acquisition research that is both relevant in application and rigorous in method. Seldom will you get the opportunity to interact with so many top DoD acquisition officials and acquisition researchers. We encourage dialogue both in the formal panel sessions and in the many opportunities we make available at meals, breaks, and the day-ending socials. Many of our researchers use these occasions to establish new teaming arrangements for future research work. In the words of one senior government official, "I would not miss this symposium for the world as it is the best forum I've found for catching up on acquisition issues and learning from the great presenters."

We expect affordability to be a major focus at this year's event. It is a central tenet of the DoD's Better Buying Power initiatives, and budget projections indicate it will continue to be important as the nation works its way out of the recession. This suggests that research with a focus on affordability will be of great interest to the DoD leadership in the year to come. Whether you're a practitioner or scholar, we invite you to participate in that research.

We gratefully acknowledge the ongoing support and leadership of our sponsors, whose foresight and vision have assured the continuing success of the ARP:

- Office of the Under Secretary of Defense (Acquisition, Technology, & Logistics)
- Director, Acquisition Career Management, ASN (RD&A)
- Program Executive Officer, SHIPS
- Commander, Naval Sea Systems Command
- Program Executive Officer, Integrated Warfare Systems
- Army Contracting Command, U.S. Army Materiel Command

- Office of the Assistant Secretary of the Air Force (Acquisition)
- Office of the Assistant Secretary of the Army (Acquisition, Logistics, & Technology)
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- Deputy Assistant Secretary of the Navy, Acquisition & Procurement
- Director of Open Architecture, DASN (RDT&E)
- Program Executive Officer, Littoral Combat Ships

We also thank the Naval Postgraduate School Foundation and acknowledge its generous contributions in support of this symposium.

James B. Greene Jr. Rear Admiral, U.S. Navy (Ret.)	Keith F. Snider, PhD Associate Professor

Panel 22. Risk-Reduction Approaches in Acquisition Management

Thursday, May 17, 2012	
1:45 p.m. – 3:15 p.m.	**Chair: Mary Lacey,** Deputy Assistant Secretary of the Navy, Research, Development, Testing, and Evaluation ***Acquiring Enterprise Systems as a Portfolio of Real Options*** Ronald Giachetti, *Naval Postgraduate School* ***The Effectiveness of Risk Management Within the DoD*** Donald McKeon, *Defense Acquisition University* ***Affordability Engineering Framework Overview*** Scott Anderson, Virginia Wydler, and Joe Duquette *The MITRE Corporation*

Mary Lacey—Lacey is the deputy assistant secretary of the Navy for Research, Development, Test, And Evaluation (RDT&E). She is the senior civilian and serves as the senior advisor to the ASN(RD&A) for research, development, test, and evaluation, and system engineering. She has oversight responsibility for all science and engineering, test and evaluation, modeling and simulation, chief systems engineering policy, practices, and processes for ASN(RD&A).

Lacey also oversees the Department of the Navy (DoN) chief systems engineering position and the DoN deputy for test and evaluation. She is the functional acquisition workforce competency leader for systems engineering, and she is responsible for the long-term stewardship of Naval Laboratories and Warfare Centers, where most of the Navy's RDT&E capabilities reside. She serves as a liaison with industry, academia, federally funded research and developments centers (FFRDCs), UARCs, and outside agencies.

Lacey entered the senior executive service in 1996 and has 38 years of federal service.

Lacey held the position of deputy program executive for Aegis Ballistic Missile Defense (BMD). She served as the civilian executive counterpart to the program executive in creating, managing, and overseeing Aegis BMD policies, practices, organization, and mission execution. She also served as acting executive director—the senior civilian advisor to the MDA director.

Lacey served as National Security Personnel Systems (NSPS) program executive officer (PEO). She was appointed by the NSPS senior executive, deputy Secretary of Defense Gordon England, and led the comprehensive policy and program office for the design and implementation of NSPS.

Lacey was technical director of the Naval Surface Warfare Center (NSWC), where she was responsible for a business of $4.6 billion and over 16,000 employees. Lacey formerly served as the director of NSWC, Indian Head Division, which specialized in Energetics and weapons systems. She also served as head of the systems research and technology department and director of science and technology for NSWC Dahlgren Division.

Lacey began her career with the Department of the Navy in 1973 as a federal junior fellow working for the Naval Ordnance Laboratory in underwater shock testing and evaluation, advanced weapons systems, firefighting technology, and nuclear weapons safety.

Lacey earned a Bachelor of Science degree in mechanical engineering from the University of Maryland, where she also completed graduate work in control systems and explosives. Lacey's awards include the Presidential Rank Distinguished and Meritorious Executive, DoD Distinguished Civilian Service, the Navy Distinguished Public Service, Superior Civilian Service, Women in Science and Engineering Lifetime Achievement, University of Maryland Distinguished Engineering Alumna, and the Federal Laboratory Consortium Laboratory Director of the Year. Lacey serves on the University of Maryland School of Engineering Board of Visitors, the Women in Engineering Advisory Board, and the International Council of Systems Engineering Foundation Board.

Lacey brings to her position a wealth of experience and valuable insight into civilian workforce issues. Throughout her career, Lacey has been actively involved in engineering workforce development. She continues to serve as a mentor and advisor to engineering professionals. She has proven expertise in managing large, diverse workforces and in leading and sustaining transformational change.

Acquiring Enterprise Systems as a Portfolio of Real Options

Ronald Giachetti—Dr. Giachetti, PhD, is a professor of systems engineering at the Naval Postgraduate School (NPS) in Monterey, CA. He teaches and conducts research in the design of enterprise systems, systems modeling, and system architecture. He has published over 50 technical articles on these topics, including a textbook entitled Design of Enterprise Systems: Theory, Methods, and Architecture. Prior to joining NPS, he was at Florida International University in Miami, FL. [regiache@nps.edu]

Abstract

The Department of Defense (DoD) has an enterprise architectural vision and an accompanying transformation plan. The enterprise transformation plan describes multiple individual projects and systems that collectively deliver the desired capabilities and enterprise architecture. These projects are performed over planning horizons that span several years or more. Deciding on what projects to invest in, when to invest in them, and whether to continue the investment as time progresses is a difficult problem because of the uncertainty involved in the operational environment, the technology, and the associated project risks. This paper argues that enterprise systems acquisition can be modeled using real options to obtain project valuations that consider the environmental uncertainty and guide acquisition decisions. Moreover, because the enterprise architecture involves many projects that are interdependent, a portfolio investment approach is called for. We present a real options framework to plan a portfolio of projects as a collection of compound real options. We illustrate how the model can be applied in a case study derived from the DoD's transformation plan. The model and method contribute an approach to value a portfolio of projects that intentionally creates options to preserve decision flexibility and acquire the target architecture's capabilities at lower cost and risk.

Introduction

The Department of Defense (DoD) is a very large and complex organization that undergoes nearly constant transformation in the "small" due to continuous improvement efforts as well as larger, more transformative changes due to large-scale projects. These projects are performed to improve operational effectiveness and efficiency, as well as to acquire new capabilities. Managing transformation on such a large scale is a formidable challenge. As is common in many large organizations, the DoD has developed a hierarchical planning process that aligns projects to strategic goals. The DoD has three documents, or plans, that are used to guide transformation.[1] The three documents relevant to transforming the business systems and processes in the DoD are the Strategic Management Plan (SMP), Business Enterprise Architecture (BEA), and Enterprise Transformation Plan (ETP). The SMP is the highest level plan for improving the DoD's business operations. It is a living document that is updated each year to reflect guidance from the Quadrennial Defense Review (QDR), external influences, and internal changes based on lessons learned. It aligns the DoD's business goals with the DoD's overall strategic goals. The BEA is a high-level design specifying the DoD's business environment using the models of the Department of Defense Architecture Framework (DoDAF). It is mandated that all DoD systems use the DoDAF to describe the system in a common format that will promote consistency and interoperability across the DoD. The BEA uses five core business missions to set priorities and to align business transformation. The five core business missions are financial management (FM), human resource management (HRM), material supply and service

[1] These documents were originally developed by the Business Transformation Agency (BTA), but this agency was disestablished on September 30, 2011, and its mission and function were assumed by the Office of the Deputy Chief Management Officer (DCMO).

management (MSSM), real property and installations lifecycle management (RPILM), and weapon systems lifecycle management (WSLM). The ETP describes the acquisition strategy for new systems that make up the target enterprise architecture.

The DoD BEA is acknowledged to be a work-in-progress in that the architectural vision is updated on a yearly basis, currently at Version 8.0. A changing target architecture is not indicative of a planning failure but recognition that the DoD is a complex, socio-technical, and open system that operates in a dynamic and uncertain environment (Giachetti, 2010). As an open system, it must constantly change to adapt to its changing environment, whether the changes are in budget, manpower, or the global threat environment.

Achievement of strategic goals and acquisition of systems to realize those goals under uncertainty involves two strategies. One strategy is to minimize risk by testing and validating architectures prior to deployment. However, even with greater testing of architectures, because testing helps resolve some of the internal uncertainty, significant external uncertainty will remain. The second strategy is to continuously adapt the architecture deployment plans to react to changes in the environment as well as the resolution of uncertainty. Here we address this last strategy with real options theory.

Real options are both a means to value investments as well as a means to define flexibility in system deployment (Trigeorgis, 2001). Koenig (2009) discussed the high level of uncertainty and, hence, risk associated with conventional engineering economic analysis of projects that have long operational lives. He suggested that the DoD environment is actually rich with options, but until now, there has been no quantitative means to value them and incorporate them into the acquisition decision process. In fact, quite an extensive amount of research has been conducted on the proposed or actual use of real options with project planning and acquisition.

Wang and de Neufville (2006) distinguished between real options on a project and real options in a project. Real options on a project are the standard options available to almost all projects, including delay, abandon, expand, and contract. Real options in a project are those options designed into the system architecture. Most research addresses real options on projects with some exceptions, such as Engel and Browning (2006), who investigated how to design adaptable architectures. In the military environment, Uchytil, Housel, Hom, Mun, and Tarantino (2007) combined real options with knowledge value analysis (KVA) to analyze four different options for the AEGIS system.

Interest has expanded beyond valuing individual projects by the real options method to the valuation of a portfolio of options. Bardhan, Bagchi, and Soustad (2004) developed an approach to prioritize information technology projects using real options. This approach and several similar approaches value the projects individual in the portfolio, which may miss the important interactions between projects. Brosch (2008) investigated a mathematical model to simultaneously value a portfolio of real options. His approach provided some insight, but the mathematical formulation was complex, and he could only solve the model for trivial problems.

This paper contributes to the literature on real options valuation in acquisition by presenting a model to value a portfolio of options rather than individual options inside the portfolio. This is accomplished by adopting a switching formulation of real options in a discrete stochastic mathematical program. The model is solved with a Monte Carlo simulation-based algorithm.

The paper is organized as follows: The background discusses transformation and enterprise architecture as conducted in the DoD. The real option portfolio model and method are presented next. An illustrative example is solved using the model and method to derive a portfolio. The paper concludes by highlighting the main contributions and discussing future research.

Decision-Making Method and Model

Figure 1 shows the flowchart for creating real options on the enterprise projects and then selecting a portfolio of those projects to maximize expected value to the organization. The model supports an acquisition decision-maker in that it does not automate the decision but provides a valuation of the portfolio. In this section, we describe the method, and in the next section, we illustrate the method with an example.

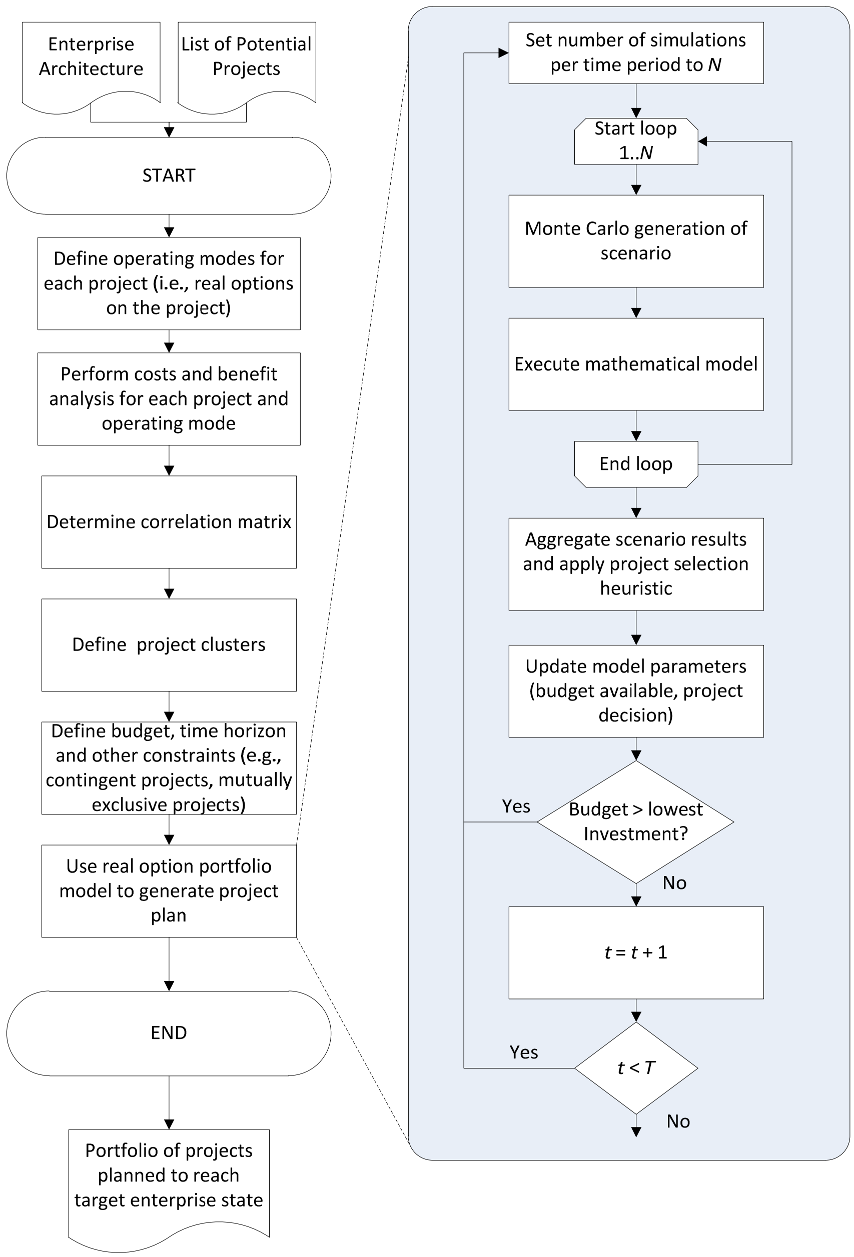

Figure 1. Portfolio Construction Algorithm

Convert Projects to Real Options

The model assumes that there are projects already identified, but in a traditional way, without consideration of decision-making flexibility. The first step is to convert the projects to real options by examining the project and mapping an option type onto the project. Option types common to almost all projects are delay, abandon, expand, and contract in addition to doing the project as planned (Trigeorgis, 1996).

Interdependence

When conducting multiple projects simultaneously in an enterprise, we need to take into consideration any interdependence between the projects. Project interdependencies arise due to the use of common resources, benefits derived from the projects, or technical considerations (Dickinson, Thornton, & Graves, 2001). The interdependencies can result in either mutually exclusive projects, contingent projects, or a correlation between project success or failure. Mutually exclusive projects are either-or projects. For example, in enterprise transformation, there may be two different projects to achieve a single goal, and only one of those projects will be performed. In our model, we enforced mutually exclusive projects through constraints. Contingent projects are when one project can only be done if another project is done. This is common with infrastructure-type projects that establish growth opportunities that are provided by subsequent projects. Such contingent projects are modeled as compound real options on the infrastructure project because it provides an opportunity to realize the future growth options. Two projects might be highly correlated such that if the value of one project increases (decreases), then the value of the second project increases (decreases). Positive effects are when two projects are complementary and a synergistic effect increases the value beyond what either project would provide singularly. A negative effect is when there is cannibalization or the projects overlap such that by doing so, both the total value is less than if they were added together. We model these interdependencies as a correlation ρ_{xy} between the cash flows or benefits of project *x* and project *y*. The correlation may be positive or negative such that $\rho_{xy} \in [-1,1]$.

Portfolio Optimization Model

The portfolio model is a stochastic mathematical model that finds the optimal sequence of project investment decisions to maximize the total net present value of the project portfolio over the planning horizon. We utilized a switching formulation of the options adapted from the work of Kulaitilaka (1998) that was later extended by Brosch (2008). In the switching formulation, each project can operate in one of several operating modes. Switching from one operating mode to another is the exercise of an option. Let a_i denote the option to operate the project in mode *i*. We let a_1 denote the default operation mode of delay or equivalently postponing investment. Initially, every project is in mode a_1, meaning that it is not being conducted. The other modes can be defined to represent different options. For example, we could define a_2 to denote the operation mode of a pilot project and a_3 to denote investment in a full-scale deployment. Given these definitions, different switches denote different options. With the three operating modes, the options available are shown in Table 1.

Table 1. Switching Options

Current Operating Mode	Next Operating Mode	Option
a_1 – delay	a_1 – delay	Delay
a_1 – delay	a_2 – pilot	Pilot
a_1 – delay	a_3 – full scale	Full scale project
a_2 – pilot	a_1 – delay	Abandon
a_2 – pilot	a_3 – full scale	Expand
a_3 – full scale	a_1 – delay	Abandon
a_3 – full scale	a_2 – pilot	contract

The decision is which operating mode switches to make in each time period. Let $x_{p,t,a,\acute{a}}$ denote the binary decision variable for project *p* in time period *t* of whether to switch from operating mode a to operating model $\acute{a}$. The decision-maker seeks to maximize the value of the portfolio so the value of all the options in the portfolio must be calculated.

The value of an option depends on the investment in the option and the expected cash flow generated from the option. The investment cost in the project option is denoted $I_{p,t,a,\acute{a}}$. One repercussion of creating options on projects is the need to determine the investment cost of all possible switches, as given in Table 1. For example, the model allows for a cost or investment to abandon a project option. This would entail costs associated with dismantling technologies, reverting to a previous operating mode, laying off project employees, and storing project materials.

The cash flow generated from a project *p* in time period *t* and operating mode *a* is

$$c_{p,t,a} = f_{p,a} + \lambda_{p,t}\theta_{p,t}, \tag{1}$$

where $f_{p,a}$ is the fixed return and $\lambda_{p,a}$ is the variable return rate that depends on the underlying asset, which is denoted by $\theta_{p,t}$. The random variable $\theta_{p,t}$ represents the uncertain future value of the underlying asset, which is the project *p* during time period *t*.

The value is calculated backwards from the end of the planning horizon to the first time period. Value for the last time period is calculated as

$$V_{p,T,a} = \sum_{\acute{a}\in A} x_{p,T,a,\acute{a}}\left(c_{p,T,a} - I_{p,T,a,\acute{a}}\right). \tag{2}$$

The value of the option for time periods other than the last one is

$$V_{p,t,a} = \sum_{\acute{a}\in A} x_{p,t,a,\acute{a}}\left(c_{p,t,a} - I_{p,t,a,\acute{a}}\right) + \frac{V_{p,t+1,\acute{a}}}{e^{r\Delta t}}, \tag{3}$$

where the denominator $e^{r\Delta t}$ discounts future values using the riskless rate of return *r*. In addition to the valuation, the model constrains the total investment in any period to be less than the total available budget and enforces consistency such that switching in one time period is consistent with the state in the next time period.

The objective is to maximize the total expected value of the portfolio. The objective function is

$$\max Z = \sum_{p\in P} \sum_{\acute{a}\in A} V_{p,1,1} x_{p,1,1,\acute{a}}. \tag{4}$$

The mathematical model presented is a discrete stochastic program that can be solved for the optimal decisions for the single scenario represented by the random variable $\theta_{p,t}$. The value of $\theta_{p,t}$ is generated by the Monte Carlo simulation method and using the method of Iman and Conover (1982) so that the resulting random variables are correlated according to the correlation matrix ρ_{xy}.

The algorithm on the right-hand side of Figure 1 has two loops. The first loop conducts *N* Monte Carlo simulations. The results from the *N* simulations are aggregated, and then a decision heuristic is applied to select which project options to invest in for time period *t*. The budget and project option variables $x_{p,t,a,\acute{a}}$ are updated. The second loop is followed if there is budget left in time period *t* such that it may be worthwhile to make another option decision. If not, then the time period is advanced and *N* Monte Carlo simulations are performed for the next time period. Thus, if we conduct *N* = 100 simulations, we do this for each time period such that with a planning horizon of four years (i.e., *T* = 4), then we perform a total of 400 simulations.

Each Monte Carlo simulation provides the optimal portfolio for the randomly generated scenario, so the method requires performing many simulations to generate a profile for decisions in the planning horizon. The decision of which options to exercise is determined by a heuristic. The heuristic is a simple best-first heuristic. The heuristic solution approach does not guarantee an optimal portfolio decision policy. We do not explore in this paper the performance of one heuristic over another; however, future research may be conducted to determine which heuristic performs better and under what circumstances.

Illustrative Example

We present a case study to illustrate the enterprise transformation framework. ABC company is a small- and medium-sized engineering and manufacturing firm of defense systems. It is a low-volume and high-mix manufacturer, performing the design, development, and system integration for electromechanical systems in the defense industry. The company also has a growing capability for research and development (R&D), including R&D under contract to larger companies. The company's revenues stand at approximately $15 million annually, which the company expects to grow to $50 million over the next five years through a strategy of further developing and exploiting its R&D capabilities. The company envisions an enterprise that has a more visible role in the early phases of defense system development and, consequently, a larger part of the value chain. Management has identified a strategy for achieving this growth and is concerned about obstacles that may prevent the fundamental changes to transform the company. The strategy includes achieving greater efficiency of operations, better integration of internal systems so they can have better coordination of activities, and better integration with customers in order to work in a more open, collaborative environment. A company of about 100 employees is different from a company of 250. The projects identified involve IT infrastructure investment, enterprise systems investment, reorganization investment, and training investment. The data required to create a real options portfolio is presented in Table 2. For each project, three operating modes are defined. The investment to switch from one operating mode to another is provided as well. The standard deviation of the random variable is required for the Monte Carlo simulation. The project correlations are shown in Table 3.

Table 2. Required Input Data for Portfolio Selection (Notional Values)

			Ipaa'			Random Variable			
			a1	a2	a3	θp,1,1	F	VC	σp
P1	a1	Maintain current organization of functional departments (i.e., delay)	0	0.8	1.2	4	0	0.9	0.7
	a2	Reorganize into program groups	0.2	0	0.2	4	0.2	1	0.7
	a3	Expand reorganization to marketing and other departments	0.3	0.1	0	4	0.3	1.2	0.7
P2	a1	delay	0	0.6	0.7	0.35	0	0	0.15
	a2	COTS -- local	0	0	0.1	0.35	0	1	0.15
	a3	Option for HR, CRM, and ERP (growth)	0	0	0	0.35	0	1.1	0.15
P3	a1	delay	0	0.45	0.55	0.3	0	0	0.3
	a2	SolidWorks upgrade to SW Simulation Premium for	0.05	0	0.08	0.3	0	1	0.3
	a3	Pro-E	0.05	0.05	0	0.3	0	1.1	0.3
P4	a1	delay	0	0.76	1	0.6	0	0	0.25
	a2	ADP-EZ Payroll (Payroll)	0.1	0	0.15	0.6	0	1	0.25
	a3	ADP -- EZ Labor (labor hr tracking)	0.1	0.1	0	0.6	0	1.2	0.25
P5	a1	delay	0	0.2	0.45	0.1	0	0	0.08
	a2	DOORS or Requirement Mgmt Tool	0	0	0.22	0.1	0	0.8	0.08
	a3	CORE Requirement Mgmt Tool	0	0	0	0.1	0	0.9	0.08

Table 3. Correlation Matrix

	P1	P2	P3	P4	P5
P1	1	0	0.25	-0.25	0.25
P2		1	0.5	-0.25	0.5
P3			1	0.5	0.5
P4				1	0.5
P5					1

The model was executed with *N* = 100 Monte Carlo simulations for each decision epoch. Figure 2 shows the results of the first 100 simulations in Period 1. Using a best-first heuristic, the decision is made to do the switch defined by $x_{1,1,1,3}$ because Project 1 switching from operating mode a_1 (the initial operating mode) to a_3 has the highest percentage. Figure 2 indicates that making this switch was part of the optimal solution in 75% of the simulated scenarios. Notice in this example that $x_{3,1,1,1}$ has an equal percentage. The tiebreaker was decided because switching in Project 1 was a positive switch rather than the "do nothing" option represented by Project 3.

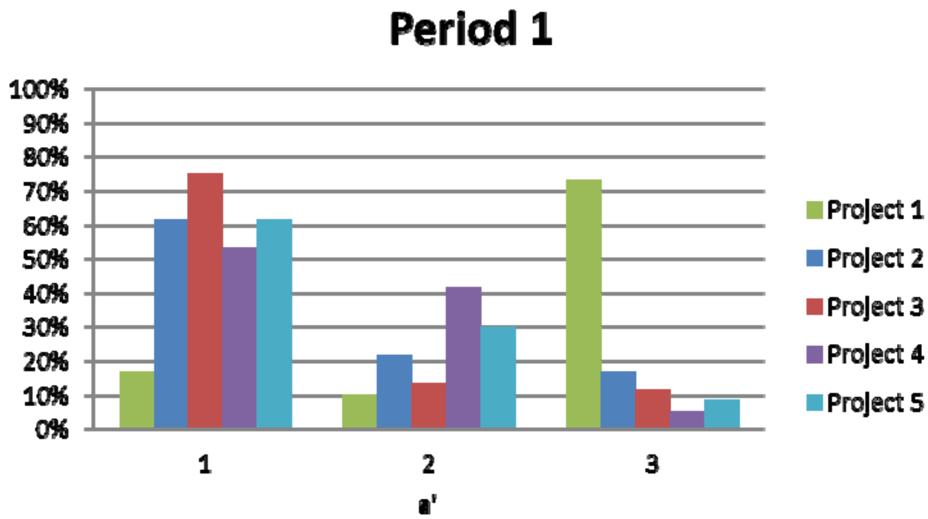

Figure 2. Aggregation of First N Monte Carlo Simulations

Following the first decision epoch, the budget is updated and the decision variable $x_{1,1,1,3}$ is set to be 1, meaning that this switch has been decided upon and fixed. The next iteration of 100 Monte Carlo simulations is conducted and the results aggregated to reveal Figure 3. Project 1 switching to Option 3 is now higher, but in a small percentage of scenarios, the optimal decision was to contract the project by switching to operating mode a_2. The next decision is to continue delaying Project 3 and to do a pilot study for Project 5.

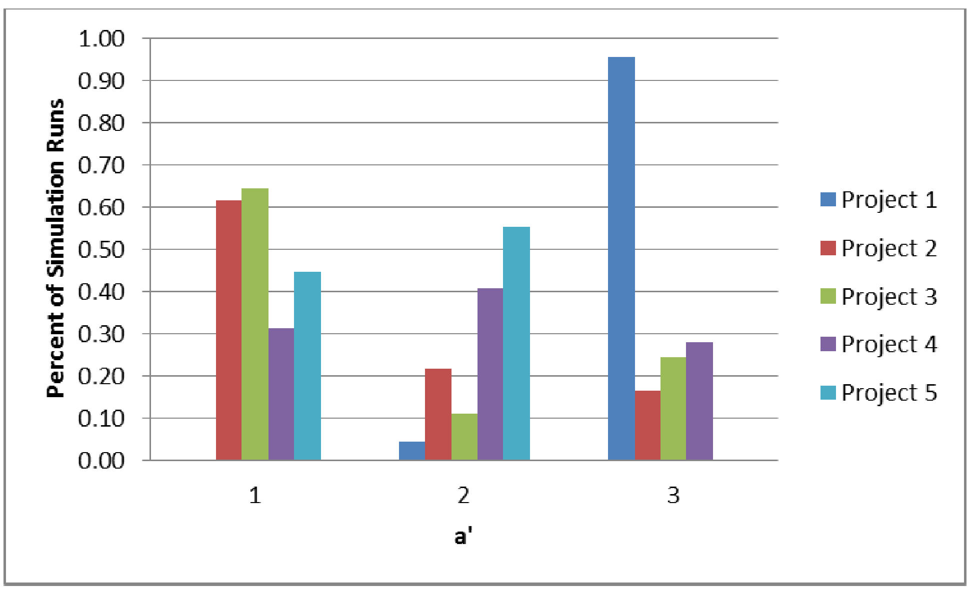

Figure 3. Aggregation of First N Monte Carlo Simulations

Discussion of Results

The discrete stochastic model for creating a portfolio is intractable due to the curse of dimensionality, so we resorted to a heuristic algorithm utilizing a Monte Carlo simulation. In the heuristic algorithm, we ran a set of simulations, aggregated the results, and applied a heuristic to make a decision. We implemented a rather unsophisticated best-first algorithm. We did not investigate other heuristics or the performance of this heuristic; we leave this for future research. In applying the heuristic, it is noted that in no cases was a switch optimal in all simulated scenarios. An interesting research question, which we have not yet investigated, is whether we can analyze the simulation runs and gain insight into scenarios in which one switch is better than another.

Conclusions

The paper was motivated by providing acquisition decision-makers with tools necessary to make informed decisions in selecting a portfolio of enterprise projects. The paper described a method to recast enterprise projects in terms of options on the project to make explicit the decision flexibility available to the decision-makers. The main contribution is a real options valuation model that is applied to the portfolio as a whole, rather than each project individually. The complexity of selecting a good portfolio is performed with an algorithm and mathematical model. Valuation of the portfolio of options is performed with a Monte Carlo simulation. The approach was illustrated with a case study of a small manufacturer. Future work will investigate applicability of the model to the warfighter side of the DoD that is non-financial and driven by acquisition of capabilities.

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